EFFECT OF CYCLIC LOADING ON CONNECTION STRENGTH OF GEOSYNTHETIC-REINFORCED STRUCTURES

by

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Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

Graduate Program in Civil Engineering

Boğaziçi University

2014

ACKNOWLEDGEMENTS

Along with the university central placement exams, this study by far the most challenging, yet valuable accomplishment work I have encountered in my life. I have found myself in desperate, hopeless situation several times where I even considered giving up. This is the place where I want to extend my gratitude to my supervisor Assos. Prof. Emre Otay, and Prof. Gökmen Ergün who never let me give up.

I want to extend my genuine gratitude to Prof. Erol Güler, for his supervision, his guidance, his constructive approach making my research to be a valuable asset to geotechnical society. More importantly, he shared his valuable experiences throughout the work, encouraging and motivating me to complete this hard work in time.

I would like to thank TÜBİTAK for the support allowed me to consantrate solely on my Ph.D. studies. If it wasn't for TUBİTAK, I could never complete my courses with 4.0/4.0 GPA and the research might never come to an end considering the fact that a special costly equipment is constructed for the research.

I also would like to thank my friends Yağmur Macit, Ercüment Başbuğ, Mustafa Koç, Ertuğrul Cem Bolcal, Ahmet Murat Odabaşı, Cüneyt Tüzün, the Boğaziçi Students Halil Karaoğlan, Tolga Yardımcı, Sevgim Nihan Akın, Cihan Cengiz, department secretary Ayşe Aydın, the whole laboratory staff who always supported my study.

Finally, I would like to thank my parents Tülay Alpçer, Erhan İçöz, Evrim İçöz, and Sibel Alpçer, not only due to the support they gave during my Ph.D., but the unconditional support, endless love, limitless patience during my whole education life.

ABSTRACT

EFFECT OF CYCLIC LOADING ON CONNECTION STRENGTH OF GEOSYNTHETIC-REINFORCED STRUCTURES

This study investigates the effect of cyclic loading over the connection strength of geosynthetic reinforced segmental (modular) block walls. For this purpose a specially designed machine has been built and reduced size cyclic loading test programme has been utilized. Geosynthetic reinforced walls have so far shown a very good performance under earthquake effects. However one of the key parameter has been generally omitted during design. This is the connection strength parameter mobilized under cyclic (repetitive) loading effects. Consequently, the research adressed this issue of whether there is a loss of strength or not after a series of cyclic loading tests. For this purpose, a typical rectangular modular block with dimensions of 19cmx19cmx39cm and two types of geosynthetic reinforcements (geotextile and geogrid) have been used during the tests. The test programme involved 3 load cycles (0%-50%, 25%-75%, 50%-75%), 2 reinforcement types, 13 normal load interval (from 150kg to 3250kg) resulting 3x2x13=78tests. All these tests are also repeated twice to get a better and more realistic results so that the total number of tests performed for the study is 78x2=156. The load cycles are determined so that a M=7.5 magnitude earthquake can be represented in the best way that is possible. For this purpose, an equivalent of 15 cycles are considered as suggested by several literature. However, it should be noted that there is no purpose of simulating a scenario earthquake, the purpose is to observe the effects of cyclic (repetitive) loading. At the end of the tests, It can be concluded that the geotextile reinforcement is more sensitive to cyclic loading than as compared with the geogrid reinforcement. It was also observed that the normal load increment, and or load cycle variation does not make significant effect on the change in the connection strength.

ÖZET

GEOSENTETİK DONATILI DUVARLARDA DEVİRLİ YÜKLEMENİN BAĞLANTI MUKAVEMETİNE ETKİSİ

Bu çalışma prekast blok (modüler blok) cephe kaplamalı geosentetik donatılı duvarların devirli yükleme koşulları altında blok-geosentetik donatı bağlantı kuvvetlerindeki etkisini araştırmaktadır. Bu amaçla bu araştırmaya özel bir ekipman tasarlanmış ve inşa ettirilmiş olup belli bir ölçekle test programı gerçekleştirilmiştir. Bilindiği üzere geosentetik donatılı duvarların deprem yükleri altında oldukça iyi performans verdiği gözlenmiştir. Buna karşılık tasarım sırasında önemli bir tasarım parametresi genelde gözardı edilmektedir. Bahsi geçen parametre devirsel (tekrarlı) yükler altında mobilize olan blok-donatı bağlantı mukavemetidir. Sonuç olarak, bu çalışma bir seri devirsel yüklemeli deney sonucunun değerlendirilmesi ile elde edilen ve yüzey elemanı-donatı arasındaki bağlantı mukavemetinde azalım olup olmadığını araştıran verileri ve sonuçları içermektedir. Bu amaçla uygulamada sıklıkla kullanılan 19cmx19cmx39cm'lik dikdörtgen bloklar kullanılmış ve donatı olarak da geotekstil ve geogrid malzemesi kullanılmıştır. Test programı kapsamında 3 devir aralığı (0%-50%, 25%-75%, 50%-75%), 2 donatı tipi ve 13 düşey yük (150kg'dan 3250kg'a kadar) kullanıldığında toplamda 2x3x13=78 test yapmaktadır. Bu testlerin her biri daha güvenilir ve hassas sonuç elde etmek için tekrarlanmış olup toplamda 78x2=156 test yapılmıştır. Devirli yükleme aralıkları ve yük devir sayısı M=7.5 büyüklüğünde bir depreme yakın olması bakımından literatürlere uygun olarak seçilmiş ve toplam yükleme/geri yükleme sayısı da 15 seçilmiştir. Buna karşılık deneylerin ilk amacının bir senaryo depremini simüle etmek olmadığı, asıl amacın devirli yüklemenin hedef sonuca etkilerin belirlenmesi olduğu anlaşılmalıdır. Deneyler sonucunda görülmüştür ki, geotekstil donatının devirsel yüklemeler sonucunda bağlantı mukavemetindeki azalışın geogrid donatıya göre daha belirgin olduğu anlaşılmıştır.

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LIST OF SYMBOLS

a	Maximum ground acceleration coefficient
a_m	Maximum horizontal acceleration coefficient in reinforced soil wall
c	Cohesion of soil
C	Reinforcement effective unit parameter
C_c	Coefficient of curvature
CD	Counter machine direction
C_u	Coefficient of uniformity
e	Eccentricity
E	Modulus of Elasticity
F_T	Total force applied by the retained fill on the back of reinforced zone
H	Wall Height
K_A	Active coefficient of earth pressure
K_{AE}	Total seismic earth pressure coeffiecient
K_{ar}	Earth pressure coefficient calculated for reinforced zone
K_P	Passive coefficient of earth pressure
k_c	Critical acceleration
k_h	Horizontal seismic coefficient
k_v	Vertical seismic coefficient
L	Reinforcement Length
L_a	Length of reinforcement in front of critical surface
L_e	Length of embedment in the resisting zone
MD	Machine direction
P	Soil-reinforcement friction angle
P_A	Active static earth pressure resultant force
P_{AE}	Total dynamic active earth force
P_d	Driving force
P_I	Inertia force acting on the active zone

P_{IR}	Inertia force
P_R	Resisting force
PVC	Poly vinyl chloride
R_c	Coverage ratio
q_{ult}	Ultimate bearing capacity
S_v	Spacing between reinforcement layers
t	Time
T_a	Allowable tensile force per unit width of reinforcement
T_{max}	Maximum tension force per unit width of wall
W_a	Weight of active zone
W_R	Weight of reinforced zone
v_m	Peak ground velocity
z	Depth

α	Scale correction factor
β	Angle of backfill slope
γ	Unit weight
γ_f	Unit weight of retained fill
φ	Internal friction angle
δ	Interface friction angle
ε	Strain
ε_{ult}	Ultimate strain
λ	Scalingfactor
μ	Soil-reinforcement friction coefficient
σ_1	Vertical principal stress
σ_3	Lateral confining stress
σ_H	Horizontal stress
σ_v	Vertical stress
τ	Shear stress
Ψ	Seismic inertia angle
ΔK_{dyn}	Incremental dynamic active earth pressure coefficient

ΔP_{dyn}	Incremental dynamic component of P_{AE}
$\Lambda\sigma_H$	Incremental of horizontal stress due to horizontal surcharge

LIST OF ACRONYMS/ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
FS	Factor of safety
GRS-RW	Geosynthetic-ReinforcedSoil Retaining Wall
HDPE	High Density Polyethylene
NCMA	National Concrete Masonry Association
PET	Polyester
PGA	Peak ground acceleration
PP	Polypropylene

1. INTRODUCTION

The rise of the usage of geosynthetic reinforced earth walls is remarkable for the last 30 years due to its economical, easy to construct function and earthquake resistant structure. However, not too many cases and data is available for the earthquake behaviour of these walls in many terms. On the other hand, it is a very well known fact that these walls are classified as "elastic" retaining walls meaning that the walls are capable of adjusting to the deformations under seismic activity. Furthermore, these walls are known to be energy absorbant.

The design of reinforced earth walls have many steps, parameters and design criteria such as internal stability, external stability, global stability and such. During these design steps, the major inputs are the very well known reinforcement materials and the soil parameters based on the geotechnical literature. The wall geometry, loads are also other known parameters that can be identified by the designer. On the other hand, the facing stability of geosynthetic reinforced earth walls utilizing modular blocks cannot be easily classified as an input that for a designer. This is mainly because the facing stability is a function of many variables such as block type, connection type (mechanical etc.), block geometry, reinforcement type, filling material etc.

The design procedure is usually carried out by using of commercially available software with limit equilibrium methods. As a result, this part of the design is either unintentionally omitted or finalized by the data provided by the manufacturer where designer has no control over. More importantly, a limit equilibrium method omits the effects of cyclic loadings such as deformations, load up and downs, and considers a seismic/dynamic load as a certain increase in the lateral loading identified as pseudo-static analysis.

The other problem with this approach is that, while load is increasing due to dynamic effects, the available strength is considered to remain same. This can be a very big assumption due to nature of the block-reinforcement connection.

As a result, this research aims to understand if there is any reduction in the connection strength of block reinforcement interface due to cyclic loading. Obviously, there are several limitations due to equipment capabilities such as a full time history of an earthquake cannot be simulated, as a result, an alternative approach is considered known as “equivalent cycles”.

The research also limits the type of reinforcements used; the reinforcement types are woven geotextile and PVC coated polyester geogrid, that are known as the two most common type of wall reinforcements. Further research options are kept alive by different types of reinforcements.

In addition, mechanically connected block-reinforcement interface (such as bodkin etc.) is also out of scope.

As explained above, the connection strength is sometimes provided by the manufacturer, mainly because this parameter can be specific to a block, and this block can be trademarked block of a certain manufacturer having certain copy rights, patents. As a result, the manufacturers run their own tests and publish the data for designers. To omit this type of problem, the block type used in this study is one of the most typical block type as identified in the coming sections.

In summary, the thesis outline can be summarized as: Chapter 2-3 and 4 are a general view for geosynthetics background, and use of these materials in construction industry.

Chapter 5 covers the general description, types of reinforced walls such as gabion walls, geosynthetic reinforced walls etc.

Chapter 6 covers the literature review section including general design rules, design rules for facing stability etc. This chapter also covers the past studies similar to this research. As can be seen, the effect of cyclic loading on connection strength is not a very widely investigated area of this type of walls.

Chapter 7 covers the methodology including the equipment construction spesific to this study, limitations of this equipment, preparation for the actual tests, calibration, specification of the materials used for the tests etc.

Chapter 8 summarizes the whole results from the tests including graphics to cover all the variables such as material change, load cycle change and normal load change.

Following Cahapter 8, Chapter 9 covers the general conclusions from all the findings, limitations, possible future studies.

The test results (both graphical and data) is presented in appendices. Appendix A covers the data recorded from the tests, and Appendix B includes the data summary and graphical output of all tests.

2. TYPE AND DESCRIPTION OF POLYMERS

2.1. Background

Within the last hundred years there has been an evolution from naturally occurring polymers to creation and use of synthetic polymers. The majority of the synthetic polymers used today include, polyethylene, nylon, polypropylene and polyester. These materials are created from low molecular weight materials such as oil (Filshill, 2010).

Synthetic polymers are used in various fields which range from packaging to everyday building materials. Recently, traditional materials are being substituted by synthetic polymers. Steel parts in cars such as car fenders (bumpers) have been replaced with ones made from Polypropylene (PP) and glass bottles of carbonated drinks have been replaced with polyethylene terephthalate (PET) bottles. In civil engineering, steel reinforcements used in soil have been replaced geosynthetics that are composed of synthetic polymers.

Synthetic polymers are used in many industries due to their increased durability, increased design flexibility, light weight, low temperature impact resistance and efficient manufacturability.

2.2. History

The first human-made plastic was invented by Alexander Parkes in 1855; he called this plastic Parkesine (later called celluloid). It was unveiled at the 1862 Great International Exhibition (Fenichell, 1996). The development of plastics has come from the use of natural plastic materials (e.g., chewing gum, shellac) to the use of chemically modified natural materials (e.g., rubber, nitrocellulose, collagen, galalite) and finally to completely synthetic molecules (e.g., bakelite, epoxy, polyvinyl chloride, polyethylene).

Bakelite, a phenol-formaldehyde polymer, was the first completely synthetic plas-

tic, first made by Leo Baekeland in 1907. The independent chemist and inventor Leo Baekeland and an assistant started their research in 1904 looking for a synthetic substitute for shellac. Bakelite was commercially introduced in 1909. Bakelite was first used to make billiard balls, but, later, was used to make molded insulation, valve parts, knobs, buttons, knife handles, many types of molded plastic containers for radios and electronic instruments, and more (Katz, 1998).

By the invention of Bakelite and other fully synthetic materials, which aren't derived from living matter, a much more stable raw material became available in civil engineering applications. Lifetimes of centuries can be predicted even for harsh environmental conditions for properly formulated and produced synthetic polymeric materials.

2.3. Definition and Properties

The word *polymer* comes from the Greek word *poly* meaning "many" and *meros* meaning "parts" (Koerner, 2005). Thus a large number of minor, similar units (parts) are used to produce the polymer. Each part which is used to produce polymer, is called *monomer*. Polymers are made by linking monomer molecules together using chemical reactions. The process by which monomers are linked each other and build up polymers is known as *polymerisation*.

Alignment of the polymer chains, bonding between polymer molecules and their chains determines polymers' individual characteristics. According to types of bonding between polymer molecules and their chains, synthetic polymers can be subdivided into 3 main groups, namely thermoplastics, elastomers and thermosets. In addition, thermoplastics, which are the most common materials used in geosynthetics, are subdivided into 2 main groups in terms of alignment of the polymer chains Figure 2.1.

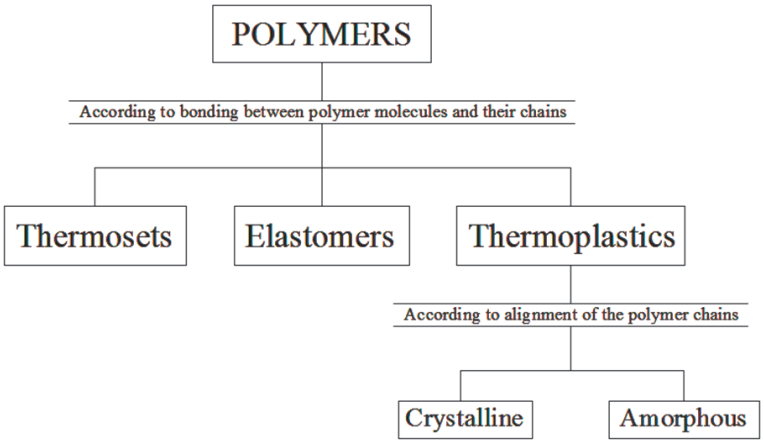


Figure 2.1. Types of Synthetic Polymers.

Thermoset polymers are rarely used polymers in geosynthetics. They are prepared by a reaction between monomers, at least one which is three or poly functional. Their closed three dimensional molecular net structure and chemical bonding (cross-linking) between polymer molecules and their chains causes a rigid behaviour. Also, their shape is retained by chemical bonding. Even though thermosets can be softened by heating, they retain their form. In order to shape them, cross-links should be broken by applying higher temperatures. Thermosets are stiff materials.

Elastomers' preparation method is same with the thermosets. Also, their shape is retained by cross-linking, so high temperatures should be applied to break cross-links and shape them. Elastomers have comparatively open three dimensional molecular structure and they are highly extensible materials. (Zanten, 1986) Elastomers are very sensitive to stress. When they subjected to stress, they can have high elongations of up to ten times their original size. Subsequent to release of stress, they recover their original shape.

Thermoplastics are the most commonly used polymers in the manufacture of geosynthetics. Thermoplastic polymer is prepared by a reaction between bi-functional monomers. They can be shaped above a specific temperature, and retain their shape after they have cooled down. Therefore, they are also known as thermosoftening plastics. Thermoplastics owe this property to bonding mechanism between polymer molecules

and their chains. There are no cross linked (chemically bonded) sites or chains to fix the polymer chain in position, so their shape retained by physical strength. Thermoplastics are stiff to relatively stiff materials when compared with thermosets. Thermoplastics can be divided into two groups in terms of crystallinity, namely crystalline and amorphous.

One can define crystallinity as the degree of aligned portions of the polymer chains. Crystallinitiy exists in every polymeric material but its degree varies but no polymer is completely crystalline. Decreasing degree of crystallinity makes material close to the amorphous form. In other words, nonaligned regions of the polymer chains are called amorphous.

Vast majority of the geosynthetics are made from amorphous or semi crystalline (there isn't any completely crystalline polymer) thermoplastics. For this reason, crystallinity is significant in the properties of polymeric geosynthetics. With the increase in crystallinitiy; stiffness/hardness, heat resistance, tensile strength and chemical resistance increases, however flexibility, impact strength diffusive permeability and stress crack resistance decreases.

Most commonly used polymers used in geosynthetics industry are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyester (PET), polyamide (PA) (nylon6/6) and polystrene (PS).

2.3.1. Polyethylene (PE)

Polyethylene is one of the most common thermoplastic polymer, that is used in bottles, plastic bags, geomembranes and more. Polyethylenes can be produced in a highly crystalline form. Molecular weight (melt-index), molecular weight distribution, degree of crsytallinity (density) and degree of stabilization are four main parameters control the processibility and performance of polyethylene. In terms of process of production, polyethylene can be divided into 3 main groups, namely:

- Low density polyethylene (LDPE) (920-930 kg/m^3)
- Linear low density polyethylene (LLDPE) (925-945 kg/m^3)
- High density polyethylene (940-960 kg/m^3)

These three types of polyethylene polymers have different production processes, especially applied pressure during production determines their properties. LDPE is the one which was developed first. Very high pressures (up to 300 MPa) are applied during the production of LDPE, which enables to control flexibility and permeability properties of the production.

Contrary to LDPE, HDPE is produced at relatively low pressures and temperatures by using chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts. This different production process makes HDPE stronger, more rigid, tougher and also makes HDPE has a better chemical resistance than the LDPE.

Third main group of polyethylene is LLDPE, which is also made a low pressure process. However, LLDPE is manufactured by co-polymerizing ethylene with a small amount of alpha-olefins (for example, 1-butene, 1-hexene and 1-octene), which lowers the density by forming short chain side branches on the linear polymer chain (Zanten, 1986).

2.3.2. Polypropylene (PP)

Polypropylene is another important thermoplastic polymer used in manufacture of geosynthetics. Polypropylene is also a crystalline polymer that is formed by polymerization of propylene monomers. Polypropylene is the lightest plastic which has a low density about 900-910 kg/m^3.

In order to define properties of PP; melt-index, degree of crystallinity/isotacticity, molecular weight distribution, degree of stabilization and copolymerization with other monomers (especially ethylene) should be investigated well.

2.3.3. Polyvinyl Chloride (PVC)

Polyvinyl chloride (commonly abbreviated as PVC) is made from vinyl chloride (VC), that is the product of the reaction between ethylene and chlorine. Also, reaction of ethylene, air and hydrochloric acid provides vinyl chloride. Polyvinyl chloride (as abbreviated as PVC) is one of the most widely produced plastic materials with polyethylene and polypropylene. PVC can be manufactured by two methods. In first method, it can be produced by heating pure vinyl chloride under pressure to about 60°C. Alternatively, VC can be polymerized as an emulsion in water which includes certain catalysts.

2.3.4. Polyester (PET)

Polyester is made by polymerization of petroleum derivatives such as, ethylene glycol with dimethyl terephthalate or with terephthalic acid. Even though the most common polyesters are thermoplastic, thermoset polyesters can be produced by changing their chemical structure. Shape of polyesters as thermoplastics might be changed by applying heat. When they are faced with flame, they extinguish themselves by shrinking away from flames.

2.3.5. Polyamide (PA) (nylon 6.6)

Polyamide (nylon) 6.6 is an aliphatic polymer, which means it is composed of chains which don't contain ring-shaped rigid structure. PA 6.6 is obtained by the polymerization of petroleum derivatives such as a salt of adipic acid and hexamethylenediamine. Generally, autoclaves are used to produce PA 6.6 in a discontinuous process. However, a continuous process can be conducted to make polyamide 6.6. (Zanten, 1986).

2.3.6. Polystyrene (PS)

Polystyrene is manufactured by polymerization of styrene, which is a petroleum derived monomer. Short-range van der Waals bondings between polymer chains are the main factor that determines the polystyrene's properties. Either rigid or foamed polystyrenes can be encountered. The most important property of polystyrene is its unit weight. Polystyrenes are light-weight materials (about 95% air), and they have very good insulation properties. In room temperature; polystyrene is solid, but it starts to flow when it is heated above 100°C. After cooling, it becomes rigid again. This feature enables manufacturers to mold it with fine detail.

Repeating molecular units of these polymers and geosynthetics they are used in are shown in Table 2.1.

Table 2.1. Repeating Molecular Units of Polymers Used in the Manufacture of Geosynthetics (Koerner, 2005).

Polymer	**Repeating Unit**	**Types of Geosynthetics**
Polyethylene (PE)	$\left[\begin{array}{cc} H & H \\ \vert & \vert \\ C & -C \\ \vert & \vert \\ H & H \end{array}\right]_n$	Geotextiles, geomembranes, geogrids, geopipe, geonets, geocomposites
Polypropylene (PP)	$\left[\begin{array}{cc} H & CH_3 \\ \vert & \vert \\ C & -C \\ \vert & \vert \\ H & H \end{array}\right]_n$	Geotextiles, geomembranes, geogrids, geocomposites
Polyvinyl chloride (PVC)	$\left[\begin{array}{cc} H & Cl \\ \vert & \vert \\ C & -C \\ \vert & \vert \\ H & H \end{array}\right]_n$	Geomembranes, geopipe, geocomposites
Polyester (Polyester (polyetyhlene terephthalate) (PET)	$\left[\begin{array}{cccccc} & & & O & & O \\ & & & \vert & & \vert \\ O- & R- & O- & C- & R- & C \end{array}\right]_n$	Geotextiles, geogrids
Polyamide (PA)	$\left[\begin{array}{cccccc} H & & H & O & & O \\ \vert & & \vert & \vert & & \vert \\ N- & (CH_2)_6- & N- & C- & (CH_2)_6- & C \end{array}\right]_n$	Geotextiles, geogrids, geocomposites
Polystyrene (PS)	$\left[\begin{array}{ccc} H & H & \\ \vert & \vert & \\ C & C & \\ \vert & \vert & \\ H & C & \\ // & & \\ H- \; C & C & -H \\ \vert & & \Vert \\ H- \; C & C & -H \\ & & \\ / & & \\ C & & \\ \vert & & \\ H & & \end{array}\right]_n$	Geocomposites, geofoam

3. TYPE AND DESCRIPTION OF TYPICAL GEOSYNTHETICS

3.1. Background

In only a very few years, geosynthetics have joined the list of traditional civil engineering construction materials. Often the use of a geosynthetic can significantly increase the safety factor, improve performance, and reduce costs in comparison with conventional construction alternatives. (Chen and Liew, 2003).

Geosynthetics are used in various disciplines such as civil, geotechnical, transportational, geoenvironmental and hydraulic engineering. In addition, they're used in private development applications including roads, airfields, railroads, embankments, retaining structures, reservoirs, canals, dams, erosion control, sediment control, landfill liners, landfill covers, mining, aquaculture and agriculture.

The vast majority of the geosynthetics used today include, geogrids, geotextiles, geomembranes, geocompozites, geosynthetic clay liners, geofoams, geopipes and geonets. Geosynthetics are available in a wide range of forms and materials, each to suit a slightly different end use. They are used for separation, reinforcement, filtration, drainage and insulation.

3.2. History

Inclusions of different sorts mixed with soil have been used for thousands of years. Thus, one can say that industry of geosynthetics is as old as civilization itself. The Babylonians used palm fronds and hemp to constructed soil-reinforced "ziggurats" more than 3000 years ago, and the Chinese have used reeds to construct a type of corduroy road since prehistoric times (Holtz, 1988). In Roman days, inclusions mixed with soil were used to stabilize roadways and their edges. In Egypt, they were also used to build steep slopes as with several pyramids and walls as well. These all early

applications were made by using natural fibers, fabrics or vegetation mixed with soil. The main problem with using natural materials (silk, vegetation, wood, cotton, etc.) in a buried environment is the biodegradation that are caused by microorganisms in the soil. However, with the invention of synthetic polymers in the beginning of the 20th century a much more stable raw material became available. This new material inspired scientists and engineers to produce geosynthetics.

The first papers on geosynthetics in the 1960s were as filters in the U.S. and as reinforcement in Europe. In the mid-1970s, Bob Holtz studied on using geotextiles to replace steel reinforcements in soil, while the Dick Bell-J.E. Steward team studied the same in the Pacific Northwest. In 1977, many manufacturers and practitioners got together because of the conference in Paris. The International Geosynthetics Society (IGS), which was founded in 1982, has subsequently organized worldwide conference every four years. Geosynthetics are available worldwide and the activity is robust and steadily growing. Historical developments in the area of geosynthetics and their applications are shown in Table 3.3.3.

3.3. Definition and Properties

The term 'Geosynthetic' has two parts: the prefix 'geo', referring to an end use associated with improving the performance of civil engineering works involving earth/ground/soil and the suffix 'synthetic', referring to the fact that the materials are almost exclusively from man-made products (Shukla and Jin, 2006). Rubber, plastics, fiberglass or other human-made synthetic materials may be used as raw material in geosynthetics. Geosynthetics are used for separation, filtration, drainage, reinforcing soil and moisture barrier.

According to their structure and technical properties, geosynthetics may be grouped into four main groups.

- Geotextiles
- Geogrids

- Geomembranes
- Geocomposites

3.3.1. Geotextiles

Geotextiles are indeed textiles in the traditional sense. In order to solve biodegredation and subsequent short lifetime problems, they consist of synthetic fibers rather than natural materials such as silk, cotton or wool. Synthetic fibers are made into geotextiles by standard weaving machinery or are matted together in a random or nonwoven manner. Also, some fibers are also knitted. Geotextiles are permeable materials across their manufactured planes and within their thickness, but degree of permeability widely varies. Geotextiles are one of the most all-purpose geosynthetics; however, it always performs at least one of the functions among :

- Separation
- Reinforcement
- Filtration
- Drainage
- Containment (barrier, when impregnated).

3.3.2. Geogrids

Instead of being a woven, nonwoven or knitted fabric, geogrids are formed into a grid-like configuration that has large apertures. These grid-like configured large apertures provides additional strength with interlocking mechanism when they are used in granular soils as reinforcement. Also, the apertures ensure vertical drainage of a reinforced free-draining soil. They can be manufactured by stretching in one (extruded uniaxial) or two directions (extruded biaxial) or made on weaving machinery by unique methods. Geogrids are mostly used as reinforcement in geotechnical engineering applications.

3.3.3. Other Types of Geosynthetics

The other types of geosynthetics is not a critical for the research. Thus, the topic does not cover them in too detail. The below figure is a general look-up for most types of geosynthetics.

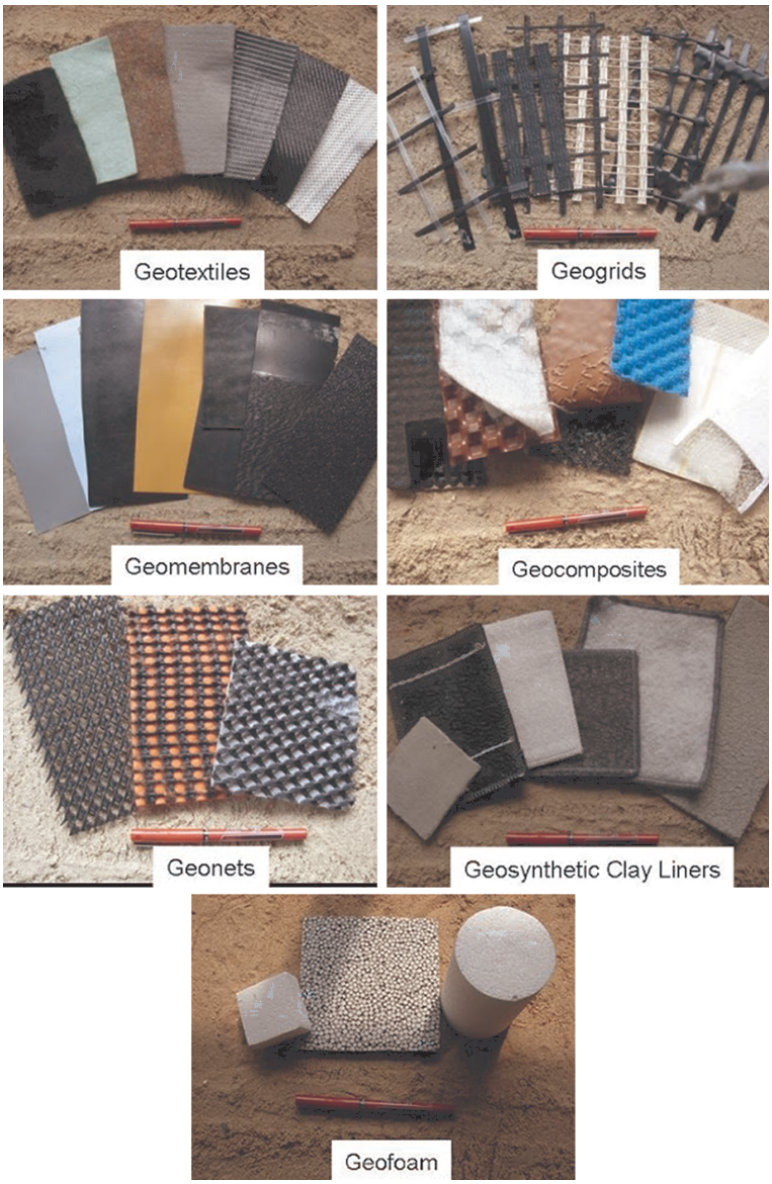


Figure 3.1. Typical Geosynthetic Materials.

Table 3.1. Historical developments in the area of geosynthetics and their applications (Shukla and Yin, 2005).

Decades	**Developments**
	The first use of fabrics in reinforcing roads was attempted by the South Carolina Highway Department in 1926 (Beckham and Mills, 1935). Polymers which form the bulk of geosynthetics did not come into commercial production until thirty years later starting with polyvinyl chloride (PVC) in 1933, low density polyethylene (LDPE) and polyamide (PA) (a.k.a. nylon) in 1939, expanded polystyrene (EPS) in 1950, poly- ester (PET) in 1953, and high density polyethylene (HDPE) and polypropylene (PP) in 1955 (Hall, 1981).The US Bureau of Reclamation has been using geomembranes in water conveyance canals since the 1950s (Staff, 1984).
Late 1950s	A range of fabrics was manufactured for use as separation and filter layers between granular fills and weak subsoils. Woven fabrics (nowadays called geotextiles) played critical filtration functions in coastal projects in The Netherlands and in the USA.
1960s	Rhone-Poulenc Textiles in France began working with nonwoven needle-punched geotextiles for quite different applications. Geotextiles found a role as beds for highway and railway track support systems. Chlorosulfonated polyethylene (CSPE) was developed around 1965.
1970s	The first geotextile used in a dam, in 1970, was a needle-punched nonwoven geotextile used as a filter for the aggregate downstream drain in the Valcross Dam (17 m high), France (Giroud, 1992). Geotextiles were incorporated as reinforcement in retaining walls, steep slopes, etc.The beginning of the ongoing process of standards development started with the formation of the ASTM D-13-18 joint committee on geosynthetics and the formation of industry task forces.The first samples of Tensar grid were made in the Blackburn laboratories of Netlon Ltd, UK, in July 1978.The first conference on geosynthetics was held in Paris in 1977. The geofoam was originally applied as a lightweight fill in Norway in 1972.
1980s	The beginning of the use of geosynthetics occurred in the construction of safe containment of environmentally hazardous wastes. Soil confinement systems based on cellular geotextile nets were first developed and evaluated in France during 1980. Netlon developed a similar concept, but on a larger scale, with the introduction of the Tensar Geocell Mattress in 1982. The first known environmental application of geonet was in 1984 for leak detection in a double-lined hazardous liquid-waste impoundment in Hopewell,Virginia. Koerner and Welsh wrote the first book on geosynthetics in 1980. The International Geosynthetics Society was established in 1983.The first volume of international journal entitled Geotextiles and Geomembranes was published in 1984.
1990s	Many standards on geosynthetics were published by the American Society of Testing Materials (ASTM), USA; the International Organization for Standardization (ISO), Switzerland; the British Standards Institution (BSI), UK; the Bureau of Indian Standards (BIS), India, etc.The second international journal entitled Geosynthetics International was first published in 1995.

4. APPLICATION OF GEOSYNTHETICS IN CONSTRUCTION INDUSTRY

4.1. Separation

Separation function of geosynthetics is convenient to separate dissimilar materials such as fine coarse material, subgrade and stone based material (roads, airfields), between various zones of earthdams, between old and new asphalt layers.

4.2. Reinforcement

Reinforcement function of geosynthetics is very critical and have very wide range of usage in civil engineering applications. These usages can be listed as:

- Over soft soils for unpaved roads, airfields, railroads, landfills, sport fieds,
- Over non-homogeneous soils,
- Over unstable landfills,
- To wrap sols in encapsulated fabric system,
- For reinforced earth wall construction,
- To aid in construction of steep slopes,
- To reinforce embankments, earth and rock dams,
- To bridge over cracked or jointed rock,
- To increase bearing capacity of soils,
- As basal reinforcement between jet gout and foundation

4.3. Filtration

The filtration function of geosynthetics have also wide range of usage such as, in place granular filters, beneath ballast under railroads, around perforated drain pipes, around crushed stone without underdrains (i.e. French drains), beneath landfills that generate leachate, as silt fence and curtain, between backfill soil and gabions.

4.4. Drainage

The drainage function of geosynthetics in civil engineering can be listed as a drain beneath sport and athletic field, a drain for roof-top gardens, drain beneath railroad ballast, drain behind a retaining wall, drain beneath a surcharge fill, drain beneath geomembranes.

5. GEOSYNTHETIC REINFORCED SOIL RETAINING WALLS

5.1. Description of Geosynthetic Reinforced Soil Retaining Walls

Geosynthetic reinforced soil retaining wall, as the name suggests, is a retaining wall reinforced with geosynthetics. Combination of geosynthetic and soil is a similar concept with reinforced concrete. Geosynthetic reinforcements have high tensile strength while they have very low compressive strength. Contrary to geosynthetic reinforcements, compressive strength of soil material is higher when compared with its tensile strength. On the other hand, soil material can be found cheaply and in large amounts while geosynthetic reinforcements are relatively expensive materials.

Thus, combination of these two materials compensates weakness of each other and improves the global characteristics of this composite material like the relationship of concrete and steel in reinforced concrete.

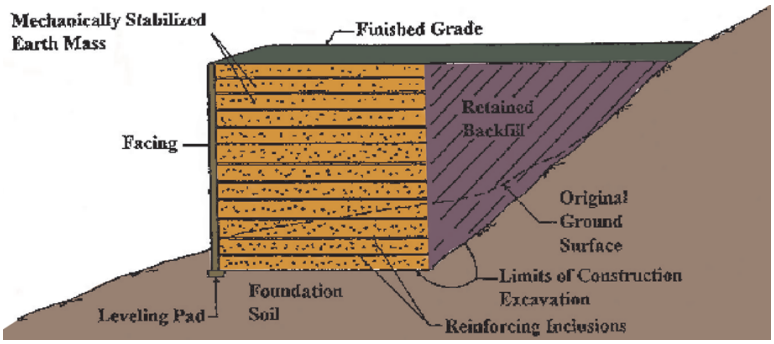


Figure 5.1. Generic Cross-Section of a MSE Wall (Elias *et al.*, 2001).

Reinforcing soil with geosynthetics improves the strength of soil. However, in order to prevent soil raveling between reinforcement layers, reinforcements should be wrapped to provide a stable facing. Also, facing materials can be used to enable engineers build steeper geosynthetic reinforced soil walls. Therefore, very steep slopes and vertical walls can be constructed safely. A simple illustration of a geosynthetic reinforced soil wall can be seen in Figure 5.1 and an illustration of a geosynthetic

reinforced earth wall detail can be seen in Figure 5.2.

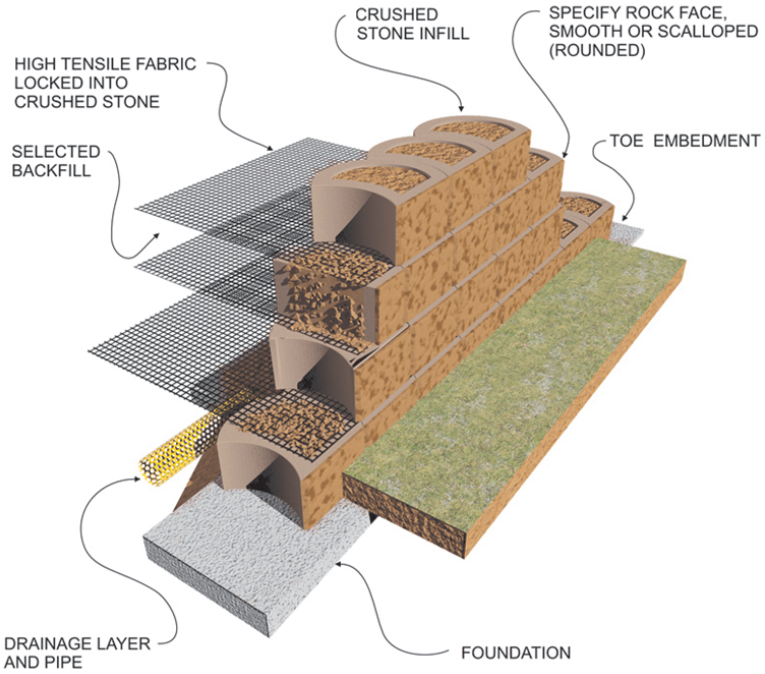


Figure 5.2. Schematic View of Geosynthetic Reinforced Retaining Wall (Terraforce, 2013).

All in all, geosynthetic reinforced soil retaining walls are considered to be typically more ductile, more tolerable to differential settlements, more adaptable to low quality backfill, easier to construct, and more economical when compared to other types of retaining structures (Enünlü, 2007).

5.2. Historical Development of Reinforced Soil Retaining Structures

The simple thought to add "inclusions" in the soil, in such a way to improve its technical properties dates back to ancient times. Through the centuries the concept of reinforced soil has been developed.

Reinforced soil concept is very ancient: 3000 years ago the Babylonians used intertwined palm branches to reinforce their "ziggurat". The Agar-Quf Ziggurat, in the actual Iraq, was made of clay bricks reinforced with woven mats of reed laid hor-

izontally on a layer of sand and gravel at vertical spacing between 0.5 m and 2.0 m. This structure was originally over 80 m high. The Romans used several types of soil reinforcement. An example is the use of timber baulks placed in the soil perpendicular to the face, for building retaining walls. The Great Wall of China, built more than 2000 years ago, contains some sections where clay and gravel were reinforced with tamarisk branches. More recently, in 1822 Colonel Pasley introduced in the British Army a form of reinforced soil, demonstrating by a series of trials that the lateral pressure on a retaining wall could be reduced if the backfill was reinforced by horizontal layers of brushwood, wooden plants or canvas (Tenax, 2006) However, using natural materials as inclusions has always been a problem, because of their limited durability and a very large uncontrollable variability in their engineering properties. In the early 1960s, French architect and engineer Henri Vidal found the modern methods of soil reinforcement for retaining wall which was called Reinforced Earth®. Reinforced Earth® is a system in which steel strip reinforcement is used in soil. With the invention of Reinforced Earth®, using a more durable reinforcement for retaining walls became available.

The reinforced soil concept has got a huge momentum with the use of polymeric materials in soil. These plastic products, specifically engineered for soil reinforcement, provide civil engineers with factory controlled characteristics, uniform behaviour, very limited variability and very high durability (Tenax, 2006).

The use of geotextiles in MSE walls and RSS started after the beneficial effect of reinforcement with geotextiles was noticed in highway embankments over weak subgrades. The first geotextile reinforced wall was constructed in France in 1971, and the first structure of this type in the United States was constructed in 1974. Since about 1980, the use of geotextiles in reinforced soil has increased significantly. Geogrids for soil reinforcement were developed around 1980. The first use of geogrid in earth reinforcement was in 1981. Extensive use of geogrid products in the United States started in about 1983, and they now comprise a growing portion of the market (Elias *et al.*, 2001).

Due to their advantages, the use of reinforced soil slope structures has increased noticeably in early 1990s, and it is estimated that several hundred reinforced soil slope structures have been constructed all over the world. According to FHWA, 70 to 100 reinforced soil slope/wall projects are being constructed yearly in connection with transportation related projects in the United States, with an estimated projected vertical face area of 130,000 m2/year. Also, it is estimated that since 1997, approximately 23,000 MSE walls have been constructed in the world.

5.3. Advantages and Disadvantages of Reinforced Soil Retaining Structures

5.3.1. Advantages of Reinforced Soil Retaining Structures

There are many advantages of MSE walls compared with conventional retaining structures such as reinforced concrete and concrete gravity retaining walls. Some advantages are:

- MSE wall construction is simple and rapid and doesn't have need of large construction equipment.
- Experienced craftsmen with special skills aren't required for MSE wall construction.
- MSE walls require less site preparation than other alternatives.
- MSE walls need less space in front of the structure for construction operations.
- Right-of-way acquisition is reduced.
- MSE structures are tolerant to deformations, so they do not need rigid, unyielding foundation support. One of the greatest advantages of MSE walls is their flexibility and capability to absorb deformations due to poor subsoil conditions in the foundations. Also, based on observations in seismically active zones, these structures have demonstrated a higher resistance to seismic loading than have rigid concrete structures.
- MSE walls are cost effective. The relatively small quantities of manufactured materials required, rapid construction, and, competition among the developers

of different proprietary systems has resulted in a cost reduction relative to traditional types of retaining walls. MSE walls are likely to be more economical than other wall systems for walls higher than about 3 m (10 ft) or where special foundations would be required for a conventional wall.

- MSE walls can be constructed to heights in excess of 25m.
- Aesthetics. Precast concrete facing elements for MSE walls can be made with various shapes and textures (with little extra cost) for aesthetic considerations.
- MSE walls can be constructed in harmony with natural environment thanks to facing units. Masonry units, timber, and gabions also can be used with advantage to blend in the environment (Elias *et al.*, 2001).

5.3.2. Disadvantages of Reinforced Soil Retaining Structures

There is no material or method without disadvantages, and MSE walls also have some disadvantages like stated below. Actually, following disadvantages may be associated with all soil reinforced structures.

- A relatively large space behind the wall or outward face is required to obtain enough wall width to satisfy internal and external stability criteria.
- Select granular fill material is required especially for MSE walls. (At sites where there is a lack of granular soils, the cost of importing suitable fill material may render the system uneconomical).
- Specifications and contracting practices of such structures haven't been completely standardized. Additionally, design and construction practice of all reinforced systems are still evolving.
- The design of soil-reinforced systems often requires a shared design responsibility between material suppliers and owners and greater input from agencies geotechnical specialists in a domain often dominated by structural engineers.
- In order to prevent the corrosion of steel reinforcing elements, suitable design criteria are required. They are also required to prevent deterioration of certain types of exposed facing elements such as geosynthetics by ultra violet rays, and potential degradation of polymer reinforcement in the ground.

5.4. The Elements of Reinforced Soil Structures

Geosynthetic reinforced soil retaining walls are composed of 5 elements, namely, reinforcement, mechanically stabilized soil mass, retained backfill, facing unit and foundation soil. Components of reinforced soil walls are shown in Figure 5.1.

5.4.1. Reinforcement

Reinforcements are inclusions, which are placed in horizontal layers throughout the height of the wall, used to provide tensile strength to hold soil mass together. These reinforcements are divided into two groups as inextensible an extensible reinforcements Steel strips (inextensible reinforcement) and geosynthetic sheets (extensible reinforcement) are the most common reinforcements used in soil walls.

- Inextensible reinforcements: Deformation of the inextensible reinforcement at failure is much less than the deformability of the soil. The most commonly used ones of this group are metallic reinforcements. Metallic reinforcements are typically made of mild steel. Metallic soil reinforcements may take the form of sheets, grids, meshes, strips, bars, rods, etc. The biggest problem of metallic reinforcements is corrosion. In order to prevent corrosion of the reinforcement, they can be galvanized or epoxy coated.
- Extensible reinforcements: The deformation of the reinforcement at failure is comparable to or even greater than the deformability of the soil (Elias *et al.*, 2001). Polymeric materials such as geogrids and geotextiles are considered extensible reinforcement. Geosynthetic reinforcements are generally made from polyethylene, polyester and polypropylene.



Figure 5.3. Metal Strip as an Inextensible Reinforcement.



Figure 5.4. Geogrid as an Extensible Reinforcement.

5.4.2. Mechanically Stabilized Soil Mass

Mechanically stabilized soil mass is a generic term used for reinforced part of the reinforced soil retaining wall. Stabilized soil mass is obtained by reinforcing soil in horizontal layers with either extensible or inextensible reinforcement. On the other hand, reinforcement makes soil behave like a coherent body.

According to FHWA; MSE walls require high quality backfill for durability, good drainage, constructability, and good soil reinforcement interaction which can be obtained from well graded, granular materials. Many MSE systems depend on friction between the reinforcing elements and the soil. In such cases, a material with high friction characteristics is specified and required. Some systems rely on passive pressure on reinforcing elements, and, in those cases, the quality of backfill is still critical. These performance requirements generally eliminate soils with high clay contents.

From a reinforcement capacity point of view, lower quality backfills could be used for MSEW structures; however, a high quality granular backfill has the advantages of being free draining, providing better durability for metallic reinforcement, and requiring less reinforcement. There are also significant handling, placement and compaction advantages in using granular soils. These include an increased rate of wall erection and improved maintenance of wall alignment tolerances (Elias *et al.*, 2001).

5.4.3. Retained Backfill

Retained backfill is the fill material located between the mechanically stabilized soil mass and the natural soil. Likewise the mechanically stabilized soil mass, the quality of retained backfill material is also has a crucial effect on geosynthetic reinforced soil retaining walls. For the reasons discussed previously for reinforced fill, use of soils containing shale, mica, gypsum, smectite, montmorillonite, organic materials or other soft particles of poor durability should be avoided.

On the other hand, the potential differential settlement or performance between the reinforced fill and retained backfill should be assessed. A transition wedge between reinforced fill and retained backfill should be taken into consideration. Upper two layers of soil reinforcement can be lengthened or reinforced zone can be extended beyond the reinforcement length to obtain a sufficient transition region. The maximum particle size in the retained backfill should be less or equal to the maximum particle size in reinforced fill, at least in this transition zone.

5.4.4. Foundation Soil

The soil below the mechanically stabilized soil mass and retained backfill is called foundation soil. Foundation soil can be considered the soil which carries the overall system of the retaining wall. Hence, foundation soil has to satisfy the design criteria specified in manuals. The bearing capacity, liquefaction potential, settlement potential and position of ground water level are some of the important factors that need to be investigated before the implementation of the reinforced earth structures.

To sum up, before the application, characteristics of foundation soil should be investigated properly. In case of necessity, foundation soil may be improved to satisfy the adequate bearing capacity and/or limiting total and/or differential settlements.

5.4.5. Facing Unit

In reinforced soil retaining walls, facing units are used to provide some form of barrier to contain the soil. Facing units can be either flexible or rigid to meet design criteria, but they have to be strong enough to back the local soil and to allow attachment of the reinforcement. Concrete panel is a good example for stiff facing units and modular block can be given as an example for flexible facing. The facing type is one of the major factors which influences settlement tolerances. In addition, the facing prevents sloughing and erosion of the backfill, and provides in certain cases drainage paths. Furthermore, facing units are the only visible part of the reinforced soil walls, so they affect the aesthetic of the wall directly. Major facing types are:

- Segmental precast concrete panel



Figure 5.5. An Example of Segmental Precast Concrete Panel.

- Welded wire grids



Figure 5.6. An Example of Welded Wire Grid Facing.

- Dry cast modular block wall (MBW) units



Figure 5.7. An Example of Modular Block Wall Facing.

- Geosynthetic facings



Figure 5.8. An Example of Wrap Around Geosynthetic Facing.

- Gabion facing



Figure 5.9. An Example of Gabion Wall Facing.

6. DESIGN OF GEOSYNTHETIC REINFORCED RETAINING WALLS AND SIMILAR STUDIES IN LITERATURE

6.1. Static and Seismic Analysis Approaches

Likewise in all civil engineering applications, loads and pressures acting on retaining walls should be defined carefully in order to make a sufficient wall design. Total lateral earth pressures acting on retaining walls have a significant effect on the behaviour of the retaining walls. These total pressures mainly consist of the static pressures and the transient dynamic pressures induced by the earthquake. Since the response of a wall is influenced by both, the most commonly used lateral earth pressure approaches are presented.

Earth pressures acting on retaining structures are strongly influenced by wall and soil movements. There are three types of lateral earth pressures depending on wall movement such as active earth pressure, passive earth pressure and at rest pressure.

Active earth pressures develop as a retaining wall moves away from the soil behind it, inducing extensional lateral strain in the soil. When the wall movement is sufficient to fully mobilize the strength of the soil behind the wall, minimum active earth pressures act on the wall (Kramer, 1996). Active earth pressures develop by very little movements of the wall. Active earth pressures develop when a wall rotates about its base and away from the backfill an amount on the order of 0.001 to 0.003 radian (a top deflection of 0.001 to 0.003h, where h is the wall height) (Enünlü, 2007).

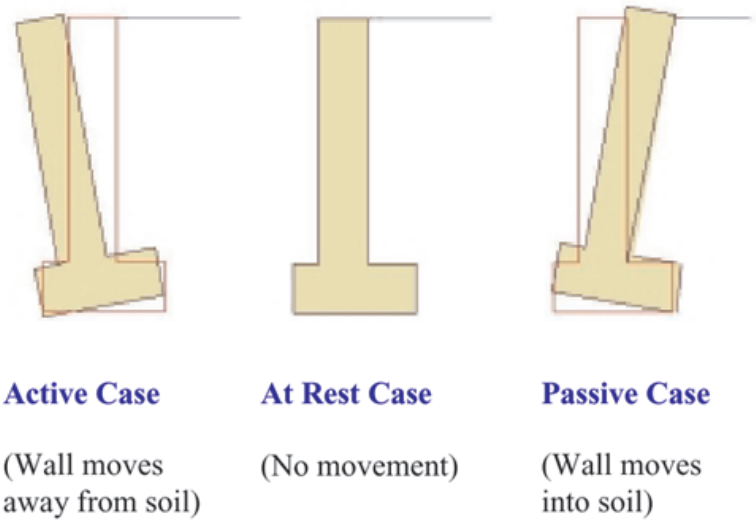


Figure 6.1. Wall Movement and Earth Pressure Types.

Passive earth pressures develop as a retaining wall moves toward the soil behind it, inducing compressive lateral strain in the soil. When the wall movement is sufficient to fully mobilize the strength of the soil behind the wall, maximum passive earth pressures act on the wall. In passive earth pressure conditions, higher horizontal stresses can be developed than for the active pressure conditions. Development of the maximum possible horizontal stress, or passive pressure, requires much larger wall rotations than for the active case, as much as 0.02 to 0.2 radians (Enünlü, 2007).

The at rest pressure develops when there is no lateral movement of the wall. At rest pressure classically occurs when the wall is restrained from movement.

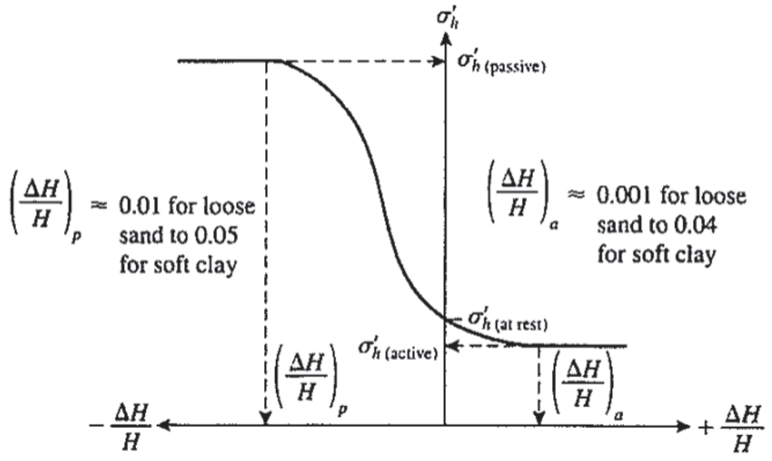


Figure 6.2. Nature of Variation of Lateral Earth Pressure at a Certain Depth (Das, 2007).

Prediction of actual retaining walls forces and deformations is an highly complicated problem. The typical approach is to estimate the forces acting on a wall and then to design the wall to resist those forces with a factor of safety high enough to produce acceptably small deformations. In many of these simplified approaches, deformations are rarely considered explicitly in design. On the other hand, nonlinear analyses are capable of predicting permanent deformations as well as wall pressures. A number of software products are available for such analyses using finite-element analysis. The most common simplified earth pressure approaches, seismic displacement approaches and finite-element analyses which are used to design retaining walls are described in the following sections.

6.1.1. Static Earth Pressures Acting on Retaining Walls

There are two widely used earth pressure theories. Coulomb published the first precise analysis of the problem of lateral earth pressure in 1776. Almost a century later, Rankine (1857) proposed a different but simpler approach to the problem. These theories were proposed to estimate the magnitudes of active earth pressure and passive earth pressures.

6.1.1.1. Rankine Theory. After Coulomb (1776), Rankine proposed the simplest theory for estimating minimum active and maximum passive earth pressures in 1857. The Rankine theory assumes;

- There is no adhesion or friction between the wall and soil.
- Lateral pressure is limited to vertical walls.
- Failure (in the backfill) occurs as a sliding wedge along an assumed failure plane defined by ϕ (angle of internal friction).
- Lateral pressure varies linearly with depth and the resultant pressure is located one-third of the height (H) above the base of the wall.
- The resultant force is parallel to the backfill surface.

For active earth pressure conditions, the pressure "p_A" at a point on the back of a retaining wall can be determined as:

$$p_A = K_A \sigma'_v - 2c\sqrt{K_A} \tag{6.1}$$

where K_A is the coefficient of minimum active earth pressure, σ'_v is the vertical effective stress at a certain depth behind the wall c is the cohesive strength of the soil.

In case of a smooth (no interface friction between wall and soil) wall and horizontal backfill, principal stress planes will be vertical and horizontal. In such a case, coefficient of active earth pressure can be formulated as

$$K_A = \frac{1 - \sin\phi}{1 + \sin\phi} = tan^2\left(45 - \frac{\phi}{2}\right) \tag{6.2}$$

When the cohesionless backfill inclined at an angle of β ($\beta \leq \phi$) with the horizontal, (Terzaghi, 1943) and (Taylor, 1948) proposed KA as:

$$K_A = \cos\beta \frac{\cos\beta - \sqrt{cos^2\beta - cos^2\phi}}{\cos\beta + \sqrt{cos^2\beta - cos^2\phi}} \tag{6.3}$$

When β=0, Equation 6.3 is equivalent to Equation 6.2. Angle of internal friction and cohesion of the soil influence the pressure distribution behind the wall which is indicated by Equation 6.1. Possible pressure distributions depending on shear strength components (ϕ and c) are shown in Figure 6.3. As it can be seen in Figure 6.3, in cohesive backfills, tensile stresses develop between the upper portion of the wall and backfill. However, use of cohesive backfill is avoided in the field due to their stress relaxation, creep and low permeability characteristics.

For dry homogeneous cohesionless backfills with unit weight γ, which are suggested and widely used instead of cohesive ones, a triangular active pressure distribution oriented parallel to the backfill surface is expected by Rankine. The active earth pressure resultant, P_A, acts at a point located H/3 above the base of a wall height, H (Figure 6.3a) with magnitude:

$$P_A = \frac{1}{2} K_A \Upsilon H^2 \tag{6.4}$$

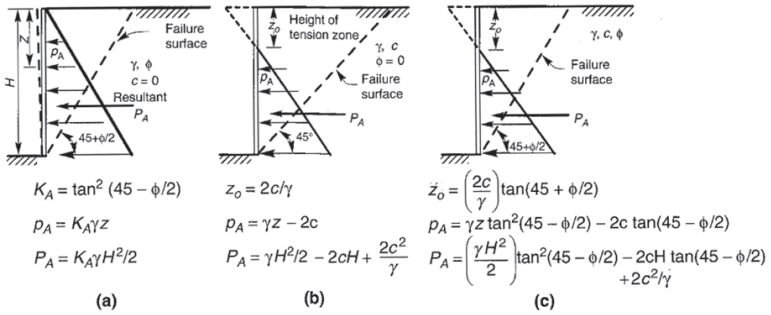


Figure 6.3. Minimum Rankine Active Earth Pressure Distributions for Backfills with Various Combinations of Frictional and Cohesive Strength: (a) Frictional Resistance, no Cohesion; (b) Cohesive Soil, no Frictional Resistance; (c) Combined Cohesion and Friction (Kramer, 1996).

For passive earth pressure conditions, the pressure "p_P" at a point on the back of a retaining wall can be determined as:

$$p_P = K_P \sigma'_v + 2c\sqrt{K_P} \tag{6.5}$$

where K_P is the coefficient of maximum passive earth pressure. In case of a smooth (no interface friction between wall and soil) wall and horizontal backfill, coefficient of passive earth pressure can be formulated as:

$$K_P = \frac{1+\sin\phi}{1-\sin\phi} = tan^2\left(45+\frac{\phi}{2}\right) \tag{6.6}$$

When the cohesionless backfill inclined at an angle of β ($\beta \leq \phi$) with the horizontal, K_P can be determined as:

$$K_P = \cos\beta\frac{\cos\beta+\sqrt{cos^2\beta-cos^2\phi}}{\cos\beta-\sqrt{cos^2\beta-cos^2\phi}} \tag{6.7}$$

When β=0, Equation 6.7 is equivalent to Equation 6.6. Angle of internal friction and cohesion of the soil influence the pressure distribution behind the wall which is indicated by Equation 6.5. Possible pressure distributions depending on shear strength components (ϕ and c) are shown in Figure 6.4.

For dry homogeneous cohesionless backfills, which are suggested and widely used instead of cohesive ones, a triangular passive pressure distribution oriented parallel to the backfill surface is expected by Rankine. The passive earth pressure resultant, PP, acts at a point located H/3 above the base of a wall height, H (Figure 6.4a) with magnitude:

$$P_P = \frac{1}{2}K_P\Upsilon H^2 \tag{6.8}$$

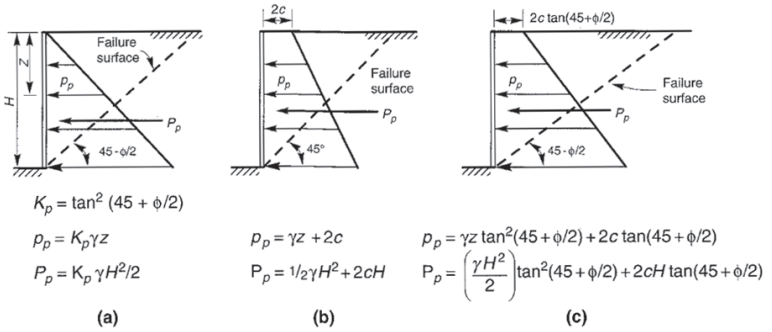


Figure 6.4. Maximum Rankine Passsive Earth Pressure Distributions for Backfills with Various Combinations of Frictional and Cohesive Strength: (a) Frictional Resistance, no Cohesion; (b) Cohesive Soil, no Frictional Resistance; (c) Combined Cohesion and Friction (Kramer, 1996).

Effective stresses are directly influenced by water in the backfill. In such a case, hydrostatic pressure that is caused by water must be added to the lateral earth pressure. Therefore, presence of water in the backfill behind a retaining wall increases total lateral thrust on a wall. Eventually, drainage of backfill must be provided to reduce the loads acting on a retaining wall.

6.1.1.2. Coulomb Theory. Coulomb developed the first theory for lateral earth pressures acting on retaining structures in 1776. Although Coulomb Theory is older than Rankine's, it is more sophisticated than Rankine Theory. The Coulomb Theory is generally similar to Rankine theory, but differences between Coulomb and Rankine Theory are:

- There is friction between the wall and soil and takes into account by using a soil-wall interface friction angle of δ. Soil-wall friction angle δ=$2\phi/3$ is commonly used, but it ranges from $\phi/2$ to $2\phi/3$ and.
- Lateral pressure is not limited to vertical walls.
- The resultant force is not necessarily parallel to the backfill surface because of the soil-wall friction δ.

Coulomb assumed a planar failure surface and obtained the force acting on the back of the retaining structure from the weight of the wedge of soil above failure surface. Wedges for active and passive pressures are given in Figure 6.5a and Figure 6.6a. In Coulomb Theory, equilibrium of forces is used to calculate the magnitude of the soil thrust acting on the wall for both minimum active and maximum passive pressures. The failure surface that produces the greatest active thrust or the smallest passive thrust can be considered critical failure plane. In order to find the critical failure plane, various analysis should be made with different potential failure planes.

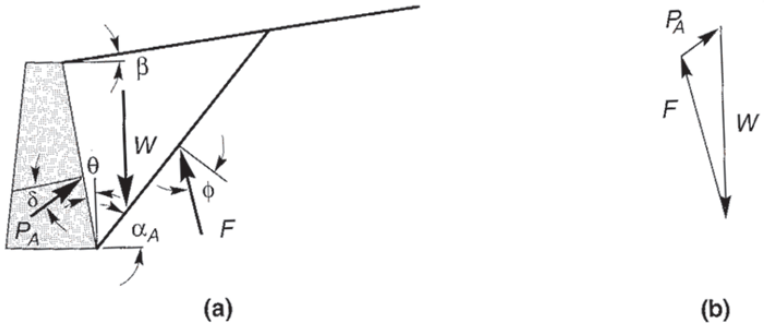


Figure 6.5. Triangular Active: (a) Triangular Active Wedge Bounded by Planar Backfill Surface, Failure Surface and Wall; (b) Force Polygon for Active Coulomb Wedge. The Critical Failure Surface is that Which Gives the Largest Value of PA (Kramer, 1996).

When minimum active earth pressure conditions develop, force equilibrium (Figure 6.5b) is used to calculate the active thrust (Figure 6.5a) on a wall. The distribution of active pressure cannot be predicted precisely. However, it can be presumed to be triangular for linear backfill surfaces without surcharge loads. Therefore, P_A acts at a point located H/3 above the height of a wall of height H for the linear backfill without surcharge load.

For critical failure plane, Equation 6.9 can be used to calculate the active thrust acting on a wall retaining a cohesionless backfill.

$$P_A = \frac{1}{2} K_A \gamma H^2 \tag{6.9}$$

coefficient of active earth pressure K_A is formulated as;

$$K_A = \frac{cos^2(\phi - \theta)}{cos^2\theta \cos(\delta + \theta) \left[1 + \sqrt{\frac{\sin(\delta+\phi)\sin(\phi-\beta)}{\cos(\delta+\theta)\cos(\beta-\theta)}}\right]^2} \tag{6.10}$$

The angles β, θ and δ are shown in Figure 6.5a. The angle of critical failure surface to the horizontal α_A is determined as:

$$\alpha_A = \phi + \tan^{-1}\left[\frac{\cos(\phi - \beta) + C_1}{C_2}\right] \tag{6.11}$$

where

$$C_1 = \sqrt{\tan(\phi - \beta)\left[\tan(\phi - \beta) + \cot(\phi - \theta)\right]\left[1 + \tan(\delta + \theta)\cot(\phi - \theta)\right]} \tag{6.12}$$

and

$$C_2 = 1 + \left\{\tan(\delta + \theta)\left[\tan(\phi - \beta) + \cot(\phi - \theta)\right]\right\} \tag{6.13}$$

For maximum passive conditions shown in Figure 6.6, Equation 6.14 can be used to calculate the passive thrust acting on a wall retaining a cohesionless backfill.

$$P_P = \frac{1}{2} K_P \gamma H^2 \tag{6.14}$$

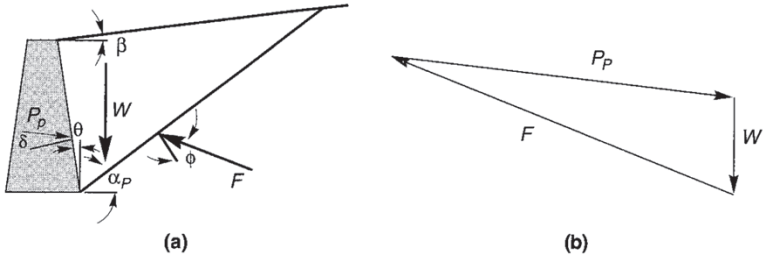


Figure 6.6. Triangular Passive: Triangular Passive Wedge Bounded by Planar Backfill Surface, Failure Surface and Wall; (b) Force Polygon for Passive Coulomb Wedge. The Critical Failure Surface is that Which Gives the Largest Value of PP (Kramer, 1996).

Coefficient of passive earth pressure KP is formulated as;

$$K_P = \frac{cos^2(\phi+\theta)}{cos^2\theta\cos(\delta-\theta)\left[1+\sqrt{\frac{\sin(\delta+\phi)\sin(\phi+\beta)}{\cos(\delta-\theta)\cos(\beta-\theta)}}\right]^2} \tag{6.15}$$

The angles β, θ and δ are shown in Figure 6.6a. The angle of critical failure surface to the horizontal ?P is determined as:

$$\alpha_P = -\phi + \tan^{-1}\left[\frac{\tan(\phi+\beta)+C_3}{C_4}\right] \tag{6.16}$$

where

$$C_3 = \sqrt{\tan(\phi+\beta)\left[\tan(\phi+\beta)+\cot(\phi+\theta)\right]\left[1+\tan(\delta-\theta)\cot(\phi+\theta)\right]} \tag{6.17}$$

and

$$C_4 = 1+\left\{\tan(\delta-\theta)\left[\tan(\phi+\beta)+\cot(\phi+\theta)\right]\right\} \tag{6.18}$$

When Rankine Theory and Coulomb Theory compared, it can be seen that Coulomb Theory can be used to calculate soil thrusts on walls with irregular backfill slopes, concentrated loads on the backfill surface an seepage forces. By considering the soil above a potential failure plane as a free body and including forces due to concentrated

loads, water pressures, and so on, the magnitude of the resultant thrust (P_A, P_P) can easily be computed (Kramer, 1996).

6.1.2. Pseudo-Static and Pseudo-Dynamic Methods for Seismic Pressures on Retaining Walls

Retaining walls are used throughout seismically active areas. Permanent deformation or collapse of retaining walls have seen due to earthquake loads in many historical cases. For this reason, behaviour of retaining walls under seismic loads should be taken into consideration while designing a retaining wall.

The response of even simplest type of retaining wall to dynamic loads is pretty difficult. Well-documented case histories involving field measurements, model tests and numerical analyses enabled researchers to develop various approaches to understand the behaviour of retaining walls under dynamic loads.

Pseudo-static and pseudo-dynamic approaches are the most simplified approaches to the seismic design for retaining walls. Such methods involve estimating the loads imposed on the wall during earthquake shaking and then ensuring that the wall resist those loads. Although the actual loading on retaining walls during earthquakes is extremely complicated, seismic pressures on retaining walls can be calculated approximately using simplified methods.

6.1.2.1. Mononobe-Okabe's Pseudo-Static Method. Okabe, (1926) and Mononobe and Matsuo, (1929) founded pseudo-static analysis to estimate the seismic earth pressures acting on retaining structures. The Mononobe-Okabe method is developed by modifying the static Coulomb theory. In Mononobe-Okabe method, pseudo-static accelerations are used to obtain pseudo-static forces. The pseudo-static accelerations are applied to a Coulomb active or passive wedge. Consequently, force equilibrium of the wedge gives the pseudo-static soil thrust acting on a retaining structure. For active case of dry and cohesionless backfill, Figure 6.7 illustrates the situation in which M-O

theory was developed. Horizontal and vertical pesudo-static forces, whose magnitudes are related to the mass of the wedge and pseudo-static accelerations, acting on the wall in addition to the forces that exist in static conditions.

$$a_h = k_h ganda_v = k_v g \tag{6.19}$$

It is known that the stability of a retaining structure is reduced by an increase in active pressure. Additionally, positive horizontal acceleration coefficient increases the total active thrust acting on retaining structure, so Mononobe-Okabe method produces seismic loads that are more critical than static loads.

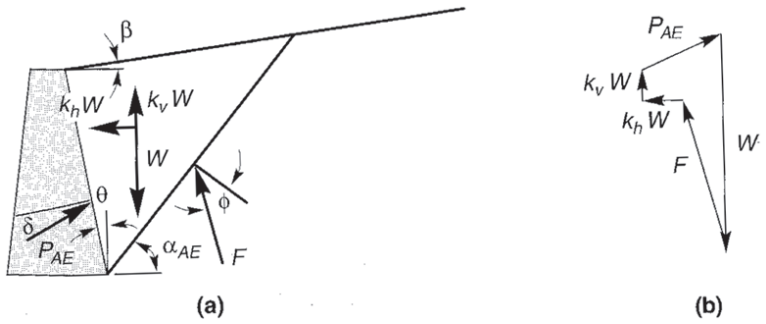


Figure 6.7. Forces Acting: (a) Forces Acting on Active Wedge in Mononobe-Okabe Analysis; (b) Force Polygon Illustrating Equilibrium of Forces Acting on Active Wedge (Kramer, 1996).

According to M-O method, the total active thrust can be expressed as;

$$P_{AE} = \frac{1}{2} K_{AE} \gamma H^2 (1 - k_v) \tag{6.20}$$

coefficient of dynamic active earth pressure K_{AE} is formulated as;

$$K_{AE} = \frac{cos^2(\phi - \theta - \psi)}{\cos\psi cos^2\theta \cos(\delta + \theta + \psi) \left[1 + \sqrt{\frac{\sin(\delta+\phi)\sin(\phi-\beta-\psi)}{\cos(\delta+\theta+\psi)\cos(\beta-\theta)}}\right]^2} \tag{6.21}$$

where $\phi - \beta \geq \psi, \gamma = \gamma_d$ and $\psi = \tan^{-1}$ [k_h/(1-k_v)]. The angle of critical failure surface to the horizontal α_{AE} is flatter than the critical failure surface for static conditions

(Zarabi-Kashani, 1979). The angle of failure surface to horizontal is determined as:

$$\alpha_{AE} = \phi - \psi + \tan^{-1}\left[\frac{-\tan(\phi-\psi-\beta)+C_{1E}}{C_{2E}}\right] \tag{6.22}$$

where

$$\begin{aligned} C_{1E} &= \sqrt{\tan(\phi-\psi-\beta)\left[\tan(\phi-\psi-\beta)+\cot(\phi-\psi-\theta)\right]} \\ &= \sqrt{\left[1+\tan(\delta+\psi+\theta)\cot(\phi-\psi-\theta)\right]} \end{aligned} \tag{6.23}$$

and

$$C_{2E} = 1 + \left\{\tan(\delta+\psi+\theta)\left[\tan(\phi-\psi-\beta)+\cot(\phi-\psi-\theta)\right]\right\} \tag{6.24}$$

According to M-O analysis, P_{AE} acts at a point H/3 above the base of a wall of height, H. On the other hand, it was seen in experimental results that P_{AE} actually acts at a higher point under dynamic loading conditions. The total active thrust P_{AE} (Equation 6.20) can be divided into a static component P_A from Coulomb's theory (Equation 6.9) and a dynamic component ΔP_{AE} (Kramer, 1996):

$$P_{AE} = P_A + \Delta P_{AE} \tag{6.25}$$

It is already known that the static component acts at H/3 above the base of the wall. Seed and Whitman (1970) recommended that dynamic component be taken to act at approximately 0.6H. Therefore, acting point of the total active thrust above the base will be:

$$h = \frac{P_A(H/3) + \Delta P_{AE}(0.6H)}{P_{AE}} \tag{6.26}$$

Relative magnitudes of P_A and P_{AE} influence the value of h. M-O analyses show that k_v, when taken as one-half to two-thirds the value of k_h, affects P_{AE} by less than

10%. Seed and Whitman (1970) concluded that vertical accelerations can be ignored when the M-O method is used to estimate P_{AE} for typical wall designs (Kramer, 1996).

For passive case of dry and cohesionless backfill, Figure 6.8 illustrates the situation in which M-O theory was developed. The parameters used in pseudo-static analysis of passive case can be determined similar to the active case. However, direction of the horizontal acceleration must be determined carefully, which influences the stability analysis of the wall. A positive horizontal acceleration coefficient causes the total passive thrust to be less than the static passive thrust, which makes the loading conditions more critical. Total passive thrust acting on a wall is calculated as:

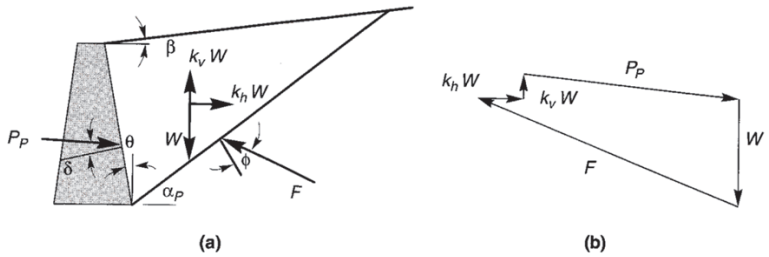


Figure 6.8. Forces Acting: (a) Forces Acting on Passive Wedge in Mononobe-Okabe Analysis; (b) Force Polygon Illustrating Equilibrium of Forces Acting on Passive Wedge (Kramer, 1996).

$$P_{PE} = \frac{1}{2} K_{PE} \gamma H^2 \left(1 - k_v\right) \tag{6.27}$$

coefficient of dynamic active earth pressure KPE is formulated as;

$$K_{PE} = \frac{cos^2(\phi + \theta - \psi)}{\cos\psi cos^2\theta \cos\left(\delta - \theta + \psi\right)\left[1 + \sqrt{\frac{\sin(\delta+\phi)\sin(\phi+\beta-\psi)}{\cos(\delta-\theta+\psi)\cos(\beta-\theta)}}\right]^2} \tag{6.28}$$

The angle of failure surface to horizontal is determined as:

$$\alpha_{PE} = \psi - \phi + \tan^{-1}\left[\frac{\tan\left(\phi + \psi + \beta\right) + C_{3E}}{C_{4E}}\right] \tag{6.29}$$

where

$$C_{3E} = \sqrt{\tan(\phi + \beta - \psi)\left[\tan(\phi + \beta - \psi) + \cot(\phi + \theta - \psi)\right]}$$
$$= \sqrt{\left[1 + \tan(\delta + \psi - \theta)\cot(\phi + \theta - \psi)\right]} \tag{6.30}$$

and

$$C_{4E} = 1 + \left\{\tan(\delta + \psi - \theta)\left[\tan(\phi + \beta - \psi) + \cot(\phi + \theta - \psi)\right]\right\} \tag{6.31}$$

Similar to active case, total passive thrust can be divided into its static and dynamic components:

$$P_{AE} = P_A + \Delta P_{AE} \tag{6.32}$$

Static and dynamic components of the total passive thrust are computed from Coulomb theory and M-O method, respectively. It must be taken into consideration that the directions of the dynamic component and static component are opposite which causes a reduction in available passive resistance.

The Mononobe-Okabe method, which is an pseudo-static extension of the Coulomb analysis, is used widely to make dynamic analysis. However, due to the shortcomings of M-O method as listed below, M-O method should be used and interpreted carefully.

- All of the limitations that Coulomb theory is subjected are also valid for Mononobe-Okabe method.
- Mononobe Okabe analysis is subject to all of the limitations of pseudo-static analyses.
- Determination of the appropriate pseudo-static coefficient is difficult.
- The analysis is not appropriate for soils (e.g., liquefiable soils) that experience significant loss of strength during earthquakes.
- Mononobe-Okabe analysis overpredicts the actual total passive thrust, particu-

larly for $\delta > \phi/2$.

6.1.2.2. Steedman-Zeng's Pseudo-Dynamic Method. The pseudo-static analysis gives the linear distribution of seismic earth pressure in a very approximate way. Determining seismic earth pressure in a simple and approximate way is possible. However, in order to account for phase difference and amplification effects within the backfill behind a retaining wall, Steedman and Zeng (1990) proposed another simple approach called pseudo-dynamic analysis can be used.

Steedman and Zeng (1990) considered in their analysis a vertical rigid retaining wall supporting a particular value of soil friction angle (ϕ) and a particular value of seismic horizontal acceleration ($k_h g$, where g is the acceleration due to gravity) only (Choudhury and Nimbalkar, 2006).

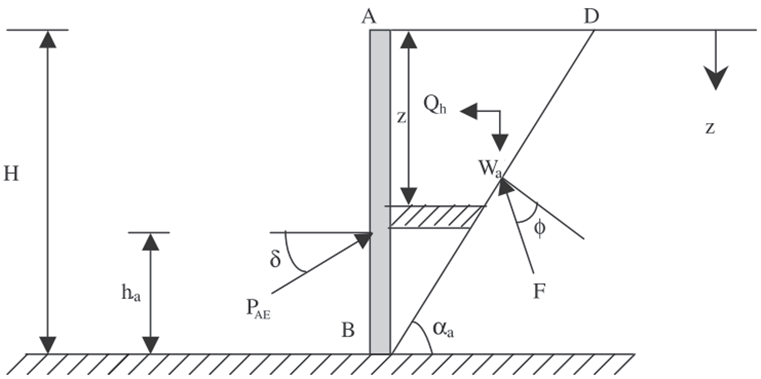


Figure 6.9. Model Retaining Wall Considered for Computation of Pseudo Dynamic Active Earth Pressure (After Choudhury and Nimbalkar, 2006).

Consider the fixed base vertical rigid retaining wall AB of height H as shown in Figure 6.9. Where, Q_h is the Horizontal seismic inertia force in active case, W_a is the Weight of the failure wedge in active case, F is the Soil reaction acting at an angle of ϕ (angle of internal friction of the soil) to the normal to the inclined failure wedge, α_a is the Angle of failure plane to the horizontal in active case, P_{AE} is the Total active thrust of the soil, δ is the Wall friction angle.

The wall is supporting a cohesionless backfill material with horizontal ground.

If the base of the wall is subjected to harmonic horizontal seismic acceleration of amplitude ahg (where g is the acceleration due to gravity) the acceleration at any depth z and time t, below the top of the wall can be expressed as:

$$a_h(z,t) = a_h \sin\left(t - \frac{H-z}{V_s}\right) \tag{6.33}$$

where, V_s is the Shear wave velocity.

The mass of the thin element of wedge at depth z is:

$$m_a(z) = \frac{\gamma}{g}\frac{H-z}{\tan\alpha_a}dz \tag{6.34}$$

where, γ is the Unit weight of backfill.

The weight of the whole wedge is,

$$W_a = \frac{1}{2}\frac{\gamma H^2}{\tan\alpha_a} \tag{6.35}$$

The total horizontal inertial force Q_h acting within the failure zone can be expressed as:

$$Q_h(t) = \int_0^H m_a(z)\, a_h(z,t)\, dz = \frac{\lambda\gamma a_h}{4\pi^2 g\tan\alpha_a}\left[2\pi H\cos\omega\zeta + \lambda(\sin\omega\zeta - \sin\omega t)\right] \tag{6.36}$$

where $\lambda=2\pi V_s/\omega$ is the wavelength of the vertically propagating shear wave and ξ=t-H/V_s. The special case of a rigid wedge is given, in the limit, as:

$$\lim_{v_s\to\infty}(Q_h)_{max} = \frac{\gamma H^2 a_h}{2g\tan\alpha_a} = \frac{a_h}{g}W_a = k_h W_a \tag{6.37}$$

which is equivalent to the pseudo-static force assumed in the Mononobe-Okabe method. The total (static+dynamic) active thrust, P_{AE}(t) can be obtained by resolving forces on the wedge and considering the equilibrium of the forces and hence P_{AE}(t) can be

expressed as follows:

$$P_{AE}(t) = \frac{W_a \sin(\alpha_a - \phi) + Q_h(t) \cos(\alpha_a - \phi)}{\cos(\delta + \phi - \alpha_a)} \tag{6.38}$$

and the total earth pressure distribution by differentiating the total soil thrust:

$$\begin{aligned} p_{AE}(t) = \frac{\partial P_{AE}(t)}{\partial z} &= \frac{\gamma z}{\tan \alpha_a} \frac{\sin(\alpha_a - \phi)}{\cos(\delta + \phi - \alpha_a)} \\ &+ \frac{k_h \gamma z}{\tan \alpha_a} \frac{\cos(\alpha_a - \phi)}{\cos(\delta + \phi - \alpha_a)} \sin\left[\omega\left(t - \frac{z}{V_s}\right)\right] \end{aligned} \tag{6.39}$$

where ω is the angular frequency of base shaking.

The first term in Equation 6.39, which increases linearly with depth and does not vary with time, represents the static earth pressure acting on wall. The resultant static thrust acts in accordance with static earth pressure theories at a point h_s=H/3 above the base of the wall. The second term represents the dynamic earth pressure. It increases as a nonlinear function of depth with a shape that depends on the ratio H/λ. A typical example of nonlinear dynamic pressure is shown in Figure 6.10. Since the dynamic pressure increases nonlinearly with depth, the position of the dynamic thrust varies with time according to the Equation 6.40 (Kramer, 1996).

$$h_d = H - \frac{2\pi^2 H^2 \cos\omega\zeta + 2\pi\lambda H \sin\omega\zeta - \lambda^2(\cos\omega\zeta - \cos\omega t)}{2\pi H \cos\omega\zeta + \pi\lambda(\sin\omega\zeta - \sin\omega t)} \tag{6.40}$$

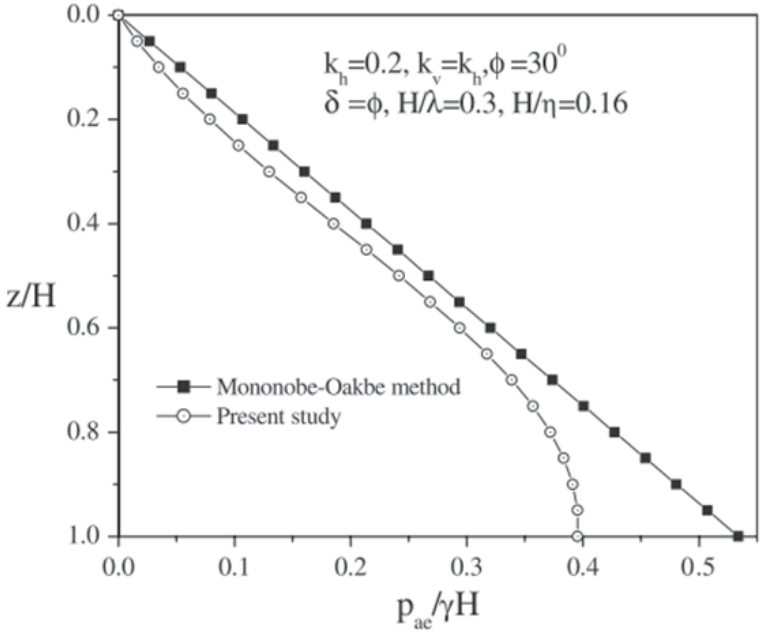


Figure 6.10. A Typical Comparison of Mononobe-Okabe and Steedman-Zeng Method for k_v=k_h=0.2, ϕ=30°, δ=ϕ, H/λ=0.3, H/η=0.16 (Choudhury and Nimbalkar, 2006).

For very low frequency motions (small H/λ, so the backfill moves essentially in phase), the point of application of the dynamic thrust is at h_d=H/3. For higher frequency motions, the point, where dynamic thrust acts on the wall, moves through the top of the wall, as illustrated in Figure 6.11.

To conclude, in pseudo-dynamic method by considering the time effect and phase change in shear and primary waves propagating in the backfill behind the rigid retaining wall, the seismic active earth pressure distribution as well as the total active thrust behind the retaining wall can be estimated. When compared to Mononobe-Okabe method, pseudo dynamic method gives more realistic non-linear active earth pressure distribution behind the retaining wall. Steedman and Zeng, (1989) found that the soil thrusts for backfills of different stiffnesses were close to those obtained when the mean shear wave velocities of the backfill were used in the pseudo-dynamic analyses. Choudhury and Nimbalkar, (2006) showed that the seismic active thrust is highly sensitive to the friction angle of the soil, ϕ and comparatively less sensitive to the wall friction angle, δ. Backfill amplification effects can also be considered by expressing a_h

as a function of depth [rather than as a constant in Equation 6.34] and repeating the integration of Equation 6.36. It should be noted that the loads acting on the wall and the height of the resultant soil thrust increases with backfill amplification (Kramer, 1996). Assuming that $a_h(z, t)$ varied linearly from the input acceleration at the base of the wall to a value twice as large at the top, Steedman and Zeng, (1990) showed good agreement with the results of centrifuge tests.

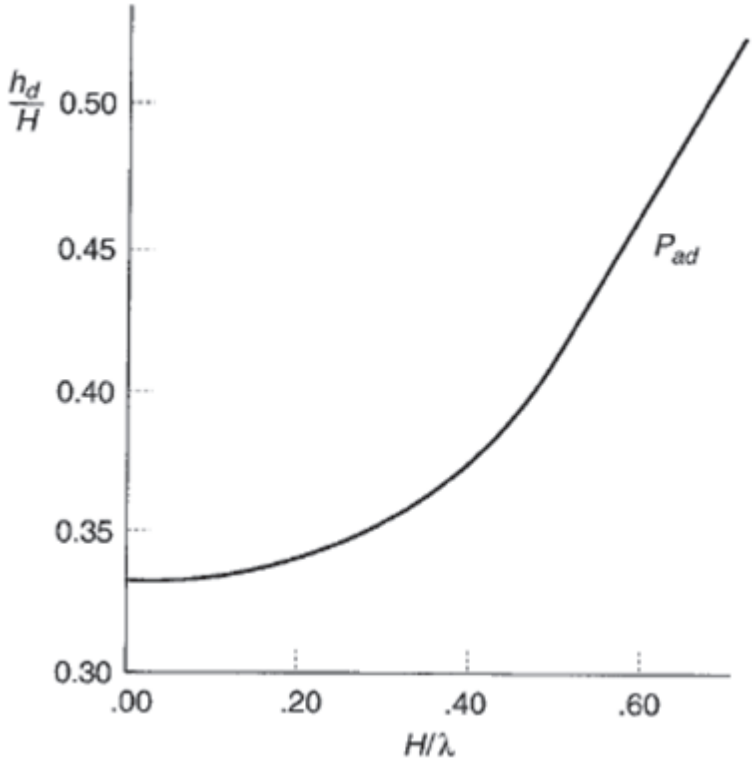


Figure 6.11. Location of Dynamic Thrust at Instant of Maximum Overturning Moment for k_h=0.2 (After Steedman and Zeng, 1990).

Passive state of horizontal earth pressure on the rigid retaining wall for seismic conditions is shown in Figure 6.12. Where, Q_{hp} is the Horizontal seismic inertia force in passive case, W_p is the Weight of the failure wedge in passive case, F is the Soil reaction acting at an angle of ϕ (angle of internal friction of the soil) to the normal to the inclined failure wedge, α_p is the Angle of failure plane to the horizontal in passive case, P_{PE} is the Total passive thrust of the soil, δ is the Wall friction angle.

Pseudo-dynamic analysis for passive seismic earth pressure conditions is similar

to active case. The mass of the thin element of thickness dz, assumed at depth z as shown in Figure 6.12 can be determined using the equation:

$$m_p(z) = \frac{\gamma}{g}\frac{H-z}{\tan\alpha_p}dz \tag{6.41}$$

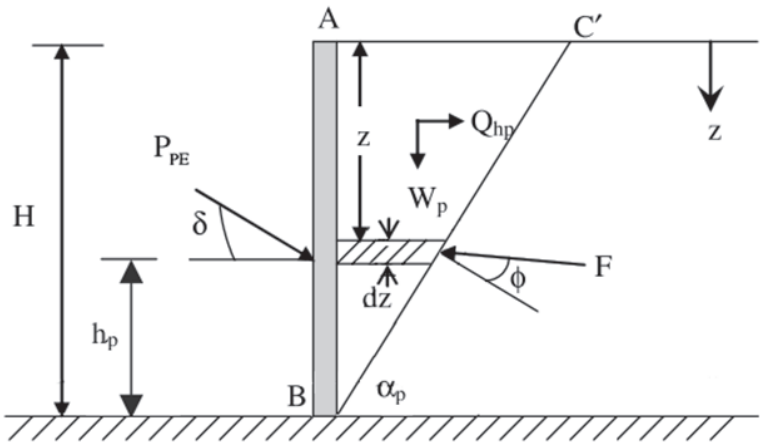


Figure 6.12. Model Retaining Wall Considered for Computation of Pseudo Dynamic Active Earth Pressure (After Choudhury *et al.*, 2006).

The weight of the failure wedge is,

$$W_p = \frac{1}{2}\frac{\gamma H^2}{\tan\alpha_p} \tag{6.42}$$

The total horizontal inertia force acting on the wall is given by,

$$Q_h(t) = \int_0^H m_p(z)\, a_h(z,t)\, dz = \frac{\lambda\gamma a_h}{4\pi^2 g\tan\alpha_p}\left[2\pi H\cos\omega\zeta + \lambda(\sin\omega\zeta - \sin\omega t)\right] \tag{6.43}$$

While determining the minimum seismic passive earth pressure, only the critical directions of Q_h (from left to right or from right to left) is taken into account. The total (seismic+dynamic) passive resistance P_{PE} can be calculated by resolving the forces on the wedge and considering the equilibrium of the forces. Therefore, P_{PE} is given as:

$$P_{PE}(t) = \frac{W_p\sin(\alpha_p+\phi) - Q_{hp}(t)\cos(\alpha_p+\phi)}{\cos(\delta+\phi+\alpha_p)} \tag{6.44}$$

P_{PE} is minimized with respect to trial inclination angle of failure surface, α_p and then the seismic passive earth pressure distribution, p_{PE} can be obtained by differentiating P_{PE} with respect to depth, z and can be expressed as follows:

$$p_{PE}(t) = \frac{\partial P_{PE}(t)}{\partial z} = \frac{\gamma z}{\tan \alpha_p} \frac{\sin(\alpha_p + \phi)}{\cos(\delta + \phi + \alpha_p)} - \frac{k_h \gamma z}{\tan \alpha_p} \frac{\cos(\alpha_p + \phi)}{\cos(\delta + \phi + \alpha_p)} \sin\left[\omega\left(t - \frac{z}{V_s}\right)\right] \tag{6.45}$$

Chouldhury *et al.*, (2006) stated that the seismic passive earth pressure is more sensitive to wall friction angle as compared to the seismic active earth pressure. By applying the pseudo- dynamic method, the seismic active earth pressures are more and seismic passive earth pressures are less as compared to those calculated by using conventional pseudo-static method of analysis. Thus the pseudo-dynamic method gives the desirable design values of seismic active and passive earth pressure coefficients compared to the existing values by pseudo-static method as it leads to safe approach of design of retaining wall against devastating effect of earthquake (Choudhury *et al.*, 2006).

6.1.3. Seismic Displacements of Retaining Walls

All of the seismic design approaches which are explained in previous sections give beneficial information about the seismic loads acting on retaining walls. Although, they can be used to calculate the factor of safety against failure; they don't provide information about permanent deformations during earthquakes and post earthquake serviceability of the wall. In some cases, even small deformations should be prevented for the serviceability of the wall. Hence, determining the displacements becomes crucial for retaining walls. Several methods have been proposed for predicting permanent deformations of yielding walls.

6.1.3.1. Newmark's Sliding Block Analysis. Newmark, (1965) developed a theory to calculate the permanent displacement of a retaining wall for a given input accelera-

tion time history. The purpose of the (Newmark, 1965) method is to estimate slope deformation for those cases where the pseudo-static factor of safety is less than 1.0. The (Newmark, 1965) method assumes that the slope will deform only during those portions of the earthquake when the out-of-slope earthquake forces cause the pseudo-static factor of safety to drop below 1.0. When this occurs, the slope will no longer be stable, and it will be accelerated downslope. The slope deformation increases when the slope is subjected to a pseudo-static factor of safety below 1.0. On the other hand, if the pseudo-static factor of safety drops below 1.0 for a mere fraction of a second, then the slope deformation will be limited (Day, 2002).

The soil mass is assumed to be a rigid block that fails in a rigid-plastic manner when the ground acceleration exceeds the critical or yield acceleration of the slope (Figure 6.13). Once sliding commences, it is assumed that the rigid mass continues to slide under the actions of the inertia force from the ground acceleration pulse and a constant resisting force. When the acceleration pulse diminishes in magnitude or reverses in direction, the relative velocity between the sliding block and the supporting ground or base eventually reduces to zero and the movement relative to the base ceases. Successive displacements take place each time the ground acceleration exceeds the critical value. Each displacement step is calculated by a double integration of the parts of the input acceleration time-history that are above the critical acceleration value and those parts that are below until the relative velocity (calculated by the first integration) between the sliding mass reduces to zero (Wood, 2008).

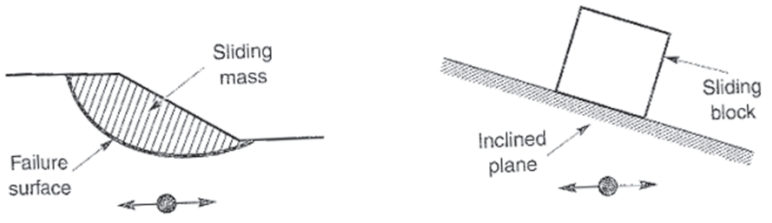


Figure 6.13. Analogy Between Potential Slope Failure and Block Resting on Inclined Plane, (Kramer, 1996).

Under static conditions; the ratio of the available static resisting force, R_s and the static driving force, D_s must be equal or greater than 1.0 in order to achieve equilibrium

of the block in the direction parallel to the plane. When the sliding is assumed purely frictional (c=0) and ϕ is the angle of friction between the block and the plane, factor of safety (FS) is given by:

$$FS = \frac{available resisting force}{static driving force} = \frac{R_s}{D_s} = \frac{W \cos\beta \tan\phi}{W \sin\beta} = \frac{\tan\phi}{\tan\beta} \tag{6.46}$$

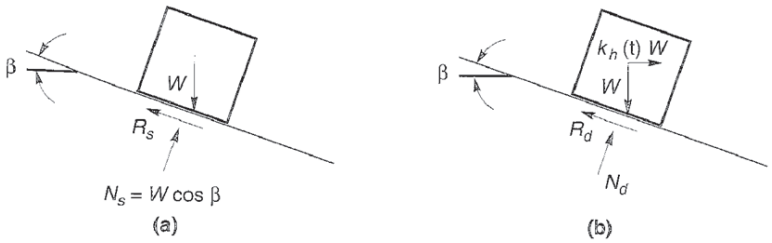


Figure 6.14. Forces Acting on A Block Resting on an Inclined Plane: (a) Static Conditions, (b) Dynamic Conditions (Kramer, 1996).

The effects of vertical accelerations will be neglected for simplicity (Figure 6.14b). Therefore, the effect of inertial forces transmitted to the block by horizontal vibration of the inclined plane with acceleration, $a_h(t)=k_h(t)g$ shall be considered for seismic case. Horizontal inertial force k_hW is generated because of the horizontal acceleration of the block. When the inertial force acts in the downslope direction, resolving forces perpendicular to the inclined plane gives:

$$FS_d(t) = \frac{available resisting force}{pseudo - static driving force} = \frac{R_d}{D_d} = \frac{[\cos\beta - k_h(t)\sin\beta]\tan\phi}{\sin\beta + k_h(t)\cos\beta} \tag{6.47}$$

It can be seen in Equation 6.47 that the FS_d decreases with the increase of k_h. In addition, some positive value of k_h (for a statically stable block) that will produce a factor of safety of 1.0. This k_h coefficient is called *yield coefficient*, k_y, and yield acceleration can be expressed as $a_y=k_hg$. Yield acceleration is the limit value of stability. In other words, it is minimum pseudo-static acceleration required to produce instability of the block and for sliding in the downslope direction it can be expressed as:

$$k_y = \tan(\phi - \beta) \tag{6.48}$$

When β and ϕ are small, sliding in the uphill direction can occur. In this case, k_y can be calculated as:

$$k_y = \frac{\tan\phi - \tan\beta}{1 + \tan\phi\tan\beta} \tag{6.49}$$

When $a_y/a_{max} \geq 0.17$, Newmark found that a reasonable upper bound to the permanent displacements, dmax, was given by:

$$d_{max} = \frac{{v^2}_{max}}{2a_y}\frac{a_{max}}{a_y} \tag{6.50}$$

6.1.3.2. Richards-Elms Method. There are very few methods available to estimate seismic displacements of rigid retaining walls. (Richard and Elms, 1979) proposed a simplified but more rational design criteria consisting in the limitation of the permanent outward displacement of the wall caused by the earthquake to an allowable value. The Richards-Elms development consisted in applying this method to retaining walls assuming that the earth thrust at failure can be computed with the Mononobe-Okabe formula this method was based on Newmark's rigid sliding block analysis (1965) and (Franklin and Chang's, 1977) solution for upper bound permanent displacements for several natural and synthetic ground motions.

The assumptions for the Richards-Elms analysis are:

- The retaining wall is rigid.
- The inertia forces due to the mass of the wall are included.
- Only the sliding of the wall and dry backfill is considered.
- After the horizontal ground acceleration exceeds the yield acceleration, the wall moves away from the backfill until the velocity of the wall motion changes.
- The backfill failure wedge moves as a rigid body with the retaining wall.

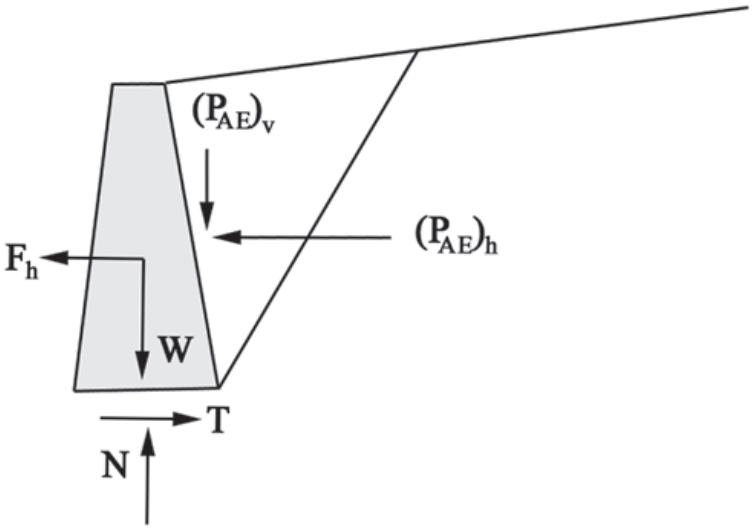


Figure 6.15. Gravity Wall Acted Upon by Gravity and Pseudo-Static Acceerations.

Yield acceleration for the wall-backfill system needs to be determined for the application of the Richards-Elms method. When the active wedge is subjected to acceleration acting toward the backfill, the resulting inertial forces will act away from the backfill. The level of acceleration that is just large enough to cause the wall to slide on its base is the yield acceleration. When the acceleration value reaches the value of yield acceleration, from the equilibrium of horizontal and vertical forces:

$$T = F_h + (P_{AE})_h and N = W + (P_{AE})_v \tag{6.51}$$

Where:

$$T = N \tan \phi_b \tag{6.52}$$

$$F_h = a_y \frac{W}{g} \tag{6.53}$$

$$(P_{AE})_h = P_{AE} \cos(\delta + \theta) \tag{6.54}$$

$$(P_{AE})_v = P_{AE} \sin(\delta + \theta) \tag{6.55}$$

The yield acceleration, a_y can be computed by using substitutions given above:

$$a_y = \left[\tan \phi_b - \frac{P_{AE} \cos(\delta + \theta) - P_{AE} \sin(\delta + \theta)}{W}\right] g \tag{6.56}$$

The value of P_{AE} in Equation 6.56 is calculated by using Mononobe-Okabe method. The yield acceleration ay must be known to calculate P_{AE} while using Mononobe-Okabe method. Therefore, the solution of the Equation 6.56 must be obtained iteratively, (Richards and Elms, 1979) prepared the following expression for permanent displacement:

$$d_{perm} = 0.087 \frac{{v^2}_{max} {a^3}_{max}}{{a^4}_y} \tag{6.57}$$

where v_{max} is the peak ground velocity, a_{max} is the peak ground acceleration for the wall-backfill system.

6.1.3.3. Whitman-Liao Method. Richards and Elms, (1979) proposed a simplified method which offers a realistic approach to the estimation of gravity wall displacements. Although the assumptions enable the calculation simpler, they neglect some aspects of the dynamic earth pressure problem. (Whitman and Liao, 1985) determined the various errors which result from the assumptions of the Richards-Elms method. The most important errors are caused by the neglect of:

- dynamic response of the backfill
- kinematic factors
- tilting mechanisms
- vertical accelerations.

After finite element analyses, effects of the dynamic response of the backfill on wall displacements were explained. Analyses show that the compliance of input motions with the natural period of the backfill causes amplification which produce greater permanent displacement than the rigid block model used by Richards and Elms.

Analyses in which the backfill wedge and wall were treated as separate blocks instead of single block model of Richards and Elms are conducted to determine the effect of kinematic factors. Zarabi-Kashani, (1979) used separate blocks approach in their analyses and showed that the kinematic requirements of horizontal and vertical displacement of the backfill wedge cause smaller displacements than the single block approach.

Richards and Elms considered only sliding in their analysis. However, studies in which tilting and sliding was considered together determined that tilting of the wall generally increases the wall displacements. Finally, consideration of vertical accelerations causes slightly larger displacements than when they are neglected. Whitman and Liao found that the permanent displacements were lognormally distributed with mean value:

$$\bar{d}_{perm} = \frac{37{v^2}_{max}}{a_{max}} exp\left(\frac{-9.4a_y}{a_{max}}\right) \tag{6.58}$$

6.1.4. Finite Element Analysis

Using numerical techniques for the design and analysis of geosynthetic reinforced soil walls offers several advantages, such as analyzing complex models more realistic and easier. There are various software products that are using numerical methods are available and they give more realistic results when compared with the traditional simplified methods.

Finite element method (FEM) is the most commonly used numerical method. It can be used to analyze various geotechnical structures such as embankments, shallow

and deep foundations. Because of their complex mechanism, analyzing the geosynthetic reinforced retaining walls using finite element method is developed recently. However, finite element analysis provides additional information compared to traditional limit-equilibrium analysis, such as deformation and tensile load in the reinforcement layers that are necessary for understanding the performance of reinforced soil structures. The results obtained from finite element analysis can be used to guide the development of more accurate limit- equilibrium design procedures (Enünlü, 2007).

On the other hand, finite element analysis is very compatible with the computer programming. Software products those using finite element method enables operator to simulate the construction sequences such as such as backfilling and the installation of reinforcement layers and wall facings. Since the computing costs have significantly reduced, modern finite element methods use a discrete approach. The soil, reinforcement, facing and their interactions are modeled separately in discrete approach.

6.2. Stability Analysis For Geosynthetic Reinforced Soil Retaining Walls

In this section, stability analyses for geosynthetic reinforced segmental retaining wall systems under static and seismic loading conditions were investigated. Such analysis consist of separate calculations to determine factors of safety against external, internal and facing modes of failure.

External stability calculations consider the reinforced soil zone and the facing column as a monolithic gravity structure. The calculation of factors of safety for external stability is similar to that used for conventional reinforced concrete gravity structures. Factors of safety against:

- base sliding,
- overturning about the toe,
- foundation bearing capacity

are evaluated for the external stability (Figure 6.16).

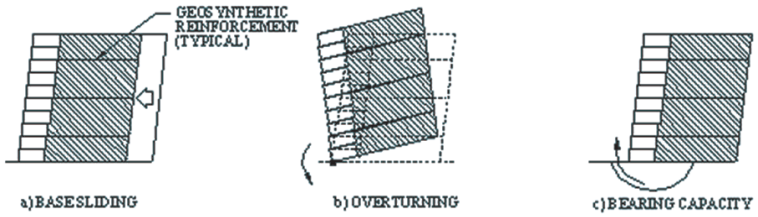


Figure 6.16. Potential External Failure Mechanisms of MSE Wall, (FHWA-NHI-00-043, 2001).

Internal stability analyses for geosynthetic reinforced soil walls are carried out to ensure that the structural integrity of the reinforced zone is preserved with respect to:

- reinforcement over-stressing within the reinforced zone,
- pullout of geosynthetic reinforcement layers from the anchorage zone and
- internal sliding along a reinforcement layer (Figure 6.17).

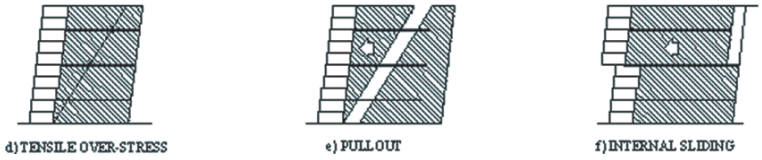


Figure 6.17. Potential Internal Failure Mechanisms of MSE Wall, (FHWA-NHI-00-043, 2001).

Facing stability analyses are carried out to ensure that the facing column is stable at all elevations above the toe of the wall and connections between the facing units and reinforcement layers are not over-stressed. Potential facing failure types of MSE walls are:

- shear failure,
- connection failure,
- local overturning,
- crest toppling (Figure 6.18)

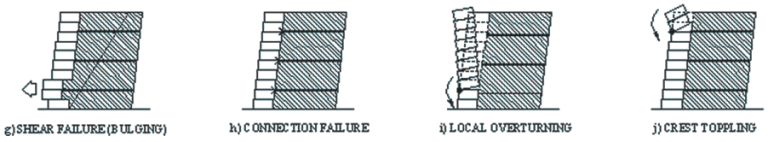


Figure 6.18. Potential Facing Failure Mechanisms of MSE Wall, (FHWA-NHI-00-043, 2001).

Minimum recommended factors of safety for static and seismic design of geosynthetic reinforced SRW structures are given in Table 6.1. In general, minimum recommended factors of safety for seismic design are taken as 75% of the values recommended for statically loaded structures following AASHTO/ FHWA practice (Kadayıfçı, 2005).

Table 6.1. Potential External Failure Mechanisms of MSE Wall.

Failure Mode	**Abbr.**	**Static**	**Dynamic**
a) Base Sliding	FS_{sl}	1.5	1.1
b) Overturning	FS_{ot}	1.5	1.1
c) Bearing Capacity	FS_{bc}	2.0	1.1
Global Stability	FS_{gl}	1.3-1.5	1.5
d) Tensile Over-Stress	FS_{os}	1.0	1.0
e) Pull Out	FS_{po}	1.5	1.1
f) Internal Sliding	FS_{sli}	1.5	1.1
g) Shear (Buging)	FS_{sc}	1.5	1.1
h) Connection	FS_{cs}	1.5	1.1
i) Local Overturning	FS_{otl}	1.5	1.1
j) Crest Toppling	FS_{otc}	1.5	1.1

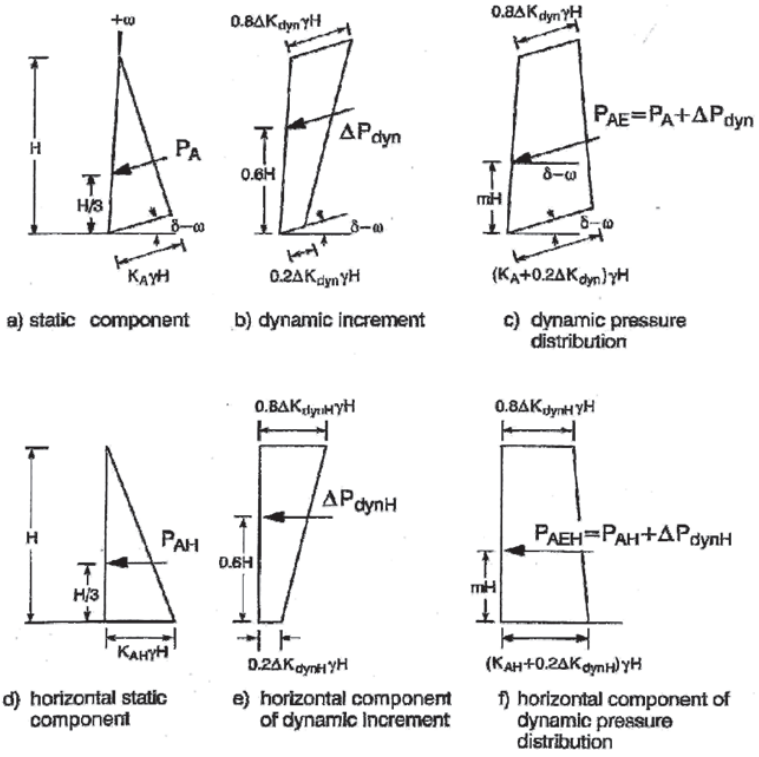


Figure 6.19. Earth Pressure Distributions Due to Soil Self-Weight, (FHWA-NHI-00-043, 2001).

6.2.1. External Stability

External stability calculations are similar to those carried out for conventional (gravity) soil retaining wall structures with the gravity mass now taken as the composite mass formed by the reinforced soil zone and the facing column. The facing column may comprise a significant part of the gravity mass, particularly for low height structures (and hence generate additional inertial forces during a seismic event). For brevity, this gravity mass is called the reinforced mass or reinforced zone in this document.

The dynamic earth pressure distribution shown in Figure 6.19f is used to calculate the destabilizing forces in otherwise conventional expressions for the factor of safety against sliding along the foundation surface, overturning about the toe of the structure and bearing capacity failure of the foundation soils. $k_h = a_c/2g$ is used to calculate the magnitude of the uniformly applied horizontal seismic coefficient value k_h, in all external stability calculations (i.e. k_h=k_h(ext)).

The peak friction angle is taken as $\phi = \phi_b$ in earth pressure and force calculations. The calculation of force components P_{AH} and ΔPd_{ynH} assumes full mobilization of inter face friction between the reinforced soil zone and the retained soil (i.e. $\delta = \phi$ with ϕ equal to lesser of ϕ_r and ϕ_b values).

The simplified geometry and body forces illustrated in Figure 6.20 are used in the external stability calculations to follow. Where, W_i is the Total weight of the reinforced zone extending from the back of the facing column to length L_{min} beyond the face of the wall and having constant height H; $W\beta$ is the Contribution of the wedge of soil in the slope above the crest of the wall at height H; and W_w is the Total weight of the facing column.

$$W_w = N_w L_w H_w \gamma_w = L_w H \gamma_w \tag{6.59}$$

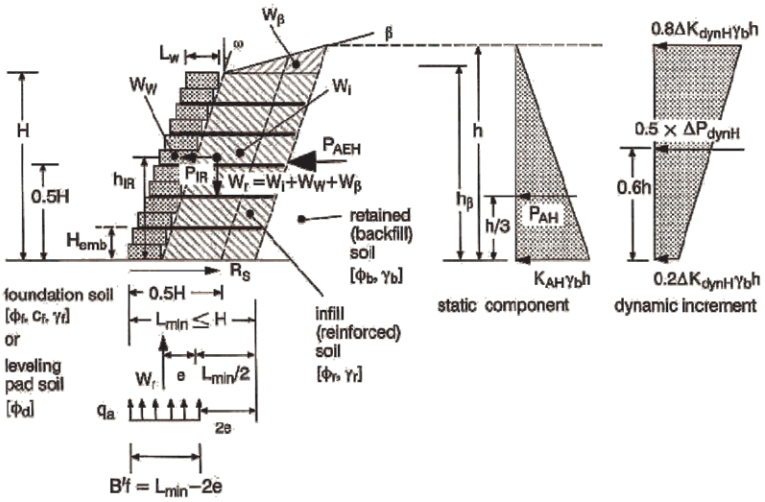


Figure 6.20. Geometry and Forces in External Stability Calculations for Reinforced SRW Structures, (FHWA-NHI-00-043, 2001).

The results of parametric analyses reported by (Bathurst and Cai, 1995) have illustrated that as the backslope angle β for the infinite slope case increases, the factors of safety against external stability modes of failure diminish rapidly and reasonable solutions even for modest values of ground acceleration are not possible. This result is due in part to the formulation of earth forces calculated using the Mononobe-Okabe

method and the conservative estimates of soil strength parameters that are routinely used for the design and analysis of geosynthetic reinforced wall systems. In order to prevent this problem from developing the following empirical rule is proposed in this design guideline: Regardless of the wall geometry and reinforcement lengths the maximum value of the reinforced zone width L_{min} (Figure 6.20) is restricted to the height of the wall H. Hence $L_{min} \leq H$. This approach has been adopted by the Reinforced Earth Company (RECO, 1990) for the design of steel strip reinforced soil wails for the same reasons given above. The total weight of the reinforced soil zone is:

$$W_r = W_w + W_i + W_\beta \tag{6.60}$$

The total weight W_r is used to calculate resisting terms in factor of safety expressions for base sliding and overturning and the applied load in bearing capacity calculations. Quantities W_i and W_β can be calculated using the following expressions:

$$W_i = (L_{min} - L_w)\, H\gamma_r \tag{6.61}$$

$$W_\beta = \frac{1}{2}\gamma_r (L_{min} - L_w)^2 \left(\frac{\tan\beta}{1 - \tan\beta \tan\omega} \right) \tag{6.62}$$

The quantity P_{IR} in Figure 6.20 denotes the horizontal inertial force due to the reinforced mass used in external stability factor of safety calculations. Different strategies have been proposed in North America to compute $P_{IR} < k_h W_r$ to ensure reasonable designs (Bathurst and Alfaro, 1996). The justification is based on the expectation that horizontal inertial forces induced in the reinforced mass and the retained (backfill) soil zone will not reach peak values at the same time during a seismic event.

The method adopted here uses the AASHTO/FHWA approach and assumes that the horizontal inertial force P_{IR} is due to an equivalent mass comprising the facing column and a portion of the reinforced soil zone extending to a distance 0.5H beyond the face of the wall. The general approach is illustrated in Figure 6.20 and applies to

any infinite backfill slope condition (i.e. $\beta > 0$). The inertial force P_{IR} is calculated using:

$$P_{IR} = k_h\,(ext)\left(W_w + W_i' + W_\beta'\right) \tag{6.63}$$

Where the reduced inertial zone weights W_i' and W_β' are calculated by substituting L_{min}=0.5H in Equation 6.61 and Equation 6.62 Hence:

$$W_i' = (0.5H - L_w)\,H\gamma_r \tag{6.64}$$

$$W_\beta' = \frac{1}{2}\gamma_r(0.5H - L_w)^2\left(\frac{\tan\beta}{1 - \tan\beta\tan\omega}\right) \tag{6.65}$$

The dynamic earth force P_{AE} is applied at the back of the reinforced mass described by the minimum reinforcement length L_{min} and height h. The quantity h can be calculated as:

$$h = H + (L_{min} - L_w)\left(\frac{\tan\beta}{1 - \tan\beta\tan\omega}\right) \tag{6.66}$$

For structures with a horizontal backslope ($\beta = 0$) the problem geometry is simplified since h = H.

The horizontal component of dynamic earth force P_{AEH} acting over depth at the back of the reinforced zone is calculated using the following expression:

$$P_{AEH} = P_{AH} + 0.5\Delta P_{dynH} = \frac{K_{AH}\gamma_b h^2}{2} + 0.5\frac{\Delta K_{dynH}\gamma_b h^2}{2} \tag{6.67}$$

Note that only 50% of the dynamic earth force increment, ΔP_{dynH}, acting over height h is considered in external stability calculations.

The application of the dynamic increment of backfill soil force ΔP_{dynH} differs from the method used by AASHTO/FHWA. AASHTO/FHWA apply ΔP_{dynH} to the

back of the inertial zone identified by the dashed line at distance 0.5H behind the wall face in Figure 6.20. For sloped backfills the method used in this document is slightly more conservative but greatly simplifies calculations. For horizontal backfills there is no difference between methods with respect to location of the dynamic force increment. However, AASHTO/FHWA guidelines assume that the interface friction angle at the boundary between the reinforced zone and backfill soil is equal in magnitude to the angle of the constant slope behind the wall crest (i.e. δ=ϕ). However, there is no justification for linking interface friction angle to slope angle. The magnitude of earth pressures for external stability calculations in this document will almost always be less than AASHTO/FHWA values since δ=$\phi \geq \beta$. In addition, AASHTO/FHWA assumes that ω=0 for walls with ω<10° and this leads to higher earth pressures and hence more conservative static and seismic designs for reinforced SRW structures using their method. The interpretation of Coulomb and Mononobe-Okabe earth pressure theory used in NCMA document provides a seamless transition between the analysis and design of statically loaded structures described in the DMSRW and the methodology for seismic loaded soil retaining wall structures.

6.2.1.1. Base Sliding. The factor of safety against base sliding (FS_{sl}) is expressed by the ratio of resistance horizontal forces to driving horizontal forces. FS_{sl} at the bottom of the reinforced mass (i.e. bottom of the lowermost facing unit and reinforced soil zone) can be expressed as:

$$FS_{sl} = \frac{R_s}{P_{IR} + P_{AH} + 0.5\Delta P_{dynH}} \tag{6.68}$$

The base sliding resistance force, R_s, (Figure 6.20) is calculated as follows:

(i) If the reinforced soil (infill) or drainage fill controls:

$$R_s = C_{ds} W_r \tan\phi \tag{6.69}$$

with $\phi = \phi_d$ or ϕ_d whichever value has the least magnitude.

(ii) If the foundation soil controls:

$$R_s = C_{ds}\left[c_f L_{min} + W_r \tan\phi_f\right] \tag{6.70}$$

Here the quantity Cds is the coefficient of direct sliding and cannot exceed unity. For soil to soil interfaces the value for this parameter can be assumed to be equal to one. For the case of a geosynthetic layer placed at the base of the reinforced soil zone, $C_{ds} <$ 1 maybe appropriate. The calculated value of FS_{sl} should not be less than 1.1 (Table 6.1).

6.2.1.2. Base Overturning. The factor of safety FS_{ot} against overturning about the toe of the facing column can be expressed as the ratio of the resisting moment M_r and driving moment Mo:

$$FS_{ot} = \frac{M_r}{M_o} \tag{6.71}$$

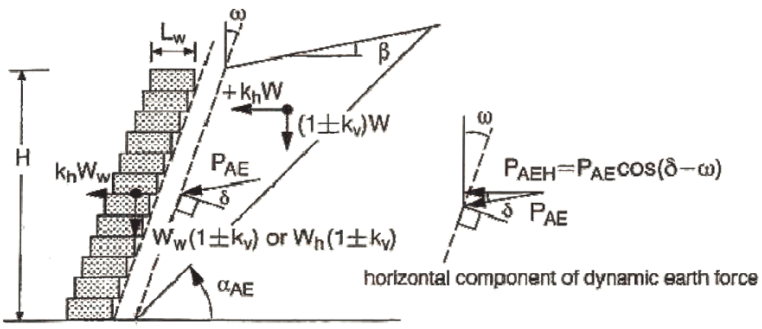


Figure 6.21. Resisting Moments for Base Overturning in External Stability Calculations for Reinforced SRW Structures, (FHWA-NHI-00-043, 2001).

The resisting moment, M_r, is given as:

$$M_r = W_w X_w + W_i X_i + W_\beta X_\beta \tag{6.72}$$

where X_w is the horizontal distance from the toe of the wall to the center of gravity of the entire facing column and can be calculated using:

$$X_w = \frac{1}{2}\left[\left(N_w - 1\right) H_w \tan\omega\right] + L_g \tag{6.73}$$

Moment arm quantities X_i and X_β are calculated as follows:

$$X_i = \frac{L_{min} + L_w + H\tan\omega}{2} \tag{6.74}$$

$$X_\beta = H\tan\omega\frac{1}{3}\left(L_w + 2L_{min}\right) \tag{6.75}$$

Then, the driving moment M_o is calculated as:

$$M_o = P_{IR} h_{IR} + P_{AH}\frac{h}{3} + 0.5\Delta P_{dynH} 0.6h \tag{6.76}$$

Here:

$$h_{IR} = \frac{k_h\left(ext\right) W_w \frac{H}{2} + k_h\left(ext\right) W'_i \frac{H}{2} + k_h\left(ext\right) W'_\beta h_\beta}{P_{IR}} \tag{6.77}$$

$$h_\beta = H + \frac{1}{3}\left(L_{min} - L_w\right)\tan\beta \tag{6.78}$$

The calculated value of FS_{ot} should not be less than 1.1 (Table 6.1).

6.2.1.3. Bearing Capacity. Conventional bearing capacity analyses are carried out with respect to the base width L of the reinforced (infill) soil mass is assumed to

act as a continuous strip footing and must have sufficient width L to prevent over-stressing of the foundation soils that may lead to shear failure of the foundation soils or excessive settlement.

Meyerhof stress distribution approach is utilized to ensure a conservative estimate of applied bearing stress. The effect of eccentricity of the resultant bearing force (net foundation load) (Figure 6.20) is to restrict compressive bearing pressures to an equivalent bearing area B'f calculated as:

$$B'_f = L_{min} - 2e \tag{6.79}$$

The Meyerh of bearing capacity approach for statically loaded geosynthetic reinforced SRW structures is modified here to include the additional base loading eccentricity developed by the external dynamic force increment ΔP_{dynH} and the inertial force P_{IR}. The factor of safety against bearing capacity failure is expressed as:

$$FS_{bc} = \frac{q_{ult}}{q_a} \tag{6.80}$$

where q_{ult} is the ultimate bearing capacity of the foundation soil and q_a the applied bearing stress at the base of the reinforced soil mass and facing column (composite mass). The magnitude of q_{ult} is calculated as follows:

$$q_{ult} = c_f N_c + \frac{1}{2}\gamma_f B'_f N_f + \gamma_f H_{emb} N_q \tag{6.81}$$

Values of bearing capacity coefficients N_c, N_g and N_q are shown in Table 6.2.

Consistent with the method used in the DMSRW the eccentricity term e can be calculated with respect to the center of the base of the reinforced zone (i.e. at distance $L_{min}/2$ from the toe of the wall) as follows:

$$e = \frac{P_{IR} h_{IR} + P_{AH}\frac{h}{3} + 0.5\Delta P_{dynH} 0.6h}{W_r}$$

$$-\frac{W_w\left(X_w-\frac{L_{min}}{2}\right)-W_i\left(X_i-\frac{L_{min}}{2}\right)-W_\chi\left(X_\beta-\frac{L_{min}}{2}\right)}{W_r} \tag{6.82}$$

The applied bearing capacity stress at the base of the reinforced zone is calculated as:

$$q_a=\frac{W_r}{B'_f} \tag{6.83}$$

The calculated value of FS_{bc} should not be less than 1.5 Table 6.1.

Table 6.2. Bearing capacity factors.

ϕ* (degree)	N_c	N_q	N_g	N_q /N_c	tanϕ
0	5.14	1.00	0.00	0.20	0.00
1	5.38	.09	0.07	0.20	0.02
2	5.63	.20	0.15	0.21	0.03
3	5.90	.31	0.24	0.22	0.05
4	6.19	.43	0.34	0.23	0.07
5	6.49	.57	0.45	0.24	0.09
6	6.81	.72	0.57	0.25	0.11
7	7.16	.88	0.71	0.26	0.12
8	7.53	2.06	0.86	0.27	0.14
9	7.92	2.25	1.03	0.28	0.16
10	8.35	2.47	1.22	0.30	0.18
11	8.80	2.71	1.44	0.31	0.19
12	9.28	2.97	1.69	0.32	0.21
13	9.81	3.26	1.97	0.33	0.23
14	10.37	3.59	2.29	0.35	0.25
15	10.98	3.94	2.65	0.36	0.27
16	11.63	4.34	3.06	0.37	0.29
17	12.34	4.77	3.53	0.39	0.31
18	13.10	5.26	4.07	0.40	0.32
19	13.93	5.80	4.68	0.42	0.34
20	14.83	6.40	5.39	0.43	0.36
21	15.82	7.07	6.20	0.45	0.38
22	16.88	7.82	7.13	0.46	0.40
23	18.05	8.66	8.20	0.48	0.42
24	19.32	9.60	9.44	0.50	0.45
25	20.72	10.66	10.88	0.51	0.47

Table 6.2. Bearing capacity factors.

ϕ* (degree)	N_c	N_q	N_g	N_q /N_c	$tan\phi$
26	22.25	11.85	12.54	0.53	0.49
27	23.94	13.20	14.47	0.55	0.51
28	25.80	14.72	16.72	0.57	0.53
29	27.86	16.44	19.34	0.59	0.55
30	30.14	18.40	22.40	0.61	0.58
31	32.67	20.63	25.99	0.63	0.60
32	35.49	23.18	30.22	0.65	0.62
33	38.64	26.09	35.19	0.68	0.65
34	42.16	29.44	41.06	0.70	0.67
35	46.12	33.30	48.03	0.72	0.70
36	50.59	37.75	56.31	0.75	0.73
37	55.63	42.92	66.19	0.77	0.75
38	61.35	48.93	78.03	0.80	0.78
39	67.87	55.96	92.25	0.32	0.81
40	75.31	64.20	109.41	0.85	0.84
41	83.86	73.90	130.22	0.88	0.87
42	93.71	85.38	155.55	0.91	0.90
43	105.11	99.02	186.54	0.94	0.93
44	118.37	115.31	224.64	0.97	0.97
45	133.88	134.88	271.76	1.01	1.00
46	152.10	158.51	330.35	1.04	1.04
47	173.64	187.21	403.67	1.08	1.07
48	199.26	222.31	496.01	1.12	1.11
49	229.93	265.51	613.16	1.15	1.15
50	266.89	319.07	762.89	1.20	1.19
* Us e ϕ_f the phi a ngle for founda tion s oils					

6.2.2. Internal Stability

6.2.2.1. Reinforcement Loads. The contributory area approach used for the static stability analysis of segmental retaining walls is extended to the dynamic loading case.

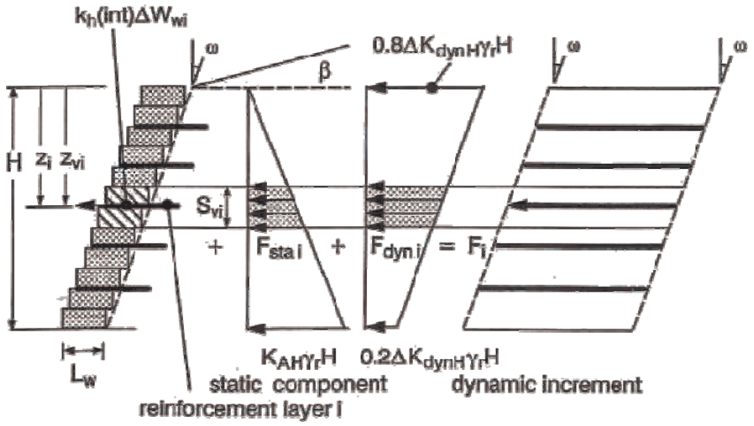


Figure 6.22. Geometry and Forces Used to Calculate Reinforcement Loads for Reinforced SRW Structures, (FHWA-NHI-00-043, 2001).

In this method the reinforcement layers are modeled as tie-backs with the tensile force, F_i, in layer i equal to the earth pressure integrated over the contributory area, S_{vi}, at the back of the facing column plus the corresponding wall inertial force increment. Hence:

$$F_i = k_h\,(int)\,\Delta W_{wi} + F_{stai} + F_{dyni} \tag{6.84}$$

where $k_h(\text{int})\Delta W_{wi}$ is the Wall inertial force increment, F_{stai} is the Static component of reinforcement load, F_{dyni} is the Dynamic component of reinforcement load.

The quantity ΔW_{wi} is the weight of the facing falling with the contributory area S_{vi} of the corresponding reinforcement layer and hence can be calculated as follows:

$$\Delta W_{wi} = S_{vi} L_w \Upsilon_w \tag{6.85}$$

referring to Figure 6.22:

$$F_{stai} = K_{AH}\Upsilon_r z_{vi} S_{vi} \tag{6.86}$$

$$F_{stai} = \left[0.8 - 0.6\frac{z_{vi}}{H}\right]\Delta_{dynH}\Upsilon_r H S_{vi} \tag{6.87}$$

The quantity z_{vi} is the distance from the crest of the wall to the mid-elevation of the contributory area S_{vi}. For constant reinforcement spacings $z_{vi} = z_i$. For non-uniform spacings $z_{vi} \neq z_i$. The contributory area for the topmost reinforcement layer is taken from the wall crest to mid-elevation between the first and second reinforcement layers from the crest. The contributory area for the bottommost layer is taken from the mid-elevation between the bottom layer and the layer immediately above, and the base elevation of the reinforced soil mass. The value of horizontal seismic coefficient (k_h=k_h(int)) used to calculate the wall inertial force increment (k_h(int)ΔW_{wi} in Equation 6.84) and dynamic component of reinforcement load (i.e. ΔK_{dynH} term in Equation 6.87) is determined from Equation 6.88.

$$k_h = \frac{a_h}{g}\left(1,45 - \frac{a_h}{g}\right) \tag{6.88}$$

6.2.2.2. Overstressing of Reinforcement. The dynamic factor of safety, FS_{os}, against over-stressing of reinforcement layer I is given by:

$$FS_{os} = \frac{T_{a(dyn)}}{F_i} \tag{6.89}$$

Here, $T_{a(dyn)}$ is the allowable tensile load for the reinforcement under seismic loading. AASHTO/FHWA guidelines recommend that the allowable strength for seismic loaded structures can be calculated using the same reduction factor approach used for statically loaded structures but with the creep reduction factor RF_{CR}=1. Equivalently, the allowable strength calculated according to the DMSRW for statically loaded structures

can be modified according to:

$$T_{a(dyn)} = T_a RF_{CR} \tag{6.90}$$

The calculated value of FS_{os} should not be less that 1.0 (Table 6.1). In other words, $T_{a(dyn)} > F_i$.

6.2.2.3. Reinforcement Anchorage (Pull-Out Failure). The reinforcement tensile load F_i must be carried by the reinforcement anchorage length which is located between the internal active failure plane (oriented at α_{ae} from horizontal) and the reinforcement free end (Figure 6.23). A common approach for anchorage capacity design is to use a simple Coulomb-type interface model in which anchorage capacity is taken to be linearly proportional to anchorage length, overburden pressure and soil shear strength.

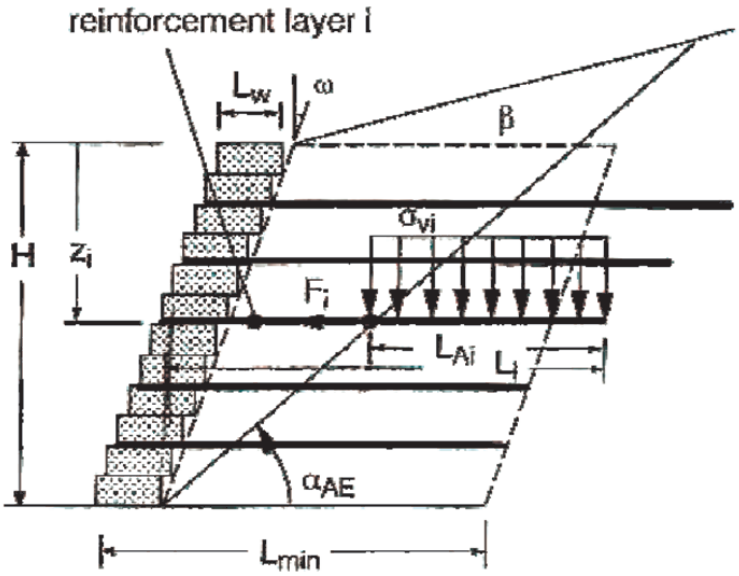


Figure 6.23. Geometry and Forces Used to Calculate Anchorage Capacity of Reinforcement Layers in SRW Structures, (FHWA-NHI-00-043, 2001).

The anchorage capacity T_{pull} i, corresponding to reinforcement layer i is calculated as follows:

$$T_{pulli} = 2L_{Ai}C_i\sigma_{vi}\tan\phi_r \tag{6.91}$$

where; L_{Ai} is the anchorage length for reinforcement layer i, C_i is the coefficient of interaction for pullout, σ_{vi} is the average overburden pressure acting over anchorage length L_{Ai} and ϕ_r is the peak friction angle of reinforced (infill) soil.

The anchorage length L_{Ai} can be expressed as:

$$L_{Ai} = L_i - L_w + (H - z_i)\left[\tan\omega - \tan\left(\frac{\pi}{2} - \alpha_{AE}\right)\right] \tag{6.92}$$

Here L_i is the total length of reinforcement layer i taken from the front face of the wall to the soil embedded end of the layer, and α_{AE} is calculated in accordance with Equation 6.23 using ψ=0. The average normal stress acting over the anchorage length can be calculated using the following expression:

$$\sigma_{vi} = \gamma_r\left[z_i + \left(\frac{H - z_i}{\tan\alpha_{AE}} - H\tan\omega + \frac{L_{Ai}}{2}\right)\tan\beta\right] \tag{6.93}$$

and the factor of safety against pullout failure is expressed as:

$$FS_{po} = \frac{T_{pulli}}{F_i} \tag{6.94}$$

The calculated value of FS_{po} should not be less than 1.1 (Table 6.1).

6.2.2.4. Internal Sliding. The factor of safety against internal sliding FS_{sli} along a reinforcement layer located at depth z below the crest of the wall can be expressed as:

$$FS_{sli} = \frac{R_s(z_i)}{\Delta P_{IR}(z_i) + \Delta P_{AEH}(z_i)} \tag{6.95}$$

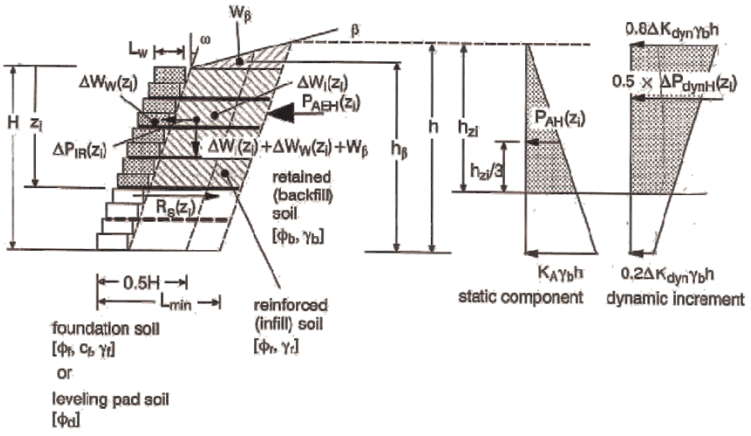


Figure 6.24. Geometry and Forces Used to Calculate Internal Sliding of Reinforcement Layers in SRW Structures, (FHWA-NHI-00-043, 2001).

The internal force contribution $\Delta P_{IR(zi)}$ is calculated as:

$$\Delta P_{IR}(z_i) = k_h(ext)\left(\Delta W_w(z_i) + \Delta W'_i(z_i) + \Delta W'_\beta\right) \tag{6.96}$$

The value of k_h(ext) used to calculate the inertial force contribution is determine from k_h=a_c/2g. Quantity ΔW_w (z_i) is the total weight of the facing column above the sliding surface located at depth z_i. Similar to the approach adopted for base sliding, the reduced reinforced zone weight DW'i (z_i) is calculated using:

$$\Delta W'_i(z_i) = (0.5H - L_w)\, z_i \gamma_r \tag{6.97}$$

Finally, the reduced reinforced zone weight in the slope above the reinforced mass, W'_β, is calculated using Equation 6.65.

$$\begin{aligned} P_{AEH}(z_i) &= P_{AH}(z_i) + 0.5\Delta P_{dynH}(z_i) \\ &= \frac{K_{AH}\gamma_b h^2{}_{zi}}{2} + \left[0.8h_{zi} - 0.3\frac{h^2{}_{zi}}{h}\right]\Delta K_{dynH}\gamma_b h \end{aligned} \tag{6.98}$$

The value of k_h, used to calculate the horizontal component of the dynamic force increment (ΔP_{dynH} (z_i)) is determined from kh=ac/2g). The quantity h_{zi} can be

calculated as:

$$h_{zi} = z_i + (L_{min} - L_w)\left(\frac{\tan\beta}{1 - \tan\beta\tan\omega}\right) \tag{6.99}$$

For structures with a horizontal backslope (β=0) the problem geometry is simplified since h_{zi}=z_i. The sliding resistance $R_S(z_i)$ corresponding to interface i is calculated using:

$$R_s(z_i) = V_u(z_i) + C_{ds}(\Delta W_i(z_i) + \Delta W_\beta)\tan\phi_r \tag{6.100}$$

The quantity $V_u(z_i)$ is the peak interface shear capacity between facing column units calculated using:

$$V_u(z_i) = a_u + \Delta W_h(z_i)\tan\lambda_u \tag{6.101}$$

The quantity C_{ds} in Equation 6.100 is the coefficient of direct sliding for the soil geosynthetic interface and cannot exceed unity. Quantity ΔW_i (z_i) is calculated as:

$$\Delta W_i(z_i) = (L_{min} - L_w)\, z_i \gamma_r \tag{6.102}$$

and W_β is calculated using Equation 6.62.

Only 50% of the external dynamic earth force increment, ΔP_{dynH} (z_i), acting over the height h_{zi} is considered for internal sliding stability calculations. The calculation of force components P_{AH} (z_i) and ΔP_{dynH} (z_i) assumes full mobilization of interface friction between the reinforced soil zone and the retained soil (i.e. δ=ϕ with ϕ equal to the lesser of ϕ_r and ϕ_b).

The calculated value of FSsli should not be less than 1.1 (Table 6.1).

6.2.3. Facing Stability

In pseudo-static seismic analysis of the facing stability of reinforced SRW structures, the following potential failure mechanisms must be examined: interface shear failure; overturning; crest toppling; and connection failure (Figure 6.18).

6.2.3.1. Interface Shear. The influence of interface shear transmission on facing column stability can be analyzed by treating the facing column as a beam in which the integrated lateral pressure (i.e. distributed load) must equal the sum of the reactions (forces in reinforcement layers). The calculation of interface shear force under dynamic loading must include the effect of wall facing inertia. The general approach is illustrated in Figure 6.25. The locally maximum interface shear forces will occur at reinforcement elevations.

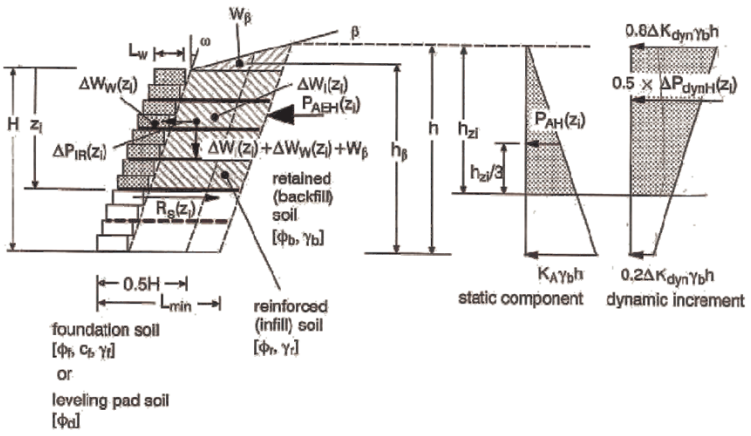


Figure 6.25. Geometry and Forces Used to Calculate Interface Shear (Bulging) and Overturning of the Facing Column for Reinforced SRW Structures, (FHWA-NHI-00-043, 2001).

The out-of-balance horizontal force S_i transmitted to an interface at depth z_i (corresponding to reinforcement layer i) is the difference in magnitude between the horizontal component of dynamic earth force plus facing column inertia) force and the sum of the horizontal loads carried by the reinforcement layers above the target

interface. Hence:

$$S_i\left(z_i\right) = k_h\left(int\right)\Delta W_w\left(z_i\right) + P_{AEH}\left(z_i\right) - \sum_{i+1}^{N} F_j \tag{6.103}$$

Here N is the number of reinforcement layers. The horizontal component of dynamic earth force P_{AEH} (z_i) acting over the depth z_i at the back of the facing column is calculated using the following expression;

$$P_{AEH}\left(z_i\right) = P_{AH}\left(z_i\right) + \Delta P_{dynH}\left(z_i\right) = \frac{K_{AH}\gamma_r {z^2}_i}{2} + \left[0.8z_i - 0.3\frac{{z^2}_i}{H}\right]\Delta K_{dynH}\gamma_r H \tag{6.104}$$

Coefficients of earth pressure (K_{AH} and ΔK_{dynH}) are calculated using ϕ=ϕ_r and 0≤ $\delta \leq \phi_r$. Typically is taken as $2\phi_r/3$ for facing stability calculations. Quantity ΔK_{dynH} in Equation 6.103 is calculated using Equation 6.88. The summation of reinforcement reactions can be calculated using Equation 6.84. The factor of safety against interface shear failure (FS_{sc}) at a reinforcement layer is:

$$FS_{sc} = \frac{V_u\left(z_i\right)}{S_i\left(z_i\right)} \tag{6.105}$$

where V_u (z_i) is the peak shear capacity of the interface calculated using Equation 6.100, The selection of interface shear strength parameters should be based on the results of laboratory interface shear data simulating the geosynthetic-modular block interface.

The calculated value of FSsc should not be less than 1.1 (Table 6.1).

6.2.3.2. Connection Failure. The dynamic factor of safety, FS_{cs}, against connection failure of the reinforcement layer with the facing column can be expressed as:

$$FS_{cs} = \frac{T_{ci}}{F_i} \tag{6.106}$$

Here, F_i is the tensile load in the reinforcement layer i calculated using Equation 6.84 and T_{ci} is the peak connection capacity for that layer calculated as:

$$T_{ci} = a_{cs} + \Delta W_h (z_i) \tan \lambda_s \tag{6.107}$$

The quantity a_{cs} is the minimum available peak connection strength in kN/m and λ_{cs} is the apparent peak interface friction angle describing the connection failure envelope (degrees) corresponding to the range of normal weight over which $\Delta W_h(z_i)$ applies. The calculated value of FS_{cs} should not be less than 1.1 (Table 6.1).

6.2.3.3. Local Overturning. The distribution of internal moments at interface elevations can also be calculated using the beam analog described in Section 6.2.3.1 for interface shear stability calculations. Internal moments that cause net outward moment at the toe of a facing unit, provide a possible failure mechanism for which an adequate factor of safety should be checked. Local peak destabilizing moments will occur at reinforcement elevations.

The factor of safety FS_{otl} against local overturning about the toe of the facing column at depth z_i below the crest of the wall can be expressed as the ratio of the resisting moments to driving moments:

$$FS_{otl} = \frac{M_r (z_i) + \sum_{i+1}^{N} T_{cj} xy_j}{M_o (z_i)} \tag{6.108}$$

The resisting moment $M_r(z_i)$ due to the facing column is calculated using:

$$M_r (z_i) = \Delta W_h (z) \, \Delta X_h (z) \tag{6.109}$$

where:

$$\Delta X_h = \frac{1}{2} \left[(N_z - 1) \, H_w \tan \omega \right] + L_g \tag{6.110}$$

and the driving moment due to earth forces, $M_o(z_i)$, is calculated using:

$$M_o\left(z_i\right) = k_h \Delta W\left(z_i\right)\frac{z_i}{2} + \frac{P_{AH}\left(z_i\right) z_i}{3} + \Delta P_{dynH}\left(z_i\right) y_{dyn}\left(z_i\right)$$
$$= k_h \Delta W\left(z_i\right) + \frac{K_{AH}\gamma_b z^3}{6}\left[\left(0.8z_i - 0.3\frac{z_i^2}{H}\right)\Delta K_{dynH}\gamma_b H\right] y_{dyn}\left(z\right) \quad (6.111)$$

where:

$$y_{dyn}\left(z_i\right) = \frac{0.4Hz_i - 0.1z_i^2}{0.8H - 0.3z_i} \quad (6.112)$$

The value of k_h used in this moment calculation is based on the value from the equation k_h=(a_h/g)(1.45-a_h/g)). The summation with T_{cj} X y_j terms in Equation 6.107 de notes the resisting moment due to the peak connection capacities of reinforcement layers and their corresponding moment arms from the target point of rotation.

The calculated value of FS_{otl} should not be less than 1.1 (Table 6.1).

Note that the scope of this research does not cover the mechanical connection of reinforcement-block (such as bodkin etc). Examples of mechanical connection types are given below.

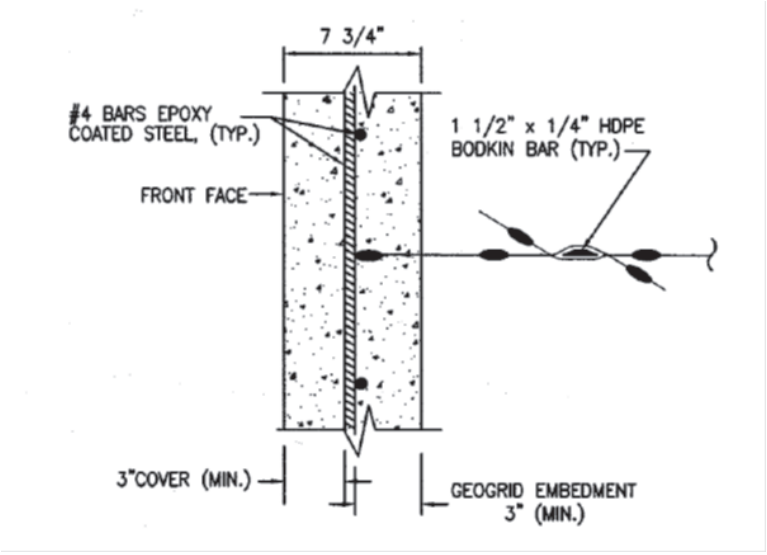


Figure 6.26. An Example of Facing Connection Using Bodkin Bar; (FHWA-NHI-00-043, 2001).



Figure 6.27. An Example of Mechanical Facing Connection, (www.tenax.net).

Please note that FHWA does not recommend fully frictional connections for places expecting significant earthquake effects, this is: *it is presently recommended that fully frictional connections not be used in locations where the combined seismic performance category is C or higher (A >0.19).* (FHWA, section 4.3.e)

6.2.3.4. Crest Toppling. Local (crest) toppling refers to the overturning of the top unreinforced portion of the facing column (Figure 6.18j). This analysis is identical to that described in Section 6.2.3.3 for conventional gravity structures but using Equation 6.88. The critical portion of the facing column is taken as the height of wall starting at the elevation of the topmost layer of reinforcement. The calculated value of FS_{otc} should not be less than 1.1 (Table 6.1).

6.3. Previous Research Studies Related to Reinforced Soil Retaining Walls

The first commercial proprietary mechanically stabilized earth (MSE) wall system was introduced in the U.S. in the 1960's. It utilized metallic strips to reinforce the soil and precast concrete panels that retain the soil at the face of the wall. Its' use worldwide

has increased dramatically since the 1970's, mainly due to its economics and aesthetics. Competitive wall systems using welded wire grids were introduced in the mid 1970's. Geosynthetic reinforced walls were introduced in the 1980's. In the 1990's, the use of geosynthetic reinforced walls increased dramatically by the introduction of segmental retaining walls (SRW) (Leshchinsky and Han, 2004).

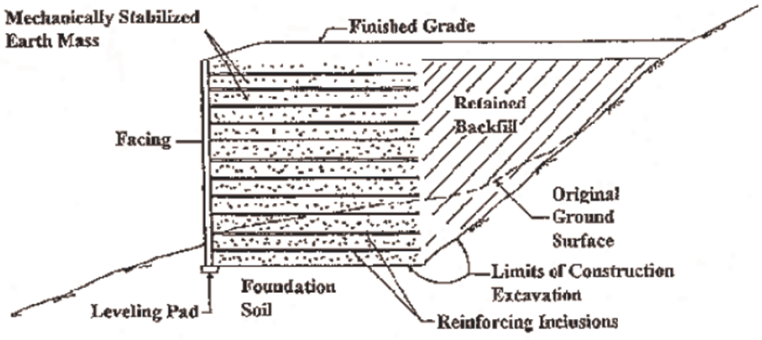


Figure 6.28. A Typical MSE Wall-Cross Sectional View.

Güler and Astarcı, (2009) investigated the frictional behavior of modular concrete blocks under different conditions. Tests were conducted with empty dry-stacked concrete blocks, sand used as infill, and gravel used as infill. The angle of friction was calculated for each case.

The schematic of the apparatus used in tests is shown in Figure 6.29. The lowest part of the apparatus was a special tray fixed on the testing table. The width of the tray was 160 cm while its depth was 80 cm. A confining piece was fixed to the tray in order to prevent the movement of the lower layer of concrete blocks. The upper layer of concrete blocks was fixed by another confining piece. These two confining pieces were welded to the tray.

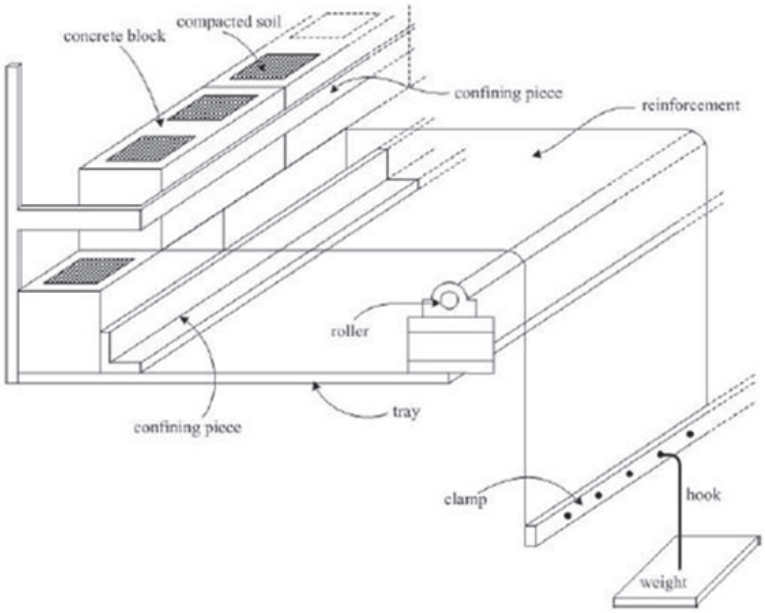


Figure 6.29. Testig Apparatus.

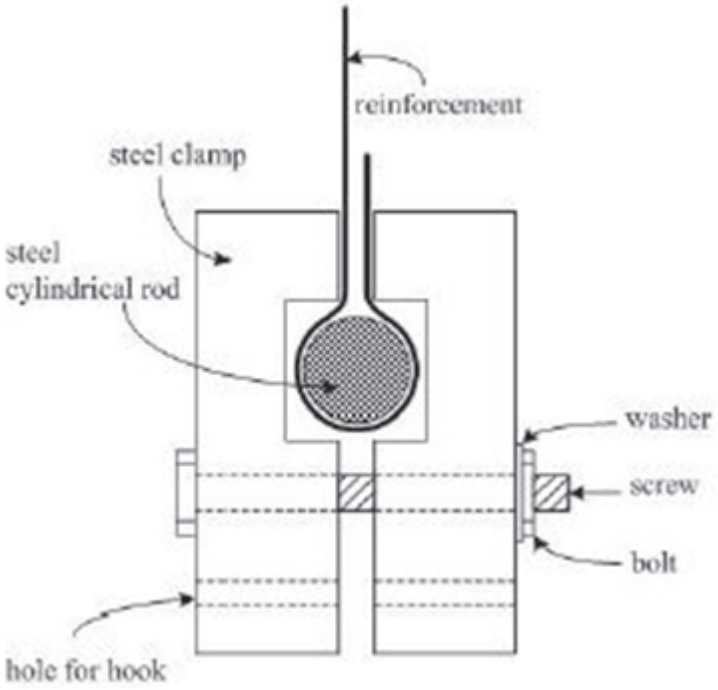


Figure 6.30. Cross-Section of the Steel Clamp.

The roller was free to rotate around an axle connected to the tray on both sides. The length of the roller was 110 cm. The tension load was applied by placing weights on three hooks hanging from a steel clamp attached to the reinforcement. The clamp

was specially designed to ensure a uniform load distribution to the geosynthetic reinforcement. The detail of the steel clamp is shown in Figure 6.30. It consisted of two pieces with channels made on the inside faces for placing a steel rod to fix the geosynthetic reinforcements and screws to tighten the clamp.

In the study, nine connection strength tests were executed in order to investigate the frictional behavior between modular concrete blocks and woven geotextile. The tests were performed either with the holes left empty or filled with sand, or gravel. The angles of friction are given in Table 6.3.

Table 6.3. Summary of Results.

Combination	**Angle of friction (degree)**
Empty Blocks - Geotextile	40.4
Sand - Geotextile	34.3
Gravel - Geotextile	45.5

The combination of gravel infill and geotextile displayed the best performance and gave the greatest value of angle of friction among the other alternatives. The combination of sand infill and geotextile gave the lowest friction angle in spite of the weight of the sand existing in the holes of concrete blocks.

Bhuiyan *et al.*, (2012) used recycled concrete aggregates and used as alternative in-filler materials for segmental retaining walls by considering preservation of natural resources and waste (concrete) minimization.As granular in-fills fresh and two different types of recycled aggregates were used in the research to compare its frictional performance with geogrid.

A series of tests were performed using a specially designed and fabricated direct shear apparatus to assess the frictional behaviour of infilled blocks with geogrid inclusion under different normal loading conditions (Figure 6.31). Test results were outlined in the form of shear stress-displacement relationship to compare the effect of recycled

aggregates against the fresh aggregate. Shear capacity envelopes were also plotted by using Mohr-Coulomb failure criteria to find out the angle of friction for each case.

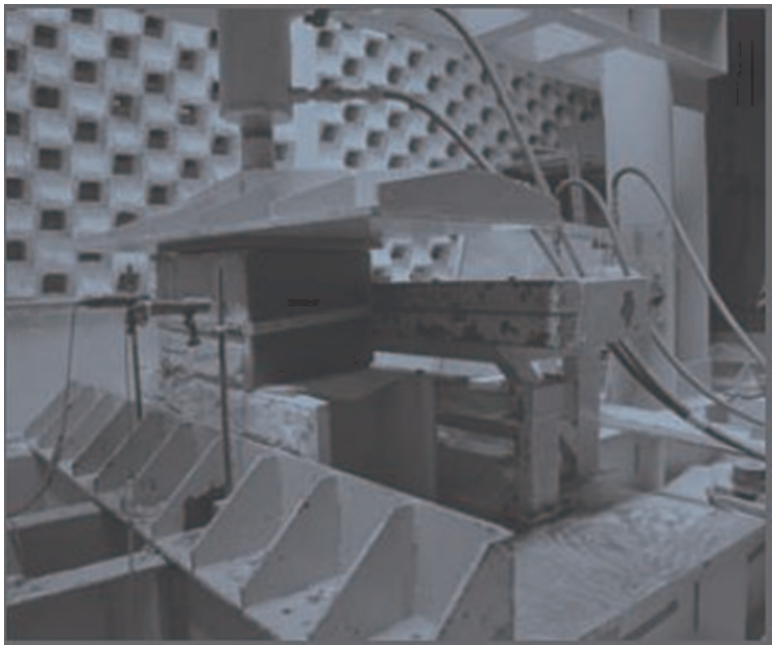


Figure 6.31. Photograph of Interface Shear Test-Setup Showing Geosynthetic Inclusion.

The results which are reported in the study show that the angles of friction of the combination of recycled aggregate in-fills and geogrid inclusion are almost equal to those with the fresh aggregate. From the study it is also found that, the strength of source concrete has almost no effect on the frictional behaviour of the blocks infilled with recycled aggregates. So, recycled concrete aggregates may be used as an alternative granular infill in segmental regaining wall constructions. The use of recycled aggregates has great advantages on concrete waste minimization and sustainable developments.

Ling *et al.*, (2005) used a validated finite element procedure for conducting a series of parametric studies on the behavior of reinforced soil walls under construction and subject to earthquake loading. The procedure utilized a nonlinear numerical algorithms that incorporated a generalized plasticity soil model and a bounding surface geosynthetic model. The reinforcement layouts, soil properties under monotonic and cyclic loadings, block interaction properties, and earthquake motions were among

major variables of investigation. The performance of the wall was presented for the facing deformation and crest surface settlement, lateral earth pressure, tensile force in the reinforcement layers, and acceleration amplification. The effects of soil properties, earthquake motions, and reinforcement layouts are issues of major design concern under earthquake loading. The deformation, reinforcement force, and earth pressure increased drastically under earthquake loading compared to end of construction. The following conclusions were drawn based on the results of parametric studies:

The end of construction and after-shaking performance of the wall was affected by the following variables, in order of significance: soil properties, earthquake motions, and reinforcement layout (length and spacing). The effects due to block interaction behavior and reinforcement cyclic properties were minimal. The effects of interaction behavior are negligibly small, however, could be subjected to the limitations of the thin interface element used in the study.

For end of construction (EOC); The facing lateral displacement was affected by the soil behavior and reinforcement layout. The maximum force in the reinforcement layers was also affected by the soil behavior and layout, but it appeared that the spacing had a greater effect than the length. The earth pressure behind the blocks was not affected much by the aforementioned variables.

For earthquake loading; The residual lateral displacement due to earthquake loading was several times larger than that at EOC. The largest lateral displacement occurred at the top of the wall. The lateral displacement was affected by factors such as soil cyclic behavior, reinforcement layout, and earthquake motions with Kobe earthquake motions rendering the largest displacement. The same effect was seen for the wall crest settlement, which was the largest behind the rear end of reinforcement.

The force in the reinforcement layers was affected by the different variables, especially earthquake motions and vertical spacing. The force could be increased by 2 to 3 times comparing EOC and earthquake loading conditions.

Earthquake loading resulted in an increase in the lateral pressure acting behind the block facing. The pressure typically doubled the value at EOC.

Amplification of acceleration was affected by the soil behavior and earthquake motions, but not the reinforcement layouts. "Weaker" soils acted as dampers to the wall whereas "stronger" soils amplified the acceleration. The amplification factor at the crest was in the range of 1.2-2.0.

The reinforcement layouts affected the wall performance, including lateral displacements, crest settlement, reinforcement force, and earth pressure. The effects of vertical spacing seem more significant compared to the length of reinforcement.

A particularly interesting point is that the effects of the cyclic hardening behavior of soil on the dynamic response of the wall cannot be simulated using simple plasticity model.

Bathurst *et al.*, (2009) investigated the facing-geogrid connection between RS-115 concrete block units and Miragrid 5XT geogrid using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the mechanical/frictional performance of these connections. A second objective was to make preliminary recommendations for the selection of long-term tensile connection capacities to be used in the design and analysis of geogrid-reinforced soil wall systems that employ RS-115 blocks in combination with Miragrid 5XT geogrid. Test apparatus is shown in Figure 6.32 and test results are shown in Figure 6.33.

The following conclusions were drawn: The peak connection strength between RS-115 units and Miragrid 5XT geogrid for walls between 3.0 and 30.0 feet in height ranged between 23% and 51% of the index tensile strength of 4700 lb/ft in the machine direction (based onASTMD6637method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009).

The trend in data for connection capacities at 3/4 inches of displacement has been plotted using a linear curve. The trend in data for peak capacities has been plotted using a bi-linear curve.

Care must be taken during the installation of RS-115 units in order to prevent accumulation of soil and rock debris at the concrete block-geogrid interface surfaces. This debris may significantly reduce the capacity of the RS-115 facing unit-geogrid system.

The design envelope in Figure 6.33 is based on an interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual (First Edition, 1993). The choice of design connection strengths may vary from site to site and quality of construction in the field may require lower design values than those taken from Figure 6.33.

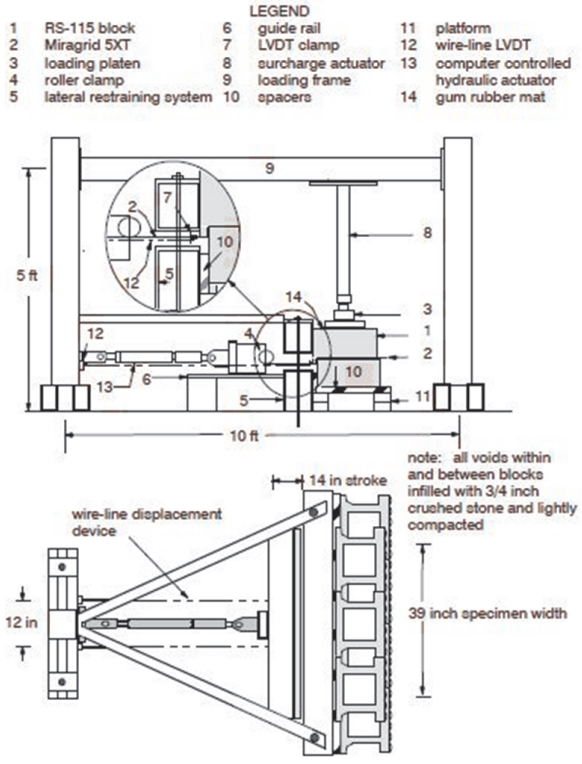


Figure 6.32. Schematic of Connection Test Apparatus Showing RS-115 Block Units and Miragrid 5XT Geogrid.

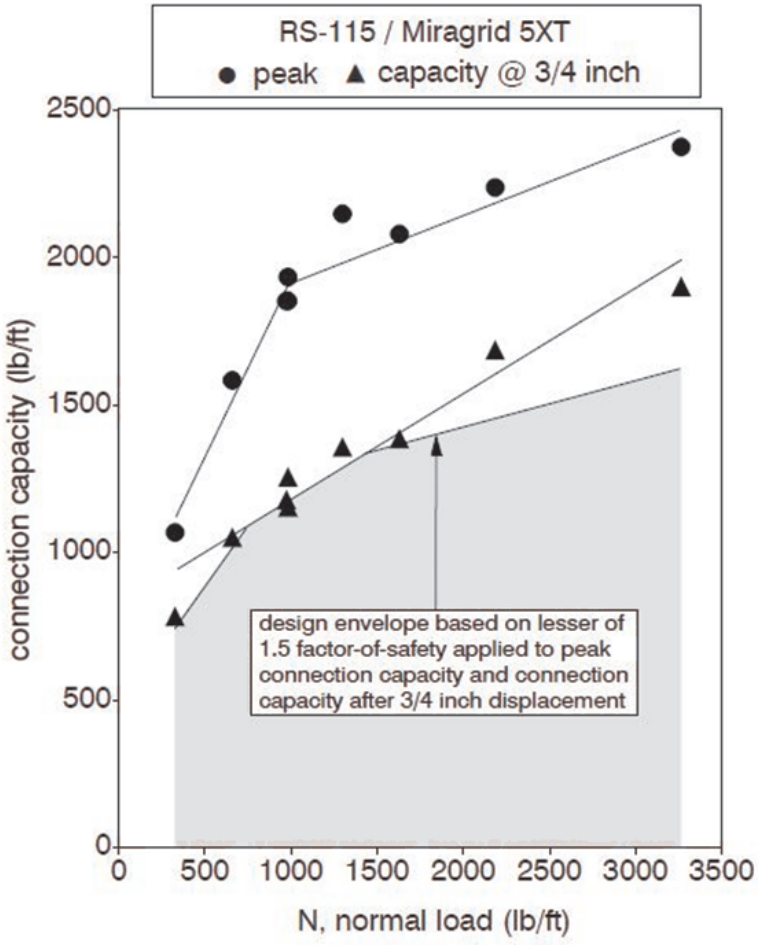


Figure 6.33. Preliminary Design Capacity Envelope for RS-115 Block Units / Miragrid 5XT Geogrid Combination.

Ling *et al.*, (2001) gave an overview on the application of geosynthetic-reinforced soil structures in Taiwan. Taiwan has a unique topography and geotechnical conditions that rendered a less conservative and more challenging design compared to that of North America, Europe and Japan. The Ji-Ji (Chi-Chi) earthquake of 1999 gave an opportunity to examine the behavior of reinforced soil structures. The performance of several modular-block reinforced soil retaining walls and reinforced slopes at the vicinity of the fault was evaluated. Reinforced structures performed better than unreinforced soil retaining walls. The failure cases were highlighted and the cause of failure was identified. The lack of seismic design consideration could be a major cause of failure. The compound failure mode, the inertia force of the blocks, and the connection stiffness and strength relative to the large dynamic earth pressure, were among major items that

would warrant further design consideration.

The Ji-Ji earthquake caused some damages to the geosynthetic-reinforced soil structures in Taiwan. A few modular block geosynthetic-reinforced soil retaining walls and reinforced slopes were damaged. Some of the lessons learned from the post-earthquake investigation are:

The failure of modular-block reinforced soil retainingwalls could be attributed to a lack of professional design as seen by arbitrary spacings used in several of the reinforced soil retaining walls, and with a mixture of unreinforced and reinforced retaining walls within a common structure.

The connection between the modular blocks and reinforcement is vital for a satisfactory performance of the structure under high seismic load. The strength and stiffness of the pins, and that of the reinforcement in the transverse direction, should be large enough to sustain the dynamic earth pressure.

The inertia of the modular blocks led to excessive deformation under seismic excitation. The structures, such as the lampposts, should not be installed at the vicinity of the modular-block walls.

For the sites where reinforced and unreinforced soil retaining structures were found, a better performance was achieved for the reinforced soil structures.

Armour *et al.*, (2004) presented a case history of the failure and rehabilitation of a 25 year old mechanically stabilized earth (MSE) bridge abutment and approach retaining walls in Soda Springs, Idaho. This MSE bridge abutment was constructed in 1978. But unfortunately, after 24 years of construction, in the summer 2002, approximately six of the precast concrete facing panels "popped out" in a localized area of one of the MSE earth retaining walls supporting the bridge approaches. The cause of failure was corrosion of the galvanized steel soil reinforcing strips at the panel connection to a point where the lateral earth pressures exceeded the connection's remaining

capacity (Figure 6.34). Some of the remedial measures were installing horizontal drilled and grouted crosstie ground anchors in the approach walls, anchored soldier piles at the abutments and a reinforced shotcrete facing structurally attached to the existing MSE facing panels. A class one corrosion protection system was utilized for all of the rock anchors and crossties. Each strand was coated with a corrosion inhibitor and then encapsulating each stands in a plastic shell. To complete the structure rehabilitation a thick reinforced shotcrete wall was designed to span between the crossties and rock anchors. The corrosive nature of the fill material should be closely monitored to prevent failure to all future projects of this type.



Figure 6.34. Corroded Metallic Soil Reinforcements (Armour, 2004).

Narejo and Ramsey, (2001) emphasized hydrologic design issues, to be the major cause of MSE wall failure. According to the authors, a comprehensive drainage and filtration plan should address the drainage at the top of a wall, and drainage and filtration at the front. The cost and benefit analysis was also conducted. The total cost of a drainage and filtration system for a wall included design, material and installation cost. The design of the filtration and drainage system was assumed to add a cost of $\$1.00/m^2$ of the wall face. The choice of drainage and filtration system, and materials to be used, will be site-specific. "Flowing" out of blocks of MSE walls can be prevented by using a filter geotextile, i.e. nonwoven needle-punched geotextile at the back of

the blocks. The high benefit/cost ratio suggested that a geosynthetic filtration and drainage system should be considered for all MSE walls.

Narejo and Ramsey, (2001) showed some of the common drainage schemes utilized at the top of a typical MSE wall (Figure 6.35). Runoff water at the top may be drained towards the face of a wall as shown in Figure 6.35a and Figure 6.35b. Alternatively, runoff water may be collected and discharged by a drainage pipe installed at suitable intervals along the wall as shown in Figure 6.35c. Figure 6.35d shows another scheme in which runoff water is drained away from the wall face. In Figure 6.35b, a second line of defense against any infiltrating water is provided by a geomembrane or geosynthetic clay liner (GCL) used along with a geotextile-wrapped pipe. The drainage ditch shown in Figure 6.35a, Figure 6.35b and Figure 6.35d should be lined with a geomembrane, GCL, clay or a combination thereof in order to prevent infiltration. In certain cases, especially in built-up areas, a layer of asphalt may be used as a surfacing. Suitable discharge points should be located along the drainage ditch to minimize travel paths and excessive accumulation of surface water. The water may be discharged in a storm water drain if one is located close to the wall. It is the authors' opinion that the alternatives shown in Figure 6.35a and Figure 6.35c should be used only if no other option is available. If water is to be drained towards the face of the wall, then the schematic shown in Figure 6.35b should be used. If a drainage pipe is to be used then it should, preferably, be located outside the reinforced zone. If allowed by the site topography, the schematic shown in Figure 6.35d has the least risk associated with it and is the most economical to implement.

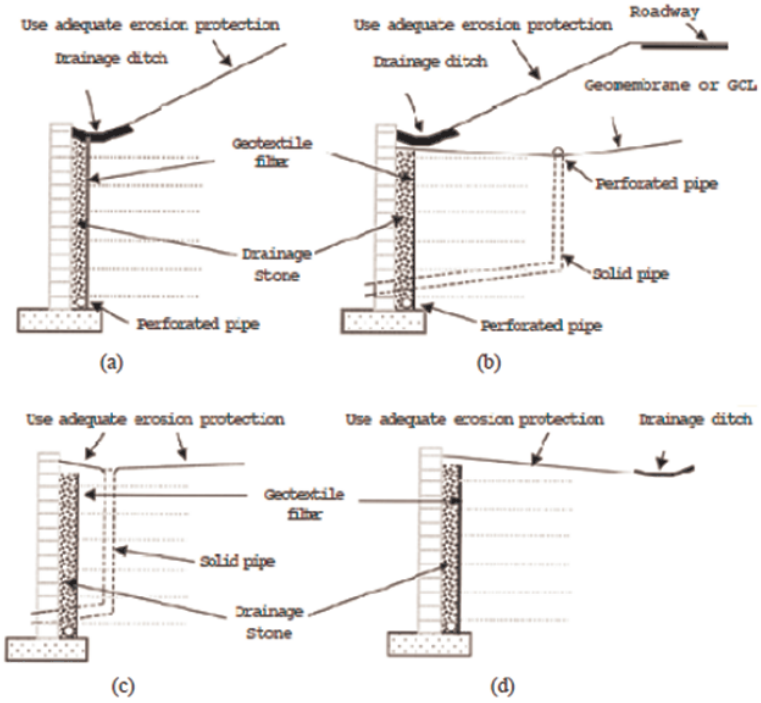


Figure 6.35. Drainage of Run-Off Water at the Top of A MSE Wall Using: (a) Lined Ditch Directly Behind the Blocks; (b) Low-Permeability Layer to Catch Infiltrating Water; (c) Drainage Pipe at Suitable Intervals Along the Wall; (d) Drainage Away From Wall Face (Narejo and Ramsey, 2001).

Figure 6.36a and Figure 6.36b show two alternative drainage schemes at the back of a wall currently being used by the industry. In Figure 6.36a, a combination of chimney drain and bottom drain is utilized, whereas Figure 6.36b shows horizontal drainage layers placed within the reinforced zone. The alternative shown in Figure 6.36b is used where seepage water is expected in the reinforced zone or where horizontal drains are provided in addition to the chimney drain shown in Figure 6.36a. There is currently much controversy regarding the effectiveness of the schematic shown in Figure 6.36b. Further testing and research is needed in this area to better understand the mechanism. In both cases, the intercepted water should be discharged at the face of the wall by one or more solid pipes located at suitable intervals along the wall (Narejo and Ramsey, 2001).

In simple situations, all that may be required is a nonwoven needle-punched

geotextile. Figure 6.37 shows a wall; where the reinforced soil is "flowing" out of the blocks as a result of water infiltrating from the top of the wall. Using a filter geotextile at the back of the blocks could have prevented this problem (Narejo and Ramsey, 2001).

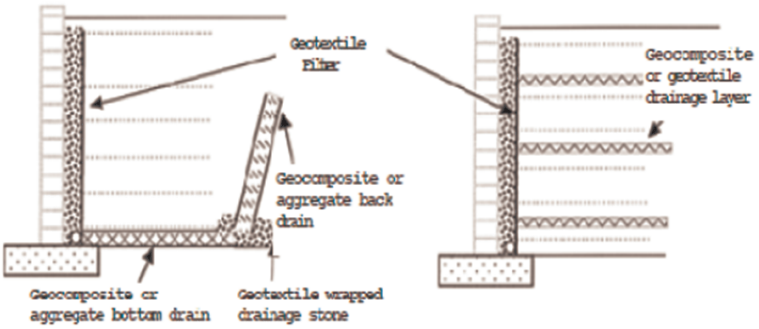


Figure 6.36. Drainage Alternatives for Seepage and Infiltrating Water: (a) Chimney and Bottom Drains; (b) Horizontal Drains (Narejo and Ramsey, 2001).



Figure 6.37. An Example of Reinforced Soil Flowing From Block Due to Water Infiltrating at the Top of a Wall (Narejo and Ramsey, 2001).

Chalermyanont and Benson, (2005) developed a technique to calculate the system probability of failure or system reliability of MSE walls. The system probability of failure is the sum of the probabilities of failure corresponding to the four common modes of failure: slope stability, sliding, overturning and bearing capacity. The reliability is the complement of the system probability of failure. Probability of internal failure is obtained from analysis of MSE walls using design charts. Probabilities for each

external failure mode are calculated using a mean factor of safety computed with conventional design equations and mean values for the soil properties as input, and a standard deviation of the factor of safety computed using an empirical equation. The analysis showed that the probability of failure typically is smaller than 0.0003, which is approximately one order of magnitude lower than the failure rate (0.01 to 0.001) for similar type of structures.

Chen *et al.*, (2007) described a successful failure analysis to determine the causes of loss of backfill sand from a mechanically stabilized earth (MSE) wall, and cracks on the concrete approach slabs on top of it. The cracks on the approach slabs may be related to the excessive loss of backfill from behind the MSE walls, and that the embankment structure may be unsafe due to potential voids under the concrete slab. Several cubic meters of sugar sand had washed out of the wall and deposited adjacent to the paneled walls. A series of destructive and nondestructive tests were conducted to determine the causes of the problems. It was found that the cracking of the approach slab and the loss of backfill were unrelated. The loss of sand is usually associated with significant amounts of water that can enter the embankment through joints, ruptured drainage pipes, approach slabs, or in the vicinity of bridge abutments. As water enters the top of the wall in any appreciable quantity, it will seek a path out through any breach in the filter fabric covering the wall panels. Once this process begins, piping will occur, carrying out the fine sand backfill with the water. To achieve these goals, some important tests were performed. They are: (i) Coring- to determine the concrete material characteristics; (ii) Ground penetration radar (GPR)- to determine the locations and extent of voids under the slab; (iii) Impulse response (IR)- to determine the locations and extent of voids behind the wall; (iv) Dynamic cone penetrometer (DCP)- to verify the voids and their extent; and e) Video survey- to determine the condition of the drainage system in the embankment structure.

It was suspected that the source of the water that was causing the seepage of embankment sand was a ruptured pipe within the embankment. The main cause of the loss of sand was attributed to the ruptured drainage pipe (As shown in Figure 6.38). The water was eroding and transporting the fine sand through the wall panels where

the geotextile filter ruptured. Grouts were used to repair areas where the geotextile filter was breached. This repair was not effective, as the grout could not resist the water pressure.

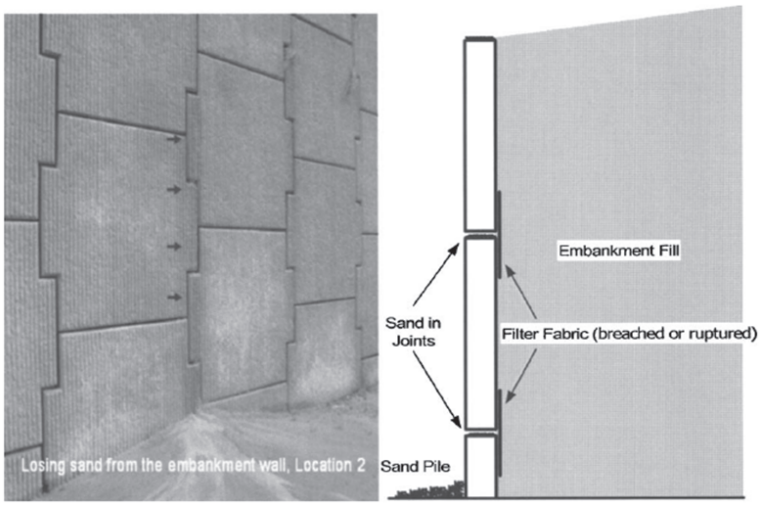


Figure 6.38. Water Carried Sand Through Breached or Ruptured Filter Fabric (Chen *et al.*, 2007).

Although there may be other reasons (e.g., high pouring temperature) that caused the cracks, aggregate is one of the main contributing factors to cracking. The southbound and northbound approach slabs were constructed with similar designs, but at different times. Apparently siliceous gravel was substituted on the southbound approach slabs only. The increased thermal expansion/contraction was therefore not adequately accommodated, leading the writers to believe it is a primary cause of the cracking. It is believed that the cracks occurred shortly after placement (e.g., the first month after construction) due to temperature variation. The spilling probably occurred gradually as pavement aged. The probability of the cracks being caused by the loss of backfill is low. It is just a coincidence that the cracks on the bridge approach slabs occurred where there is sand loss. A close inspection of the MSE wall revealed a 50 mm open gap between the riprap and the sidewall, as shown in Figure 6.39. District personnel indicated that the settlement of the riprap shortly after construction caused the riprap joint to open. It was also observed that the water drained from the bridge deck directly fell on the riprap joint, as shown in Figure 6.40. Because of the wide opening of this particular joint, water could easily enter the embankment. The water

then carried the sand out wherever the geotextile filters were breached. Water was also observed flowing out of this joint when the drain pipe was flushed. IR tests were carried out on the face of the wall to quantify the extent of the damage to the wall (Chen *et al.*, 2007).



Figure 6.39. Wide Opening Between Riprap Joint and Sidewall Permits Water to Enter Riprap. Water Carries Sand Through Breached or Rupture Filter Fabric (Chen *et al.*, 2007).

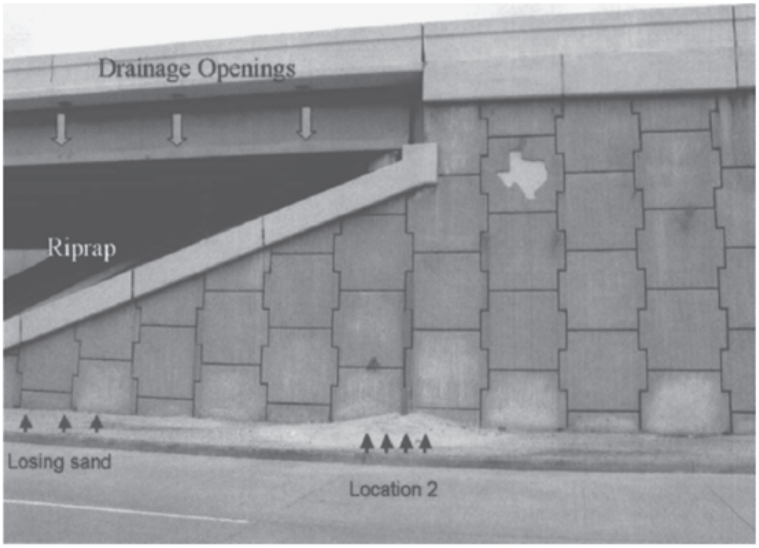


Figure 6.40. Drainage Opening on Bridge Deck That Permits Water to Fall Straight Through Riprap Joint (Chen *et al.*, 2007).

7. TEST SETUP AND METHODOLOGY

7.1. General

In this chapter, the equipment properties used for the tests, the equipment setup, capabilities, limitations, material selection, material properties, test algorithm is presented.

7.2. Equipment

The tests to determine connection strength require specially designed equipment. The typical equipment must satisfy several requirements such as:

- must be strong enough to apply necessary test load,
- the loads exerted must be followed so that the failure load can be recorded precisely,
- must be rigid enough so that the equipment itself do not deform, change shape and/or fail,
- must be practical so that necessary number of tests can be performed.

The existing equipment in the Boğaziçi University soil mechanics laboratory can only meet 2 of the 4 criteria listed above. (Guler and Astarcı, 2009) used this equipment to investigate the frictional behavior of modular blocks using different infills (and with no infill) for a limited height of wall.

As presented in Figure 7.1, using the existing equipment will limit the total load that can be used because the machines limit is set by the amount of blocks that can be put on top of each other. This limit is approximately only 225-300kg. Considering one row is about 75kg and height is 25cm, this corresponds to only 0.75m to 1.0m of wall (Please refer to Figure 7.4.). However, in the practice, the wall heights are usually above 6m for most of the highway project and can rise (but not limited to) to 15m.

There are several project reported having total heights over 30m (A typical highway wall with h_{max}=8m and a wall with a total height of 16m is presented in Figure 7.2 and Figure 7.3).



Figure 7.1. Existing Test Equipment - Karl Terzaghi Soil Mechanicas Laboratory, Boğaziçi University.



Figure 7.2. Typical Highway Wall, h_{max}=6m.



Figure 7.3. A Wall with h_{max}=16m.

Another problem using the available equipment is due to the fact that all the loading must be done manually, in other words, initially blocks must be lifted and laid by hand, then the voids must be filled with gravel, then another row of blocks must be lifted and this procedure must continue to reach desired height. After block construction, then, counterweight (in the form of steel weights) must be put one by one. Upon compeltion of the test, the blocks must be removed one by one while all the gravel is set free creating a mess in the testing environment requiring a proper clean-up. As a result, only for one test takes significant amount of time and manpower. Considering the fact that, this type of research requires significant amount of tests for wide range of load intervals, using the available equipment is not feasible.



Figure 7.4. Existing Equipment Testing Procedure.

More importantly, the above limitations are only for typical static loading. Considering the research topic of this thesis, there is another factor making the use of available equipment is not impossible, that is: Due to nature of this equipment, applying cycling loading is not only difficult but impossible.

As a result, a necessity of constructing a research-spesific equipment arised. This new machine is designed to be sturdy enough so that the structure remains intact and much higher loads can be applied in a more practical way allowing required number of tests to be performed for wide range of load interval.



Figure 7.5. New Equipment - Side View.

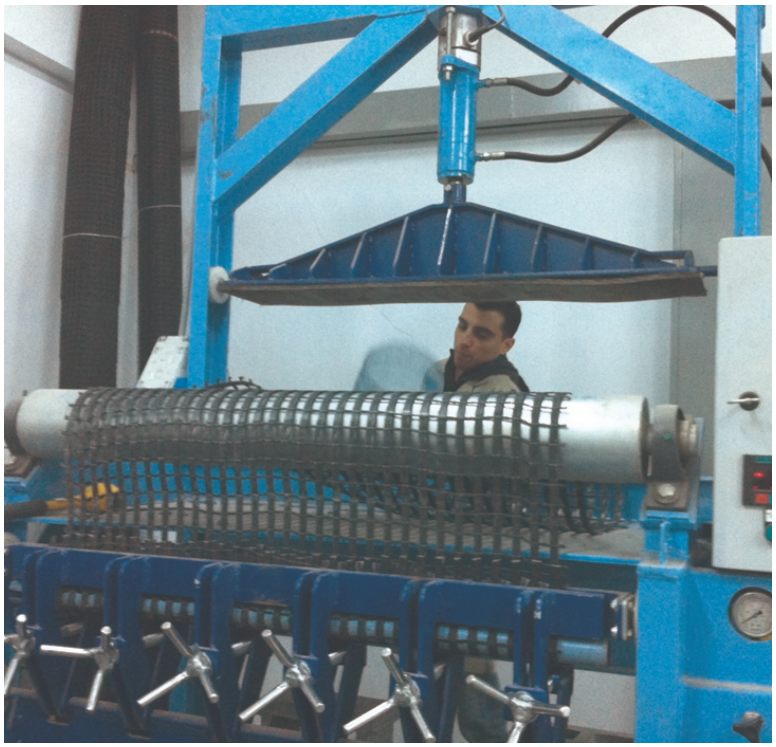


Figure 7.6. New Equipment - Front View.

Main parts of the new equipment can be as follows:

Upper piston: Used to exert normal load over the blocks. The total capacity is up to 7000kg. The pressure due to this force is equivalent to 30m of wall height.



Figure 7.7. New Equipment - Upper Piston.

Lower Piston: Use to apply pull out load. The capacity is around 4.000kg, effectively, 3500kg can be achieved.



Figure 7.8. New Equipment - Lower Piston.

Pressure Gauges and Read-Out Panel: Lower Piston: Use to apply pull out load. The capacity is around 8000kg, effectively, 7000kg can be achieved.



Figure 7.9. New Equipment - Pressure Gauges and Digital Read - Out.

7.3. Material

In order to eliminate any material related problem, standardized, high quality material needed to be selected. Major materials used for the tests are modular blocks, geosysnthetics (geogrid and geotextile), gravel.

7.3.1. Modular Concrete Blocks

There are numerous modular concrete blocks used in the market. Obviously, using different blocks will end up giving different results in terms of connection strength between reinforcing element and block. Typical blocks that are used in retaining wall construction is presented in Figure 7.10.



Figure 7.10. Material - Typical Modular Blocks.

In order to get the most standardized result, it is preffered to use the most common type of block. This is 19cmx19cmx39cm rectangular blocks (Figure 7.11).



Figure 7.11. Material - Concrete Modular Blocks Used in the Tests.

The technical spesification for the test blocks is given in Table 7.3.1.

Table 7.1. Modular Block Technical Specification.

Dimensions (cm)	
Weight	17.5 kg.
Density	2.3gr/cm^3
Available Colors	Yellow-Red-Gray
28-day Compressive Strength	17.5MPa
Max. Water Absorbtion	6%

7.3.2. Gravel (Filling Material)

Other key material for facing stability is the filling material. In general, filling material must be granular, free draining material. Typically, clean ≠2 or ≠3 (or mix of both) is used. Rarely, sand is also utilized. Regardless of the material selected, the filling material must be clean, and the particles must be angular.

The material used in test is presented in Figure 7.12.



Figure 7.12. Material - Gravel.

7.3.3. Geosynthetic Reinforcement

There are several geosynthetic reinforcement types that can be used for reinforced earth wall. The most common types are geogrid and woven geotextile. The detailed information for these materials are given in the previous sections. For the test programme, two most common types of reinforcement is utilized: **Woven Polypropylene Geotextile 120kN/120kN** This type of geotextile is widely used for wall construction. However the strength is usually limited to 80kN/80kN. On the other hand, to reduce the elastic deformation of the reinforcement, stronger material is used. The relevant material properties are listed below:

Table 7.2. Geotextile Properties Used in the Tests.

Texture	
Material	Polypropylene (PP)
Nominal Tensile Strength - MD	120 kN/m
Nominal Tensile Strength - CMD	120 kN/m
Static Puncture Resistance	15kN
Elongation at Nominal Strength	14%
Strength at 2% Strain	26 kN/m
Strength at 3% Strain	39 kN/m
Strength at 5% Strain	75 kN/m

The geotextile is specially ordered to be used in the test. One roll of geotextile used for the test is presented in Figure 7.13.



Figure 7.13. Geotextile Used in the Tests.

Woven PVC Coated Polyester Geogrid 300kN/60kN This type of geogrid

is also very common in the reinforced wall industry. Polyester geogrids are well known for low elongation and low creep potential. On the other hand, it is also beneficial to use the strongest available material possible. In the domestic market, the strongest reinforcement that could be found was 120kN/40kN (this is having 120kN/m ultimate strength in MD and 40kN in CD). After a wide research, 300kN/60kN was found and imported. This strength allowed tests to be performed with minimal elongation that could lead false interpretation. The relevant material properties are listed below:

Table 7.3. Geogrid Properties Used in The Tests.

Texture	
Material	Polyester, PVC Coated
Nominal Tensile Strength - MD	300 kN/m
Nominal Tensile Strength - CMD	60 kN/m
Elongation at Nominal Strength	12%
Strength at 2% Strain	60 kN/m
Strength at 5% Strain	120 kN/m

The geogrid used for the tests is presented in Figure 7.14, Figure 7.15 and Figure 7.16.



Figure 7.14. Geogrid Mesh Opening Size.



Figure 7.15. Geogrid Used in the Tests.

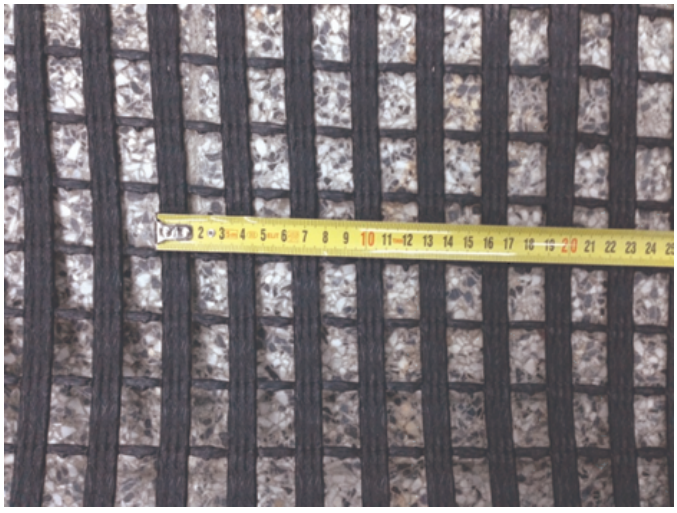


Figure 7.16. Geogrid Mesh Opening Size.

7.4. Preparation and Initial Test Runs

In this sub-section, test preparation before starting the actual tests. In summary, several adjustments for the machine, calibrations, maintenances, material supply and several test runs are explained.

7.4.1. Machine Adjustments and Calibrations

Before commencing any test, several adjustments and calibrations are performed. The original pressure pump was too strong to apply any controlled cyclic loading. In other words, the load increment was too high, as a result, the targeted cyclic loads could not be reached precisely. Thus, a smaller pump is replaced by the existing pump. Afterwards, the load calibration is done. Due to the nature of the work, there were several electrical and mechanical failures. In order to overcome this problem, the manufacturer from İzmit was brought to Boğaziçi Soil Mechanics laboratory to do necessary fixes.



Figure 7.17. Maintenance Works After an Electrical Problem.

7.4.2. Material Selection and Supply

In this sub-section, the material supply procedure, and the necessity of these materials are explained. In section 7.3, the materials that are directly used in the

tests has been explained. These are blocks, geosynthetic reinforcement and the gravel. As explained before, there are spesific reasons for these materials to be used in the research. On the other hand, there are other materials that needed to be utilized for accurate and proper testing.

Additional Rubber Pad The rubber pad has two roles; one is to distribute the load exerted by the upper piston onto the blocks, secondly; to adjust the lower block height so that the pull-out force can be applied along an horizontal plane (the leveling of the blocks is explained in the further section).



Figure 7.18. Rubber Pad Supply and Transportation.

Health and Safety Equipment In order to safely perform the tests, safety tools such as safety glasses, working gloves, high utility apron is supplied.

Working and Measuring Tools There are several tools needed to be used. These are rubber covered hammer, tape measure, cutting tool, water level.

7.4.3. Test Runs

Before commencing any work, several test runs are also performed to see the machine capability, material adequacy, to decide the additional adjustments. These runs are performed using the available blocks, and geogrid in the lab. A sample test run setup has been presented in Figure 7.19.

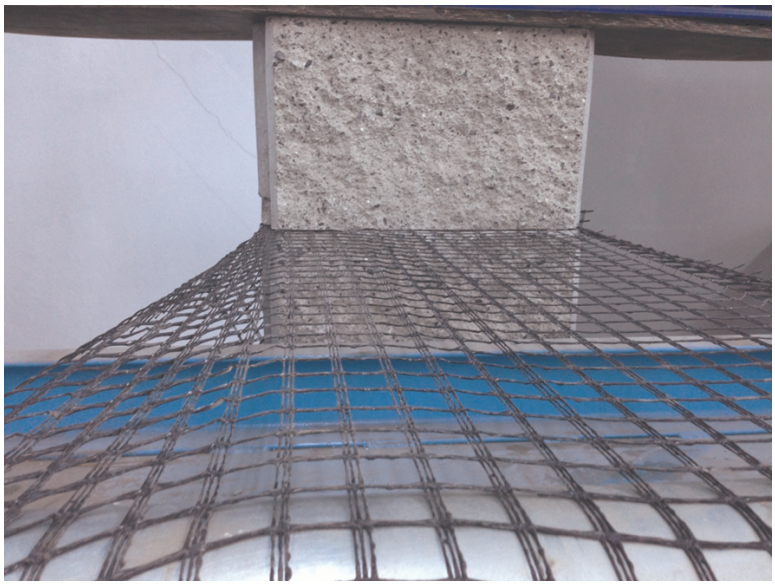


Figure 7.19. Test Run Setup -1.



Figure 7.20. Test Run Setup -2.

As can be seen from the Figures, the initial geogrid used for testing is relatively weaker. It has been observed that significant elongations occurred making the test readings difficult to follow. After the test runs, necessary material supply and calibration of the equipment, the tests targeting the research has been initialized.

7.5. Testing Programme

In this sub-section, the testing programme is given. Since the aim of the test is to determine the effect of cyclic loading on geosynthetic reinforcement-modular block interface resistance (connection strength), a cyclic loading programme must be set referencing to static resistance.

Number of equivalent cycles Initially, the number of cycles must be set. Although, the research is not targeting to directly simulate earthquake loading, it is beneficial to reference load cycles and cycle number to a model/design earthquake.

To simulate earthquake loading cycles, the time history and numerous loading/unloading cycles are expressed in terms of equivalent cycles of ground motion. This approach was initially developed in conjunction with an early procedure for eval-

uation of liquefaction potential proposed by Seed, 1975. In other words, to represent an irregular time history of shear stress by a uniform series of harmonic stress cycles, the concept of equivalent number of significant stress cycles was developed. This targets 65% of the maximum actual shear stress. The equivalent number of uniform cycles with 65% of the maximum shear stress is listed versus the earthquake magnitude is given in Figure 7.4.

Table 7.4. Number of Equivalent Load Cycles for Different Magnitude Earthquake.

Earthquake Magnitude	**Number of Equivalent Stress Cycles**
5.25	2-3
6.0	5
6.75	10
7.5	15
8.5	26

As a result, M=7.5, corresponding to 15 equivalent cycles is picked for the number of cycles during testing.

Determine cycle intervals As mentioned, the equivalent cycle approach targets 65% of maximum actual stress. As a result, the test programme must cover similar load intervals referencing the static maximum pull out/connection resistance (this is actually the shear resistance of the block-reinforcement intervals). As a result, 3 load cycles are considered: 0%-50% 15 cycles:

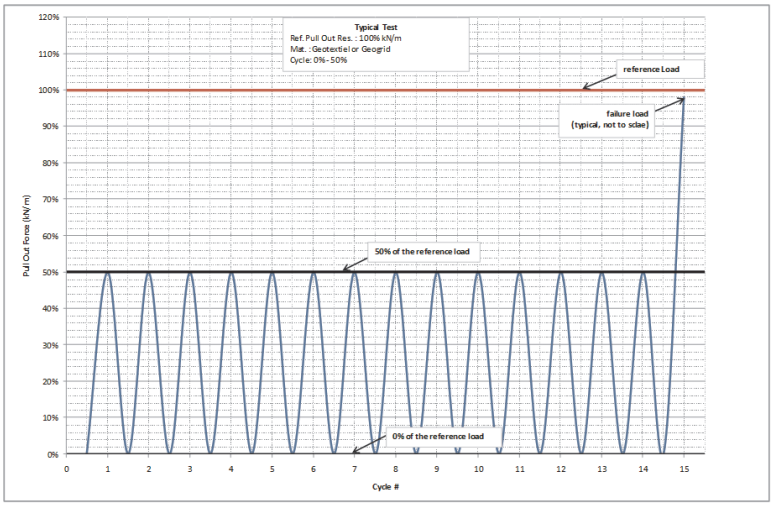


Figure 7.21. Typical Test For 0%-50% Load Cycle.

For this load cycle, a repetitive load of 0%-50% of reference load is applied 15 times and then the pull-out load is increased until failure. The reference load is explained in the coming section. 25%-75% 15 cycles

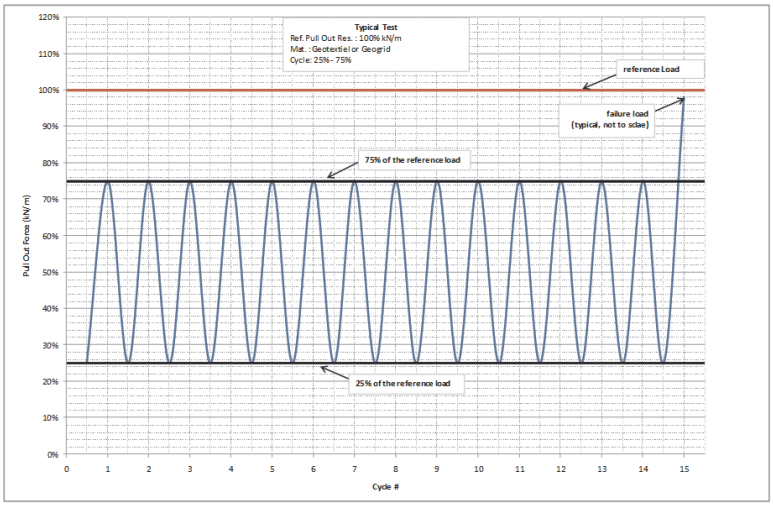


Figure 7.22. Typical Test For 25%-75% Load Cycle.

Similarly, a repetitive load of 25%-75% of reference load is applied 15 times and then the pull-out load is increased until failure. 50%-75% 15 cycles

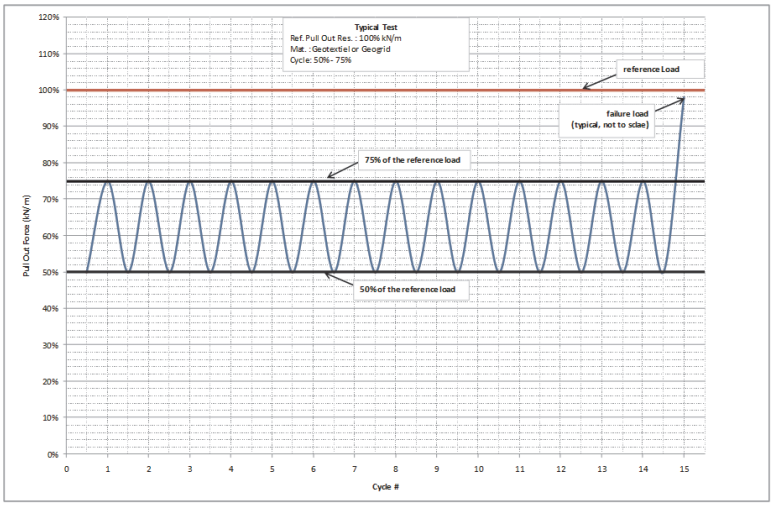


Figure 7.23. Typical Test For 50%-75% Load Cycle.

Finally, a repetitive load of 50%-75% of reference load is applied 15 times and then the pull-out load is increased until failure.

Loading Rate and Test Duration Although, the aim of the project is not to reflect an earthquake, it is a good idea to limit the total test duration so that a better basis of understanding and future interpretation. The typical earthquake duration as a function of magnitude having epicentral distances less than 10km is given in the below table (Chang and Krinitzsky, 1977).

Table 7.5. Typical Durations at Epicentral Distances Less Than 10km.

Earthquake Magnitude	**Duration (sec)**	
	Rock Sites	**Soil sites**
5.0	4	8
5.5	6	12
6.0	8	16
6.5	11	23
7.0	16	32
7.5	22	45
8.0	31	62
8.5	43	86

As given in the table, for M=7.5 magnitude earthquake takes from 22 to 45 seconds depending on the subsurface conditions. On the other hand, it is a well known fact that as as the epicentral distance increases the duration becomes longer, becoming up to 2minutes for M=7.5 magnitude earthquake. The cyclic test durations to determine connection strength is variable and effected by many factors such as the normal load magnitude (lower normal load result in shorter loading cycle), the choice of the cycle (i.e. a 0%-50% takes shorter time than 50%-75%). As a result a normal load of 150kg with 0%-50% cycle is the shortest test where a 3250kg normal load with 50%-75% is the longest. The total duration is between 60 seconds 150 seconds, resulting a loading frequency of 0.1hz to 0.25hz (or a period of 4 seconds to 10 seconds).

Normal load intervals The normal load that will be exerted on the blocks has two parts; one is the limitation of the upper piston (i.e. the source of normal load), second is the limitation of the lower piston (i.e. the source of pull-out force). Combining these two limitations, the upper limit for normal load is set to 3250-3300 kg corresponding to an equivalent wall height of 14.0m. Setting the upper limit is followed by setting load intervals. For the research, it is ideal to keep the load increments as close as possible,

as a result, the 13 load intervals are set as: 150 kg-350 kg-550 kg-750 kg-950 kg-1150 kg-1450 kg-1750 kg-2050 kg-2350 kg-2650 kg-2950 kg-3250 kg

Number of tests The number of tests is set by the combination of all variables:

- Materials: 2 types (Geogrid and Geotextile)
- Cycle intervals: 3 cycles (0%-50%, 25%-75%, 50%-75%)
- Normal load intervals: 13 intervals (150 kg-350 kg-550 kg-750 kg-950 kg-1150 kg-1450 kg-1750 kg-2050 kg-2350 kg-2650 kg-2950 kg-3250 kg)
- Further more, all tests are repeated twice

As a result the total number of cycling loading tests are: 2x3x13x2=156 tests The summary table for tests are given in Table 7.6.

The table columns can be summarized as: 1st Column test identification number presented in in 3-1, 3-2, 3-2, 3-4, 3-5, 3-6 corresponding to 3rd normal load interval. 2nd and 3rd Column: The experiment type is the cycle intervals are 0%-50%, 25%-75%, 50%-75%. as stated before. 4th and 5th Column: The material (reinforcement type) and strength used in the test. The alternatives are geotextile (for the first 13 tests) and geogrid (for the tests from 14 to 26) 6th column: The actual total normal load in kg exerted by the upper piston. 7th column: The actual total normal load in kN exerted by the upper piston. This the multiplication of 4th column by 0.00981. 8th column: The actual total normal load converted to unit length. This is obtained by dividing the 5th column by 0.78m (0.78m is the length of two blocks having 39cm width as given in Chapter 7).

7.6. Actual Test Runs

For the actual test runs (upon doing required calibration, selecting proper materials as explained in the previous sections) the actual tests initiated. Step-by-step testing procedure is presented in the following sub-sections.

Table 7.6. Test Summary Table.

Test #	Experiment Type	Cycle	Material	Strength	Total Normal Load kg	Total Normal Load kN	Unit Normal Load kN/m	Equivalent Height m
1-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	150	1.47	1.89	0.65
1-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	155	1.52	1.95	0.67
1-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	145	1.42	1.82	0.63
1-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	150	1.47	1.89	0.65
1-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	155	1.52	1.95	0.67
1-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	150	1.47	1.89	0.65
2-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	350	3.43	4.40	1.51
2-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	355	3.48	4.46	1.53
2-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	350	3.43	4.40	1.52
2-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	360	3.53	4.53	1.55
2-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	345	3.38	4.34	1.49
2-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	340	3.43	4.28	1.47
3-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	550	5.40	6.92	2.38
3-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	550	5.40	6.92	2.38
3-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	560	5.49	7.04	2.42
3-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	555	5.44	6.98	2.40
3-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	545	5.35	6.85	2.35
3-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	555	5.44	6.98	2.40
4-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	750	7.36	9.43	3.24
4-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	755	7.41	9.50	3.26
4-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	760	7.46	9.56	3.28
4-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	750	7.36	9.43	3.24
4-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	750	7.36	9.43	3.24
4-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	745	7.31	9.37	3.22
5-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	950	9.32	11.95	4.10
5-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	950	9.32	11.95	4.10
5-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	960	9.42	12.07	4.15
5-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	940	9.22	11.82	4.06
5-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	950	9.32	11.95	4.10
5-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	960	9.42	12.07	4.15
6-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	1150	11.28	14.46	4.97
6-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	1160	11.38	14.59	5.01
6-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	1160	11.38	14.59	5.01
6-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	1150	11.28	14.46	4.97
6-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	1150	11.28	14.46	4.97
6-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	1150	11.28	14.46	4.97
7-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	1500	14.72	18.87	6.48
7-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	1450	14.22	18.24	6.26
7-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	1450	14.22	18.24	6.26
7-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	1500	14.72	18.87	6.48
7-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	1450	14.22	18.24	6.26
7-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	1500	14.72	18.87	6.48

Table 7.6. Test Summary Table.

Test #	Experiment Type	Cycle	Material	Strength	Total Normal Load kg	Total Normal Load kN	Unit Normal Load kN/m	Equivalent Height m
8-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	1800	17.66	22.64	7.77
8-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	1750	17.17	22.01	7.56
8-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	1800	17.66	22.64	7.77
8-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	1750	17.17	22.01	7.56
8-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	1750	17.17	22.01	7.56
8-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	1700	16.68	21.38	7.34
9-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2050	20.11	25.78	8.85
9-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2050	20.11	25.78	8.85
9-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2100	20.60	26.41	9.07
9-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2050	20.11	25.78	8.85
9-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2050	20.11	25.78	8.85
9-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2050	20.11	25.78	8.85
10-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2350	23.05	29.56	10.15
10-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2350	23.05	29.56	10.15
10-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2300	22.56	28.93	9.93
10-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2300	22.56	28.93	9.93
10-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2400	23.54	30.18	10.36
10-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2400	23.54	30.18	10.36
11-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2650	26.00	33.33	11.44
11-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2650	26.00	33.33	11.44
11-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2650	26.00	33.33	11.44
11-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2600	25.51	32.70	11.23
11-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2600	25.51	32.70	11.23
11-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2650	26.00	33.33	11.44
12-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2900	28.45	36.47	12.52
12-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	2900	28.45	36.47	12.52
12-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2950	28.94	37.10	12.74
12-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	2950	28.94	37.10	12.74
12-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2950	28.94	37.10	12.74
12-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	2950	28.94	37.10	12.74
13-1	Cyclic	0%-50%	Geotextile PP	120kN/120kN	3250	31.88	40.88	14.03
13-2	Cyclic	0%-50%	Geotextile PP	120kN/120kN	3250	31.88	40.88	14.03
13-3	Cyclic	25%-75%	Geotextile PP	120kN/120kN	3250	31.88	40.88	14.03
13-4	Cyclic	25%-75%	Geotextile PP	120kN/120kN	3250	31.88	40.88	14.03
13-5	Cyclic	50%-75%	Geotextile PP	120kN/120kN	3200	31.39	40.25	13.82
13-6	Cyclic	50%-75%	Geotextile PP	120kN/120kN	3200	31.39	40.25	13.82
14-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	150	1.47	1.89	0.65
14-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	150	1.47	1.89	0.65
14-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	150	1.47	1.89	0.65
14-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	150	1.47	1.89	0.65
14-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	160	1.57	2.01	0.69
14-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	160	1.57	2.01	0.69

Table 7.6. Test Summary Table.

Test #	Experiment Type	Cycle	Material	Strength	Total Normal Load kg	Total Normal Load kN	Unit Normal Load kN/m	Equivalent Height m
15-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	350	3.43	4.40	1.51
15-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	350	3.43	4.40	1.51
15-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	350	3.43	4.40	1.51
15-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	350	3.43	4.40	1.51
15-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	350	3.43	4.40	1.51
15-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	350	3.43	4.40	1.51
16-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	550	5.40	6.92	2.38
16-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	550	5.40	6.92	2.38
16-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	560	5.49	7.04	2.42
16-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	560	5.49	7.04	2.42
16-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	550	5.40	6.92	2.38
16-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	550	5.40	6.92	2.38
17-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	740	7.26	9.31	3.20
17-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	740	7.26	9.31	3.20
17-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	750	7.36	9.43	3.24
17-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	750	7.36	9.43	3.24
17-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	740	7.26	9.31	3.20
17-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	740	7.26	9.31	3.20
18-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	950	9.32	11.95	4.10
18-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	950	9.32	11.95	4.10
18-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	950	9.32	11.95	4.10
18-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	950	9.32	11.95	4.10
18-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	950	9.32	11.95	4.10
18-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	950	9.32	11.95	4.10
19-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	1150	11.28	14.46	4.97
19-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	1150	11.28	14.46	4.97
19-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	1100	10.79	13.83	4.75
19-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	1100	10.79	13.83	4.75
19-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	1150	11.28	14.46	4.97
19-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	1150	11.28	14.46	4.97
20-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	1450	14.22	18.24	6.26
20-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	1450	14.22	18.24	6.26
20-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	1450	14.22	18.24	6.26
20-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	1450	14.22	18.24	6.26
20-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	1450	14.22	18.24	6.26
20-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	1450	14.22	18.24	6.26
21-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	1750	17.17	22.01	7.56
21-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	1750	17.17	22.01	7.56
21-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	1800	17.66	22.64	7.77
21-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	1800	17.66	22.64	7.77
21-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	1750	17.17	22.01	7.56
21-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	1750	17.17	22.01	7.56

Table 7.6. Test Summary Table.

Test #	Experiment Type	Cycle	Material	Strength	Total Normal Load kg	Total Normal Load kN	Unit Normal Load kN/m	Equivalent Height m
22-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2100	20.60	26.41	9.07
22-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2100	20.60	26.41	9.07
22-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2050	20.11	25.78	8.85
22-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2050	20.11	25.78	8.85
22-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2050	20.11	25.78	8.85
22-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2050	20.11	25.78	8.85
23-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2350	23.05	29.56	10.15
23-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2350	23.05	29.56	10.15
23-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2350	23.05	29.56	10.15
23-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2350	23.05	29.56	10.15
23-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2400	23.54	30.18	10.36
23-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2400	23.54	30.18	10.36
24-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2650	26.00	33.33	11.44
24-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2650	26.00	33.33	11.44
24-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2650	26.00	33.33	11.44
24-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2650	26.00	33.33	11.44
24-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2650	26.00	33.33	11.44
24-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2650	26.00	33.33	11.44
25-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2950	28.94	37.10	12.74
25-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	2950	28.94	37.10	12.74
25-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2950	28.94	37.10	12.74
25-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	2950	28.94	37.10	12.74
25-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2950	28.94	37.10	12.74
25-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	2950	28.94	37.10	12.74
26-1	Cyclic	0%-50%	Geogrid PET	300kN/60kN	3250	31.88	40.88	14.03
26-2	Cyclic	0%-50%	Geogrid PET	300kN/60kN	3250	31.88	40.88	14.03
26-3	Cyclic	25%-75%	Geogrid PET	300kN/60kN	3300	32.37	41.50	14.25
26-4	Cyclic	25%-75%	Geogrid PET	300kN/60kN	3300	32.37	41.50	14.25
26-5	Cyclic	50%-75%	Geogrid PET	300kN/60kN	3300	32.37	41.50	14.25
26-6	Cyclic	50%-75%	Geogrid PET	300kN/60kN	3300	32.37	41.50	14.25

7.6.1. Cutting Reinforcement

The reinforcement (either geogrid or geotextile) needed to be cut to pre-determined test dimensions as presented below. Wider or too long dimensioning will end up testing more difficult.



Figure 7.24. Cutting Reinforcement (Cutting of Geogrid is Presented Here).

7.6.2. Setting Up Intimal Block Height

One of the crucial adjustment is to make sure that the top of the lower block is level with the geosynthetic pullout direction. On the other hand, the block heights have wide range. The machine setup is for 25cm (can be considered as the upper limit for an individual block height). However, as explained in the previous sections, the block used in the research has an height of 19cm. The 6-cm difference is compensated using rubber pads having 1-cm thickness. The rubber pads are cut down to necessary dimensions and stacked on top of each other to reach the desired elevation of 25cm.



Figure 7.25. Rubber Pad Dimensioning and Cutting.

Rubber pads are stacked below the lower block as presented below.



Figure 7.26. Rubber Pad Stacked Below Lower Block.

Leveling of the reinforcement with respect to pull-out direction is also checked directly from the reinforcement.



Figure 7.27. Leveling Check - Front View.



Figure 7.28. Leveling Check - Side View.

7.6.3. Setting Blocks, Reinforcement and Filling with Gravel

Another step is to setting blocks, laying the reinforcement and filling the voids of modular blocks with gravel. In order to this, the first row of block (the height adjustment of the intimal row of block is expalined in the previous sub-section) is set, then the voids are filled with gravel.



Figure 7.29. Filling Voids of First Row of Blocks.



Figure 7.30. Voids Filled With Gravel.

Afterwards, the reinforcement is laid, second row of block is placed and voids are

filled with gravel as presented below.



Figure 7.31. Voids Filled With Gravel.

The load transfer from the lower piston to the reinforcement is by a mechanism involving the fixing of the reinforcement to the lower piston using the clamps as presented below. Consequently, the clamps must be fixed tight enough to prevent slippage of the reinforcement from the lower part of the machine. The clamps are tightened using rubber covered hammer.



Figure 7.32. Fixing Clamps.

7.6.4. Video Synchronization

The cyclic loading is a relatively fast testing. As a result, the actual load during each cycle changes very rapidly. Due to limitation of the equipment, there is no digital data recorded during loading/unloading. It is also impossible to record and continue testing spontaneously. Same problems are also valid for determination of the exact pull-out force.

In order to overcome this problem and get more accurate results, synchronization is utilized using two sets of video cameras. The tests are recorded, and than rendered after tests are completed.



Figure 7.33. Video Synchronization Setup.

7.6.5. Determining Reference Static Test Results

Upon completion of the test setup, the initial setup is to determine the static connection strength value as a reference. Using similar load intervals, the idealized reference connection strength values are presented below for both geotextile and geogrid. The static reference connection strength is determined from the ongoing research project by Ph.D. candidate Halil Karaoğlan. Please note that, all values are divided by two in order to reflect the shear force mobilized on one side.

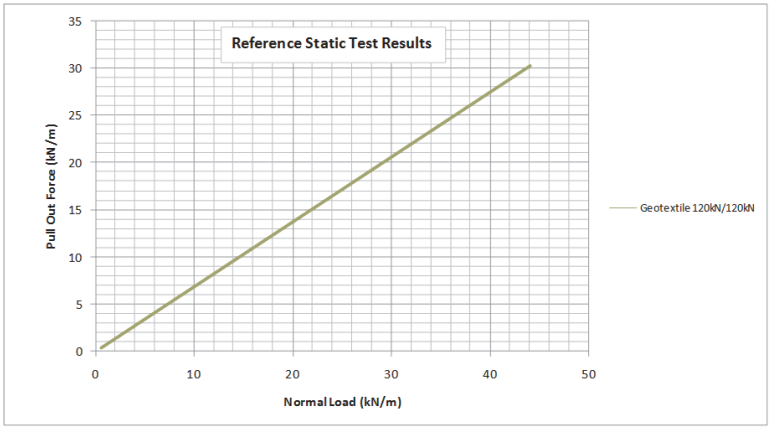


Figure 7.34. Reference Static Test Results - Use of Geotextile 120kN/ 120kN.

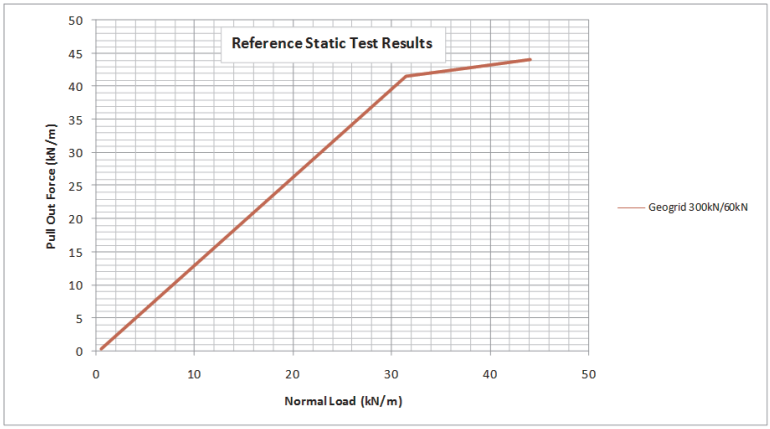


Figure 7.35. Reference Static Test Results - Use of Geogrid 300kN/ 60kN.

The connection strength of the geogrid-block interface seems to increase linearly to a certain normal load increment and then following a flatter line. This is probably due to the fact that the interlocking mechanism is mobilized using the junction strength of the geogrid between the MD and CMD direction. Consequently, the point where the line becomes flatter is probably due to the yield of these junctions.

Completing all the required pre-studies, as summarized above, the tests required to determine the effect of cyclic loading are performed and the results are summarized in section 8 and full data given in the appendices A and B. In Appendix A, the pull out load for each cycle and for each cycle interval is given. In appendix B, the test summary data for each test, and the graphical output is given. An example data is presented in the next section.

8. RESULTS

8.1. General

In this chapter, the test results that are performed as explained in detail in the methodology section is listed.

Two set of tests were performed for each normal (axial) load level. Each set consisted of 3 load cycles (the details are in methodology section): 0%-50%, 25%-75%, 50%-75%. All these tests were performed for two type of material: Polypropylene Woven Geotextile, PVC Coated Polyester Woven Geogrid. As a summary:

$\neq$ of Sets: 2 Load Cycles: 0%-50%, 25%-75%, 50%-75%. Material Types: Geotextile (Woven, PP), Geogrid (Woven, PVC Coated Polyester) Total Number of Normal Load: 13 As a result, the total number of tests are 2x3x2x13=156tests The list of tests are given in the previous section, the result of each test is given in this chapter. In addition to individual test results, the graphical summary and interpretation is also given at the end of this chapter.

8.2. Graphical Outputs of Tests

The full graphical output and test data summary is given in the appendix. Below, a summary of tests is presented so that the interpretation of the full data can be easier.

1st Column: Test identification number presented in in 3-1, 3-2, 3-2, 3-4, 3-5, 3-6 corresponding to 3rd normal load interval.

2nd Cloumn: The experiment type is the cycle intervals are 0%-50%, 25%-75%, 50%-75%, as stated before.

3rd Column: The material (reinforcement type) used in the test. The alternatives

are geotextiler (for the first 13 tests) and geogrid (for the tests from 14 to 26).

4th column: The actual total normal load in kg exerted by the upper piston.

5th column: The actual total normal load in kN exerted by the upper piston. This the multiplication of 4th column by 0.00981.

6th column: The actual total normal load converted to unit length. This is obtained by dividing the 5th column by 0.78m (0.78m is the length of two blocks having 39cm width as given in Chapter 7).

7th column: Equivalent height: The total weight of the blocks having this wall height. 1 block filled with gravel weighs approximately 22kg.

Considering the block height of 19cm and block width of 39cm, 1m of block for unit length exerts a pressure of 22*0.00981/0.19/0.39=2.91kN/m. Thus dividing 6th column to 2.91 gives the 7th column.

8th, 9th and 10th column: This is the pull out resistance (along one side of the reinforcement) of this cyclic load test (after applying 15 cycles of load usisng 0%-50% load cycles and the load for each cycle is given in appendix A). The pull-out resistance is calculated in the same manner as 4th, 5th and 6th column.

11th Column: The reference value given herein is the reference pull-out resistance obtained by static load tests as given in chapter 7.

Below, there are 6 samples of tests data and graphical outputs are presented as an example.

Table 8.1. Test 3-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-1	Cyclic 0% -50%	Geotextile 120kN 120kN	550	5.4	6.92	2.38	347	3.40	4.36	4.69

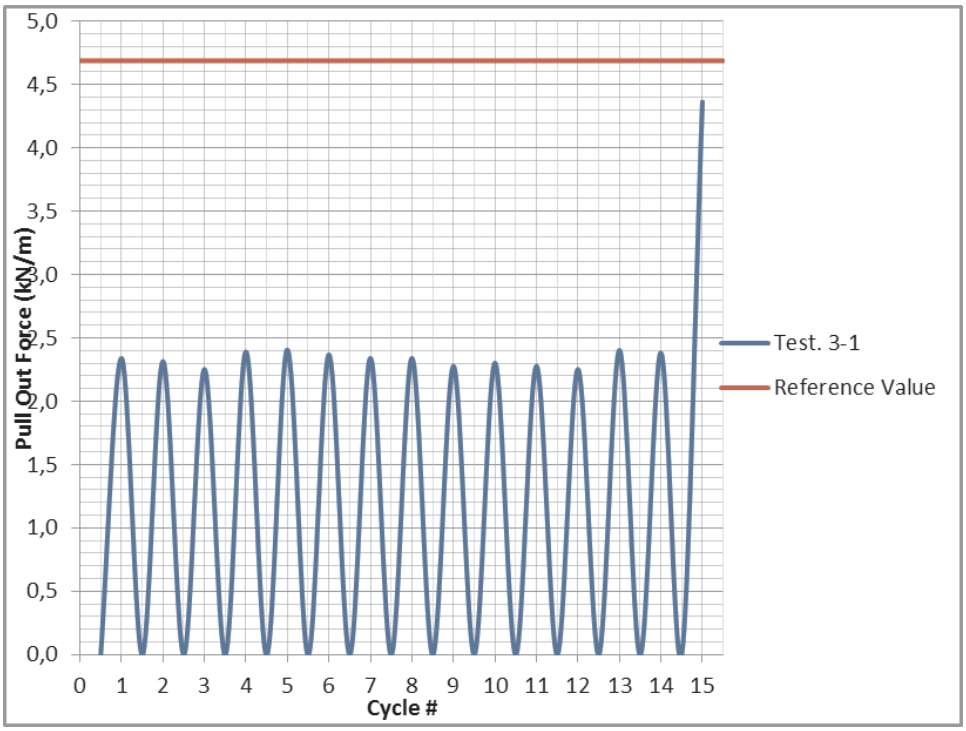


Figure 8.1. Graphical Output of Test 3-1.

As explained, this test data and graphical output is for: Material type: Geotextile, Load cycle: 0%-50%, Normal Load: 550kg.

Table 8.2. Test 3-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-4	Cyclic 25% -75%	Geotextile 120kN 120kN	555	5.4	6.98	2.40	349	3.42	4.39	4.73

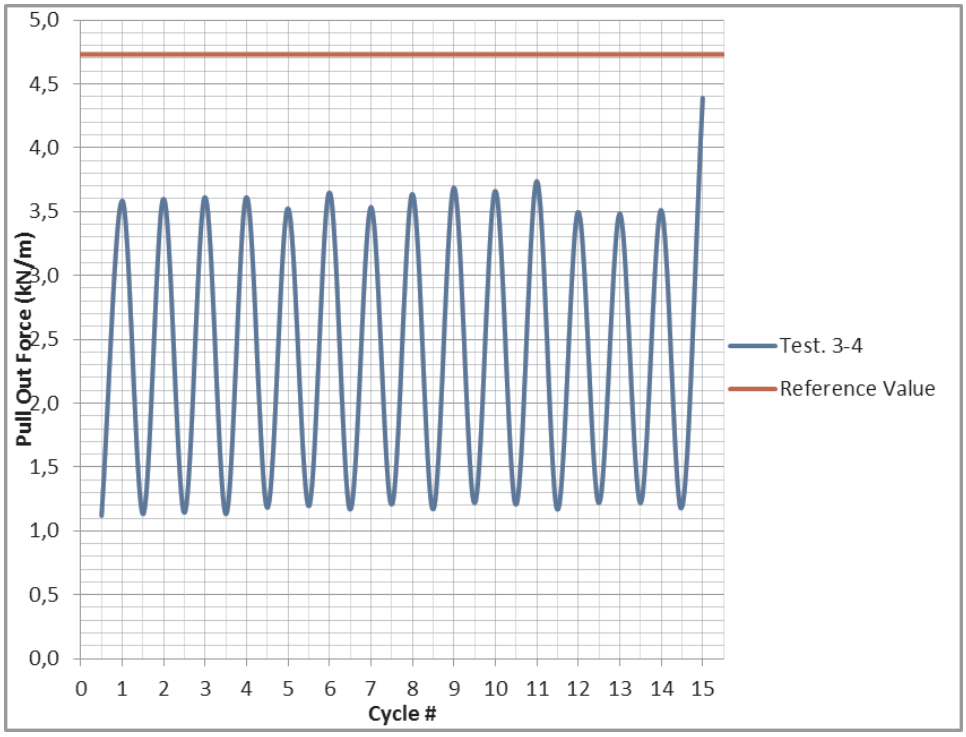


Figure 8.2. Graphical Output of Test 3-4.

This test data and graphical output is for: Material type: Geotextile, Load cycle: 25%-75%, Normal Load: 555kg.

Table 8.3. Test 3-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-6	Cyclic 50% -75%	Geotextile 120kN 120kN	555	5.4	6.98	2.40	349	3.83	4.91	4.73

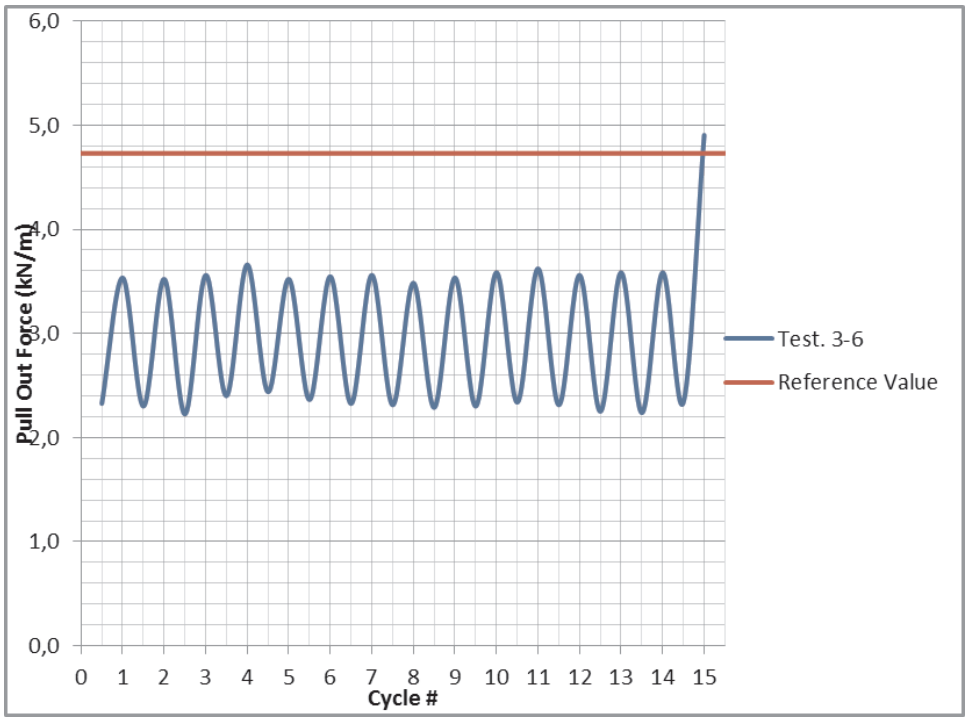


Figure 8.3. Graphical Output of Test 3-6.

This test data and graphical output is for: Material type: Geotextile, Load cycle: 50%-75%, Normal Load: 555kg.

Table 8.4. Test 18-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-2	Cyclic 0% 50%	Geotextile 300kN 60kN	950	9.3	11.95	4.10	1180	11.58	14.84	15.56

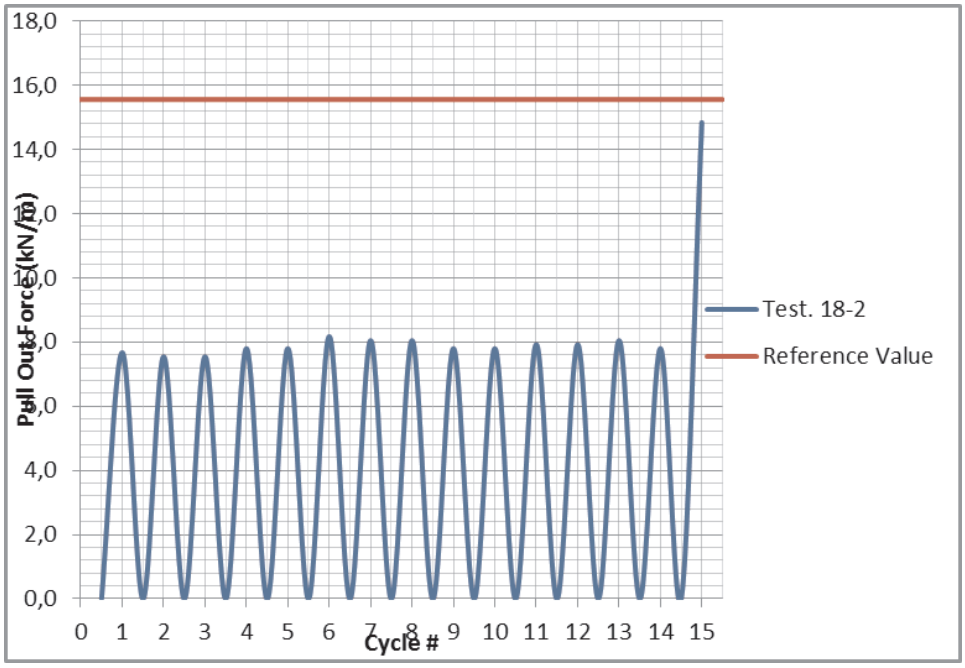


Figure 8.4. Graphical Output of Test 18-2.

This test data and graphical output is for: Material type: Geogrid, Load cycle: 0%-50%, Normal Load: 950kg.

Table 8.5. Test 18-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-4	Cyclic 25% 75%	Geotextile 300kN 60kN	950	9.3	11.95	4.10	1150	11.28	14.46	15.56

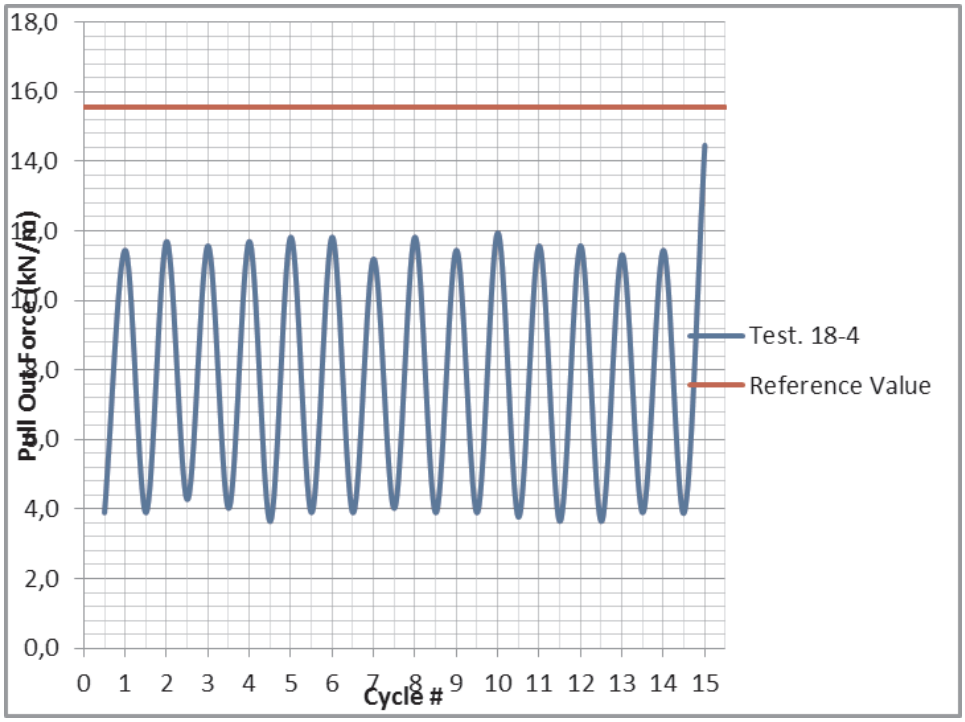


Figure 8.5. Graphical Output of Test 18-4.

This test data and graphical output is for: Material type: Geogrid, Load cycle: 25%-75%, Normal Load: 950kg.

Table 8.6. Test 18-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-5	Cyclic 50% 75%	Geotextile 300kN 60kN	950	9.3	11.95	4.10	1170	11.48	14.72	15.56

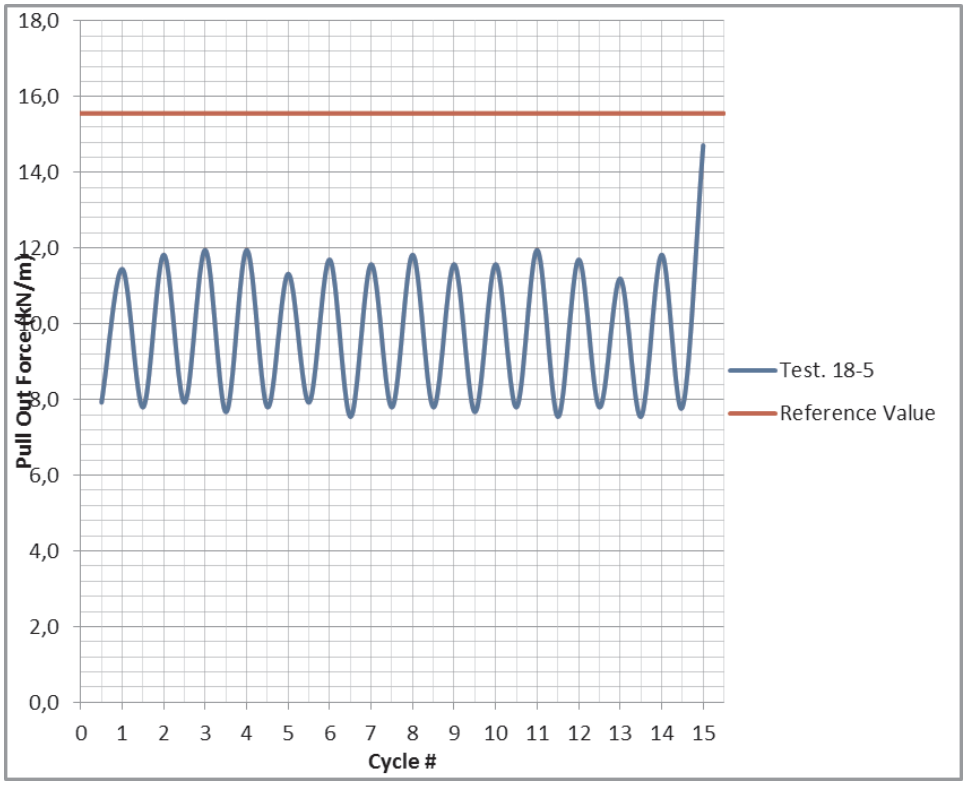


Figure 8.6. Graphical Output of Test 18-5.

This test data and graphical output is for: Material type: Geogrid, Load cycle: 50%-75%, Normal Load: 950kg.

8.3. Test Results

The test results summary table is presented in Table 8.7. The column explanations are given previously in the report.

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-1	Cyclic 0%-50%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	88	0.86	1.11	1.23
1-2	Cyclic 0%-50%	Geotextile 120kN/120kN	155	1.52	1.95	0.67	90	0.88	1.13	1.27
1-3	Cyclic 25%-75%	Geotextile 120kN/120kN	145	1.42	1.82	0.63	87	0.85	1.09	1.19
1-4	Cyclic 25%-75%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	93	0.91	1.17	1.23
1-5	Cyclic 50%-75%	Geotextile 120kN/120kN	155	1.52	1.95	0.67	90	0.88	1.13	1.27
1-6	Cyclic 50%-75%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	91	0.89	1.14	1.23
2-1	Cyclic 0%-50%	Geotextile 120kN/120kN	350	3.43	4.40	1.51	216	2.12	2.72	2.96
2-2	Cyclic 0%-50%	Geotextile 120kN/120kN	355	3.48	4.46	1.53	222	2.18	2.79	3.00
2-3	Cyclic 25%-75%	Geotextile 120kN/120kN	350	3.43	4.40	1.51	219	2.15	2.75	2.96
2-4	Cyclic 25%-75%	Geotextile 120kN/120kN	360	3.53	4.53	1.55	225	2.21	2.83	3.05
2-5	Cyclic 50%-75%	Geotextile 120kN/120kN	345	3.38	4.34	1.49	215	2.11	2.70	2.92
2-6	Cyclic 50%-75%	Geotextile 120kN/120kN	340	3.34	4.28	1.47	215	2.11	2.70	2.87
3-1	Cyclic 0%-50%	Geotextile 120kN/120kN	550	5.40	6.92	2.38	347	3.40	4.36	4.69
3-2	Cyclic 0%-50%	Geotextile 120kN/120kN	550	5.40	6.92	2.38	346	3.40	4.36	4.69
3-3	Cyclic 25%-75%	Geotextile 120kN/120kN	560	5.49	7.04	2.42	351	3.44	4.41	4.77
3-4	Cyclic 25%-75%	Geotextile 120kN/120kN	555	5.44	6.98	2.40	349	3.42	4.39	4.73
3-5	Cyclic 50%-75%	Geotextile 120kN/120kN	545	5.35	6.85	2.35	341	3.35	4.29	4.64
3-6	Cyclic 50%-75%	Geotextile 120kN/120kN	555	5.44	6.98	2.40	390	3.83	4.91	4.73
4-1	Cyclic 0%-50%	Geotextile 120kN/120kN	750	7.36	9.43	3.24	475	4.66	5.97	6.42
4-2	Cyclic 0%-50%	Geotextile 120kN/120kN	755	7.41	9.50	3.26	470	4.61	5.91	6.46
4-3	Cyclic 25%-75%	Geotextile 120kN/120kN	760	7.46	9.56	3.28	480	4.71	6.04	6.50
4-4	Cyclic 25%-75%	Geotextile 120kN/120kN	750	7.36	9.43	3.24	475	4.66	5.97	6.42
4-5	Cyclic 50%-75%	Geotextile 120kN/120kN	750	7.36	9.43	3.24	470	4.61	5.91	6.42
4-6	Cyclic 50%-75%	Geotextile 120kN/120kN	745	7.31	9.37	3.22	465	4.56	4.85	6.37

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-1	Cyclic 0%-50%	Geotextile 120kN/120kN	950	9.31	11.95	4.10	615	6.03	7.73	8.14
5-2	Cyclic 0%-50%	Geotextile 120kN/120kN	950	9.32	11.95	4.10	605	5.94	7.61	8.14
5-3	Cyclic 25%-75%	Geotextile 120kN/120kN	960	9.42	12.07	4.14	610	5.98	7.67	8.23
5-4	Cyclic 25%-75%	Geotextile 120kN/120kN	940	9.22	11.82	4.06	595	5.84	7.48	8.06
5-5	Cyclic 50%-75%	Geotextile 120kN/120kN	950	9.32	11.95	4.10	600	5.89	7.55	8.14
5-6	Cyclic 50%-75%	Geotextile 120kN/120kN	960	9.42	12.07	4.15	605	5.94	7.61	8.23
6-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1150	11.28	14.46	4.97	740	7.26	9.31	9.87
6-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1160	11.38	14.59	5.01	735	7.21	9.24	9.96
6-3	Cyclic 25%-75%	Geotextile 120kN/120kN	1160	11.38	14.59	5.01	740	7.26	9.31	9.96
6-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1150	11.28	14.46	4.97	790	7.75	9.94	7.87
6-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1150	11.28	14.46	4.97	725	7.11	9.12	9.87
6-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1150	11.28	14.46	4.97	720	7.06	9.06	9.87
7-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1500	14.72	18.87	6.48	935	9.17	11.76	12.90
7-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1450	14.22	18.24	6.26	940	9.22	11.82	12.46
7-3	Cyclic 25%-75%	Geotextile 120kN/120kN	1450	14.22	18.24	6.26	1000	9.81	12.58	12.46
7-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1500	14.72	18.87	6.48	925	9.07	11.63	12.90
7-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1450	14.22	18.24	6.26	945	9.27	11.89	12.46
7-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1500	14.72	18.87	6.48	960	9.42	12.07	12.90
8-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1800	17.66	22.64	7.77	1145	11.23	14.40	15.49
8-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1750	17.17	22.01	7.56	1120	10.99	14.09	15.06
8-3	Cyclic 25%-75%	Geotextile 120kN/120kN	1800	17.66	22.64	7.77	1130	11.09	14.21	15.49
8-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1750	17.17	22.01	7.56	1125	11.04	14.15	15.06
8-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1750	17.17	22.01	7.56	1120	10.99	14.09	15.06
8-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1700	16.68	21.38	7.34	1100	1079	13.83	14.62

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1250	12.26	15.72	17.65
9-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1315	12.90	16.54	17.65
9-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2100	20.60	26.41	9.07	1460	14.32	18.36	18.08
9-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1290	12.65	16.22	17.65
9-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1300	12.75	16.35	17.65
9-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1280	12.56	16.10	17.65
10-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2350	23.05	29.56	10.15	1470	14.42	18.49	20.24
10-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2350	23.05	29.56	10.15	1540	15.11	19.37	20.24
10-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2300	22.56	28.93	9.93	1420	13.93	17.86	19.81
10-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2300	22.56	28.93	9.93	1650	16.19	20.75	19.81
10-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2400	23.54	30.18	10.36	1510	14.81	18.99	20.67
10-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2400	23.54	30.18	10.36	1550	15.21	19.49	20.67
11-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1600	15.70	20.12	22.83
11-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1680	16.48	21.13	22.83
11-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1720	16.87	21.63	22.83
11-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2600	25.51	32.70	11.23	1700	16.68	21.38	22.40
11-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2600	25.51	32.70	11.23	1720	16.87	21.63	22.40
11-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1670	16.38	21.00	22.83
12-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2900	28.45	36.47	12.52	1870	18.34	23.52	24.99
12-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2900	28.45	36.47	12.52	1750	17.17	41661	24.99
12-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	1890	18.54	23.77	25.42
12-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	2050	20.11	25.78	25.42
12-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	1880	18.44	23.64	25.42
12-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	1900	18.64	23.90	25.42

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-1	Cyclic 0%-50%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2300	22.56	28.93	28.02
13-2	Cyclic 0%-50%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2040	20.01	25.66	28.02
13-3	Cyclic 25%-75%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2150	21.09	27.04	28.04
13-4	Cyclic 25%-75%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2060	20.21	25.91	28.02
13-5	Cyclic 50%-75%	Geotextile 120kN/120kN	3200	31.39	40.25	13.82	2030	19.91	25.53	27.58
13-6	Cyclic 50%-75%	Geotextile 120kN/120kN	3200	31.39	40.25	13.82	2000	19.62	25.15	27.58
14-1	Cyclic 0%-50%	Geogrid 300kN/60kN	150	1.47	1.89	0.65	160	1.57	2.01	2.16
14-2	Cyclic 0%-50%	Geogrid 300kN/60kN	150	1.47	1.89	0.65	165	1.62	2.08	2.16
14-3	Cyclic 25%-75%	Geogrid 300kN/60kN	150	1.47	1.89	0.65	162	1.59	2.04	2.16
14-4	Cyclic 25%-75%	Geogrid 300kN/60kN	150	1.47	1.89	0.65	160	1.57	2.01	2.16
14-5	Cyclic 50%-75%	Geogrid 300kN/60kN	160	1.57	2.01	0.69	195	1.91	2.45	2.33
14-6	Cyclic 50%-75%	Geogrid 300kN/60kN	160	1.57	2.01	0.69	170	1.67	2.14	2.33
15-1	Cyclic 0%-50%	Geogrid 300kN/60kN	350	3.43	4.40	1.51	420	4.12	5.28	5.51
15-2	Cyclic 0%-50%	Geogrid 300kN/60kN	350	3.43	4.40	1.51	480	4.71	6.04	5.51
15-3	Cyclic 25%-75%	Geogrid 300kN/60kN	350	3.43	4.40	1.51	415	4.07	5.22	5.51
15-4	Cyclic 25%-75%	Geogrid 300kN/60kN	350	3.43	4.40	1.51	420	4.12	5.28	5.51
15-5	Cyclic 50%-75%	Geogrid 300kN/60kN	350	3.43	4.40	1.51	430	4.22	5.41	5.51
15-6	Cyclic 50%-75%	Geogrid 300kN/60kN	350	3.43	4.40	1.51	410	4.02	5.16	5.51
16-1	Cyclic 0%-50%	Geogrid 300kN/60kN	550	5.40	6.92	2.38	670	6.57	8.43	8.86
16-2	Cyclic 0%-50%	Geogrid 300kN/60kN	550	5.40	6.92	2.38	680	6.67	8.55	8.86
16-3	Cyclic 25%-75%	Geogrid 300kN/60kN	560	5.49	7.04	2.42	660	6.47	8.30	9.03
16-4	Cyclic 25%-75%	Geogrid 300kN/60kN	560	5.49	7.04	2.42	690	6.77	8.68	9.03
16-5	Cyclic 50%-75%	Geogrid 300kN/60kN	550	5.40	6.92	2.38	690	6.77	8.68	8.86
16-6	Cyclic 50%-75%	Geogrid 300kN/60kN	550	5.40	6.92	2.38	660	6.47	8.30	8.86

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-1	Cyclic 0%-50%	Geogrid 300kN/60kN	740	7.26	9.31	3.20	920	9.03	11.57	12.04
17-2	Cyclic 0%-50%	Geogrid 300kN/60kN	740	7.26	9.31	3.20	910	8.93	11.45	12.04
17-3	Cyclic 25%-75%	Geogrid 300kN/60kN	750	7.36	9.43	3.24	910	8.93	11.45	12.21
17-4	Cyclic 25%-75%	Geogrid 300kN/60kN	750	7.36	9.43	3.24	910	8.93	11.45	12.21
17-5	Cyclic 50%-75%	Geogrid 300kN/60kN	740	7.26	9.43	3.20	920	9.03	11.57	12.04
17-6	Cyclic 50%-75%	Geogrid 300kN/60kN	740	7.26	9.31	3.20	910	9.93	11.45	12.04
18-1	Cyclic 0%-50%	Geogrid 300kN/60kN	950	9.32	11.95	4.10	1190	11.67	14.97	15.56
18-2	Cyclic 0%-50%	Geogrid 300kN/60kN	950	9.32	11.95	4.10	1180	11.58	14.84	15.56
18-3	Cyclic 25%-75%	Geogrid 300kN/60kN	950	9.32	11.95	4.10	1170	11.48	14.72	15.56
18-4	Cyclic 25%-75%	Geogrid 300kN/60kN	950	9.32	11.95	4.10	1150	11.28	14.46	15.56
18-5	Cyclic 50%-75%	Geogrid 300kN/60kN	950	9.32	11.95	4.10	1170	11.48	14.72	15.56
18-6	Cyclic 50%-75%	Geogrid 300kN/60kN	950	9.32	11.95	4.10	1180	11.58	14.84	15.56
19-1	Cyclic 0%-50%	Geogrid 300kN/60kN	1150	11.28	14.46	4.97	1420	13.93	17.86	18.90
19-2	Cyclic 0%-50%	Geogrid 300kN/60kN	1150	11.28	14.46	4.97	1450	14.22	18.24	18.90
19-3	Cyclic 25%-75%	Geogrid 300kN/60kN	1100	10.79	13.83	4.75	1370	13.44	17.23	18.07
19-4	Cyclic 25%-75%	Geogrid 300kN/60kN	1100	10.79	13.83	4.75	1380	13.54	17.36	18.07
19-5	Cyclic 50%-75%	Geogrid 300kN/60kN	1150	11.28	14.46	4.97	1400	13.73	17.61	18.90
19-6	Cyclic 50%-75%	Geogrid 300kN/60kN	1150	11.28	14.46	4.97	1450	14.22	18.24	18.90
20-1	Cyclic 0%-50%	Geogrid 300kN/60kN	1450	14.22	18.24	6.26	1820	17.85	22.89	23.93
20-2	Cyclic 0%-50%	Geogrid 300kN/60kN	1450	14.22	18.24	6.26	1770	17.36	22.26	23.93
20-3	Cyclic 25%-75%	Geogrid 300kN/60kN	1450	14.22	18.24	6.26	1830	17.95	23.02	23.93
20-4	Cyclic 25%-75%	Geogrid 300kN/60kN	1450	14.22	18.24	6.26	1750	17.17	22.01	23.93
20-5	Cyclic 50%-75%	Geogrid 300kN/60kN	1450	14.22	18.24	6.26	1820	17.85	22.89	23.93
20-6	Cyclic 50%-75%	Geogrid 300kN/60kN	1450	14.22	18.24	6.26	1920	18.84	24.15	23.93

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-1	Cyclic 0%-50%	Geogrid 300kN/60kN	1750	17.17	22.01	7.56	2290	22.46	28.80	28.95
21-2	Cyclic 0%-50%	Geogrid 300kN/60kN	1750	17.17	22.01	7.56	2210	21.68	27.80	28.95
21-3	Cyclic 25%-75%	Geogrid 300kN/60kN	1800	17.66	22.64	7.77	2200	21.58	27.67	29.79
21-4	Cyclic 25%-75%	Geogrid 300kN/60kN	1800	17.66	22.64	7.77	2250	22.07	28.30	29.79
21-5	Cyclic 50%-75%	Geogrid 300kN/60kN	1750	17.17	22.01	7.56	2200	21.58	27.67	28.95
21-6	Cyclic 50%-75%	Geogrid 300kN/60kN	1750	17.17	22.01	7.56	2200	21.58	27.67	28.95
22-1	Cyclic 0%-50%	Geogrid 300kN/60kN	2100	20.60	26.41	9.07	2670	26.19	33.58	34.81
22-2	Cyclic 0%-50%	Geogrid 300kN/60kN	2100	20.60	26.41	9.07	2600	25.51	32.70	34.81
22-3	Cyclic 25%-75%	Geogrid 300kN/60kN	2050	20.11	25.78	8.85	2600	25.51	32.70	33.97
22-4	Cyclic 25%-75%	Geogrid 300kN/60kN	2050	20.11	25.78	8.85	2550	25.02	32.07	33.97
22-5	Cyclic 50%-75%	Geogrid 300kN/60kN	2050	20.11	25.78	8.85	2600	25.51	32.70	33.97
22-6	Cyclic 50%-75%	Geogrid 300kN/60kN	2050	20.11	25.78	8.85	2600	25.51	32.70	33.97
23-1	Cyclic 0%-50%	Geogrid 300kN/60kN	2350	23.05	29.56	10.15	3150	30.90	39.62	38.99
23-2	Cyclic 0%-50%	Geogrid 300kN/60kN	2350	23.05	29.56	10.15	2950	28.94	37.10	38.99
23-3	Cyclic 25%-75%	Geogrid 300kN/60kN	2350	23.05	29.56	10.15	2900	28.45	36.47	38.99
23-4	Cyclic 25%-75%	Geogrid 300kN/60kN	2350	23.05	29.56	10.15	2950	28.94	37.10	38.99
23-5	Cyclic 50%-75%	Geogrid 300kN/60kN	2400	23.54	30.18	10.36	3000	29.43	37.73	39.83
23-6	Cyclic 50%-75%	Geogrid 300kN/60kN	2400	23.54	30.18	10.36	3100	30.41	38.99	39.83
24-1	Cyclic 0%-50%	Geogrid 300kN/60kN	2650	26.00	33.33	11.44	3100	30.41	38.99	41.88
24-2	Cyclic 0%-50%	Geogrid 300kN/60kN	2650	26.00	33.33	11.44	3200	31.39	40.25	41.88
24-3	Cyclic 25%-75%	Geogrid 300kN/60kN	2650	26.00	33.33	11.44	3050	29.92	38.36	41.88
24-4	Cyclic 25%-75%	Geogrid 300kN/60kN	2650	26.00	33.33	11.44	3050	29.92	38.36	41.88
24-5	Cyclic 50%-75%	Geogrid 300kN/60kN	2650	26.00	33.33	11.44	3150	30.90	39.62	41.88
24-6	Cyclic 50%-75%	Geogrid 300kN/60kN	2650	26.00	33.33	11.44	3150	30.90	39.62	41.88

Table 8.7. Test Results Summary Table.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-1	Cyclic 0%-50%	Geogrid 300kN/60kN	2950	28.94	37.10	12.74	3100	30.41	38.99	42.63
25-2	Cyclic 0%-50%	Geogrid 300kN/60kN	2950	28.94	37.10	12.74	3200	31.39	40.25	42.63
25-3	Cyclic 25%-75%	Geogrid 300kN/60kN	2950	28.94	37.10	12.74	3050	29.92	38.36	42.63
25-4	Cyclic 25%-75%	Geogrid 300kN/60kN	2950	28.94	37.10	12.74	3050	29.92	38.36	42.63
25-5	Cyclic 50%-75%	Geogrid 300kN/60kN	2950	28.94	37.10	12.74	3150	30.90	39.62	42.63
25-6	Cyclic 50%-75%	Geogrid 300kN/60kN	2950	28.94	37.10	12.74	3150	30.90	39.62	42.63
26-1	Cyclic 0%-50%	Geogrid 300kN/60kN	3250	31.88	40.88	14.03	3300	32.37	41.50	43.39
26-2	Cyclic 0%-50%	Geogrid 300kN/60kN	3250	31.88	40.88	14.03	3250	31.88	40.88	43.39
26-3	Cyclic 25%-75%	Geogrid 300kN/60kN	3300	32.37	41.50	14.25	3350	32.86	42.13	43.51
26-4	Cyclic 25%-75%	Geogrid 300kN/60kN	3300	32.37	41.50	14.25	3300	32.37	41.50	43.51
26-5	Cyclic 50%-75%	Geogrid 300kN/60kN	3300	32.37	41.50	14.25	3250	31.88	40.88	43.51
26-6	Cyclic 50%-75%	Geogrid 300kN/60kN	3300	32.37	41.50	14.25	3400	33.35	42.76	43.51

The below chart is presented with the purpose of listing the change in the pull out resistance (connection strength) in percentage with respect to static results for geotextile reinforcement.

Table 8.8. Change in the Connection Strength Summary Table - Geotextile.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
1-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1.11	1.23	-10.10
1-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1.13	1.27	-11.17
1-3	Cyclic 25%-75%	Geotextile 120kN/120kN	1.09	1.19	-7.88
1-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1.17	1.23	-4.99
1-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1.13	1.27	-11.17
1-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1.14	1.23	-7.03
2-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2.72	2.96	-8.20
2-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2.79	3.00	-7.00
2-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2.75	2.96	-6.92
2-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2.83	3.05	-7.08
2-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2.70	2.92	-7.27
2-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2.70	2.87	-5.87
3-1	Cyclic 0%-50%	Geotextile 120kN/120kN	4.36	4.69	-6.89
3-2	Cyclic 0%-50%	Geotextile 120kN/120kN	4.35	4.69	-7.16
3-3	Cyclic 25%-75%	Geotextile 120kN/120kN	4.41	4.77	-7.52
3-4	Cyclic 25%-75%	Geotextile 120kN/120kN	4.39	4.73	-7.21
3-5	Cyclic 50%-75%	Geotextile 120kN/120kN	4.29	4.64	-7.65
3-6	Cyclic 50%-75%	Geotextile 120kN/120kN	4.91	4.73	3.69
4-1	Cyclic 0%-50%	Geotextile 120kN/120kN	5.97	6.42	-6.88
4-2	Cyclic 0%-50%	Geotextile 120kN/120kN	5.91	6.46	-8.47
4-3	Cyclic 25%-75%	Geotextile 120kN/120kN	6.04	6.50	-7.15
4-4	Cyclic 25%-75%	Geotextile 120kN/120kN	5.97	6.42	-6.88
4-5	Cyclic 50%-75%	Geotextile 120kN/120kN	5.91	6.42	-7.86
4-6	Cyclic 50%-75%	Geotextile 120kN/120kN	5.85	6.37	-8.22

Table 8.8. Change in the Connection Strength Summary Table - Geotextile.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
5-1	Cyclic 0%-50%	Geotextile 120kN/120kN	7.73	8.14	-5.02
5-2	Cyclic 0%-50%	Geotextile 120kN/120kN	7.61	8.14	-6.56
5-3	Cyclic 25%-75%	Geotextile 120kN/120kN	7.67	8.23	-6.78
5-4	Cyclic 25%-75%	Geotextile 120kN/120kN	7.48	8.06	-7.12
5-5	Cyclic 50%-75%	Geotextile 120kN/120kN	7.55	8.14	-7.33
5-6	Cyclic 50%-75%	Geotextile 120kN/120kN	7.61	8.23	-7.54
6-1	Cyclic 0%-50%	Geotextile 120kN/120kN	9.31	9.87	-5.72
6-2	Cyclic 0%-50%	Geotextile 120kN/120kN	9.24	9.96	-7.17
6-3	Cyclic 25%-75%	Geotextile 120kN/120kN	9.31	9.96	-6.54
6-4	Cyclic 25%-75%	Geotextile 120kN/120kN	9.94	9.87	0.65
6-5	Cyclic 50%-75%	Geotextile 120kN/120kN	9.12	9.87	-7.63
6-6	Cyclic 50%-75%	Geotextile 120kN/120kN	9.06	9.87	-8.27
7-1	Cyclic 0%-50%	Geotextile 120kN/120kN	11.76	12.90	-8.81
7-2	Cyclic 0%-50%	Geotextile 120kN/120kN	11.82	12.46	-5.14
7-3	Cyclic 25%-75%	Geotextile 120kN/120kN	12.58	12.46	0.91
7-4	Cyclic 25%-75%	Geotextile 120kN/120kN	11.63	12.90	-9.79
7-5	Cyclic 50%-75%	Geotextile 120kN/120kN	11.89	12.46	-4.64
7-6	Cyclic 50%-75%	Geotextile 120kN/120kN	12.07	12.90	-6.37
8-1	Cyclic 0%-50%	Geotextile 120kN/120kN	14.40	15.49	-7.02
8-2	Cyclic 0%-50%	Geotextile 120kN/120kN	14.09	15.06	-6.44
8-3	Cyclic 25%-75%	Geotextile 120kN/120kN	14.21	15.49	-8.24
8-4	Cyclic 25%-75%	Geotextile 120kN/120kN	14.15	15.06	-6.02
8-5	Cyclic 50%-75%	Geotextile 120kN/120kN	14.09	15.06	-6.44
8-6	Cyclic 50%-75%	Geotextile 120kN/120kN	13.83	14.62	-5.40

Table 8.8. Change in the Connection Strength Summary Table - Geotextile.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
9-1	Cyclic 0%-50%	Geotextile 120kN/120kN	15.72	17.65	-10.92
9-2	Cyclic 0%-50%	Geotextile 120kN/120kN	16.54	17.65	-6.28
9-3	Cyclic 25%-75%	Geotextile 120kN/120kN	18.36	18.08	1.56
9-4	Cyclic 25%-75%	Geotextile 120kN/120kN	16.22	17.65	-8.07
9-5	Cyclic 50%-75%	Geotextile 120kN/120kN	16.35	17.65	-7.35
9-6	Cyclic 50%-75%	Geotextile 120kN/120kN	16.10	17.65	-8.78
10-1	Cyclic 0%-50%	Geotextile 120kN/120kN	18.49	20.24	-8.65
10-2	Cyclic 0%-50%	Geotextile 120kN/120kN	19.37	20.24	-4.31
10-3	Cyclic 25%-75%	Geotextile 120kN/120kN	17.86	19.81	-9.84
10-4	Cyclic 25%-75%	Geotextile 120kN/120kN	20.75	19.81	4.77
10-5	Cyclic 50%-75%	Geotextile 120kN/120kN	18.99	20.67	-8.13
10-6	Cyclic 50%-75%	Geotextile 120kN/120kN	19.49	20.67	-5.70
11-1	Cyclic 0%-50%	Geotextile 120kN/120kN	20.12	22.83	-11.86
11-2	Cyclic 0%-50%	Geotextile 120kN/120kN	21.13	22.83	-7.46
11-3	Cyclic 25%-75%	Geotextile 120kN/120kN	21.63	22.83	-5.25
11-4	Cyclic 25%-75%	Geotextile 120kN/120kN	21.38	22.40	-4.55
11-5	Cyclic 50%-75%	Geotextile 120kN/120kN	21.63	22.40	-3.43
11-6	Cyclic 50%-75%	Geotextile 120kN/120kN	21.00	22.83	-8.01
12-1	Cyclic 0%-50%	Geotextile 120kN/120kN	23.52	24.99	-5.89
12-2	Cyclic 0%-50%	Geotextile 120kN/120kN	22.01	24.99	-11.93
12-3	Cyclic 25%-75%	Geotextile 120kN/120kN	23.77	25.42	-6.50
12-4	Cyclic 25%-75%	Geotextile 120kN/120kN	25.78	25.42	1.41
12-5	Cyclic 50%-75%	Geotextile 120kN/120kN	23.64	25.42	-7.00
12-6	Cyclic 50%-75%	Geotextile 120kN/120kN	23.90	25.42	-6.01

Table 8.8. Change in the Connection Strength Summary Table - Geotextile.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
13-1	Cyclic 0%-50%	Geotextile 120kN/120kN	28.93	28.02	3.25
13-2	Cyclic 0%-50%	Geotextile 120kN/120kN	25.66	28.02	-8.42
13-3	Cyclic 25%-75%	Geotextile 120kN/120kN	27.04	28.02	-3.48
13-4	Cyclic 25%-75%	Geotextile 120kN/120kN	25.91	28.02	-7.52
13-5	Cyclic 50%-75%	Geotextile 120kN/120kN	25.53	27.58	-7.44
13-6	Cyclic 50%-75%	Geotextile 120kN/120kN	25.15	27.58	-8.81

Considering the average reduction -regardless of the load cycle and normal load- cyclic loading adversely effected connection strength with respect to static tests (for geotextile reinforcement) with an average value of 6.4%.

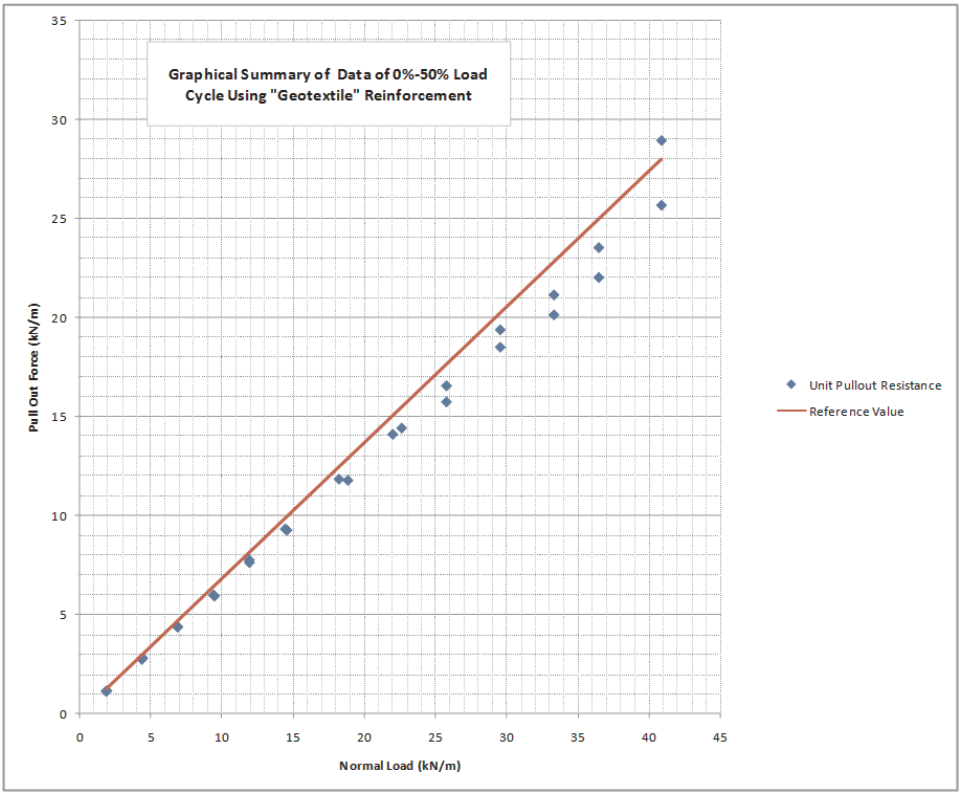


Figure 8.7. Graphical Summary of Data for Load Cycle of 0%-50% Using Geotextile Reinforcement.

The average reduction for this load cycle of 0%-50% testing is found to be 7.3% that is very close to be the value found for all test data.

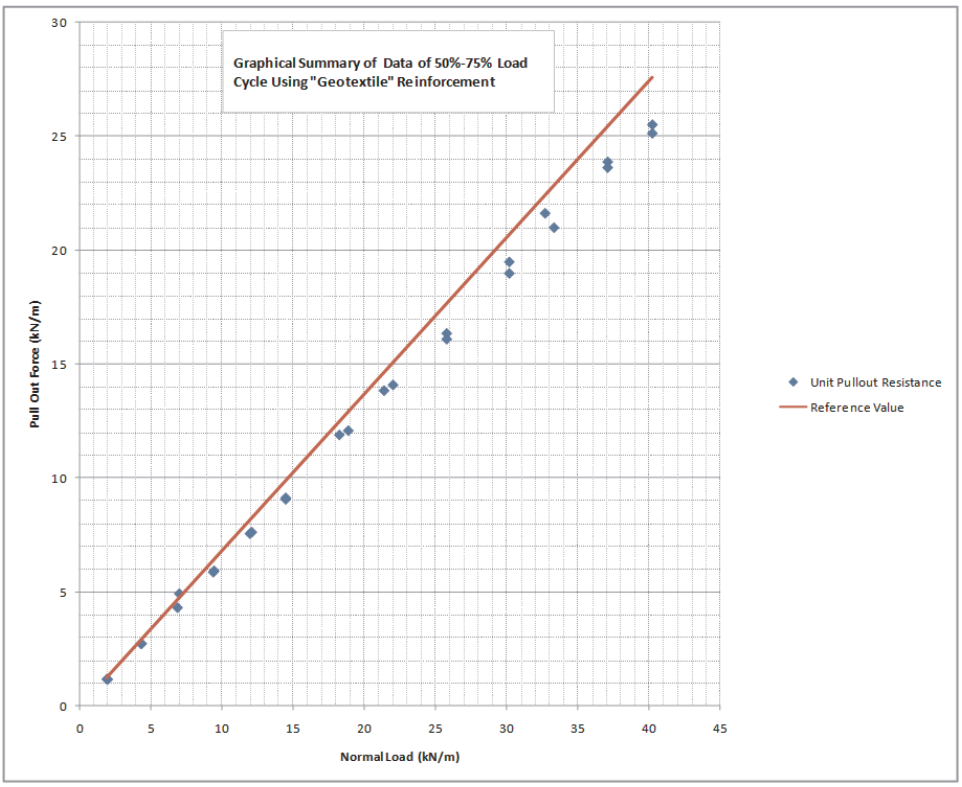


Figure 8.8. Graphical Summary of Data for Load Cycle of 25%-75% Using Geotextile Reinforcement.

The average reduction for this load cycle of 25%-75% testing is found to be 5.2% that is very close to be the value found for all test data.

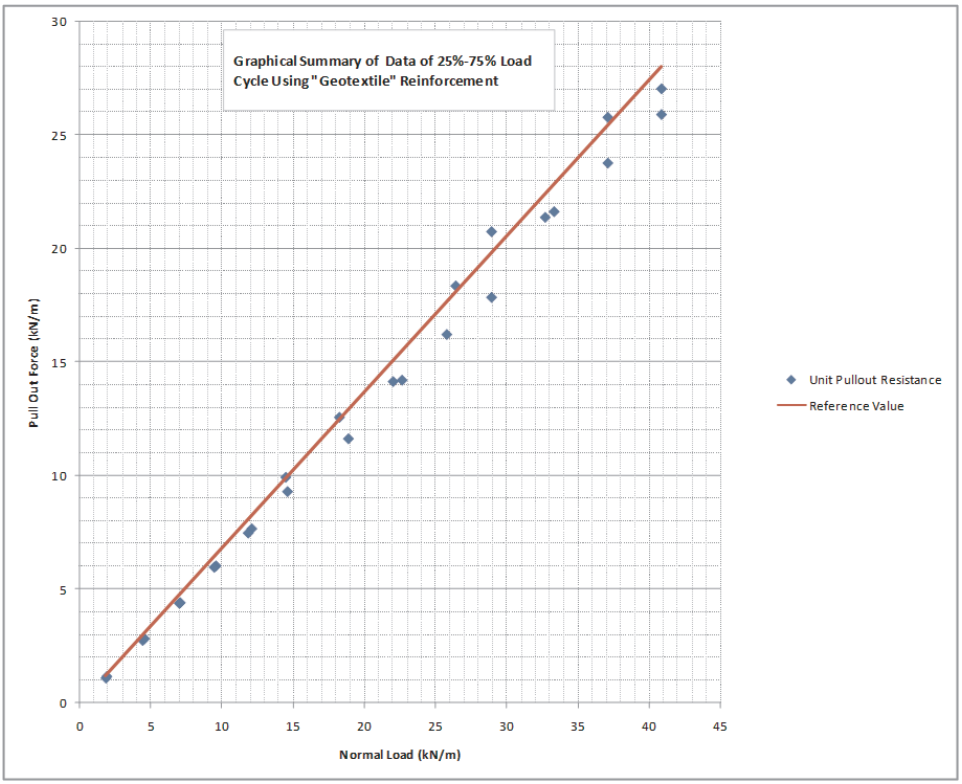


Figure 8.9. Graphical Summary of Data for Load Cycle of 50%-75% Using Geotextile Reinforcement.

The average reduction for this load cycle of 50%-75% testing is found to be 6.8% that is very close to be the value found for all test data.

Another table is prepared to assess the effect of normal load increment over the connection strength and presented below.

Table 8.9. Average Change in the Connection Strength Summary Table for Each Normal Load Increment - Geotextile Reinforcement.

Normal Load (kg)	150	350	550	750	950	1150	1450	1750	2050	2350	2650	2950	3250
% Change In The Connection Strength	-8.7%	-7.1%	-5.5%	-7.6%	-6.7%	-5.8%	-5.6%	-6.6%	-6.6%	-5.3%	-6.8%	-6.0%	-5.4%

As can be seen from the table, the effect of normal load change does not make any significant variation over the connection strength reduction amount.

Finally, the full data is plotted on the same graph to better understand the scatter of connection strength reduction and presented below.

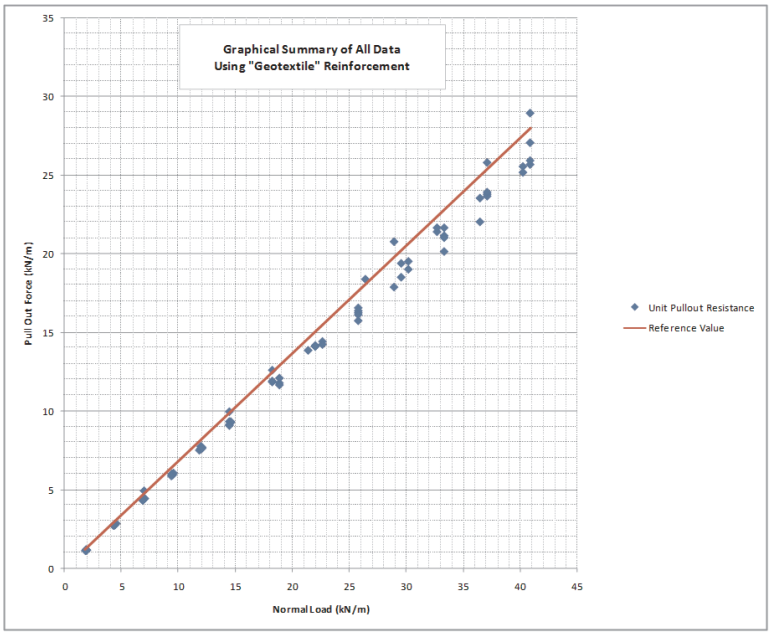


Figure 8.10. Graphical Summary of All Tests Using Geotextile Reinforcement.

As clearly presented in Figures and tables, the reduction of the connection strength due to cycling loading is randomly variable and cannot be tied to a spesific rule in terms load cycles and/or normal load increment.

Similar study has been repeated for geogrid reinforcement and using the test results presented in Table 8.7. The below table for geogrid reinforcement is obtained giving the percent change of the connection strength reduction.

Table 8.10. Change in the Connection Strength Summary Table - Geogrid.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
14-1	Cyclic 0%-50%	Geogrid 300kN/60kN	2.01	2.16	-7.1%
14-2	Cyclic 0%-50%	Geogrid 300kN/60kN	2.08	2.16	-4.1%
14-3	Cyclic 25%-75%	Geogrid 300kN/60kN	2.04	2.16	-5.9%
14-4	Cyclic 25%-75%	Geogrid 300kN/60kN	2.01	2.16	-7.1%
14-5	Cyclic 50%-75%	Geogrid 300kN/60kN	2.45	2.33	5.2%
14-6	Cyclic 50%-75%	Geogrid 300kN/60kN	2.14	2.33	-8.3%
15-1	Cyclic 0%-50%	Geogrid 300kN/60kN	5.28	5.51	-4.2%
15-2	Cyclic 0%-50%	Geogrid 300kN/60kN	6.04	5.51	9.5%
15-3	Cyclic 25%-75%	Geogrid 300kN/60kN	5.22	5.51	-5.3%
15-4	Cyclic 25%-75%	Geogrid 300kN/60kN	5.28	5.51	-4.2%
15-5	Cyclic 50%-75%	Geogrid 300kN/60kN	5.41	5.51	-1.9%
15-6	Cyclic 50%-75%	Geogrid 300kN/60kN	5.16	5.51	-6.5%
16-1	Cyclic 0%-50%	Geogrid 300kN/60kN	8.43	8.86	-4.9%
16-2	Cyclic 0%-50%	Geogrid 300kN/60kN	8.55	8.86	-3.5%
16-3	Cyclic 25%-75%	Geogrid 300kN/60kN	8.30	9.03	-8.1%
16-4	Cyclic 25%-75%	Geogrid 300kN/60kN	8.68	9.03	-3.9%
16-5	Cyclic 50%-75%	Geogrid 300kN/60kN	8.68	8.86	-2.1%
16-6	Cyclic 50%-75%	Geogrid 300kN/60kN	8.30	8.86	-6.3%
17-1	Cyclic 0%-50%	Geogrid 300kN/60kN	11.57	12.04	-3.9%
17-2	Cyclic 0%-50%	Geogrid 300kN/60kN	11.45	12.04	-5.0%
17-3	Cyclic 25%-75%	Geogrid 300kN/60kN	11.45	12.21	-6.3%
17-4	Cyclic 25%-75%	Geogrid 300kN/60kN	11.45	12.21	-6.3%
17-5	Cyclic 50%-75%	Geogrid 300kN/60kN	11.57	12.04	-3.9%
17-6	Cyclic 50%-75%	Geogrid 300kN/60kN	11.45	12.04	-5.0%

Table 8.10. Change in the Connection Strength Summary Table - Geogrid.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
18-1	Cyclic 0%-50%	Geogrid 300kN/60kN	14.97	15.56	-3.8%
18-2	Cyclic 0%-50%	Geogrid 300kN/60kN	14.84	15.56	-4.6%
18-3	Cyclic 25%-75%	Geogrid 300kN/60kN	14.72	15.56	-5.4%
18-4	Cyclic 25%-75%	Geogrid 300kN/60kN	14.46	15.56	-7.0%
18-5	Cyclic 50%-75%	Geogrid 300kN/60kN	14.72	15.56	-5.4%
18-6	Cyclic 50%-75%	Geogrid 300kN/60kN	14.84	15.56	-4.6%
19-1	Cyclic 0%-50%	Geogrid 300kN/60kN	17.86	18.90	-5.5%
19-2	Cyclic 0%-50%	Geogrid 300kN/60kN	18.24	18.90	-3.5%
19-3	Cyclic 25%-75%	Geogrid 300kN/60kN	17.23	18.07	-4.6%
19-4	Cyclic 25%-75%	Geogrid 300kN/60kN	17.36	18.07	-3.9%
19-5	Cyclic 50%-75%	Geogrid 300kN/60kN	17.61	18.90	-6.9%
19-6	Cyclic 50%-75%	Geogrid 300kN/60kN	18.24	18.90	-3.5%
20-1	Cyclic 0%-50%	Geogrid 300kN/60kN	22.89	23.93	-4.3%
20-2	Cyclic 0%-50%	Geogrid 300kN/60kN	22.26	23.93	-7.0%
20-3	Cyclic 25%-75%	Geogrid 300kN/60kN	23.02	23.93	-3.8%
20-4	Cyclic 25%-75%	Geogrid 300kN/60kN	22.01	23.93	-8.0%
20-5	Cyclic 50%-75%	Geogrid 300kN/60kN	22.89	23.93	-4.3%
20-6	Cyclic 50%-75%	Geogrid 300kN/60kN	24.15	23.93	0.9%
21-1	Cyclic 0%-50%	Geogrid 300kN/60kN	28.80	28.95	-0.5%
21-2	Cyclic 0%-50%	Geogrid 300kN/60kN	27.80	28.95	-4.0%
21-3	Cyclic 25%-75%	Geogrid 300kN/60kN	27.67	29.79	-7.1%
21-4	Cyclic 25%-75%	Geogrid 300kN/60kN	28.30	29.79	-5.0%
21-5	Cyclic 50%-75%	Geogrid 300kN/60kN	27.67	28.95	-4.4%
21-6	Cyclic 50%-75%	Geogrid 300kN/60kN	27.67	28.95	-4.4%

Table 8.10. Change in the Connection Strength Summary Table - Geogrid.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
22-1	Cyclic 0%-50%	Geogrid 300kN/60kN	33.58	34.81	-3.5%
22-2	Cyclic 0%-50%	Geogrid 300kN/60kN	32.70	34.81	-6.1%
22-3	Cyclic 25%-75%	Geogrid 300kN/60kN	32.70	33.97	-3.7%
22-4	Cyclic 25%-75%	Geogrid 300kN/60kN	32.07	33.97	-5.6%
22-5	Cyclic 50%-75%	Geogrid 300kN/60kN	32.70	33.97	-3.7%
22-6	Cyclic 50%-75%	Geogrid 300kN/60kN	32.70	33.97	-3.7%
23-1	Cyclic 0%-50%	Geogrid 300kN/60kN	39.62	38.99	1.6%
23-2	Cyclic 0%-50%	Geogrid 300kN/60kN	37.10	38.99	-4.8%
23-3	Cyclic 25%-75%	Geogrid 300kN/60kN	36.47	38.99	-6.5%
23-4	Cyclic 25%-75%	Geogrid 300kN/60kN	37.10	38.99	-4.8%
23-5	Cyclic 50%-75%	Geogrid 300kN/60kN	37.73	39.83	-5.3%
23-6	Cyclic 50%-75%	Geogrid 300kN/60kN	38.99	39.83	-2.1%
24-1	Cyclic 0%-50%	Geogrid 300kN/60kN	38.99	41.88	-6.9%
24-2	Cyclic 0%-50%	Geogrid 300kN/60kN	40.25	41.88	-3.9%
24-3	Cyclic 25%-75%	Geogrid 300kN/60kN	38.36	41.88	-8.4%
24-4	Cyclic 25%-75%	Geogrid 300kN/60kN	38.36	41.88	-8.4%
24-5	Cyclic 50%-75%	Geogrid 300kN/60kN	39.62	41.88	-5.4%
24-6	Cyclic 50%-75%	Geogrid 300kN/60kN	39.62	41.88	-5.4%
25-1	Cyclic 0%-50%	Geogrid 300kN/60kN	38.99	42.63	-8.5%
25-2	Cyclic 0%-50%	Geogrid 300kN/60kN	40.25	42.63	-5.6%
25-3	Cyclic 25%-75%	Geogrid 300kN/60kN	38.36	42.63	-10.0%
25-4	Cyclic 25%-75%	Geogrid 300kN/60kN	38.36	42.63	-10.0%
25-5	Cyclic 50%-75%	Geogrid 300kN/60kN	39.62	42.63	-7.1%
25-6	Cyclic 50%-75%	Geogrid 300kN/60kN	39.62	42.63	-7.1%

Table 8.10. Change in the Connection Strength Summary Table - Geogrid.

Test #	Experiment Type	Material	Unit Pullout Resistance kN/m	Reference Value kN/m	Change in the Pull Out Resistance %
26-1	Cyclic 0%-50%	Geogrid 300kN/60kN	41.50	43.39	-4.3%
26-2	Cyclic 0%-50%	Geogrid 300kN/60kN	40.88	43.39	-5.8%
26-3	Cyclic 25%-75%	Geogrid 300kN/60kN	42.13	43.51	-3.2%
26-4	Cyclic 25%-75%	Geogrid 300kN/60kN	41.50	43.51	-4.6%
26-5	Cyclic 50%-75%	Geogrid 300kN/60kN	40.88	43.51	-6.1%
26-6	Cyclic 50%-75%	Geogrid 300kN/60kN	42.76	43.51	-1.7%

Considering the average reduction -regardless of the load cycle and normal load- cyclic loading adversely effected connection strength with respect to static tests (for geogrid reinforcement) with an average value of 4.7%.

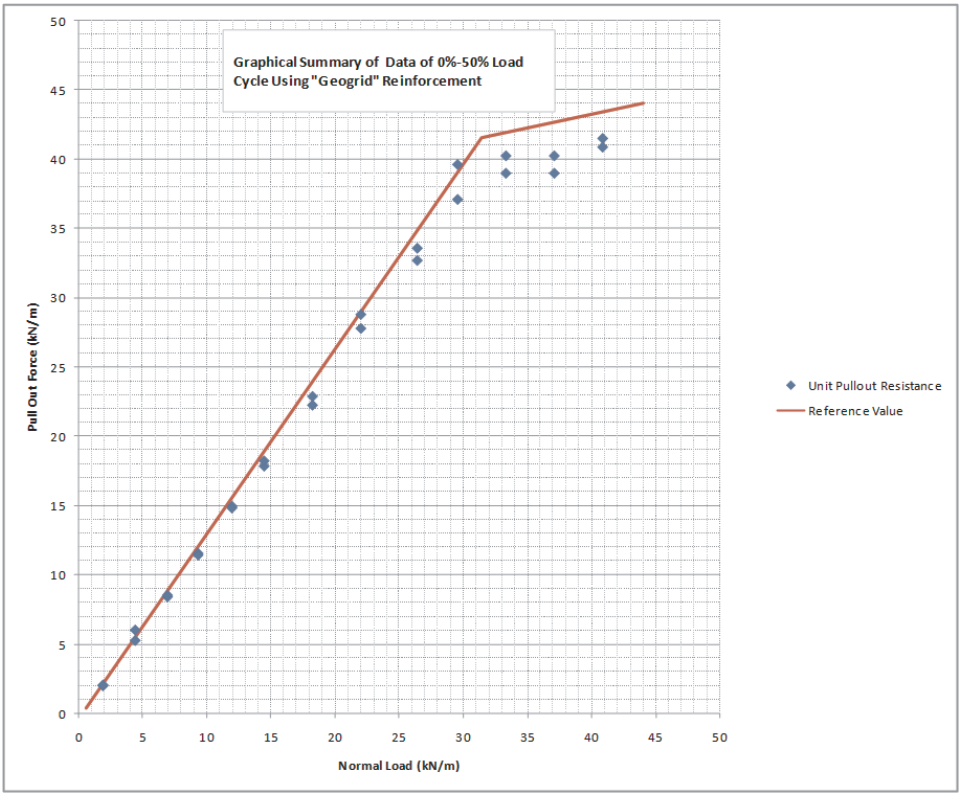


Figure 8.11. Graphical Summary of Data for Load Cycle of 0%-50% Using Geogrid Reinforcement.

The average reduction for this load cycle of 0%-50% testing is found to be 4.0% that is very close to be the value found for all test data.

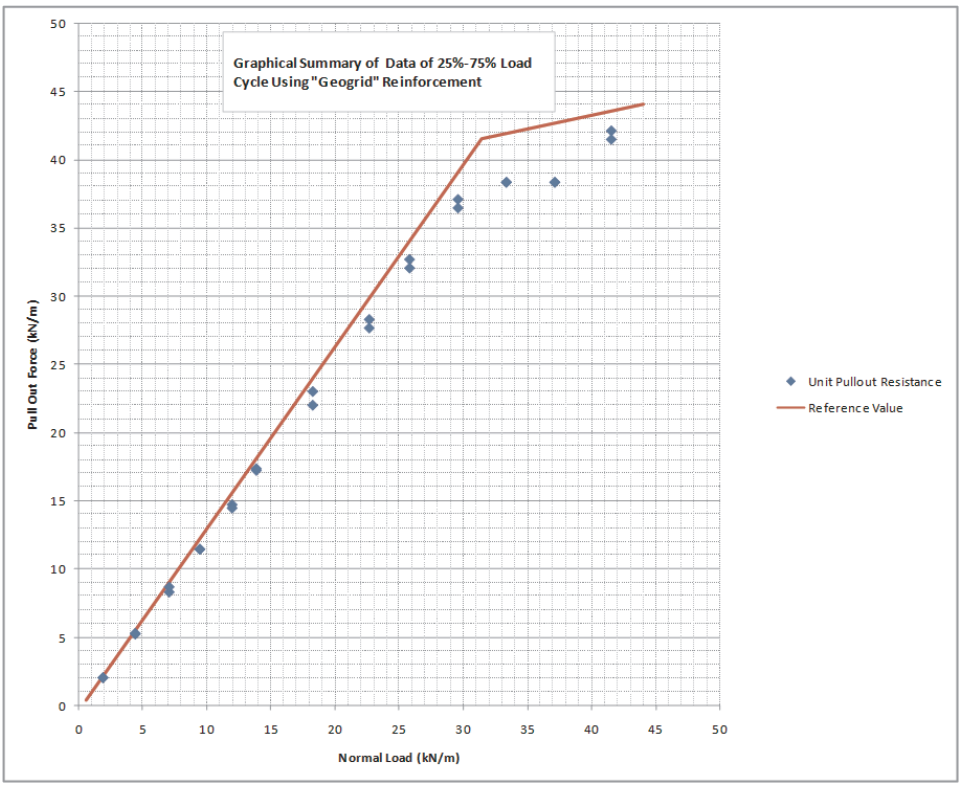


Figure 8.12. Graphical Summary of Data for Load Cycle of 25%-75% Using Geogrid Reinforcement.

The average reduction for this load cycle of 25%-75% testing is found to be 6.0% that is very close to be the value found for all test data.

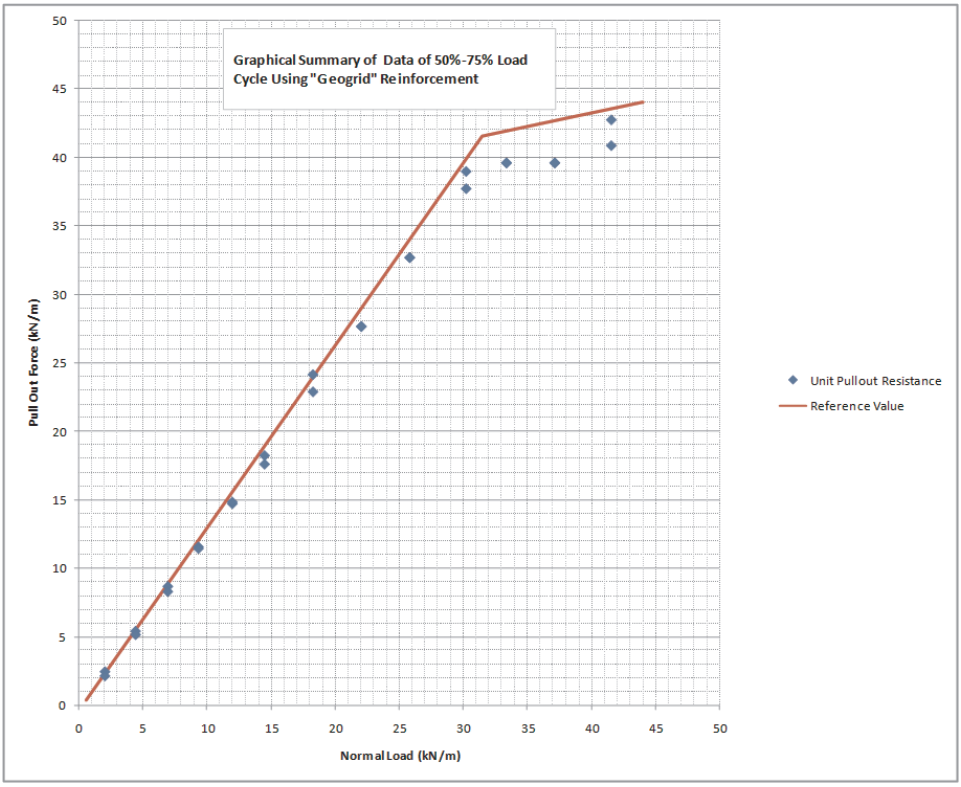


Figure 8.13. Graphical Summary of Data for Load Cycle of 50%-75% Using Geogrid Reinforcement.

The average reduction for this load cycle of 50%-75% testing is found to be 4.2% that is very close to be the value found for all test data.

Another table is prepared to assess the effect of normal load increment over the connection strength and presented below.

Table 8.11. Average Change in the Connection Strength Summary Table for Each Normal Load Increment - Geogrid Reinforcement.

Normal Load (kg)	150	350	550	750	950	1150	1450	1750	2050	2350	2650	2950	3250
% Change In The Connection Strength	-4.6%	-2.1%	-4.8%	-5.0%	-5.1%	-4.7%	-4.4%	-4.2%	-4.4%	-3.7%	-6.4%	-8.1%	-4.3%

As can be seen from the table, the effect of normal load change does not make any significant variation over the connection strength reduction amount.

Finally, the full data is plotted on the same graph to better understand the scatter of connection strength reduction and presented below.

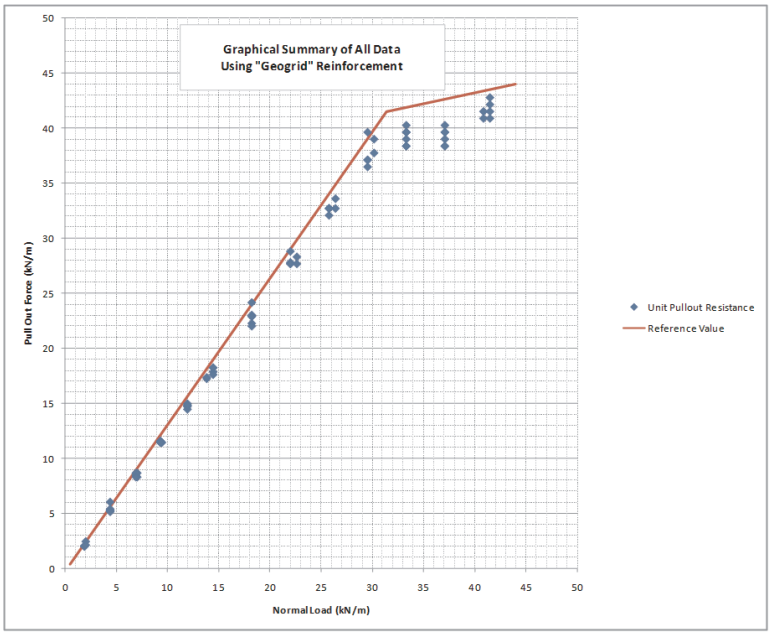


Figure 8.14. Graphical Summary of All Tests Using Geogrid Reinforcement.

As clearly presented in Figures and tables, the reduction of the connection strength due to cycling loading is randomly variable and cannot be tied to a spesific rule in terms load cycles and/or normal load increment.

A general interpretation of the test results for both types of reinforcement is presented in Table 8.3.

Table 8.12. A General Interpretation of All Tests.

Material	Total Number of Tests	The Number of Tests with Connection Strength Reduction	The Percentage of Tests with Connection Strength Reduction	Average Change in the Connection Strength Due to Cyclic Loading
Geogrid 300kN/60kN	78	74	95%	-4.7%
Geotextile 120kN/120kN	78	71	91%	-6.4%

Based on these findings, the general conclusions are presented in the next chapter.

9. CONCLUSIONS

This study investigates the effect of cyclic loading effects over the connection strength of geosynthetic reinforced retaining structures for non-mechanically connected geosynthetic-block facing. The tests are utilized using the following materials:

- Block: Typical concrete modular block with dimensions of 19cmx19cmx39cm
- Reinforcement: 2 types of reinforcements are utilized, one is 120 kN / 120 kN Polypropylene Woven Geotextile andthe other one is 300 kN / 60 kN PVC Coated Polyester Geotextile.

The general conclusions can be drawn from the study can be summarized as:

- As very well known, the connection strength is a function of many parameters such as block dimensions, reinforcement (geosynthetic) type, infilling material.
- As per this study, the effect of cyclic loading over the connection strength is simulated and interpreted, this can also be considered as a good simulation of an earthquake with M=7.5 magnitude considering the fact that the amount of load cycles, duration and load intervals are tried to kept similar.
- There is no standardized method to determine the dynamic connection strength parameter for the wall design, as such, the aim of the study is to make a comparison between the static connection strength values with the connection strength after repetitive (cyclic) loading.
- After comprehensive research and tests, the following effect of cyclic loading over the connection strength has been determined:
  (i) The effect of cyclic loading over the connection strength is a function of material (or material type)
  (ii) Except for couple of number of tests, the connection strength followed by a series of load cycles is always lower than the actual static connection strength.
  (iii) The reduction of the connection strength is reduced by an average of 6.4%

for polypropylene woven geotextile, 4.7% for PVC coated polyester woven geogrid considering all variables together (such as normal load increment, load cycles etc.)

(iv) These two geosynthetic types are the most common geosynthetic types used for reinforced earth wall construction.

(v) The reason for the difference between the reduction percentages of different reinforcement type is not determined.

(vi) Since the major difference between the two reinforcements is that the facing connection mechanism of geotextile is only frictional, and for the geogrid, there is both interlocking (with the gravel infilling) and friction, it can be concluded that the only frictional connection type is more sensitive to cyclic loading.

(vii) Furthermore, FHWA also does not recommend fully frictional connections for places expecting significant earthquake effects as given in the literature review section.

(viii) However, It should also be noted that, there are other factors that might be a reason of this sensitivity such as the major strength difference between the two reinforcement types. Using similar strength materials may merge the results.

- As per these findings, it is suggested that a reduction of connection strength must be considered up to 10% for wall designs to remain in the safe side for cyclic loading case. This reduction may not be crtical for typical walls of having heights of less then 10m, however as the wall heights are increasing, the connection strength is a critical design parameter (especially for lower row of blocks). In case the existing design is not satisfactory in terms of connection strength, the practical solution is to lower the vertical geogrid spacing. As stating this, one must note that it is also a cost issue, however, while decreasing the spacing, no need to use major geogrid, minor geogrid of 2m length will be satisfactory making this adjustment feasible and easily applicable in the field.
- For future works, several other tests, standardizations can be applied as a follow-up research. These are:

(i) Using other reinforcement types is necessary to compare the effect of different

reinforcing elements. These can be extruded polyethelene reinforcement, glass-fiber woven geotextile (this type of geotextile has a very low strain value compared to other types of reinforcements), polyester woven geotextile (very high strength values reaching up tp 1500kN/m can be achieved using this type of reinforcement).

(ii) Using reinforcing elements of different type (or material) but having similar strength and mechanical characteristics. For instance, a geogrid of having 300kN/300kN can be compared with a woven polyester geotextile having the same strength value. This way, the question of whether only frictional facing connections are more sensitive or not can be answered in a better way.

(iii) Same geosynthetic reinforcement but having a wide range of strength characteristics can be evaluated to better determine the effect of material strength over the reduction of connection strength due to cyclic loading. For instance, the polyester geogrid of having tensile strength from 20kN/20kN to very high values such as 500kN/100kN can be used.

(iv) Another possible effect is that, during earthqukes, not only horizontal component of lateral force change but also there is a change in the vertical loading conditions. Considering that this parameter is also neglected during design phase, a setup and testing programme canbe utilized that can further take into account the effect of vertical loading component of earthquake on the connection strength.

- The scope of the research is to reflect the behaviour under eathquake loading, therefore high amplitude and only 15 cycles is considered. Thus, naturally, the load cycles are significant in terms of loading conditions, however the test can be done with lower cycling loads but the number of cycles can be much more reflecting other loading conditions besides earthquake. In other words, earthquake loading -due to its nature - is relatively short but exerting sudded and high amount of forces, whereas, for instance, traffic activity, printing machines, coastal activities can be considered as much higher number of loading cycles with relatively smaller forces.
- In addition, the scope of the research is to make a comparison between the connection strength under static and the cyclic loading. As a result, based on the

spesifications, these tests are defined as short tests. On the other hand, the spesfications also suggest long term testing. Thus, after applying load cycles, a long term testing can be utilized. At this point, it is unknown that whether the connection strength values will merge at the end of long term tests. However, it should be noted that, to employ long term tests, the test room must have a climate control capability as it is very well known fact that long term testing of geosynthetics is temperature dependent.

- As mentioned above, the connection strength is more critical for higher walls. Due to the equipment limitations, the research is limited to 3250kg-3300kg of normal load corresponding to approximately 14m of wall height. For future studies, higher walls can be simulated such as 20m, 30m and more.
- As per the findings, the percent reduction of the connection strength does not change significantly due to a change in the normal load amount and/or load cycles, however the material type has the biggest effect on the reduction.

APPENDIX A: NUMERICAL DATA OF PULL-OUT TESTS

Table A.5. Test 3-1, 3-2, 3-3 Numerical Data.

Test. 3-1				Test. 3-2				Test. 3-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	92	0.9	1.2
	186	1.8	2.3		181	1.8	2.3		280	2.7	3.5
2	0	0.0	0.0	2	0	0.0	0.0	2	95	0.9	1.2
	184	1.8	2.3		182	1.8	2.3		283	2.8	3.6
3	0	0.0	0.0	3	0	0.0	0.0	3	93	0.9	1.2
	179	1.8	2.3		186	1.8	2.3		281	2.8	3.5
4	0	0.0	0.0	4	0	0.0	0.0	4	89	0.9	1.1
	190	1.9	2.4		189	1.9	2.4		284	2.8	3.6
5	0	0.0	0.0	5	0	0.0	0.0	5	93	0.9	1.2
	191	1.9	2.4		180	1.8	2.3		285	2.8	3.6
6	0	0.0	0.0	6	0	0.0	0.0	6	96	0.9	1.2
	188	1.8	2.4		183	1.8	2.3		287	2.8	3.6
7	0	0.0	0.0	7	0	0.0	0.0	7	94	0.9	1.2
	186	1.8	2.3		186	1.8	2.3		289	2.8	3.6
8	0	0.0	0.0	8	0	0.0	0.0	8	95	0.9	1.2
	186	1.8	2.3		186	1.8	2.3		279	2.7	3.5
9	0	0.0	0.0	9	0	0.0	0.0	9	99	1.0	1.2
	181	1.8	2.3		189	1.9	2.4		289	2.8	3.6
10	0	0.0	0.0	10	0	0.0	0.0	10	94	0.9	1.2
	183	1.8	2.3		180	1.8	2.3		285	2.8	3.6
11	0	0.0	0.0	11	0	0.0	0.0	11	93	0.9	1.2
	181	1.8	2.3		179	1.8	2.3		280	2.7	3.5
12	0	0.0	0.0	12	0	0.0	0.0	12	91	0.9	1.1
	179	1.8	2.3		181	1.8	2.3		285	2.8	3.6
13	0	0.0	0.0	13	0	0.0	0.0	13	96	0.9	1.2
	191	1.9	2.4		189	1.9	2.4		287	2.8	3.6
14	0	0.0	0.0	14	0	0.0	0.0	14	93	0.9	1.2
	189	1.9	2.4		190	1.9	2.4		283	2.8	3.6
15	0	0.0	0.0	15	0	0.0	0.0	15	94	0.9	1.2
	347	3.4	4.4		346	3.4	4.4		351	3.4	4.4

Table A.6. Test 3-4, 3-5, 3-6 Numerical Data.

Test. 3-4				Test. 3-5				Test. 3-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	89	0.9	1.1	1	186	1.8	2.3	1	185	1.8	2.3
	285	2.8	3.6		280	2.7	3.5		281	2.8	3.5
2	90	0.9	1.1	2	184	1.8	2.3	2	183	1.8	2.3
	286	2.8	3.6		279	2.7	3.5		280	2.7	3.5
3	91	0.9	1.1	3	179	1.8	2.3	3	177	1.7	2.2
	287	2.8	3.6		285	2.8	3.6		283	2.8	3.6
4	90	0.9	1.1	4	190	1.9	2.4	4	191	1.9	2.4
	287	2.8	3.6		295	2.9	3.7		291	2.9	3.7
5	94	0.9	1.2	5	191	1.9	2.4	5	194	1.9	2.4
	280	2.7	3.5		291	2.9	3.7		280	2.7	3.5
6	95	0.9	1.2	6	183	1.8	2.3	6	188	1.8	2.4
	290	2.8	3.6		279	2.7	3.5		282	2.8	3.5
7	93	0.9	1.2	7	186	1.8	2.3	7	185	1.8	2.3
	281	2.8	3.5		282	2.8	3.5		283	2.8	3.6
8	96	0.9	1.2	8	186	1.8	2.3	8	184	1.8	2.3
	289	2.8	3.6		275	2.7	3.5		277	2.7	3.5
9	93	0.9	1.2	9	183	1.8	2.3	9	182	1.8	2.3
	293	2.9	3.7		288	2.8	3.6		281	2.8	3.5
10	97	1.0	1.2	10	183	1.8	2.3	10	183	1.8	2.3
	291	2.9	3.7		281	2.8	3.5		285	2.8	3.6
11	96	0.9	1.2	11	181	1.8	2.3	11	186	1.8	2.3
	297	2.9	3.7		280	2.7	3.5		288	2.8	3.6
12	93	0.9	1.2	12	179	1.8	2.3	12	184	1.8	2.3
	278	2.7	3.5		284	2.8	3.6		283	2.8	3.6
13	97	1.0	1.2	13	191	1.9	2.4	13	179	1.8	2.3
	277	2.7	3.5		286	2.8	3.6		285	2.8	3.6
14	97	1.0	1.2	14	189	1.9	2.4	14	178	1.7	2.2
	279	2.7	3.5		286	2.8	3.6		285	2.8	3.6
15	94	0.9	1.2	15	191	1.9	2.4	15	186	1.8	2.3
	349	3.4	4.4		341	3.3	4.3		390	3.8	4.9

Table A.7. Test 4-1, 4-2, 4-3 Numerical Data.

Test. 4-1				Test. 4-2				Test. 4-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	130	1.3	1.6
	255	2.5	3.2		260	2.6	3.3		385	3.8	4.8
2	0	0.0	0.0	2	0	0.0	0.0	2	130	1.3	1.6
	260	2.6	3.3		255	2.5	3.2		390	3.8	4.9
3	0	0.0	0.0	3	0	0.0	0.0	3	125	1.2	1.6
	255	2.5	3.2		260	2.6	3.3		385	3.8	4.8
4	0	0.0	0.0	4	0	0.0	0.0	4	125	1.2	1.6
	250	2.5	3.1		255	2.5	3.2		385	3.8	4.8
5	0	0.0	0.0	5	0	0.0	0.0	5	120	1.2	1.5
	260	2.6	3.3		255	2.5	3.2		395	3.9	5.0
6	0	0.0	0.0	6	0	0.0	0.0	6	125	1.2	1.6
	265	2.6	3.3		250	2.5	3.1		390	3.8	4.9
7	0	0.0	0.0	7	0	0.0	0.0	7	120	1.2	1.5
	270	2.6	3.4		245	2.4	3.1		390	3.8	4.9
8	0	0.0	0.0	8	0	0.0	0.0	8	135	1.3	1.7
	265	2.6	3.3		255	2.5	3.2		395	3.9	5.0
9	0	0.0	0.0	9	0	0.0	0.0	9	130	1.3	1.6
	255	2.5	3.2		250	2.5	3.1		385	3.8	4.8
10	0	0.0	0.0	10	0	0.0	0.0	10	120	1.2	1.5
	250	2.5	3.1		255	2.5	3.2		385	3.8	4.8
11	0	0.0	0.0	11	0	0.0	0.0	11	125	1.2	1.6
	245	2.4	3.1		250	2.5	3.1		385	3.8	4.8
12	0	0.0	0.0	12	0	0.0	0.0	12	130	1.3	1.6
	245	2.4	3.1		255	2.5	3.2		380	3.7	4.8
13	0	0.0	0.0	13	0	0.0	0.0	13	130	1.3	1.6
	250	2.5	3.1		260	2.6	3.3		395	3.9	5.0
14	0	0.0	0.0	14	0	0.0	0.0	14	120	1.2	1.5
	255	2.5	3.2		260	2.6	3.3		385	3.8	4.8
15	0	0.0	0.0	15	0	0.0	0.0	15	125	1.2	1.6
	475	4.7	6.0		470	4.6	5.9		480	4.7	6.0

Table A.8. Test 4-4, 4-5, 4-6 Numerical Data.

Test. 4-4				Test. 4-5				Test. 4-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	120	1.2	1.5	1	255	2.5	3.2	1	240	2.4	3.0
	380	3.7	4.8		380	3.7	4.8		400	3.9	5.0
2	125	1.2	1.6	2	245	2.4	3.1	2	245	2.4	3.1
	395	3.9	5.0		400	3.9	5.0		410	4.0	5.2
3	125	1.2	1.6	3	240	2.4	3.0	3	255	2.5	3.2
	400	3.9	5.0		395	3.9	5.0		390	3.8	4.9
4	120	1.2	1.5	4	260	2.6	3.3	4	250	2.5	3.1
	400	3.9	5.0		385	3.8	4.8		385	3.8	4.8
5	125	1.2	1.6	5	265	2.6	3.3	5	250	2.5	3.1
	390	3.8	4.9		395	3.9	5.0		375	3.7	4.7
6	130	1.3	1.6	6	245	2.4	3.1	6	245	2.4	3.1
	390	3.8	4.9		400	3.9	5.0		385	3.8	4.8
7	125	1.2	1.6	7	245	2.4	3.1	7	250	2.5	3.1
	395	3.9	5.0		380	3.7	4.8		380	3.7	4.8
8	120	1.2	1.5	8	255	2.5	3.2	8	255	2.5	3.2
	400	3.9	5.0		395	3.9	5.0		385	3.8	4.8
9	125	1.2	1.6	9	240	2.4	3.0	9	260	2.6	3.3
	385	3.8	4.8		405	4.0	5.1		375	3.7	4.7
10	130	1.3	1.6	10	260	2.6	3.3	10	250	2.5	3.1
	390	3.8	4.9		380	3.7	4.8		370	3.6	4.7
11	140	1.4	1.8	11	255	2.5	3.2	11	240	2.4	3.0
	395	3.9	5.0		390	3.8	4.9		365	3.6	4.6
12	130	1.3	1.6	12	245	2.4	3.1	12	255	2.5	3.2
	400	3.9	5.0		385	3.8	4.8		375	3.7	4.7
13	130	1.3	1.6	13	240	2.4	3.0	13	260	2.6	3.3
	380	3.7	4.8		390	3.8	4.9		395	3.9	5.0
14	125	1.2	1.6	14	245	2.4	3.1	14	255	2.5	3.2
	380	3.7	4.8		395	3.9	5.0		400	3.9	5.0
15	130	1.3	1.6	15	260	2.6	3.3	15	260	2.6	3.3
	475	4.7	6.0		470	4.6	5.9		465	4.6	5.8

Table A.9. Test 5-1, 5-2, 5-3 Numerical Data.

Test. 5-1				Test. 5-2				Test. 5-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	160	1.6	2.0
	320	3.1	4.0		315	3.1	4.0		490	4.8	6.2
2	0	0.0	0.0	2	0	0.0	0.0	2	165	1.6	2.1
	315	3.1	4.0		320	3.1	4.0		495	4.9	6.2
3	0	0.0	0.0	3	0	0.0	0.0	3	170	1.7	2.1
	335	3.3	4.2		330	3.2	4.2		490	4.8	6.2
4	0	0.0	0.0	4	0	0.0	0.0	4	155	1.5	1.9
	320	3.1	4.0		325	3.2	4.1		495	4.9	6.2
5	0	0.0	0.0	5	0	0.0	0.0	5	170	1.7	2.1
	330	3.2	4.2		320	3.1	4.0		500	4.9	6.3
6	0	0.0	0.0	6	0	0.0	0.0	6	175	1.7	2.2
	325	3.2	4.1		330	3.2	4.2		505	5.0	6.4
7	0	0.0	0.0	7	0	0.0	0.0	7	160	1.6	2.0
	320	3.1	4.0		325	3.2	4.1		485	4.8	6.1
8	0	0.0	0.0	8	0	0.0	0.0	8	155	1.5	1.9
	330	3.2	4.2		335	3.3	4.2		505	5.0	6.4
9	0	0.0	0.0	9	0	0.0	0.0	9	170	1.7	2.1
	325	3.2	4.1		315	3.1	4.0		480	4.7	6.0
10	0	0.0	0.0	10	0	0.0	0.0	10	160	1.6	2.0
	335	3.3	4.2		320	3.1	4.0		500	4.9	6.3
11	0	0.0	0.0	11	0	0.0	0.0	11	170	1.7	2.1
	315	3.1	4.0		325	3.2	4.1		505	5.0	6.4
12	0	0.0	0.0	12	0	0.0	0.0	12	150	1.5	1.9
	320	3.1	4.0		325	3.2	4.1		475	4.7	6.0
13	0	0.0	0.0	13	0	0.0	0.0	13	155	1.5	1.9
	325	3.2	4.1		335	3.3	4.2		495	4.9	6.2
14	0	0.0	0.0	14	0	0.0	0.0	14	170	1.7	2.1
	335	3.3	4.2		325	3.2	4.1		500	4.9	6.3
15	0	0.0	0.0	15	0	0.0	0.0	15	160	1.6	2.0
	615	6.0	7.7		605	5.9	7.6		610	6.0	7.7

Table A.10. Test 5-4, 5-5, 5-6 Numerical Data.

Test. 5-4				Test. 5-5				Test. 5-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	155	1.5	1.9	1	325	3.2	4.1	1	240	2.4	3.0
	500	4.9	6.3		500	4.9	6.3		400	3.9	5.0
2	165	1.6	2.1	2	320	3.1	4.0	2	245	2.4	3.1
	505	5.0	6.4		500	4.9	6.3		410	4.0	5.2
3	150	1.5	1.9	3	315	3.1	4.0	3	255	2.5	3.2
	480	4.7	6.0		495	4.9	6.2		390	3.8	4.9
4	150	1.5	1.9	4	330	3.2	4.2	4	250	2.5	3.1
	490	4.8	6.2		485	4.8	6.1		385	3.8	4.8
5	160	1.6	2.0	5	315	3.1	4.0	5	250	2.5	3.1
	475	4.7	6.0		500	4.9	6.3		375	3.7	4.7
6	145	1.4	1.8	6	335	3.3	4.2	6	245	2.4	3.1
	470	4.6	5.9		505	5.0	6.4		385	3.8	4.8
7	145	1.4	1.8	7	330	3.2	4.2	7	250	2.5	3.1
	475	4.7	6.0		495	4.9	6.2		380	3.7	4.8
8	155	1.5	1.9	8	320	3.1	4.0	8	255	2.5	3.2
	505	5.0	6.4		485	4.8	6.1		385	3.8	4.8
9	170	1.7	2.1	9	320	3.1	4.0	9	260	2.6	3.3
	495	4.9	6.2		480	4.7	6.0		375	3.7	4.7
10	165	1.6	2.1	10	310	3.0	3.9	10	250	2.5	3.1
	490	4.8	6.2		485	4.8	6.1		370	3.6	4.7
11	170	1.7	2.1	11	320	3.1	4.0	11	240	2.4	3.0
	500	4.9	6.3		475	4.7	6.0		365	3.6	4.6
12	175	1.7	2.2	12	330	3.2	4.2	12	255	2.5	3.2
	505	5.0	6.4		500	4.9	6.3		375	3.7	4.7
13	165	1.6	2.1	13	335	3.3	4.2	13	260	2.6	3.3
	500	4.9	6.3		505	5.0	6.4		395	3.9	5.0
14	155	1.5	1.9	14	315	3.1	4.0	14	255	2.5	3.2
	505	5.0	6.4		485	4.8	6.1		400	3.9	5.0
15	165	1.6	2.1	15	310	3.0	3.9	15	260	2.6	3.3
	595	5.8	7.5		600	5.9	7.5		605	5.9	7.6

Table A.11. Test 6-1, 6-2, 6-3 Numerical Data.

Test. 6-1				Test. 6-2				Test. 6-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	200	2.0	2.5
	400	3.9	5.0		385	3.8	4.8		595	5.8	7.5
2	0	0.0	0.0	2	0	0.0	0.0	2	190	1.9	2.4
	400	3.9	5.0		395	3.9	5.0		600	5.9	7.5
3	0	0.0	0.0	3	0	0.0	0.0	3	195	1.9	2.5
	395	3.9	5.0		405	4.0	5.1		605	5.9	7.6
4	0	0.0	0.0	4	0	0.0	0.0	4	190	1.9	2.4
	395	3.9	5.0		385	3.8	4.8		605	5.9	7.6
5	0	0.0	0.0	5	0	0.0	0.0	5	200	2.0	2.5
	390	3.8	4.9		385	3.8	4.8		610	6.0	7.7
6	0	0.0	0.0	6	0	0.0	0.0	6	205	2.0	2.6
	400	3.9	5.0		390	3.8	4.9		600	5.9	7.5
7	0	0.0	0.0	7	0	0.0	0.0	7	195	1.9	2.5
	395	3.9	5.0		405	4.0	5.1		605	5.9	7.6
8	0	0.0	0.0	8	0	0.0	0.0	8	190	1.9	2.4
	385	3.8	4.8		410	4.0	5.2		595	5.8	7.5
9	0	0.0	0.0	9	0	0.0	0.0	9	195	1.9	2.5
	390	3.8	4.9		390	3.8	4.9		590	5.8	7.4
10	0	0.0	0.0	10	0	0.0	0.0	10	200	2.0	2.5
	410	4.0	5.2		390	3.8	4.9		605	5.9	7.6
11	0	0.0	0.0	11	0	0.0	0.0	11	190	1.9	2.4
	395	3.9	5.0		385	3.8	4.8		585	5.7	7.4
12	0	0.0	0.0	12	0	0.0	0.0	12	195	1.9	2.5
	390	3.8	4.9		390	3.8	4.9		595	5.8	7.5
13	0	0.0	0.0	13	0	0.0	0.0	13	185	1.8	2.3
	400	3.9	5.0		395	3.9	5.0		595	5.8	7.5
14	0	0.0	0.0	14	0	0.0	0.0	14	180	1.8	2.3
	405	4.0	5.1		405	4.0	5.1		580	5.7	7.3
15	0	0.0	0.0	15	0	0.0	0.0	15	200	2.0	2.5
	740	7.3	9.3		735	7.2	9.2		740	7.3	9.3

Table A.12. Test 6-4, 6-5, 6-6 Numerical Data.

Test. 6-4				Test. 6-5				Test. 6-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	190	1.9	2.4	1	400	3.9	5.0	1	375	3.7	4.7
	590	5.8	7.4		600	5.9	7.5		610	6.0	7.7
2	185	1.8	2.3	2	390	3.8	4.9	2	380	3.7	4.8
	580	5.7	7.3		590	5.8	7.4		605	5.9	7.6
3	185	1.8	2.3	3	395	3.9	5.0	3	395	3.9	5.0
	585	5.7	7.4		590	5.8	7.4		590	5.8	7.4
4	195	1.9	2.5	4	390	3.8	4.9	4	370	3.6	4.7
	610	6.0	7.7		570	5.6	7.2		580	5.7	7.3
5	195	1.9	2.5	5	395	3.9	5.0	5	395	3.9	5.0
	615	6.0	7.7		610	6.0	7.7		605	5.9	7.6
6	185	1.8	2.3	6	405	4.0	5.1	6	405	4.0	5.1
	590	5.8	7.4		595	5.8	7.5		615	6.0	7.7
7	185	1.8	2.3	7	385	3.8	4.8	7	405	4.0	5.1
	575	5.6	7.2		580	5.7	7.3		590	5.8	7.4
8	200	2.0	2.5	8	375	3.7	4.7	8	380	3.7	4.8
	580	5.7	7.3		610	6.0	7.7		570	5.6	7.2
9	185	1.8	2.3	9	380	3.7	4.8	9	385	3.8	4.8
	600	5.9	7.5		600	5.9	7.5		575	5.6	7.2
10	195	1.9	2.5	10	390	3.8	4.9	10	395	3.9	5.0
	600	5.9	7.5		590	5.8	7.4		580	5.7	7.3
11	200	2.0	2.5	11	370	3.6	4.7	11	400	3.9	5.0
	600	5.9	7.5		580	5.7	7.3		600	5.9	7.5
12	210	2.1	2.6	12	395	3.9	5.0	12	405	4.0	5.1
	590	5.8	7.4		605	5.9	7.6		610	6.0	7.7
13	185	1.8	2.3	13	405	4.0	5.1	13	410	4.0	5.2
	600	5.9	7.5		615	6.0	7.7		570	5.6	7.2
14	190	1.9	2.4	14	405	4.0	5.1	14	400	3.9	5.0
	600	5.9	7.5		590	5.8	7.4		570	5.6	7.2
15	195	1.9	2.5	15	400	3.9	5.0	15	375	3.7	4.7
	790	7.7	9.9		725	7.1	9.1		720	7.1	9.1

Table A.13. Test 7-1, 7-2, 7-3 Numerical Data.

Test. 7-1				Test. 7-2				Test. 7-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	200	2.0	2.5
	500	4.9	6.3		515	5.1	6.5		595	5.8	7.5
2	0	0.0	0.0	2	0	0.0	0.0	2	190	1.9	2.4
	520	5.1	6.5		525	5.2	6.6		600	5.9	7.5
3	0	0.0	0.0	3	0	0.0	0.0	3	195	1.9	2.5
	510	5.0	6.4		530	5.2	6.7		605	5.9	7.6
4	0	0.0	0.0	4	0	0.0	0.0	4	190	1.9	2.4
	525	5.2	6.6		515	5.1	6.5		605	5.9	7.6
5	0	0.0	0.0	5	0	0.0	0.0	5	200	2.0	2.5
	530	5.2	6.7		505	5.0	6.4		610	6.0	7.7
6	0	0.0	0.0	6	0	0.0	0.0	6	205	2.0	2.6
	505	5.0	6.4		500	4.9	6.3		600	5.9	7.5
7	0	0.0	0.0	7	0	0.0	0.0	7	195	1.9	2.5
	500	4.9	6.3		510	5.0	6.4		605	5.9	7.6
8	0	0.0	0.0	8	0	0.0	0.0	8	190	1.9	2.4
	520	5.1	6.5		520	5.1	6.5		595	5.8	7.5
9	0	0.0	0.0	9	0	0.0	0.0	9	195	1.9	2.5
	530	5.2	6.7		530	5.2	6.7		590	5.8	7.4
10	0	0.0	0.0	10	0	0.0	0.0	10	200	2.0	2.5
	500	4.9	6.3		525	5.2	6.6		605	5.9	7.6
11	0	0.0	0.0	11	0	0.0	0.0	11	190	1.9	2.4
	510	5.0	6.4		530	5.2	6.7		585	5.7	7.4
12	0	0.0	0.0	12	0	0.0	0.0	12	195	1.9	2.5
	520	5.1	6.5		535	5.2	6.7		595	5.8	7.5
13	0	0.0	0.0	13	0	0.0	0.0	13	185	1.8	2.3
	525	5.2	6.6		525	5.2	6.6		595	5.8	7.5
14	0	0.0	0.0	14	0	0.0	0.0	14	180	1.8	2.3
	500	4.9	6.3		515	5.1	6.5		580	5.7	7.3
15	0	0.0	0.0	15	0	0.0	0.0	15	200	2.0	2.5
	935	9.2	11.8		940	9.2	11.8		1000	9.8	12.6

Table A.14. Test 7-4, 7-5, 7-6 Numerical Data.

Test. 7-4				Test. 7-5				Test. 7-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	190	1.9	2.4	1	480	4.7	6.0	1	500	4.9	6.3
	590	5.8	7.4		770	7.6	9.7		770	7.6	9.7
2	185	1.8	2.3	2	485	4.8	6.1	2	510	5.0	6.4
	580	5.7	7.3		775	7.6	9.7		765	7.5	9.6
3	185	1.8	2.3	3	500	4.9	6.3	3	490	4.8	6.2
	585	5.7	7.4		755	7.4	9.5		765	7.5	9.6
4	195	1.9	2.5	4	510	5.0	6.4	4	480	4.7	6.0
	610	6.0	7.7		750	7.4	9.4		770	7.6	9.7
5	195	1.9	2.5	5	505	5.0	6.4	5	500	4.9	6.3
	615	6.0	7.7		765	7.5	9.6		760	7.5	9.6
6	185	1.8	2.3	6	510	5.0	6.4	6	485	4.8	6.1
	590	5.8	7.4		760	7.5	9.6		755	7.4	9.5
7	185	1.8	2.3	7	505	5.0	6.4	7	500	4.9	6.3
	575	5.6	7.2		765	7.5	9.6		790	7.7	9.9
8	200	2.0	2.5	8	485	4.8	6.1	8	500	4.9	6.3
	580	5.7	7.3		760	7.5	9.6		770	7.6	9.7
9	185	1.8	2.3	9	500	4.9	6.3	9	480	4.7	6.0
	600	5.9	7.5		785	7.7	9.9		765	7.5	9.6
10	195	1.9	2.5	10	510	5.0	6.4	10	485	4.8	6.1
	600	5.9	7.5		790	7.7	9.9		775	7.6	9.7
11	200	2.0	2.5	11	480	4.7	6.0	11	510	5.0	6.4
	600	5.9	7.5		785	7.7	9.9		750	7.4	9.4
12	210	2.1	2.6	12	505	5.0	6.4	12	480	4.7	6.0
	590	5.8	7.4		775	7.6	9.7		780	7.7	9.8
13	185	1.8	2.3	13	495	4.9	6.2	13	470	4.6	5.9
	600	5.9	7.5		765	7.5	9.6		750	7.4	9.4
14	190	1.9	2.4	14	490	4.8	6.2	14	485	4.8	6.1
	600	5.9	7.5		755	7.4	9.5		790	7.7	9.9
15	195	1.9	2.5	15	500	4.9	6.3	15	490	4.8	6.2
	925	9.1	11.6		945	9.3	11.9		960	9.4	12.1

Table A.15. Test 8-1, 8-2, 8-3 Numerical Data.

Test. 8-1				Test. 8-2				Test. 8-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	300	2.9	3.8
	600	5.9	7.5		650	6.4	8.2		900	8.8	11.3
2	0	0.0	0.0	2	0	0.0	0.0	2	320	3.1	4.0
	620	6.1	7.8		620	6.1	7.8		930	9.1	11.7
3	0	0.0	0.0	3	0	0.0	0.0	3	310	3.0	3.9
	630	6.2	7.9		600	5.9	7.5		940	9.2	11.8
4	0	0.0	0.0	4	0	0.0	0.0	4	320	3.1	4.0
	590	5.8	7.4		630	6.2	7.9		880	8.6	11.1
5	0	0.0	0.0	5	0	0.0	0.0	5	300	2.9	3.8
	600	5.9	7.5		620	6.1	7.8		940	9.2	11.8
6	0	0.0	0.0	6	0	0.0	0.0	6	310	3.0	3.9
	610	6.0	7.7		590	5.8	7.4		930	9.1	11.7
7	0	0.0	0.0	7	0	0.0	0.0	7	280	2.7	3.5
	630	6.2	7.9		600	5.9	7.5		950	9.3	11.9
8	0	0.0	0.0	8	0	0.0	0.0	8	290	2.8	3.6
	620	6.1	7.8		610	6.0	7.7		900	8.8	11.3
9	0	0.0	0.0	9	0	0.0	0.0	9	300	2.9	3.8
	610	6.0	7.7		620	6.1	7.8		900	8.8	11.3
10	0	0.0	0.0	10	0	0.0	0.0	10	320	3.1	4.0
	615	6.0	7.7		630	6.2	7.9		910	8.9	11.4
11	0	0.0	0.0	11	0	0.0	0.0	11	310	3.0	3.9
	600	5.9	7.5		630	6.2	7.9		900	8.8	11.3
12	0	0.0	0.0	12	0	0.0	0.0	12	310	3.0	3.9
	610	6.0	7.7		600	5.9	7.5		940	9.2	11.8
13	0	0.0	0.0	13	0	0.0	0.0	13	290	2.8	3.6
	620	6.1	7.8		610	6.0	7.7		940	9.2	11.8
14	0	0.0	0.0	14	0	0.0	0.0	14	310	3.0	3.9
	630	6.2	7.9		620	6.1	7.8		950	9.3	11.9
15	0	0.0	0.0	15	0	0.0	0.0	15	300	2.9	3.8
	1145	11.2	14.4		1120	11.0	14.1		1130	11.1	14.2

Table A.16. Test 8-4, 8-5, 8-6 Numerical Data.

Test. 8-4				Test. 8-5				Test. 8-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	310	3.0	3.9	1	600	5.9	7.5	1	600	5.9	7.5
	900	8.8	11.3		920	9.0	11.6		900	8.8	11.3
2	280	2.7	3.5	2	590	5.8	7.4	2	590	5.8	7.4
	920	9.0	11.6		880	8.6	11.1		890	8.7	11.2
3	300	2.9	3.8	3	580	5.7	7.3	3	590	5.8	7.4
	900	8.8	11.3		930	9.1	11.7		930	9.1	11.7
4	300	2.9	3.8	4	570	5.6	7.2	4	570	5.6	7.2
	910	8.9	11.4		940	9.2	11.8		950	9.3	11.9
5	320	3.1	4.0	5	600	5.9	7.5	5	610	6.0	7.7
	910	8.9	11.4		890	8.7	11.2		890	8.7	11.2
6	310	3.0	3.9	6	590	5.8	7.4	6	600	5.9	7.5
	900	8.8	11.3		940	9.2	11.8		940	9.2	11.8
7	310	3.0	3.9	7	590	5.8	7.4	7	580	5.7	7.3
	930	9.1	11.7		920	9.0	11.6		930	9.1	11.7
8	290	2.8	3.6	8	600	5.9	7.5	8	590	5.8	7.4
	940	9.2	11.8		900	8.8	11.3		910	8.9	11.4
9	320	3.1	4.0	9	600	5.9	7.5	9	600	5.9	7.5
	880	8.6	11.1		930	9.1	11.7		930	9.1	11.7
10	320	3.1	4.0	10	590	5.8	7.4	10	600	5.9	7.5
	930	9.1	11.7		940	9.2	11.8		940	9.2	11.8
11	310	3.0	3.9	11	580	5.7	7.3	11	600	5.9	7.5
	940	9.2	11.8		880	8.6	11.1		890	8.7	11.2
12	310	3.0	3.9	12	620	6.1	7.8	12	610	6.0	7.7
	890	8.7	11.2		940	9.2	11.8		940	9.2	11.8
13	290	2.8	3.6	13	580	5.7	7.3	13	590	5.8	7.4
	940	9.2	11.8		930	9.1	11.7		930	9.1	11.7
14	290	2.8	3.6	14	620	6.1	7.8	14	600	5.9	7.5
	920	9.0	11.6		950	9.3	11.9		950	9.3	11.9
15	320	3.1	4.0	15	600	5.9	7.5	15	590	5.8	7.4
	1125	11.0	14.1		1120	11.0	14.1		1100	10.8	13.8

Table A.17. Test 9-1, 9-2, 9-3 Numerical Data.

Test. 9-1				Test. 9-2				Test. 9-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	350	3.4	4.4
	700	6.9	8.8		690	6.8	8.7		1050	10.3	13.2
2	0	0.0	0.0	2	0	0.0	0.0	2	360	3.5	4.5
	690	6.8	8.7		720	7.1	9.1		1050	10.3	13.2
3	0	0.0	0.0	3	0	0.0	0.0	3	350	3.4	4.4
	700	6.9	8.8		710	7.0	8.9		1070	10.5	13.5
4	0	0.0	0.0	4	0	0.0	0.0	4	370	3.6	4.7
	700	6.9	8.8		700	6.9	8.8		1080	10.6	13.6
5	0	0.0	0.0	5	0	0.0	0.0	5	350	3.4	4.4
	710	7.0	8.9		700	6.9	8.8		1060	10.4	13.3
6	0	0.0	0.0	6	0	0.0	0.0	6	350	3.4	4.4
	700	6.9	8.8		690	6.8	8.7		1050	10.3	13.2
7	0	0.0	0.0	7	0	0.0	0.0	7	340	3.3	4.3
	720	7.1	9.1		700	6.9	8.8		1060	10.4	13.3
8	0	0.0	0.0	8	0	0.0	0.0	8	350	3.4	4.4
	690	6.8	8.7		700	6.9	8.8		1070	10.5	13.5
9	0	0.0	0.0	9	0	0.0	0.0	9	380	3.7	4.8
	700	6.9	8.8		710	7.0	8.9		1090	10.7	13.7
10	0	0.0	0.0	10	0	0.0	0.0	10	370	3.6	4.7
	720	7.1	9.1		700	6.9	8.8		1080	10.6	13.6
11	0	0.0	0.0	11	0	0.0	0.0	11	360	3.5	4.5
	730	7.2	9.2		720	7.1	9.1		1090	10.7	13.7
12	0	0.0	0.0	12	0	0.0	0.0	12	350	3.4	4.4
	720	7.1	9.1		700	6.9	8.8		1080	10.6	13.6
13	0	0.0	0.0	13	0	0.0	0.0	13	340	3.3	4.3
	700	6.9	8.8		710	7.0	8.9		1060	10.4	13.3
14	0	0.0	0.0	14	0	0.0	0.0	14	340	3.3	4.3
	720	7.1	9.1		700	6.9	8.8		1070	10.5	13.5
15	0	0.0	0.0	15	0	0.0	0.0	15	360	3.5	4.5
	1250	12.3	15.7		1315	12.9	16.5		1460	14.3	18.4

Table A.18. Test 9-4, 9-5, 9-6 Numerical Data.

Test. 9-4				Test. 9-5				Test. 9-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	340	3.3	4.3	1	690	6.8	8.7	1	720	7.1	9.1
	1060	10.4	13.3		1060	10.4	13.3		1060	10.4	13.3
2	360	3.5	4.5	2	700	6.9	8.8	2	720	7.1	9.1
	1040	10.2	13.1		1050	10.3	13.2		1060	10.4	13.3
3	350	3.4	4.4	3	700	6.9	8.8	3	700	6.9	8.8
	1070	10.5	13.5		1040	10.2	13.1		1090	10.7	13.7
4	380	3.7	4.8	4	710	7.0	8.9	4	700	6.9	8.8
	1040	10.2	13.1		1060	10.4	13.3		1050	10.3	13.2
5	340	3.3	4.3	5	750	7.4	9.4	5	750	7.4	9.4
	1060	10.4	13.3		1040	10.2	13.1		1030	10.1	13.0
6	350	3.4	4.4	6	710	7.0	8.9	6	710	7.0	8.9
	1040	10.2	13.1		1050	10.3	13.2		1070	10.5	13.5
7	350	3.4	4.4	7	700	6.9	8.8	7	710	7.0	8.9
	1070	10.5	13.5		1070	10.5	13.5		1040	10.2	13.1
8	340	3.3	4.3	8	730	7.2	9.2	8	730	7.2	9.2
	1080	10.6	13.6		1100	10.8	13.8		1100	10.8	13.8
9	380	3.7	4.8	9	690	6.8	8.7	9	720	7.1	9.1
	1020	10.0	12.8		1040	10.2	13.1		1070	10.5	13.5
10	360	3.5	4.5	10	700	6.9	8.8	10	720	7.1	9.1
	1070	10.5	13.5		1070	10.5	13.5		1090	10.7	13.7
11	360	3.5	4.5	11	710	7.0	8.9	11	710	7.0	8.9
	1060	10.4	13.3		1080	10.6	13.6		1090	10.7	13.7
12	350	3.4	4.4	12	690	6.8	8.7	12	690	6.8	8.7
	1040	10.2	13.1		1020	10.0	12.8		1020	10.0	12.8
13	330	3.2	4.2	13	680	6.7	8.6	13	680	6.7	8.6
	1030	10.1	13.0		1030	10.1	13.0		1060	10.4	13.3
14	360	3.5	4.5	14	690	6.8	8.7	14	700	6.9	8.8
	1020	10.0	12.8		1050	10.3	13.2		1040	10.2	13.1
15	350	3.4	4.4	15	720	7.1	9.1	15	730	7.2	9.2
	1290	12.7	16.2		1300	12.8	16.4		1280	12.6	16.1

Table A.19. Test 10-1, 10-2, 10-3 Numerical Data.

Test. 10-1				Test. 10-2				Test. 10-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	400	3.9	5.0
	820	8.0	10.3		800	7.8	10.1		1200	11.8	15.1
2	0	0.0	0.0	2	0	0.0	0.0	2	440	4.3	5.5
	820	8.0	10.3		800	7.8	10.1		1220	12.0	15.3
3	0	0.0	0.0	3	0	0.0	0.0	3	440	4.3	5.5
	790	7.7	9.9		810	7.9	10.2		1200	11.8	15.1
4	0	0.0	0.0	4	0	0.0	0.0	4	420	4.1	5.3
	820	8.0	10.3		820	8.0	10.3		1160	11.4	14.6
5	0	0.0	0.0	5	0	0.0	0.0	5	400	3.9	5.0
	830	8.1	10.4		830	8.1	10.4		1160	11.4	14.6
6	0	0.0	0.0	6	0	0.0	0.0	6	380	3.7	4.8
	840	8.2	10.6		830	8.1	10.4		1150	11.3	14.5
7	0	0.0	0.0	7	0	0.0	0.0	7	390	3.8	4.9
	850	8.3	10.7		800	7.8	10.1		1200	11.8	15.1
8	0	0.0	0.0	8	0	0.0	0.0	8	400	3.9	5.0
	800	7.8	10.1		820	8.0	10.3		1220	12.0	15.3
9	0	0.0	0.0	9	0	0.0	0.0	9	420	4.1	5.3
	820	8.0	10.3		820	8.0	10.3		1250	12.3	15.7
10	0	0.0	0.0	10	0	0.0	0.0	10	410	4.0	5.2
	780	7.7	9.8		800	7.8	10.1		1220	12.0	15.3
11	0	0.0	0.0	11	0	0.0	0.0	11	400	3.9	5.0
	820	8.0	10.3		810	7.9	10.2		1200	11.8	15.1
12	0	0.0	0.0	12	0	0.0	0.0	12	400	3.9	5.0
	800	7.8	10.1		800	7.8	10.1		1250	12.3	15.7
13	0	0.0	0.0	13	0	0.0	0.0	13	380	3.7	4.8
	830	8.1	10.4		820	8.0	10.3		1180	11.6	14.8
14	0	0.0	0.0	14	0	0.0	0.0	14	390	3.8	4.9
	810	7.9	10.2		800	7.8	10.1		1190	11.7	15.0
15	0	0.0	0.0	15	0	0.0	0.0	15	410	4.0	5.2
	1470	14.4	18.5		1540	15.1	19.4		1420	13.9	17.9

Table A.20. Test 10-4, 10-5, 10-6 Numerical Data.

Test. 10-4				Test. 10-5				Test. 10-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	390	3.8	4.9	1	800	7.8	10.1	1	790	7.7	9.9
	1210	11.9	15.2		1210	11.9	15.2		1220	12.0	15.3
2	460	4.5	5.8	2	810	7.9	10.2	2	800	7.8	10.1
	1210	11.9	15.2		1250	12.3	15.7		1260	12.4	15.8
3	450	4.4	5.7	3	820	8.0	10.3	3	810	7.9	10.2
	1190	11.7	15.0		1180	11.6	14.8		1190	11.7	15.0
4	410	4.0	5.2	4	800	7.8	10.1	4	780	7.7	9.8
	1200	11.8	15.1		1180	11.6	14.8		1200	11.8	15.1
5	420	4.1	5.3	5	810	7.9	10.2	5	820	8.0	10.3
	1220	12.0	15.3		1200	11.8	15.1		1220	12.0	15.3
6	400	3.9	5.0	6	820	8.0	10.3	6	800	7.8	10.1
	1250	12.3	15.7		1250	12.3	15.7		1200	11.8	15.1
7	380	3.7	4.8	7	830	8.1	10.4	7	810	7.9	10.2
	1190	11.7	15.0		1200	11.8	15.1		1180	11.6	14.8
8	400	3.9	5.0	8	850	8.3	10.7	8	820	8.0	10.3
	1210	11.9	15.2		1150	11.3	14.5		1250	12.3	15.7
9	420	4.1	5.3	9	800	7.8	10.1	9	820	8.0	10.3
	1230	12.1	15.5		1200	11.8	15.1		1230	12.1	15.5
10	420	4.1	5.3	10	800	7.8	10.1	10	800	7.8	10.1
	1220	12.0	15.3		1220	12.0	15.3		1250	12.3	15.7
11	390	3.8	4.9	11	780	7.7	9.8	11	780	7.7	9.8
	1220	12.0	15.3		1190	11.7	15.0		1190	11.7	15.0
12	400	3.9	5.0	12	810	7.9	10.2	12	810	7.9	10.2
	1240	12.2	15.6		1200	11.8	15.1		1180	11.6	14.8
13	380	3.7	4.8	13	790	7.7	9.9	13	800	7.8	10.1
	1170	11.5	14.7		1180	11.6	14.8		1160	11.4	14.6
14	410	4.0	5.2	14	840	8.2	10.6	14	850	8.3	10.7
	1210	11.9	15.2		1230	12.1	15.5		1250	12.3	15.7
15	400	3.9	5.0	15	820	8.0	10.3	15	790	7.7	9.9
	1650	16.2	20.8		1510	14.8	19.0		1550	15.2	19.5

Table A.21. Test 11-1, 11-2, 11-3 Numerical Data.

Test. 11-1				Test. 11-2				Test. 11-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	450	4.4	5.7
	900	8.8	11.3		880	8.6	11.1		1350	13.2	17.0
2	0	0.0	0.0	2	0	0.0	0.0	2	440	4.3	5.5
	920	9.0	11.6		880	8.6	11.1		1320	12.9	16.6
3	0	0.0	0.0	3	0	0.0	0.0	3	440	4.3	5.5
	900	8.8	11.3		890	8.7	11.2		1350	13.2	17.0
4	0	0.0	0.0	4	0	0.0	0.0	4	450	4.4	5.7
	920	9.0	11.6		900	8.8	11.3		1400	13.7	17.6
5	0	0.0	0.0	5	0	0.0	0.0	5	450	4.4	5.7
	950	9.3	11.9		910	8.9	11.4		1350	13.2	17.0
6	0	0.0	0.0	6	0	0.0	0.0	6	450	4.4	5.7
	900	8.8	11.3		910	8.9	11.4		1380	13.5	17.4
7	0	0.0	0.0	7	0	0.0	0.0	7	420	4.1	5.3
	910	8.9	11.4		920	9.0	11.6		1350	13.2	17.0
8	0	0.0	0.0	8	0	0.0	0.0	8	420	4.1	5.3
	890	8.7	11.2		890	8.7	11.2		1300	12.8	16.4
9	0	0.0	0.0	9	0	0.0	0.0	9	460	4.5	5.8
	880	8.6	11.1		880	8.6	11.1		1350	13.2	17.0
10	0	0.0	0.0	10	0	0.0	0.0	10	470	4.6	5.9
	860	8.4	10.8		860	8.4	10.8		1400	13.7	17.6
11	0	0.0	0.0	11	0	0.0	0.0	11	450	4.4	5.7
	900	8.8	11.3		910	8.9	11.4		1350	13.2	17.0
12	0	0.0	0.0	12	0	0.0	0.0	12	440	4.3	5.5
	900	8.8	11.3		890	8.7	11.2		1400	13.7	17.6
13	0	0.0	0.0	13	0	0.0	0.0	13	460	4.5	5.8
	910	8.9	11.4		940	9.2	11.8		1380	13.5	17.4
14	0	0.0	0.0	14	0	0.0	0.0	14	480	4.7	6.0
	890	8.7	11.2		880	8.6	11.1		1450	14.2	18.2
15	0	0.0	0.0	15	0	0.0	0.0	15	460	4.5	5.8
	1600	15.7	20.1		1680	16.5	21.1		1720	16.9	21.6

Table A.22. Test 11-4, 11-5, 11-6 Numerical Data.

Test. 11-4				Test. 11-5				Test. 11-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	440	4.3	5.5	1	900	8.8	11.3	1	900	8.8	11.3
	1340	13.1	16.9		1370	13.4	17.2		1380	13.5	17.4
2	440	4.3	5.5	2	920	9.0	11.6	2	900	8.8	11.3
	1330	13.0	16.7		1350	13.2	17.0		1360	13.3	17.1
3	460	4.5	5.8	3	920	9.0	11.6	3	900	8.8	11.3
	1370	13.4	17.2		1340	13.1	16.9		1390	13.6	17.5
4	470	4.6	5.9	4	890	8.7	11.2	4	920	9.0	11.6
	1400	13.7	17.6		1360	13.3	17.1		1390	13.6	17.5
5	450	4.4	5.7	5	910	8.9	11.4	5	890	8.7	11.2
	1350	13.2	17.0		1370	13.4	17.2		1400	13.7	17.6
6	440	4.3	5.5	6	920	9.0	11.6	6	900	8.8	11.3
	1370	13.4	17.2		1400	13.7	17.6		1350	13.2	17.0
7	440	4.3	5.5	7	900	8.8	11.3	7	920	9.0	11.6
	1350	13.2	17.0		1380	13.5	17.4		1380	13.5	17.4
8	430	4.2	5.4	8	920	9.0	11.6	8	890	8.7	11.2
	1350	13.2	17.0		1400	13.7	17.6		1350	13.2	17.0
9	460	4.5	5.8	9	920	9.0	11.6	9	920	9.0	11.6
	1340	13.1	16.9		1350	13.2	17.0		1400	13.7	17.6
10	450	4.4	5.7	10	900	8.8	11.3	10	880	8.6	11.1
	1400	13.7	17.6		1380	13.5	17.4		1370	13.4	17.2
11	480	4.7	6.0	11	880	8.6	11.1	11	910	8.9	11.4
	1330	13.0	16.7		1350	13.2	17.0		1400	13.7	17.6
12	460	4.5	5.8	12	910	8.9	11.4	12	910	8.9	11.4
	1440	14.1	18.1		1300	12.8	16.4		1350	13.2	17.0
13	500	4.9	6.3	13	890	8.7	11.2	13	900	8.8	11.3
	1300	12.8	16.4		1380	13.5	17.4		1380	13.5	17.4
14	430	4.2	5.4	14	940	9.2	11.8	14	980	9.6	12.3
	1300	12.8	16.4		1400	13.7	17.6		1360	13.3	17.1
15	450	4.4	5.7	15	920	9.0	11.6	15	890	8.7	11.2
	1700	16.7	21.4		1720	16.9	21.6		1670	16.4	21.0

Table A.23. Test 12-1, 12-2, 12-3 Numerical Data.

Test. 12-1				Test. 12-2				Test. 12-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	500	4.9	6.3
	1020	10.0	12.8		1000	9.8	12.6		1500	14.7	18.9
2	0	0.0	0.0	2	0	0.0	0.0	2	500	4.9	6.3
	1000	9.8	12.6		980	9.6	12.3		1550	15.2	19.5
3	0	0.0	0.0	3	0	0.0	0.0	3	480	4.7	6.0
	950	9.3	11.9		1050	10.3	13.2		1500	14.7	18.9
4	0	0.0	0.0	4	0	0.0	0.0	4	510	5.0	6.4
	1050	10.3	13.2		1000	9.8	12.6		1550	15.2	19.5
5	0	0.0	0.0	5	0	0.0	0.0	5	490	4.8	6.2
	950	9.3	11.9		1050	10.3	13.2		1450	14.2	18.2
6	0	0.0	0.0	6	0	0.0	0.0	6	520	5.1	6.5
	1000	9.8	12.6		950	9.3	11.9		1550	15.2	19.5
7	0	0.0	0.0	7	0	0.0	0.0	7	500	4.9	6.3
	1050	10.3	13.2		1000	9.8	12.6		1500	14.7	18.9
8	0	0.0	0.0	8	0	0.0	0.0	8	520	5.1	6.5
	1000	9.8	12.6		1000	9.8	12.6		1450	14.2	18.2
9	0	0.0	0.0	9	0	0.0	0.0	9	530	5.2	6.7
	950	9.3	11.9		950	9.3	11.9		1500	14.7	18.9
10	0	0.0	0.0	10	0	0.0	0.0	10	500	4.9	6.3
	1000	9.8	12.6		950	9.3	11.9		1450	14.2	18.2
11	0	0.0	0.0	11	0	0.0	0.0	11	490	4.8	6.2
	1000	9.8	12.6		1050	10.3	13.2		1500	14.7	18.9
12	0	0.0	0.0	12	0	0.0	0.0	12	480	4.7	6.0
	1050	10.3	13.2		1000	9.8	12.6		1550	15.2	19.5
13	0	0.0	0.0	13	0	0.0	0.0	13	470	4.6	5.9
	1000	9.8	12.6		1000	9.8	12.6		1500	14.7	18.9
14	0	0.0	0.0	14	0	0.0	0.0	14	480	4.7	6.0
	950	9.3	11.9		1050	10.3	13.2		1500	14.7	18.9
15	0	0.0	0.0	15	0	0.0	0.0	15	500	4.9	6.3
	1870	18.3	23.5		1750	17.2	22.0		1890	18.5	23.8

Table A.24. Test 12-4, 12-5, 12-6 Numerical Data.

Test. 12-4				Test. 12-5				Test. 12-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	490	4.8	6.2	1	1000	9.8	12.6	1	990	9.7	12.5
	1500	14.7	18.9		1450	14.2	18.2		1500	14.7	18.9
2	510	5.0	6.4	2	980	9.6	12.3	2	1010	9.9	12.7
	1500	14.7	18.9		1500	14.7	18.9		1450	14.2	18.2
3	500	4.9	6.3	3	1020	10.0	12.8	3	1000	9.8	12.6
	1500	14.7	18.9		1500	14.7	18.9		1450	14.2	18.2
4	520	5.1	6.5	4	1000	9.8	12.6	4	980	9.6	12.3
	1500	14.7	18.9		1500	14.7	18.9		1550	15.2	19.5
5	480	4.7	6.0	5	1050	10.3	13.2	5	970	9.5	12.2
	1450	14.2	18.2		1550	15.2	19.5		1500	14.7	18.9
6	530	5.2	6.7	6	990	9.7	12.5	6	1010	9.9	12.7
	1450	14.2	18.2		1500	14.7	18.9		1450	14.2	18.2
7	510	5.0	6.4	7	980	9.6	12.3	7	980	9.6	12.3
	1500	14.7	18.9		1450	14.2	18.2		1500	14.7	18.9
8	520	5.1	6.5	8	970	9.5	12.2	8	950	9.3	11.9
	1500	14.7	18.9		1500	14.7	18.9		1500	14.7	18.9
9	540	5.3	6.8	9	1010	9.9	12.7	9	950	9.3	11.9
	1550	15.2	19.5		1550	15.2	19.5		1500	14.7	18.9
10	530	5.2	6.7	10	1000	9.8	12.6	10	1000	9.8	12.6
	1500	14.7	18.9		1500	14.7	18.9		1450	14.2	18.2
11	490	4.8	6.2	11	970	9.5	12.2	11	980	9.6	12.3
	1450	14.2	18.2		1450	14.2	18.2		1500	14.7	18.9
12	490	4.8	6.2	12	980	9.6	12.3	12	1020	10.0	12.8
	1550	15.2	19.5		1550	15.2	19.5		1500	14.7	18.9
13	460	4.5	5.8	13	950	9.3	11.9	13	1000	9.8	12.6
	1450	14.2	18.2		1450	14.2	18.2		1550	15.2	19.5
14	500	4.9	6.3	14	990	9.7	12.5	14	1000	9.8	12.6
	1450	14.2	18.2		1550	15.2	19.5		1550	15.2	19.5
15	480	4.7	6.0	15	1020	10.0	12.8	15	990	9.7	12.5
	2050	20.1	25.8		1880	18.4	23.6		1900	18.6	23.9

Table A.25. Test 13-1, 13-2, 13-3 Numerical Data.

Test. 14-1				Test. 14-2				Test. 14-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	550	5.4	6.9
	1120	11.0	14.1		1100	10.8	13.8		1600	15.7	20.1
2	0	0.0	0.0	2	0	0.0	0.0	2	560	5.5	7.0
	1100	10.8	13.8		1080	10.6	13.6		1700	16.7	21.4
3	0	0.0	0.0	3	0	0.0	0.0	3	580	5.7	7.3
	1150	11.3	14.5		1100	10.8	13.8		1650	16.2	20.8
4	0	0.0	0.0	4	0	0.0	0.0	4	580	5.7	7.3
	1150	11.3	14.5		1100	10.8	13.8		1600	15.7	20.1
5	0	0.0	0.0	5	0	0.0	0.0	5	550	5.4	6.9
	1000	9.8	12.6		1150	11.3	14.5		1650	16.2	20.8
6	0	0.0	0.0	6	0	0.0	0.0	6	560	5.5	7.0
	1100	10.8	13.8		1050	10.3	13.2		1700	16.7	21.4
7	0	0.0	0.0	7	0	0.0	0.0	7	600	5.9	7.5
	1150	11.3	14.5		1100	10.8	13.8		1750	17.2	22.0
8	0	0.0	0.0	8	0	0.0	0.0	8	530	5.2	6.7
	1000	9.8	12.6		1100	10.8	13.8		1600	15.7	20.1
9	0	0.0	0.0	9	0	0.0	0.0	9	560	5.5	7.0
	1050	10.3	13.2		1100	10.8	13.8		1650	16.2	20.8
10	0	0.0	0.0	10	0	0.0	0.0	10	550	5.4	6.9
	1100	10.8	13.8		1050	10.3	13.2		1650	16.2	20.8
11	0	0.0	0.0	11	0	0.0	0.0	11	580	5.7	7.3
	1100	10.8	13.8		1150	11.3	14.5		1700	16.7	21.4
12	0	0.0	0.0	12	0	0.0	0.0	12	540	5.3	6.8
	1150	11.3	14.5		1100	10.8	13.8		1650	16.2	20.8
13	0	0.0	0.0	13	0	0.0	0.0	13	570	5.6	7.2
	1100	10.8	13.8		1150	11.3	14.5		1600	15.7	20.1
14	0	0.0	0.0	14	0	0.0	0.0	14	600	5.9	7.5
	1050	10.3	13.2		1150	11.3	14.5		1650	16.2	20.8
15	0	0.0	0.0	15	0	0.0	0.0	15	610	6.0	7.7
	2300	22.6	28.9		2040	20.0	25.7		2150	21.1	27.0

Table A.26. Test 13-4, 13-5, 13-6 Numerical Data.

Test. 14-4				Test. 14-5				Test. 14-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	560	5.5	7.0	1	1100	10.8	13.8	1	1080	10.6	13.6
	1550	15.2	19.5		1600	15.7	20.1		1650	16.2	20.8
2	580	5.7	7.3	2	1100	10.8	13.8	2	1080	10.6	13.6
	1650	16.2	20.8		1650	16.2	20.8		1700	16.7	21.4
3	600	5.9	7.5	3	1160	11.4	14.6	3	1160	11.4	14.6
	1650	16.2	20.8		1700	16.7	21.4		1650	16.2	20.8
4	550	5.4	6.9	4	1150	11.3	14.5	4	1100	10.8	13.8
	1600	15.7	20.1		1650	16.2	20.8		1650	16.2	20.8
5	600	5.9	7.5	5	1050	10.3	13.2	5	1100	10.8	13.8
	1700	16.7	21.4		1600	15.7	20.1		1600	15.7	20.1
6	560	5.5	7.0	6	1120	11.0	14.1	6	1130	11.1	14.2
	1600	15.7	20.1		1650	16.2	20.8		1700	16.7	21.4
7	600	5.9	7.5	7	1200	11.8	15.1	7	1180	11.6	14.8
	1650	16.2	20.8		1700	16.7	21.4		1650	16.2	20.8
8	580	5.7	7.3	8	1100	10.8	13.8	8	1070	10.5	13.5
	1600	15.7	20.1		1650	16.2	20.8		1600	15.7	20.1
9	590	5.8	7.4	9	1090	10.7	13.7	9	1060	10.4	13.3
	1600	15.7	20.1		1650	16.2	20.8		1650	16.2	20.8
10	600	5.9	7.5	10	1100	10.8	13.8	10	1050	10.3	13.2
	1600	15.7	20.1		1600	15.7	20.1		1650	16.2	20.8
11	610	6.0	7.7	11	1160	11.4	14.6	11	1040	10.2	13.1
	1700	16.7	21.4		1650	16.2	20.8		1700	16.7	21.4
12	600	5.9	7.5	12	1080	10.6	13.6	12	1080	10.6	13.6
	1700	16.7	21.4		1650	16.2	20.8		1700	16.7	21.4
13	570	5.6	7.2	13	1140	11.2	14.3	13	1100	10.8	13.8
	1650	16.2	20.8		1550	15.2	19.5		1550	15.2	19.5
14	550	5.4	6.9	14	1200	11.8	15.1	14	1150	11.3	14.5
	1650	16.2	20.8		1600	15.7	20.1		1650	16.2	20.8
15	550	5.4	6.9	15	1100	10.8	13.8	15	1150	11.3	14.5
	2060	20.2	25.9		2030	19.9	25.5		2000	19.6	25.2

Table A.27. Test 14-1, 14-2, 14-3 Numerical Data.

Test. 14-1				Test. 14-2				Test. 14-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	45	0.4	0.6
	85	0.8	1.1		80	0.8	1.0		130	1.3	1.6
2	0	0.0	0.0	2	0	0.0	0.0	2	40	0.4	0.5
	85	0.8	1.1		85	0.8	1.1		130	1.3	1.6
3	0	0.0	0.0	3	0	0.0	0.0	3	45	0.4	0.6
	80	0.8	1.0		85	0.8	1.1		135	1.3	1.7
4	0	0.0	0.0	4	0	0.0	0.0	4	45	0.4	0.6
	90	0.9	1.1		90	0.9	1.1		130	1.3	1.6
5	0	0.0	0.0	5	0	0.0	0.0	5	40	0.4	0.5
	85	0.8	1.1		90	0.9	1.1		135	1.3	1.7
6	0	0.0	0.0	6	0	0.0	0.0	6	40	0.4	0.5
	90	0.9	1.1		80	0.8	1.0		130	1.3	1.6
7	0	0.0	0.0	7	0	0.0	0.0	7	40	0.4	0.5
	85	0.8	1.1		80	0.8	1.0		125	1.2	1.6
8	0	0.0	0.0	8	0	0.0	0.0	8	45	0.4	0.6
	90	0.9	1.1		85	0.8	1.1		125	1.2	1.6
9	0	0.0	0.0	9	0	0.0	0.0	9	45	0.4	0.6
	85	0.8	1.1		90	0.9	1.1		130	1.3	1.6
10	0	0.0	0.0	10	0	0.0	0.0	10	50	0.5	0.6
	85	0.8	1.1		85	0.8	1.1		130	1.3	1.6
11	0	0.0	0.0	11	0	0.0	0.0	11	50	0.5	0.6
	90	0.9	1.1		85	0.8	1.1		135	1.3	1.7
12	0	0.0	0.0	12	0	0.0	0.0	12	45	0.4	0.6
	85	0.8	1.1		90	0.9	1.1		125	1.2	1.6
13	0	0.0	0.0	13	0	0.0	0.0	13	45	0.4	0.6
	90	0.9	1.1		85	0.8	1.1		125	1.2	1.6
14	0	0.0	0.0	14	0	0.0	0.0	14	40	0.4	0.5
	85	0.8	1.1		85	0.8	1.1		130	1.3	1.6
15	0	0.0	0.0	15	0	0.0	0.0	15	45	0.4	0.6
	160	1.6	2.0		165	1.6	2.1		162	1.6	2.0

Table A.28. Test 14-4, 14-5, 14-6 Numerical Data.

Test. 14-4				Test. 14-5				Test. 14-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	40	0.4	0.5	1	90	0.9	1.1	1	95	0.9	1.2
	125	1.2	1.6		135	1.3	1.7		140	1.4	1.8
2	40	0.4	0.5	2	95	0.9	1.2	2	105	1.0	1.3
	120	1.2	1.5		135	1.3	1.7		125	1.2	1.6
3	45	0.4	0.6	3	100	1.0	1.3	3	100	1.0	1.3
	130	1.3	1.6		130	1.3	1.6		135	1.3	1.7
4	45	0.4	0.6	4	95	0.9	1.2	4	90	0.9	1.1
	135	1.3	1.7		130	1.3	1.6		130	1.3	1.6
5	45	0.4	0.6	5	95	0.9	1.2	5	95	0.9	1.2
	140	1.4	1.8		135	1.3	1.7		130	1.3	1.6
6	40	0.4	0.5	6	90	0.9	1.1	6	90	0.9	1.1
	135	1.3	1.7		125	1.2	1.6		135	1.3	1.7
7	35	0.3	0.4	7	95	0.9	1.2	7	105	1.0	1.3
	125	1.2	1.6		125	1.2	1.6		125	1.2	1.6
8	35	0.3	0.4	8	95	0.9	1.2	8	90	0.9	1.1
	130	1.3	1.6		130	1.3	1.6		130	1.3	1.6
9	35	0.3	0.4	9	90	0.9	1.1	9	85	0.8	1.1
	135	1.3	1.7		125	1.2	1.6		130	1.3	1.6
10	35	0.3	0.4	10	100	1.0	1.3	10	95	0.9	1.2
	130	1.3	1.6		125	1.2	1.6		130	1.3	1.6
11	40	0.4	0.5	11	100	1.0	1.3	11	90	0.9	1.1
	130	1.3	1.6		130	1.3	1.6		125	1.2	1.6
12	45	0.4	0.6	12	95	0.9	1.2	12	95	0.9	1.2
	125	1.2	1.6		135	1.3	1.7		130	1.3	1.6
13	45	0.4	0.6	13	95	0.9	1.2	13	85	0.8	1.1
	130	1.3	1.6		140	1.4	1.8		140	1.4	1.8
14	40	0.4	0.5	14	100	1.0	1.3	14	90	0.9	1.1
	140	1.4	1.8		125	1.2	1.6		130	1.3	1.6
15	40	0.4	0.5	15	85	0.8	1.1	15	90	0.9	1.1
	160	1.6	2.0		195	1.9	2.5		170	1.7	2.1

Table A.29. Test 15-1, 15-2, 15-3 Numerical Data.

Test. 15-1				Test. 15-2				Test. 15-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	110	1.1	1.4
	220	2.2	2.8		215	2.1	2.7		330	3.2	4.2
2	0	0.0	0.0	2	0	0.0	0.0	2	110	1.1	1.4
	220	2.2	2.8		220	2.2	2.8		325	3.2	4.1
3	0	0.0	0.0	3	0	0.0	0.0	3	105	1.0	1.3
	200	2.0	2.5		220	2.2	2.8		335	3.3	4.2
4	0	0.0	0.0	4	0	0.0	0.0	4	115	1.1	1.4
	225	2.2	2.8		215	2.1	2.7		340	3.3	4.3
5	0	0.0	0.0	5	0	0.0	0.0	5	105	1.0	1.3
	210	2.1	2.6		210	2.1	2.6		320	3.1	4.0
6	0	0.0	0.0	6	0	0.0	0.0	6	105	1.0	1.3
	210	2.1	2.6		225	2.2	2.8		320	3.1	4.0
7	0	0.0	0.0	7	0	0.0	0.0	7	110	1.1	1.4
	225	2.2	2.8		210	2.1	2.6		315	3.1	4.0
8	0	0.0	0.0	8	0	0.0	0.0	8	115	1.1	1.4
	230	2.3	2.9		230	2.3	2.9		330	3.2	4.2
9	0	0.0	0.0	9	0	0.0	0.0	9	110	1.1	1.4
	225	2.2	2.8		235	2.3	3.0		340	3.3	4.3
10	0	0.0	0.0	10	0	0.0	0.0	10	110	1.1	1.4
	220	2.2	2.8		230	2.3	2.9		350	3.4	4.4
11	0	0.0	0.0	11	0	0.0	0.0	11	115	1.1	1.4
	230	2.3	2.9		220	2.2	2.8		325	3.2	4.1
12	0	0.0	0.0	12	0	0.0	0.0	12	110	1.1	1.4
	230	2.3	2.9		210	2.1	2.6		340	3.3	4.3
13	0	0.0	0.0	13	0	0.0	0.0	13	115	1.1	1.4
	200	2.0	2.5		225	2.2	2.8		310	3.0	3.9
14	0	0.0	0.0	14	0	0.0	0.0	14	120	1.2	1.5
	225	2.2	2.8		230	2.3	2.9		360	3.5	4.5
15	0	0.0	0.0	15	0	0.0	0.0	15	110	1.1	1.4
	420	4.1	5.3		480	4.7	6.0		415	4.1	5.2

Table A.30. Test 15-4, 15-5, 15-6 Numerical Data.

Test. 15-4				Test. 15-5				Test. 15-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	105	1.0	1.3	1	210	2.1	2.6	1	220	2.2	2.8
	320	3.1	4.0		340	3.3	4.3		350	3.4	4.4
2	110	1.1	1.4	2	220	2.2	2.8	2	200	2.0	2.5
	310	3.0	3.9		330	3.2	4.2		310	3.0	3.9
3	110	1.1	1.4	3	210	2.1	2.6	3	220	2.2	2.8
	340	3.3	4.3		350	3.4	4.4		340	3.3	4.3
4	105	1.0	1.3	4	230	2.3	2.9	4	230	2.3	2.9
	330	3.2	4.2		320	3.1	4.0		320	3.1	4.0
5	120	1.2	1.5	5	240	2.4	3.0	5	250	2.5	3.1
	320	3.1	4.0		310	3.0	3.9		300	2.9	3.8
6	105	1.0	1.3	6	235	2.3	3.0	6	220	2.2	2.8
	310	3.0	3.9		350	3.4	4.4		330	3.2	4.2
7	105	1.0	1.3	7	210	2.1	2.6	7	210	2.1	2.6
	320	3.1	4.0		350	3.4	4.4		330	3.2	4.2
8	110	1.1	1.4	8	240	2.4	3.0	8	230	2.3	2.9
	320	3.1	4.0		310	3.0	3.9		320	3.1	4.0
9	115	1.1	1.4	9	220	2.2	2.8	9	220	2.2	2.8
	340	3.3	4.3		330	3.2	4.2		320	3.1	4.0
10	120	1.2	1.5	10	220	2.2	2.8	10	220	2.2	2.8
	330	3.2	4.2		320	3.1	4.0		330	3.2	4.2
11	110	1.1	1.4	11	210	2.1	2.6	11	210	2.1	2.6
	340	3.3	4.3		330	3.2	4.2		340	3.3	4.3
12	115	1.1	1.4	12	220	2.2	2.8	12	220	2.2	2.8
	350	3.4	4.4		340	3.3	4.3		310	3.0	3.9
13	120	1.2	1.5	13	210	2.1	2.6	13	220	2.2	2.8
	340	3.3	4.3		310	3.0	3.9		330	3.2	4.2
14	105	1.0	1.3	14	220	2.2	2.8	14	220	2.2	2.8
	310	3.0	3.9		310	3.0	3.9		330	3.2	4.2
15	120	1.2	1.5	15	220	2.2	2.8	15	210	2.1	2.6
	420	4.1	5.3		430	4.2	5.4		410	4.0	5.2

Table A.31. Test 16-1, 16-2, 16-3 Numerical Data.

Test. 16-1				Test. 16-2				Test. 16-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	180	1.8	2.3
	350	3.4	4.4		355	3.5	4.5		540	5.3	6.8
2	0	0.0	0.0	2	0	0.0	0.0	2	180	1.8	2.3
	350	3.4	4.4		350	3.4	4.4		535	5.2	6.7
3	0	0.0	0.0	3	0	0.0	0.0	3	175	1.7	2.2
	330	3.2	4.2		360	3.5	4.5		550	5.4	6.9
4	0	0.0	0.0	4	0	0.0	0.0	4	185	1.8	2.3
	345	3.4	4.3		345	3.4	4.3		550	5.4	6.9
5	0	0.0	0.0	5	0	0.0	0.0	5	165	1.6	2.1
	340	3.3	4.3		350	3.4	4.4		530	5.2	6.7
6	0	0.0	0.0	6	0	0.0	0.0	6	165	1.6	2.1
	340	3.3	4.3		355	3.5	4.5		550	5.4	6.9
7	0	0.0	0.0	7	0	0.0	0.0	7	180	1.8	2.3
	355	3.5	4.5		330	3.2	4.2		545	5.3	6.9
8	0	0.0	0.0	8	0	0.0	0.0	8	185	1.8	2.3
	350	3.4	4.4		360	3.5	4.5		560	5.5	7.0
9	0	0.0	0.0	9	0	0.0	0.0	9	180	1.8	2.3
	345	3.4	4.3		365	3.6	4.6		570	5.6	7.2
10	0	0.0	0.0	10	0	0.0	0.0	10	180	1.8	2.3
	340	3.3	4.3		350	3.4	4.4		570	5.6	7.2
11	0	0.0	0.0	11	0	0.0	0.0	11	175	1.7	2.2
	350	3.4	4.4		340	3.3	4.3		555	5.4	7.0
12	0	0.0	0.0	12	0	0.0	0.0	12	170	1.7	2.1
	350	3.4	4.4		330	3.2	4.2		530	5.2	6.7
13	0	0.0	0.0	13	0	0.0	0.0	13	195	1.9	2.5
	330	3.2	4.2		345	3.4	4.3		540	5.3	6.8
14	0	0.0	0.0	14	0	0.0	0.0	14	200	2.0	2.5
	355	3.5	4.5		360	3.5	4.5		520	5.1	6.5
15	0	0.0	0.0	15	0	0.0	0.0	15	190	1.9	2.4
	670	6.6	8.4		680	6.7	8.6		660	6.5	8.3

Table A.32. Test 16-4, 16-5, 16-6 Numerical Data.

Test. 16-4				Test. 16-5				Test. 16-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	190	1.9	2.4	1	360	3.5	4.5	1	320	3.1	4.0
	530	5.2	6.7		540	5.3	6.8		510	5.0	6.4
2	190	1.9	2.4	2	350	3.4	4.4	2	330	3.2	4.2
	560	5.5	7.0		550	5.4	6.9		530	5.2	6.7
3	195	1.9	2.5	3	340	3.3	4.3	3	340	3.3	4.3
	550	5.4	6.9		560	5.5	7.0		530	5.2	6.7
4	180	1.8	2.3	4	370	3.6	4.7	4	350	3.4	4.4
	550	5.4	6.9		550	5.4	6.9		540	5.3	6.8
5	180	1.8	2.3	5	380	3.7	4.8	5	320	3.1	4.0
	540	5.3	6.8		540	5.3	6.8		550	5.4	6.9
6	185	1.8	2.3	6	350	3.4	4.4	6	350	3.4	4.4
	540	5.3	6.8		560	5.5	7.0		550	5.4	6.9
7	190	1.9	2.4	7	370	3.6	4.7	7	340	3.3	4.3
	560	5.5	7.0		545	5.3	6.9		560	5.5	7.0
8	200	2.0	2.5	8	340	3.3	4.3	8	330	3.2	4.2
	560	5.5	7.0		570	5.6	7.2		540	5.3	6.8
9	170	1.7	2.1	9	350	3.4	4.4	9	330	3.2	4.2
	520	5.1	6.5		510	5.0	6.4		520	5.1	6.5
10	170	1.7	2.1	10	380	3.7	4.8	10	340	3.3	4.3
	530	5.2	6.7		530	5.2	6.7		510	5.0	6.4
11	180	1.8	2.3	11	340	3.3	4.3	11	350	3.4	4.4
	555	5.4	7.0		570	5.6	7.2		560	5.5	7.0
12	170	1.7	2.1	12	350	3.4	4.4	12	360	3.5	4.5
	550	5.4	6.9		510	5.0	6.4		540	5.3	6.8
13	175	1.7	2.2	13	350	3.4	4.4	13	370	3.6	4.7
	550	5.4	6.9		530	5.2	6.7		550	5.4	6.9
14	170	1.7	2.1	14	340	3.3	4.3	14	340	3.3	4.3
	560	5.5	7.0		540	5.3	6.8		560	5.5	7.0
15	180	1.8	2.3	15	340	3.3	4.3	15	350	3.4	4.4
	690	6.8	8.7		690	6.8	8.7		660	6.5	8.3

Table A.33. Test 17-1, 17-2, 17-3 Numerical Data.

Test. 17-1				Test. 17-2				Test. 17-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	240	2.4	3.0
	500	4.9	6.3		480	4.7	6.0		750	7.4	9.4
2	0	0.0	0.0	2	0	0.0	0.0	2	250	2.5	3.1
	500	4.9	6.3		500	4.9	6.3		730	7.2	9.2
3	0	0.0	0.0	3	0	0.0	0.0	3	260	2.6	3.3
	480	4.7	6.0		460	4.5	5.8		735	7.2	9.2
4	0	0.0	0.0	4	0	0.0	0.0	4	250	2.5	3.1
	480	4.7	6.0		470	4.6	5.9		720	7.1	9.1
5	0	0.0	0.0	5	0	0.0	0.0	5	250	2.5	3.1
	470	4.6	5.9		470	4.6	5.9		740	7.3	9.3
6	0	0.0	0.0	6	0	0.0	0.0	6	240	2.4	3.0
	460	4.5	5.8		480	4.7	6.0		740	7.3	9.3
7	0	0.0	0.0	7	0	0.0	0.0	7	240	2.4	3.0
	450	4.4	5.7		480	4.7	6.0		750	7.4	9.4
8	0	0.0	0.0	8	0	0.0	0.0	8	250	2.5	3.1
	500	4.9	6.3		490	4.8	6.2		750	7.4	9.4
9	0	0.0	0.0	9	0	0.0	0.0	9	250	2.5	3.1
	480	4.7	6.0		500	4.9	6.3		740	7.3	9.3
10	0	0.0	0.0	10	0	0.0	0.0	10	230	2.3	2.9
	470	4.6	5.9		460	4.5	5.8		730	7.2	9.2
11	0	0.0	0.0	11	0	0.0	0.0	11	240	2.4	3.0
	480	4.7	6.0		460	4.5	5.8		730	7.2	9.2
12	0	0.0	0.0	12	0	0.0	0.0	12	250	2.5	3.1
	490	4.8	6.2		480	4.7	6.0		750	7.4	9.4
13	0	0.0	0.0	13	0	0.0	0.0	13	240	2.4	3.0
	490	4.8	6.2		470	4.6	5.9		750	7.4	9.4
14	0	0.0	0.0	14	0	0.0	0.0	14	240	2.4	3.0
	480	4.7	6.0		470	4.6	5.9		730	7.2	9.2
15	0	0.0	0.0	15	0	0.0	0.0	15	250	2.5	3.1
	920	9.0	11.6		910	8.9	11.4		910	8.9	11.4

Table A.34. Test 17-4, 17-5, 17-6 Numerical Data.

Test. 17-4				Test. 17-5				Test. 17-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	230	2.3	2.9	1	490	4.8	6.2	1	460	4.5	5.8
	740	7.3	9.3		750	7.4	9.4		710	7.0	8.9
2	240	2.4	3.0	2	460	4.5	5.8	2	480	4.7	6.0
	730	7.2	9.2		730	7.2	9.2		720	7.1	9.1
3	250	2.5	3.1	3	470	4.6	5.9	3	480	4.7	6.0
	750	7.4	9.4		735	7.2	9.2		730	7.2	9.2
4	250	2.5	3.1	4	480	4.7	6.0	4	480	4.7	6.0
	720	7.1	9.1		720	7.1	9.1		730	7.2	9.2
5	240	2.4	3.0	5	470	4.6	5.9	5	480	4.7	6.0
	710	7.0	8.9		740	7.3	9.3		710	7.0	8.9
6	230	2.3	2.9	6	460	4.5	5.8	6	460	4.5	5.8
	710	7.0	8.9		740	7.3	9.3		740	7.3	9.3
7	230	2.3	2.9	7	460	4.5	5.8	7	450	4.4	5.7
	730	7.2	9.2		720	7.1	9.1		720	7.1	9.1
8	240	2.4	3.0	8	500	4.9	6.3	8	460	4.5	5.8
	730	7.2	9.2		730	7.2	9.2		720	7.1	9.1
9	240	2.4	3.0	9	490	4.8	6.2	9	460	4.5	5.8
	750	7.4	9.4		740	7.3	9.3		740	7.3	9.3
10	250	2.5	3.1	10	470	4.6	5.9	10	460	4.5	5.8
	720	7.1	9.1		730	7.2	9.2		720	7.1	9.1
11	250	2.5	3.1	11	470	4.6	5.9	11	470	4.6	5.9
	730	7.2	9.2		730	7.2	9.2		720	7.1	9.1
12	240	2.4	3.0	12	460	4.5	5.8	12	460	4.5	5.8
	740	7.3	9.3		750	7.4	9.4		720	7.1	9.1
13	240	2.4	3.0	13	480	4.7	6.0	13	470	4.6	5.9
	710	7.0	8.9		740	7.3	9.3		710	7.0	8.9
14	250	2.5	3.1	14	470	4.6	5.9	14	480	4.7	6.0
	710	7.0	8.9		730	7.2	9.2		720	7.1	9.1
15	240	2.4	3.0	15	490	4.8	6.2	15	460	4.5	5.8
	910	8.9	11.4		920	9.0	11.6		910	8.9	11.4

Table A.35. Test 18-1, 18-2, 18-3 Numerical Data.

Test. 18-1				Test. 18-2				Test. 18-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	300	2.9	3.8
	620	6.1	7.8		610	6.0	7.7		900	8.8	11.3
2	0	0.0	0.0	2	0	0.0	0.0	2	300	2.9	3.8
	630	6.2	7.9		600	5.9	7.5		920	9.0	11.6
3	0	0.0	0.0	3	0	0.0	0.0	3	320	3.1	4.0
	620	6.1	7.8		600	5.9	7.5		930	9.1	11.7
4	0	0.0	0.0	4	0	0.0	0.0	4	310	3.0	3.9
	650	6.4	8.2		620	6.1	7.8		940	9.2	11.8
5	0	0.0	0.0	5	0	0.0	0.0	5	310	3.0	3.9
	600	5.9	7.5		620	6.1	7.8		950	9.3	11.9
6	0	0.0	0.0	6	0	0.0	0.0	6	320	3.1	4.0
	620	6.1	7.8		650	6.4	8.2		950	9.3	11.9
7	0	0.0	0.0	7	0	0.0	0.0	7	300	2.9	3.8
	620	6.1	7.8		640	6.3	8.0		900	8.8	11.3
8	0	0.0	0.0	8	0	0.0	0.0	8	310	3.0	3.9
	630	6.2	7.9		640	6.3	8.0		950	9.3	11.9
9	0	0.0	0.0	9	0	0.0	0.0	9	310	3.0	3.9
	650	6.4	8.2		620	6.1	7.8		970	9.5	12.2
10	0	0.0	0.0	10	0	0.0	0.0	10	320	3.1	4.0
	600	5.9	7.5		620	6.1	7.8		960	9.4	12.1
11	0	0.0	0.0	11	0	0.0	0.0	11	320	3.1	4.0
	600	5.9	7.5		630	6.2	7.9		950	9.3	11.9
12	0	0.0	0.0	12	0	0.0	0.0	12	300	2.9	3.8
	620	6.1	7.8		630	6.2	7.9		920	9.0	11.6
13	0	0.0	0.0	13	0	0.0	0.0	13	290	2.8	3.6
	610	6.0	7.7		640	6.3	8.0		890	8.7	11.2
14	0	0.0	0.0	14	0	0.0	0.0	14	300	2.9	3.8
	610	6.0	7.7		620	6.1	7.8		890	8.7	11.2
15	0	0.0	0.0	15	0	0.0	0.0	15	300	2.9	3.8
	1190	11.7	15.0		1180	11.6	14.8		1170	11.5	14.7

Table A.36. Test 18-4, 18-5, 18-6 Numerical Data.

Test. 18-4				Test. 18-5				Test. 18-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	310	3.0	3.9	1	630	6.2	7.9	1	610	6.0	7.7
	910	8.9	11.4		910	8.9	11.4		920	9.0	11.6
2	310	3.0	3.9	2	620	6.1	7.8	2	620	6.1	7.8
	930	9.1	11.7		940	9.2	11.8		950	9.3	11.9
3	340	3.3	4.3	3	630	6.2	7.9	3	620	6.1	7.8
	920	9.0	11.6		950	9.3	11.9		920	9.0	11.6
4	320	3.1	4.0	4	610	6.0	7.7	4	600	5.9	7.5
	930	9.1	11.7		950	9.3	11.9		960	9.4	12.1
5	290	2.8	3.6	5	620	6.1	7.8	5	590	5.8	7.4
	940	9.2	11.8		900	8.8	11.3		950	9.3	11.9
6	310	3.0	3.9	6	630	6.2	7.9	6	600	5.9	7.5
	940	9.2	11.8		930	9.1	11.7		940	9.2	11.8
7	310	3.0	3.9	7	600	5.9	7.5	7	590	5.8	7.4
	890	8.7	11.2		920	9.0	11.6		930	9.1	11.7
8	320	3.1	4.0	8	620	6.1	7.8	8	620	6.1	7.8
	940	9.2	11.8		940	9.2	11.8		950	9.3	11.9
9	310	3.0	3.9	9	620	6.1	7.8	9	610	6.0	7.7
	910	8.9	11.4		920	9.0	11.6		930	9.1	11.7
10	310	3.0	3.9	10	610	6.0	7.7	10	600	5.9	7.5
	950	9.3	11.9		920	9.0	11.6		950	9.3	11.9
11	300	2.9	3.8	11	620	6.1	7.8	11	640	6.3	8.0
	920	9.0	11.6		950	9.3	11.9		940	9.2	11.8
12	290	2.8	3.6	12	600	5.9	7.5	12	600	5.9	7.5
	920	9.0	11.6		930	9.1	11.7		930	9.1	11.7
13	290	2.8	3.6	13	620	6.1	7.8	13	620	6.1	7.8
	900	8.8	11.3		890	8.7	11.2		910	8.9	11.4
14	310	3.0	3.9	14	600	5.9	7.5	14	610	6.0	7.7
	910	8.9	11.4		940	9.2	11.8		950	9.3	11.9
15	310	3.0	3.9	15	620	6.1	7.8	15	600	5.9	7.5
	1150	11.3	14.5		1170	11.5	14.7		1180	11.6	14.8

Table A.37. Test 19-1, 19-2, 19-3 Numerical Data.

Test. 19-1				Test. 19-2				Test. 19-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	350	3.4	4.4
	750	7.4	9.4		740	7.3	9.3		1100	10.8	13.8
2	0	0.0	0.0	2	0	0.0	0.0	2	350	3.4	4.4
	760	7.5	9.6		730	7.2	9.2		1050	10.3	13.2
3	0	0.0	0.0	3	0	0.0	0.0	3	370	3.6	4.7
	760	7.5	9.6		750	7.4	9.4		1100	10.8	13.8
4	0	0.0	0.0	4	0	0.0	0.0	4	330	3.2	4.2
	750	7.4	9.4		760	7.5	9.6		1050	10.3	13.2
5	0	0.0	0.0	5	0	0.0	0.0	5	370	3.6	4.7
	720	7.1	9.1		770	7.6	9.7		1050	10.3	13.2
6	0	0.0	0.0	6	0	0.0	0.0	6	380	3.7	4.8
	720	7.1	9.1		780	7.7	9.8		1100	10.8	13.8
7	0	0.0	0.0	7	0	0.0	0.0	7	390	3.8	4.9
	740	7.3	9.3		750	7.4	9.4		1100	10.8	13.8
8	0	0.0	0.0	8	0	0.0	0.0	8	360	3.5	4.5
	750	7.4	9.4		740	7.3	9.3		1000	9.8	12.6
9	0	0.0	0.0	9	0	0.0	0.0	9	360	3.5	4.5
	750	7.4	9.4		740	7.3	9.3		1050	10.3	13.2
10	0	0.0	0.0	10	0	0.0	0.0	10	380	3.7	4.8
	770	7.6	9.7		750	7.4	9.4		1100	10.8	13.8
11	0	0.0	0.0	11	0	0.0	0.0	11	340	3.3	4.3
	750	7.4	9.4		760	7.5	9.6		1100	10.8	13.8
12	0	0.0	0.0	12	0	0.0	0.0	12	340	3.3	4.3
	740	7.3	9.3		760	7.5	9.6		1050	10.3	13.2
13	0	0.0	0.0	13	0	0.0	0.0	13	380	3.7	4.8
	750	7.4	9.4		720	7.1	9.1		1050	10.3	13.2
14	0	0.0	0.0	14	0	0.0	0.0	14	350	3.4	4.4
	780	7.7	9.8		720	7.1	9.1		1100	10.8	13.8
15	0	0.0	0.0	15	0	0.0	0.0	15	350	3.4	4.4
	1420	13.9	17.9		1450	14.2	18.2		1370	13.4	17.2

Table A.38. Test 19-4, 19-5, 19-6 Numerical Data.

Test. 19-4				Test. 19-5				Test. 19-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	340	3.3	4.3	1	740	7.3	9.3	1	720	7.1	9.1
	1050	10.3	13.2		1050	10.3	13.2		1100	10.8	13.8
2	340	3.3	4.3	2	750	7.4	9.4	2	750	7.4	9.4
	1100	10.8	13.8		1100	10.8	13.8		1100	10.8	13.8
3	350	3.4	4.4	3	760	7.5	9.6	3	740	7.3	9.3
	1100	10.8	13.8		1150	11.3	14.5		1150	11.3	14.5
4	350	3.4	4.4	4	750	7.4	9.4	4	740	7.3	9.3
	1000	9.8	12.6		1200	11.8	15.1		1150	11.3	14.5
5	360	3.5	4.5	5	750	7.4	9.4	5	740	7.3	9.3
	1050	10.3	13.2		1100	10.8	13.8		1050	10.3	13.2
6	340	3.3	4.3	6	780	7.7	9.8	6	730	7.2	9.2
	1050	10.3	13.2		1100	10.8	13.8		1050	10.3	13.2
7	370	3.6	4.7	7	780	7.7	9.8	7	750	7.4	9.4
	1050	10.3	13.2		1100	10.8	13.8		1050	10.3	13.2
8	380	3.7	4.8	8	740	7.3	9.3	8	750	7.4	9.4
	1050	10.3	13.2		1150	11.3	14.5		1150	11.3	14.5
9	400	3.9	5.0	9	710	7.0	8.9	9	720	7.1	9.1
	1100	10.8	13.8		1150	11.3	14.5		1150	11.3	14.5
10	390	3.8	4.9	10	750	7.4	9.4	10	780	7.7	9.8
	1100	10.8	13.8		1150	11.3	14.5		1200	11.8	15.1
11	380	3.7	4.8	11	730	7.2	9.2	11	750	7.4	9.4
	1050	10.3	13.2		1100	10.8	13.8		1050	10.3	13.2
12	340	3.3	4.3	12	730	7.2	9.2	12	710	7.0	8.9
	1100	10.8	13.8		1050	10.3	13.2		1100	10.8	13.8
13	350	3.4	4.4	13	750	7.4	9.4	13	800	7.8	10.1
	1100	10.8	13.8		1050	10.3	13.2		1050	10.3	13.2
14	360	3.5	4.5	14	750	7.4	9.4	14	720	7.1	9.1
	1050	10.3	13.2		1100	10.8	13.8		1050	10.3	13.2
15	360	3.5	4.5	15	750	7.4	9.4	15	740	7.3	9.3
	1380	13.5	17.4		1400	13.7	17.6		1450	14.2	18.2

Table A.39. Test 20-1, 20-2, 20-3 Numerical Data.

Test. 20-1				Test. 20-2				Test. 20-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	480	4.7	6.0
	950	9.3	11.9		1000	9.8	12.6		1450	14.2	18.2
2	0	0.0	0.0	2	0	0.0	0.0	2	490	4.8	6.2
	1000	9.8	12.6		950	9.3	11.9		1400	13.7	17.6
3	0	0.0	0.0	3	0	0.0	0.0	3	500	4.9	6.3
	1000	9.8	12.6		950	9.3	11.9		1400	13.7	17.6
4	0	0.0	0.0	4	0	0.0	0.0	4	510	5.0	6.4
	900	8.8	11.3		900	8.8	11.3		1400	13.7	17.6
5	0	0.0	0.0	5	0	0.0	0.0	5	500	4.9	6.3
	950	9.3	11.9		950	9.3	11.9		1500	14.7	18.9
6	0	0.0	0.0	6	0	0.0	0.0	6	510	5.0	6.4
	950	9.3	11.9		1000	9.8	12.6		1400	13.7	17.6
7	0	0.0	0.0	7	0	0.0	0.0	7	500	4.9	6.3
	1000	9.8	12.6		950	9.3	11.9		1450	14.2	18.2
8	0	0.0	0.0	8	0	0.0	0.0	8	460	4.5	5.8
	950	9.3	11.9		1000	9.8	12.6		1400	13.7	17.6
9	0	0.0	0.0	9	0	0.0	0.0	9	470	4.6	5.9
	950	9.3	11.9		950	9.3	11.9		1450	14.2	18.2
10	0	0.0	0.0	10	0	0.0	0.0	10	460	4.5	5.8
	1000	9.8	12.6		950	9.3	11.9		1500	14.7	18.9
11	0	0.0	0.0	11	0	0.0	0.0	11	480	4.7	6.0
	900	8.8	11.3		950	9.3	11.9		1500	14.7	18.9
12	0	0.0	0.0	12	0	0.0	0.0	12	480	4.7	6.0
	900	8.8	11.3		1000	9.8	12.6		1450	14.2	18.2
13	0	0.0	0.0	13	0	0.0	0.0	13	500	4.9	6.3
	950	9.3	11.9		900	8.8	11.3		1450	14.2	18.2
14	0	0.0	0.0	14	0	0.0	0.0	14	500	4.9	6.3
	950	9.3	11.9		950	9.3	11.9		1400	13.7	17.6
15	0	0.0	0.0	15	0	0.0	0.0	15	480	4.7	6.0
	1820	17.9	22.9		1770	17.4	22.3		1830	18.0	23.0

Table A.40. Test 20-4, 20-5, 20-6 Numerical Data.

Test. 20-4				Test. 20-5				Test. 20-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	500	4.9	6.3	1	1000	9.8	12.6	1	950	9.3	11.9
	1500	14.7	18.9		1450	14.2	18.2		1400	13.7	17.6
2	510	5.0	6.4	2	950	9.3	11.9	2	1000	9.8	12.6
	1500	14.7	18.9		1450	14.2	18.2		1500	14.7	18.9
3	500	4.9	6.3	3	1000	9.8	12.6	3	1000	9.8	12.6
	1400	13.7	17.6		1500	14.7	18.9		1400	13.7	17.6
4	500	4.9	6.3	4	1050	10.3	13.2	4	1050	10.3	13.2
	1450	14.2	18.2		1400	13.7	17.6		1450	14.2	18.2
5	490	4.8	6.2	5	1000	9.8	12.6	5	950	9.3	11.9
	1500	14.7	18.9		1450	14.2	18.2		1500	14.7	18.9
6	480	4.7	6.0	6	900	8.8	11.3	6	900	8.8	11.3
	1450	14.2	18.2		1500	14.7	18.9		1400	13.7	17.6
7	480	4.7	6.0	7	900	8.8	11.3	7	950	9.3	11.9
	1400	13.7	17.6		1450	14.2	18.2		1400	13.7	17.6
8	470	4.6	5.9	8	950	9.3	11.9	8	1000	9.8	12.6
	1400	13.7	17.6		1450	14.2	18.2		1400	13.7	17.6
9	500	4.9	6.3	9	1000	9.8	12.6	9	900	8.8	11.3
	1450	14.2	18.2		1500	14.7	18.9		1500	14.7	18.9
10	510	5.0	6.4	10	1050	10.3	13.2	10	950	9.3	11.9
	1450	14.2	18.2		1500	14.7	18.9		1500	14.7	18.9
11	500	4.9	6.3	11	1000	9.8	12.6	11	950	9.3	11.9
	1450	14.2	18.2		1450	14.2	18.2		1400	13.7	17.6
12	500	4.9	6.3	12	950	9.3	11.9	12	900	8.8	11.3
	1500	14.7	18.9		1450	14.2	18.2		1500	14.7	18.9
13	500	4.9	6.3	13	1050	10.3	13.2	13	1050	10.3	13.2
	1400	13.7	17.6		1500	14.7	18.9		1450	14.2	18.2
14	460	4.5	5.8	14	950	9.3	11.9	14	900	8.8	11.3
	1500	14.7	18.9		1450	14.2	18.2		1400	13.7	17.6
15	460	4.5	5.8	15	950	9.3	11.9	15	900	8.8	11.3
	1750	17.2	22.0		1820	17.9	22.9		1920	18.8	24.1

Table A.41. Test 21-1, 21-2, 21-3 Numerical Data.

Test. 21-1				Test. 21-2				Test. 21-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	600	5.9	7.5
	1150	11.3	14.5		1100	10.8	13.8		1750	17.2	22.0
2	0	0.0	0.0	2	0	0.0	0.0	2	650	6.4	8.2
	1200	11.8	15.1		1150	11.3	14.5		1750	17.2	22.0
3	0	0.0	0.0	3	0	0.0	0.0	3	650	6.4	8.2
	1150	11.3	14.5		1200	11.8	15.1		1700	16.7	21.4
4	0	0.0	0.0	4	0	0.0	0.0	4	600	5.9	7.5
	1200	11.8	15.1		1200	11.8	15.1		1700	16.7	21.4
5	0	0.0	0.0	5	0	0.0	0.0	5	600	5.9	7.5
	1200	11.8	15.1		1150	11.3	14.5		1650	16.2	20.8
6	0	0.0	0.0	6	0	0.0	0.0	6	550	5.4	6.9
	1200	11.8	15.1		1100	10.8	13.8		1650	16.2	20.8
7	0	0.0	0.0	7	0	0.0	0.0	7	600	5.9	7.5
	1150	11.3	14.5		1150	11.3	14.5		1700	16.7	21.4
8	0	0.0	0.0	8	0	0.0	0.0	8	600	5.9	7.5
	1100	10.8	13.8		1200	11.8	15.1		1800	17.7	22.6
9	0	0.0	0.0	9	0	0.0	0.0	9	650	6.4	8.2
	1150	11.3	14.5		1100	10.8	13.8		1800	17.7	22.6
10	0	0.0	0.0	10	0	0.0	0.0	10	600	5.9	7.5
	1100	10.8	13.8		1100	10.8	13.8		1750	17.2	22.0
11	0	0.0	0.0	11	0	0.0	0.0	11	600	5.9	7.5
	1150	11.3	14.5		1100	10.8	13.8		1700	16.7	21.4
12	0	0.0	0.0	12	0	0.0	0.0	12	550	5.4	6.9
	1200	11.8	15.1		1150	11.3	14.5		1700	16.7	21.4
13	0	0.0	0.0	13	0	0.0	0.0	13	550	5.4	6.9
	1150	11.3	14.5		1200	11.8	15.1		1750	17.2	22.0
14	0	0.0	0.0	14	0	0.0	0.0	14	600	5.9	7.5
	1100	10.8	13.8		1150	11.3	14.5		1800	17.7	22.6
15	0	0.0	0.0	15	0	0.0	0.0	15	600	5.9	7.5
	2290	22.5	28.8		2210	21.7	27.8		2200	21.6	27.7

Table A.42. Test 21-4, 21-5, 21-6 Numerical Data.

Test. 21-4				Test. 21-5				Test. 21-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	550	5.4	6.9	1	1050	10.3	13.2	1	1150	11.3	14.5
	1700	16.7	21.4		1750	17.2	22.0		1800	17.7	22.6
2	600	5.9	7.5	2	1150	11.3	14.5	2	1050	10.3	13.2
	1750	17.2	22.0		1650	16.2	20.8		1600	15.7	20.1
3	600	5.9	7.5	3	1150	11.3	14.5	3	1100	10.8	13.8
	1650	16.2	20.8		1700	16.7	21.4		1750	17.2	22.0
4	650	6.4	8.2	4	1200	11.8	15.1	4	1100	10.8	13.8
	1700	16.7	21.4		1650	16.2	20.8		1700	16.7	21.4
5	650	6.4	8.2	5	1150	11.3	14.5	5	1150	11.3	14.5
	1700	16.7	21.4		1700	16.7	21.4		1750	17.2	22.0
6	550	5.4	6.9	6	1150	11.3	14.5	6	1200	11.8	15.1
	1750	17.2	22.0		1750	17.2	22.0		1650	16.2	20.8
7	620	6.1	7.8	7	1200	11.8	15.1	7	1200	11.8	15.1
	1750	17.2	22.0		1800	17.7	22.6		1750	17.2	22.0
8	650	6.4	8.2	8	1150	11.3	14.5	8	1100	10.8	13.8
	1800	17.7	22.6		1850	18.1	23.3		1800	17.7	22.6
9	600	5.9	7.5	9	1100	10.8	13.8	9	1100	10.8	13.8
	1800	17.7	22.6		1800	17.7	22.6		1800	17.7	22.6
10	600	5.9	7.5	10	1100	10.8	13.8	10	1050	10.3	13.2
	1650	16.2	20.8		1750	17.2	22.0		1700	16.7	21.4
11	550	5.4	6.9	11	1150	11.3	14.5	11	1100	10.8	13.8
	1700	16.7	21.4		1750	17.2	22.0		1750	17.2	22.0
12	550	5.4	6.9	12	1150	11.3	14.5	12	1250	12.3	15.7
	1650	16.2	20.8		1800	17.7	22.6		1750	17.2	22.0
13	600	5.9	7.5	13	1050	10.3	13.2	13	1200	11.8	15.1
	1800	17.7	22.6		1850	18.1	23.3		1700	16.7	21.4
14	550	5.4	6.9	14	1150	11.3	14.5	14	1100	10.8	13.8
	1750	17.2	22.0		1700	16.7	21.4		1650	16.2	20.8
15	550	5.4	6.9	15	1100	10.8	13.8	15	1150	11.3	14.5
	2250	22.1	28.3		2200	21.6	27.7		2200	21.6	27.7

Table A.43. Test 22-1, 22-2, 22-3 Numerical Data.

Test. 22-1				Test. 22-2				Test. 22-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	650	6.4	8.2
	1300	12.8	16.4		1350	13.2	17.0		2000	19.6	25.2
2	0	0.0	0.0	2	0	0.0	0.0	2	700	6.9	8.8
	1400	13.7	17.6		1400	13.7	17.6		2000	19.6	25.2
3	0	0.0	0.0	3	0	0.0	0.0	3	650	6.4	8.2
	1450	14.2	18.2		1300	12.8	16.4		2050	20.1	25.8
4	0	0.0	0.0	4	0	0.0	0.0	4	700	6.9	8.8
	1400	13.7	17.6		1250	12.3	15.7		2100	20.6	26.4
5	0	0.0	0.0	5	0	0.0	0.0	5	750	7.4	9.4
	1300	12.8	16.4		1250	12.3	15.7		2100	20.6	26.4
6	0	0.0	0.0	6	0	0.0	0.0	6	700	6.9	8.8
	1250	12.3	15.7		1300	12.8	16.4		2150	21.1	27.0
7	0	0.0	0.0	7	0	0.0	0.0	7	650	6.4	8.2
	1300	12.8	16.4		1300	12.8	16.4		2050	20.1	25.8
8	0	0.0	0.0	8	0	0.0	0.0	8	600	5.9	7.5
	1350	13.2	17.0		1350	13.2	17.0		2050	20.1	25.8
9	0	0.0	0.0	9	0	0.0	0.0	9	700	6.9	8.8
	1400	13.7	17.6		1300	12.8	16.4		2100	20.6	26.4
10	0	0.0	0.0	10	0	0.0	0.0	10	700	6.9	8.8
	1450	14.2	18.2		1350	13.2	17.0		2100	20.6	26.4
11	0	0.0	0.0	11	0	0.0	0.0	11	650	6.4	8.2
	1400	13.7	17.6		1350	13.2	17.0		2050	20.1	25.8
12	0	0.0	0.0	12	0	0.0	0.0	12	650	6.4	8.2
	1400	13.7	17.6		1400	13.7	17.6		2050	20.1	25.8
13	0	0.0	0.0	13	0	0.0	0.0	13	700	6.9	8.8
	1350	13.2	17.0		1350	13.2	17.0		2100	20.6	26.4
14	0	0.0	0.0	14	0	0.0	0.0	14	650	6.4	8.2
	1350	13.2	17.0		1350	13.2	17.0		2000	19.6	25.2
15	0	0.0	0.0	15	0	0.0	0.0	15	700	6.9	8.8
	2670	26.2	33.6		2600	25.5	32.7		2600	25.5	32.7

Table A.44. Test 22-4, 22-5, 22-6 Numerical Data.

Test. 22-4				Test. 22-5				Test. 22-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	700	6.9	8.8	1	1300	12.8	16.4	1	1400	13.7	17.6
	2050	20.1	25.8		2000	19.6	25.2		2150	21.1	27.0
2	650	6.4	8.2	2	1350	13.2	17.0	2	1350	13.2	17.0
	2100	20.6	26.4		2050	20.1	25.8		2150	21.1	27.0
3	700	6.9	8.8	3	1350	13.2	17.0	3	1400	13.7	17.6
	2100	20.6	26.4		2050	20.1	25.8		2100	20.6	26.4
4	700	6.9	8.8	4	1400	13.7	17.6	4	1300	12.8	16.4
	2050	20.1	25.8		2000	19.6	25.2		2000	19.6	25.2
5	650	6.4	8.2	5	1350	13.2	17.0	5	1350	13.2	17.0
	2050	20.1	25.8		2100	20.6	26.4		2050	20.1	25.8
6	700	6.9	8.8	6	1350	13.2	17.0	6	1400	13.7	17.6
	2100	20.6	26.4		2100	20.6	26.4		2150	21.1	27.0
7	650	6.4	8.2	7	1400	13.7	17.6	7	1300	12.8	16.4
	2100	20.6	26.4		2050	20.1	25.8		2150	21.1	27.0
8	650	6.4	8.2	8	1350	13.2	17.0	8	1350	13.2	17.0
	2050	20.1	25.8		2100	20.6	26.4		2050	20.1	25.8
9	650	6.4	8.2	9	1300	12.8	16.4	9	1350	13.2	17.0
	2050	20.1	25.8		2150	21.1	27.0		2050	20.1	25.8
10	700	6.9	8.8	10	1300	12.8	16.4	10	1250	12.3	15.7
	2150	21.1	27.0		2100	20.6	26.4		2050	20.1	25.8
11	700	6.9	8.8	11	1350	13.2	17.0	11	1300	12.8	16.4
	2050	20.1	25.8		2100	20.6	26.4		2100	20.6	26.4
12	750	7.4	9.4	12	1350	13.2	17.0	12	1350	13.2	17.0
	2100	20.6	26.4		2050	20.1	25.8		2150	21.1	27.0
13	650	6.4	8.2	13	1350	13.2	17.0	13	1300	12.8	16.4
	2050	20.1	25.8		2150	21.1	27.0		2100	20.6	26.4
14	650	6.4	8.2	14	1400	13.7	17.6	14	1350	13.2	17.0
	2050	20.1	25.8		2050	20.1	25.8		2050	20.1	25.8
15	650	6.4	8.2	15	1350	13.2	17.0	15	1350	13.2	17.0
	2550	25.0	32.1		2600	25.5	32.7		2600	25.5	32.7

Table A.45. Test 23-1, 23-2, 23-3 Numerical Data.

Test. 23-1				Test. 23-2				Test. 23-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	800	7.8	10.1
	1600	15.7	20.1		1500	14.7	18.9		2350	23.1	29.6
2	0	0.0	0.0	2	0	0.0	0.0	2	750	7.4	9.4
	1500	14.7	18.9		1450	14.2	18.2		2300	22.6	28.9
3	0	0.0	0.0	3	0	0.0	0.0	3	700	6.9	8.8
	1550	15.2	19.5		1600	15.7	20.1		2400	23.5	30.2
4	0	0.0	0.0	4	0	0.0	0.0	4	750	7.4	9.4
	1500	14.7	18.9		1550	15.2	19.5		2450	24.0	30.8
5	0	0.0	0.0	5	0	0.0	0.0	5	750	7.4	9.4
	1550	15.2	19.5		1550	15.2	19.5		2400	23.5	30.2
6	0	0.0	0.0	6	0	0.0	0.0	6	800	7.8	10.1
	1600	15.7	20.1		1550	15.2	19.5		2300	22.6	28.9
7	0	0.0	0.0	7	0	0.0	0.0	7	750	7.4	9.4
	1650	16.2	20.8		1500	14.7	18.9		2250	22.1	28.3
8	0	0.0	0.0	8	0	0.0	0.0	8	850	8.3	10.7
	1500	14.7	18.9		1450	14.2	18.2		2400	23.5	30.2
9	0	0.0	0.0	9	0	0.0	0.0	9	750	7.4	9.4
	1550	15.2	19.5		1600	15.7	20.1		2350	23.1	29.6
10	0	0.0	0.0	10	0	0.0	0.0	10	800	7.8	10.1
	1450	14.2	18.2		1650	16.2	20.8		2300	22.6	28.9
11	0	0.0	0.0	11	0	0.0	0.0	11	850	8.3	10.7
	1450	14.2	18.2		1550	15.2	19.5		2250	22.1	28.3
12	0	0.0	0.0	12	0	0.0	0.0	12	850	8.3	10.7
	1450	14.2	18.2		1600	15.7	20.1		2300	22.6	28.9
13	0	0.0	0.0	13	0	0.0	0.0	13	750	7.4	9.4
	1550	15.2	19.5		1500	14.7	18.9		2250	22.1	28.3
14	0	0.0	0.0	14	0	0.0	0.0	14	750	7.4	9.4
	1550	15.2	19.5		1500	14.7	18.9		2350	23.1	29.6
15	0	0.0	0.0	15	0	0.0	0.0	15	750	7.4	9.4
	3150	30.9	39.6		2950	28.9	37.1		2900	28.4	36.5

Table A.46. Test 23-4, 23-5, 23-6 Numerical Data.

Test. 23-4				Test. 23-5				Test. 23-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	750	7.4	9.4	1	1550	15.2	19.5	1	1600	15.7	20.1
	2250	22.1	28.3		2250	22.1	28.3		2300	22.6	28.9
2	800	7.8	10.1	2	1600	15.7	20.1	2	1650	16.2	20.8
	2350	23.1	29.6		2300	22.6	28.9		2350	23.1	29.6
3	850	8.3	10.7	3	1650	16.2	20.8	3	1500	14.7	18.9
	2350	23.1	29.6		2300	22.6	28.9		2250	22.1	28.3
4	750	7.4	9.4	4	1500	14.7	18.9	4	1450	14.2	18.2
	2400	23.5	30.2		2400	23.5	30.2		2350	23.1	29.6
5	700	6.9	8.8	5	1650	16.2	20.8	5	1450	14.2	18.2
	2350	23.1	29.6		2450	24.0	30.8		2400	23.5	30.2
6	750	7.4	9.4	6	1500	14.7	18.9	6	1500	14.7	18.9
	2300	22.6	28.9		2350	23.1	29.6		2350	23.1	29.6
7	750	7.4	9.4	7	1550	15.2	19.5	7	1550	15.2	19.5
	2250	22.1	28.3		2400	23.5	30.2		2450	24.0	30.8
8	800	7.8	10.1	8	1550	15.2	19.5	8	1600	15.7	20.1
	2350	23.1	29.6		2300	22.6	28.9		2500	24.5	31.4
9	750	7.4	9.4	9	1600	15.7	20.1	9	1550	15.2	19.5
	2300	22.6	28.9		2250	22.1	28.3		2300	22.6	28.9
10	750	7.4	9.4	10	1650	16.2	20.8	10	1450	14.2	18.2
	2250	22.1	28.3		2250	22.1	28.3		2400	23.5	30.2
11	700	6.9	8.8	11	1700	16.7	21.4	11	1500	14.7	18.9
	2300	22.6	28.9		2350	23.1	29.6		2300	22.6	28.9
12	750	7.4	9.4	12	1500	14.7	18.9	12	1550	15.2	19.5
	2350	23.1	29.6		2300	22.6	28.9		2300	22.6	28.9
13	800	7.8	10.1	13	1500	14.7	18.9	13	1600	15.7	20.1
	2400	23.5	30.2		2450	24.0	30.8		2400	23.5	30.2
14	750	7.4	9.4	14	1550	15.2	19.5	14	1500	14.7	18.9
	2350	23.1	29.6		2250	22.1	28.3		2250	22.1	28.3
15	800	7.8	10.1	15	1550	15.2	19.5	15	1600	15.7	20.1
	2950	28.9	37.1		3000	29.4	37.7		3100	30.4	39.0

Table A.47. Test 24-1, 24-2, 24-3 Numerical Data.

Test. 24-1				Test. 24-2				Test. 24-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	800	7.8	10.1
	1650	16.2	20.8		1700	16.7	21.4		2500	24.5	31.4
2	0	0.0	0.0	2	0	0.0	0.0	2	850	8.3	10.7
	1650	16.2	20.8		1650	16.2	20.8		2550	25.0	32.1
3	0	0.0	0.0	3	0	0.0	0.0	3	900	8.8	11.3
	1550	15.2	19.5		1700	16.7	21.4		2600	25.5	32.7
4	0	0.0	0.0	4	0	0.0	0.0	4	850	8.3	10.7
	1750	17.2	22.0		1600	15.7	20.1		2450	24.0	30.8
5	0	0.0	0.0	5	0	0.0	0.0	5	800	7.8	10.1
	1700	16.7	21.4		1650	16.2	20.8		2400	23.5	30.2
6	0	0.0	0.0	6	0	0.0	0.0	6	850	8.3	10.7
	1650	16.2	20.8		1700	16.7	21.4		2500	24.5	31.4
7	0	0.0	0.0	7	0	0.0	0.0	7	800	7.8	10.1
	1650	16.2	20.8		1600	15.7	20.1		2550	25.0	32.1
8	0	0.0	0.0	8	0	0.0	0.0	8	900	8.8	11.3
	1550	15.2	19.5		1550	15.2	19.5		2600	25.5	32.7
9	0	0.0	0.0	9	0	0.0	0.0	9	850	8.3	10.7
	1600	15.7	20.1		1600	15.7	20.1		2450	24.0	30.8
10	0	0.0	0.0	10	0	0.0	0.0	10	800	7.8	10.1
	1650	16.2	20.8		1650	16.2	20.8		2400	23.5	30.2
11	0	0.0	0.0	11	0	0.0	0.0	11	850	8.3	10.7
	1600	15.7	20.1		1600	15.7	20.1		2550	25.0	32.1
12	0	0.0	0.0	12	0	0.0	0.0	12	900	8.8	11.3
	1650	16.2	20.8		1650	16.2	20.8		2600	25.5	32.7
13	0	0.0	0.0	13	0	0.0	0.0	13	850	8.3	10.7
	1700	16.7	21.4		1700	16.7	21.4		2450	24.0	30.8
14	0	0.0	0.0	14	0	0.0	0.0	14	800	7.8	10.1
	1650	16.2	20.8		1750	17.2	22.0		2450	24.0	30.8
15	0	0.0	0.0	15	0	0.0	0.0	15	850	8.3	10.7
	3100	30.4	39.0		3200	31.4	40.2		3050	29.9	38.4

Table A.48. Test 24-4, 24-5, 24-6 Numerical Data.

Test. 24-4				Test. 24-5				Test. 24-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	850	8.3	10.7	1	1600	15.7	20.1	1	1550	15.2	19.5
	2550	25.0	32.1		2500	24.5	31.4		2550	25.0	32.1
2	800	7.8	10.1	2	1650	16.2	20.8	2	1750	17.2	22.0
	2500	24.5	31.4		2500	24.5	31.4		2450	24.0	30.8
3	850	8.3	10.7	3	1700	16.7	21.4	3	1650	16.2	20.8
	2550	25.0	32.1		2500	24.5	31.4		2400	23.5	30.2
4	750	7.4	9.4	4	1750	17.2	22.0	4	1650	16.2	20.8
	2450	24.0	30.8		2450	24.0	30.8		2400	23.5	30.2
5	800	7.8	10.1	5	1700	16.7	21.4	5	1700	16.7	21.4
	2450	24.0	30.8		2500	24.5	31.4		2450	24.0	30.8
6	800	7.8	10.1	6	1550	15.2	19.5	6	1600	15.7	20.1
	2550	25.0	32.1		2600	25.5	32.7		2500	24.5	31.4
7	750	7.4	9.4	7	1600	15.7	20.1	7	1650	16.2	20.8
	2600	25.5	32.7		2450	24.0	30.8		2550	25.0	32.1
8	850	8.3	10.7	8	1650	16.2	20.8	8	1650	16.2	20.8
	2450	24.0	30.8		2500	24.5	31.4		2600	25.5	32.7
9	750	7.4	9.4	9	1700	16.7	21.4	9	1600	15.7	20.1
	2500	24.5	31.4		2550	25.0	32.1		2650	26.0	33.3
10	800	7.8	10.1	10	1700	16.7	21.4	10	1650	16.2	20.8
	2500	24.5	31.4		2500	24.5	31.4		2600	25.5	32.7
11	800	7.8	10.1	11	1650	16.2	20.8	11	1550	15.2	19.5
	2600	25.5	32.7		2550	25.0	32.1		2500	24.5	31.4
12	850	8.3	10.7	12	1600	15.7	20.1	12	1550	15.2	19.5
	2550	25.0	32.1		2600	25.5	32.7		2450	24.0	30.8
13	800	7.8	10.1	13	1750	17.2	22.0	13	1600	15.7	20.1
	2400	23.5	30.2		2450	24.0	30.8		2500	24.5	31.4
14	850	8.3	10.7	14	1700	16.7	21.4	14	1700	16.7	21.4
	2500	24.5	31.4		2550	25.0	32.1		2500	24.5	31.4
15	850	8.3	10.7	15	1650	16.2	20.8	15	1600	15.7	20.1
	3050	29.9	38.4		3150	30.9	39.6		3150	30.9	39.6

Table A.49. Test 25-1, 25-2, 25-3 Numerical Data.

Test. 25-1				Test. 25-2				Test. 25-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	850	8.3	10.7
	1750	17.2	22.0		1650	16.2	20.8		2550	25.0	32.1
2	0	0.0	0.0	2	0	0.0	0.0	2	900	8.8	11.3
	1750	17.2	22.0		1700	16.7	21.4		2600	25.5	32.7
3	0	0.0	0.0	3	0	0.0	0.0	3	950	9.3	11.9
	1650	16.2	20.8		1750	17.2	22.0		2650	26.0	33.3
4	0	0.0	0.0	4	0	0.0	0.0	4	850	8.3	10.7
	1800	17.7	22.6		1650	16.2	20.8		2600	25.5	32.7
5	0	0.0	0.0	5	0	0.0	0.0	5	900	8.8	11.3
	1700	16.7	21.4		1750	17.2	22.0		2650	26.0	33.3
6	0	0.0	0.0	6	0	0.0	0.0	6	950	9.3	11.9
	1750	17.2	22.0		1750	17.2	22.0		2600	25.5	32.7
7	0	0.0	0.0	7	0	0.0	0.0	7	900	8.8	11.3
	1700	16.7	21.4		1700	16.7	21.4		2550	25.0	32.1
8	0	0.0	0.0	8	0	0.0	0.0	8	900	8.8	11.3
	1700	16.7	21.4		1650	16.2	20.8		2600	25.5	32.7
9	0	0.0	0.0	9	0	0.0	0.0	9	900	8.8	11.3
	1650	16.2	20.8		1700	16.7	21.4		2650	26.0	33.3
10	0	0.0	0.0	10	0	0.0	0.0	10	850	8.3	10.7
	1700	16.7	21.4		1750	17.2	22.0		2550	25.0	32.1
11	0	0.0	0.0	11	0	0.0	0.0	11	850	8.3	10.7
	1800	17.7	22.6		1800	17.7	22.6		2600	25.5	32.7
12	0	0.0	0.0	12	0	0.0	0.0	12	850	8.3	10.7
	1650	16.2	20.8		1750	17.2	22.0		2650	26.0	33.3
13	0	0.0	0.0	13	0	0.0	0.0	13	900	8.8	11.3
	1750	17.2	22.0		1700	16.7	21.4		2600	25.5	32.7
14	0	0.0	0.0	14	0	0.0	0.0	14	850	8.3	10.7
	1700	16.7	21.4		1700	16.7	21.4		2450	24.0	30.8
15	0	0.0	0.0	15	0	0.0	0.0	15	900	8.8	11.3
	3100	30.4	39.0		3200	31.4	40.2		3050	29.9	38.4

Table A.50. Test 25-4, 25-5, 25-6 Numerical Data.

Test. 25-4				Test. 25-5				Test. 25-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	900	8.8	11.3	1	1700	16.7	21.4	1	1750	17.2	22.0
	2500	24.5	31.4		2600	25.5	32.7		2550	25.0	32.1
2	850	8.3	10.7	2	1750	17.2	22.0	2	1800	17.7	22.6
	2550	25.0	32.1		2550	25.0	32.1		2500	24.5	31.4
3	950	9.3	11.9	3	1800	17.7	22.6	3	1650	16.2	20.8
	2600	25.5	32.7		2600	25.5	32.7		2600	25.5	32.7
4	900	8.8	11.3	4	1800	17.7	22.6	4	1600	15.7	20.1
	2650	26.0	33.3		2450	24.0	30.8		2450	24.0	30.8
5	950	9.3	11.9	5	1850	18.1	23.3	5	1650	16.2	20.8
	2650	26.0	33.3		2550	25.0	32.1		2550	25.0	32.1
6	800	7.8	10.1	6	1650	16.2	20.8	6	1700	16.7	21.4
	2600	25.5	32.7		2550	25.0	32.1		2600	25.5	32.7
7	850	8.3	10.7	7	1600	15.7	20.1	7	1750	17.2	22.0
	2600	25.5	32.7		2450	24.0	30.8		2550	25.0	32.1
8	900	8.8	11.3	8	1600	15.7	20.1	8	1750	17.2	22.0
	2700	26.5	34.0		2500	24.5	31.4		2600	25.5	32.7
9	850	8.3	10.7	9	1550	15.2	19.5	9	1700	16.7	21.4
	2600	25.5	32.7		2600	25.5	32.7		2650	26.0	33.3
10	800	7.8	10.1	10	1700	16.7	21.4	10	1700	16.7	21.4
	2650	26.0	33.3		2550	25.0	32.1		2800	27.5	35.2
11	850	8.3	10.7	11	1750	17.2	22.0	11	1650	16.2	20.8
	2650	26.0	33.3		2600	25.5	32.7		2500	24.5	31.4
12	900	8.8	11.3	12	1750	17.2	22.0	12	1650	16.2	20.8
	2700	26.5	34.0		2650	26.0	33.3		2500	24.5	31.4
13	950	9.3	11.9	13	1800	17.7	22.6	13	1700	16.7	21.4
	2650	26.0	33.3		2650	26.0	33.3		2600	25.5	32.7
14	800	7.8	10.1	14	1750	17.2	22.0	14	1800	17.7	22.6
	2500	24.5	31.4		2550	25.0	32.1		2600	25.5	32.7
15	850	8.3	10.7	15	1700	16.7	21.4	15	1700	16.7	21.4
	3050	29.9	38.4		3150	30.9	39.6		3150	30.9	39.6

Table A.51. Test 26-1, 26-2, 26-3 Numerical Data.

Test. 26-1				Test. 26-2				Test. 26-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	900	8.8	11.3
	1800	17.7	22.6		1700	16.7	21.4		2650	26.0	33.3
2	0	0.0	0.0	2	0	0.0	0.0	2	950	9.3	11.9
	1800	17.7	22.6		1750	17.2	22.0		2650	26.0	33.3
3	0	0.0	0.0	3	0	0.0	0.0	3	1000	9.8	12.6
	1700	16.7	21.4		1800	17.7	22.6		2550	25.0	32.1
4	0	0.0	0.0	4	0	0.0	0.0	4	950	9.3	11.9
	1850	18.1	23.3		1750	17.2	22.0		2550	25.0	32.1
5	0	0.0	0.0	5	0	0.0	0.0	5	950	9.3	11.9
	1750	17.2	22.0		1850	18.1	23.3		2650	26.0	33.3
6	0	0.0	0.0	6	0	0.0	0.0	6	1000	9.8	12.6
	1800	17.7	22.6		1850	18.1	23.3		2700	26.5	34.0
7	0	0.0	0.0	7	0	0.0	0.0	7	850	8.3	10.7
	1800	17.7	22.6		1700	16.7	21.4		2700	26.5	34.0
8	0	0.0	0.0	8	0	0.0	0.0	8	950	9.3	11.9
	1850	18.1	23.3		1800	17.7	22.6		2500	24.5	31.4
9	0	0.0	0.0	9	0	0.0	0.0	9	950	9.3	11.9
	1700	16.7	21.4		1750	17.2	22.0		2550	25.0	32.1
10	0	0.0	0.0	10	0	0.0	0.0	10	900	8.8	11.3
	1750	17.2	22.0		1800	17.7	22.6		2600	25.5	32.7
11	0	0.0	0.0	11	0	0.0	0.0	11	900	8.8	11.3
	1750	17.2	22.0		1850	18.1	23.3		2650	26.0	33.3
12	0	0.0	0.0	12	0	0.0	0.0	12	950	9.3	11.9
	1800	17.7	22.6		1800	17.7	22.6		2650	26.0	33.3
13	0	0.0	0.0	13	0	0.0	0.0	13	850	8.3	10.7
	1700	16.7	21.4		1750	17.2	22.0		2700	26.5	34.0
14	0	0.0	0.0	14	0	0.0	0.0	14	850	8.3	10.7
	1750	17.2	22.0		1750	17.2	22.0		2600	25.5	32.7
15	0	0.0	0.0	15	0	0.0	0.0	15	950	9.3	11.9
	3300	32.4	41.5		3250	31.9	40.9		3350	32.9	42.1

Table A.52. Test 26-4, 26-5, 26-6 Numerical Data.

Test. 26-4				Test. 26-5				Test. 26-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	950	9.3	11.9	1	1750	17.2	22.0	1	1800	17.7	22.6
	2550	25.0	32.1		2550	25.0	32.1		2500	24.5	31.4
2	900	8.8	11.3	2	1850	18.1	23.3	2	1800	17.7	22.6
	2650	26.0	33.3		2600	25.5	32.7		2600	25.5	32.7
3	850	8.3	10.7	3	1800	17.7	22.6	3	1750	17.2	22.0
	2600	25.5	32.7		2650	26.0	33.3		2700	26.5	34.0
4	900	8.8	11.3	4	1750	17.2	22.0	4	1650	16.2	20.8
	2700	26.5	34.0		2550	25.0	32.1		2550	25.0	32.1
5	950	9.3	11.9	5	1700	16.7	21.4	5	1700	16.7	21.4
	2650	26.0	33.3		2650	26.0	33.3		2600	25.5	32.7
6	1000	9.8	12.6	6	1750	17.2	22.0	6	1700	16.7	21.4
	2700	26.5	34.0		2700	26.5	34.0		2600	25.5	32.7
7	950	9.3	11.9	7	1800	17.7	22.6	7	1700	16.7	21.4
	2550	25.0	32.1		2650	26.0	33.3		2700	26.5	34.0
8	850	8.3	10.7	8	1750	17.2	22.0	8	1650	16.2	20.8
	2700	26.5	34.0		2500	24.5	31.4		2550	25.0	32.1
9	800	7.8	10.1	9	1750	17.2	22.0	9	1700	16.7	21.4
	2600	25.5	32.7		2550	25.0	32.1		2600	25.5	32.7
10	850	8.3	10.7	10	1700	16.7	21.4	10	1750	17.2	22.0
	2600	25.5	32.7		2600	25.5	32.7		2650	26.0	33.3
11	900	8.8	11.3	11	1750	17.2	22.0	11	1750	17.2	22.0
	2700	26.5	34.0		2650	26.0	33.3		2700	26.5	34.0
12	950	9.3	11.9	12	1800	17.7	22.6	12	1800	17.7	22.6
	2650	26.0	33.3		2650	26.0	33.3		2500	24.5	31.4
13	950	9.3	11.9	13	1750	17.2	22.0	13	1750	17.2	22.0
	2600	25.5	32.7		2600	25.5	32.7		2500	24.5	31.4
14	900	8.8	11.3	14	1750	17.2	22.0	14	1800	17.7	22.6
	2600	25.5	32.7		2600	25.5	32.7		2550	25.0	32.1
15	850	8.3	10.7	15	1700	16.7	21.4	15	1850	18.1	23.3
	3300	32.4	41.5		3250	31.9	40.9		3400	33.4	42.8

Table A.1. Test 1-1, 1-2, 1-3 Numerical Data.

Test. 1-1				Test. 1-2				Test. 1-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0 49	0.0 0.5	0.0 0.6	1	0 48	0.0 0.5	0.0 0.6	1	24 72	0.2 0.7	0.3 0.9
2	0 48	0.0 0.5	0.0 0.6	2	0 49	0.0 0.5	0.0 0.6	2	20 80	0.2 0.8	0.3 1.0
3	0 46	0.0 0.5	0.0 0.6	3	0 46	0.0 0.5	0.0 0.6	3	25 76	0.2 0.7	0.3 1.0
4	0 51	0.0 0.5	0.0 0.6	4	0 51	0.0 0.5	0.0 0.6	4	22 75	0.2 0.7	0.3 0.9
5	0 49	0.0 0.5	0.0 0.6	5	0 49	0.0 0.5	0.0 0.6	5	30 73	0.3 0.7	0.4 0.9
6	0 46	0.0 0.5	0.0 0.6	6	0 50	0.0 0.5	0.0 0.6	6	24 75	0.2 0.7	0.3 0.9
7	0 48	0.0 0.5	0.0 0.6	7	0 50	0.0 0.5	0.0 0.6	7	20 78	0.2 0.8	0.3 1.0
8	0 51	0.0 0.5	0.0 0.6	8	0 48	0.0 0.5	0.0 0.6	8	25 71	0.2 0.7	0.3 0.9
9	0 50	0.0 0.5	0.0 0.6	9	0 47	0.0 0.5	0.0 0.6	9	28 78	0.3 0.8	0.4 1.0
10	0 49	0.0 0.5	0.0 0.6	10	0 49	0.0 0.5	0.0 0.6	10	24 73	0.2 0.7	0.3 0.9
11	0 46	0.0 0.5	0.0 0.6	11	0 48	0.0 0.5	0.0 0.6	11	30 75	0.3 0.7	0.4 0.9
12	0 47	0.0 0.5	0.0 0.6	12	0 51	0.0 0.5	0.0 0.6	12	30 76	0.3 0.7	0.4 1.0
13	0 49	0.0 0.5	0.0 0.6	13	0 46	0.0 0.5	0.0 0.6	13	29 75	0.3 0.7	0.4 0.9
14	0 51	0.0 0.5	0.0 0.6	14	0 49	0.0 0.5	0.0 0.6	14	31 79	0.3 0.8	0.4 1.0
15	0 88	0.0 0.9	0.0 1.1	15	0 90	0.0 0.9	0.0 1.1	15	24 87	0.2 0.9	0.3 1.1

Table A.2. Test 1-4, 1-5, 1-6 Numerical Data.

Test. 1-1				Test. 1-2				Test. 1-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	23	0.2	0.3	1	49	0.5	0.6	1	52	0.5	0.7
	69	0.7	0.9		72	0.7	0.9		75	0.7	0.9
2	25	0.2	0.3	2	51	0.5	0.6	2	51	0.5	0.6
	80	0.8	1.0		79	0.8	1.0		78	0.8	1.0
3	22	0.2	0.3	3	48	0.5	0.6	3	49	0.5	0.6
	74	0.7	0.9		74	0.7	0.9		70	0.7	0.9
4	23	0.2	0.3	4	49	0.5	0.6	4	45	0.4	0.6
	75	0.7	0.9		70	0.7	0.9		74	0.7	0.9
5	28	0.3	0.4	5	45	0.4	0.6	5	49	0.5	0.6
	71	0.7	0.9		75	0.7	0.9		71	0.7	0.9
6	25	0.2	0.3	6	46	0.5	0.6	6	50	0.5	0.6
	74	0.7	0.9		74	0.7	0.9		71	0.7	0.9
7	22	0.2	0.3	7	51	0.5	0.6	7	52	0.5	0.7
	72	0.7	0.9		76	0.7	1.0		74	0.7	0.9
8	21	0.2	0.3	8	51	0.5	0.6	8	45	0.4	0.6
	71	0.7	0.9		81	0.8	1.0		75	0.7	0.9
9	25	0.2	0.3	9	48	0.5	0.6	9	49	0.5	0.6
	77	0.8	1.0		72	0.7	0.9		73	0.7	0.9
10	21	0.2	0.3	10	49	0.5	0.6	10	48	0.5	0.6
	72	0.7	0.9		73	0.7	0.9		74	0.7	0.9
11	22	0.2	0.3	11	46	0.5	0.6	11	46	0.5	0.6
	73	0.7	0.9		75	0.7	0.9		76	0.7	1.0
12	26	0.3	0.3	12	50	0.5	0.6	12	49	0.5	0.6
	74	0.7	0.9		74	0.7	0.9		77	0.8	1.0
13	28	0.3	0.4	13	49	0.5	0.6	13	46	0.5	0.6
	70	0.7	0.9		76	0.7	1.0		74	0.7	0.9
14	27	0.3	0.3	14	51	0.5	0.6	14	50	0.5	0.6
	77	0.8	1.0		77	0.8	1.0		81	0.8	1.0
15	26	0.3	0.3	15	50	0.5	0.6	15	51	0.5	0.6
	93	0.9	1.2		90	0.9	1.1		91	0.9	1.1

Table A.3. Test 2-1, 2-2, 2-3 Numerical Data.

Test. 1-1				Test. 1-2				Test. 1-3			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	0	0.0	0.0	1	0	0.0	0.0	1	58	0.6	0.7
	112	1.1	1.4		120	1.2	1.5		175	1.7	2.2
2	0	0.0	0.0	2	0	0.0	0.0	2	60	0.6	0.8
	115	1.1	1.4		120	1.2	1.5		170	1.7	2.1
3	0	0.0	0.0	3	0	0.0	0.0	3	62	0.6	0.8
	119	1.2	1.5		115	1.1	1.4		182	1.8	2.3
4	0	0.0	0.0	4	0	0.0	0.0	4	61	0.6	0.8
	115	1.1	1.4		121	1.2	1.5		172	1.7	2.2
5	0	0.0	0.0	5	0	0.0	0.0	5	65	0.6	0.8
	118	1.2	1.5		122	1.2	1.5		180	1.8	2.3
6	0	0.0	0.0	6	0	0.0	0.0	6	60	0.6	0.8
	118	1.2	1.5		125	1.2	1.6		170	1.7	2.1
7	0	0.0	0.0	7	0	0.0	0.0	7	58	0.6	0.7
	120	1.2	1.5		115	1.1	1.4		176	1.7	2.2
8	0	0.0	0.0	8	0	0.0	0.0	8	59	0.6	0.7
	121	1.2	1.5		118	1.2	1.5		171	1.7	2.2
9	0	0.0	0.0	9	0	0.0	0.0	9	61	0.6	0.8
	115	1.1	1.4		120	1.2	1.5		180	1.8	2.3
10	0	0.0	0.0	10	0	0.0	0.0	10	60	0.6	0.8
	120	1.2	1.5		121	1.2	1.5		170	1.7	2.1
11	0	0.0	0.0	11	0	0.0	0.0	11	59	0.6	0.7
	121	1.2	1.5		120	1.2	1.5		174	1.7	2.2
12	0	0.0	0.0	12	0	0.0	0.0	12	63	0.6	0.8
	126	1.2	1.6		115	1.1	1.4		184	1.8	2.3
13	0	0.0	0.0	13	0	0.0	0.0	13	59	0.6	0.7
	125	1.2	1.6		120	1.2	1.5		173	1.7	2.2
14	0	0.0	0.0	14	0	0.0	0.0	14	58	0.6	0.7
	118	1.2	1.5		122	1.2	1.5		172	1.7	2.2
15	0	0.0	0.0	15	0	0.0	0.0	15	57	0.6	0.7
	216	2.1	2.7		222	2.2	2.8		219	2.1	2.8

Table A.4. Test 2-4, 2-5, 2-6 Numerical Data.

Test. 2-4				Test. 2-5				Test. 2-6			
Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m	Cycle #	Pull Out Load kg	Pull Out Load kN	Unit Pull Out kN/m
1	60	0.6	0.8	1	110	1.1	1.4	1	109	1.1	1.4
	170	1.7	2.1		175	1.7	2.2		175	1.7	2.2
2	59	0.6	0.7	2	120	1.2	1.5	2	114	1.1	1.4
	177	1.7	2.2		170	1.7	2.1		172	1.7	2.2
3	60	0.6	0.8	3	115	1.1	1.4	3	118	1.2	1.5
	176	1.7	2.2		175	1.7	2.2		179	1.8	2.3
4	55	0.5	0.7	4	120	1.2	1.5	4	114	1.1	1.4
	172	1.7	2.2		171	1.7	2.2		173	1.7	2.2
5	61	0.6	0.8	5	116	1.1	1.5	5	109	1.1	1.4
	181	1.8	2.3		177	1.7	2.2		176	1.7	2.2
6	57	0.6	0.7	6	119	1.2	1.5	6	117	1.1	1.5
	179	1.8	2.3		171	1.7	2.2		177	1.7	2.2
7	55	0.5	0.7	7	120	1.2	1.5	7	119	1.2	1.5
	176	1.7	2.2		172	1.7	2.2		178	1.7	2.2
8	59	0.6	0.7	8	113	1.1	1.4	8	109	1.1	1.4
	175	1.7	2.2		174	1.7	2.2		171	1.7	2.2
9	58	0.6	0.7	9	117	1.1	1.5	9	116	1.1	1.5
	174	1.7	2.2		176	1.7	2.2		169	1.7	2.1
10	63	0.6	0.8	10	109	1.1	1.4	10	115	1.1	1.4
	178	1.7	2.2		169	1.7	2.1		174	1.7	2.2
11	59	0.6	0.7	11	107	1.0	1.3	11	108	1.1	1.4
	176	1.7	2.2		170	1.7	2.1		179	1.8	2.3
12	57	0.6	0.7	12	113	1.1	1.4	12	111	1.1	1.4
	179	1.8	2.3		176	1.7	2.2		171	1.7	2.2
13	60	0.6	0.8	13	118	1.2	1.5	13	111	1.1	1.4
	177	1.7	2.2		172	1.7	2.2		176	1.7	2.2
14	61	0.6	0.8	14	119	1.2	1.5	14	110	1.1	1.4
	174	1.7	2.2		176	1.7	2.2		174	1.7	2.2
15	63	0.6	0.8	15	112	1.1	1.4	15	112	1.1	1.4
	225	2.2	2.8		215	2.1	2.7		215	2.1	2.7

APPENDIX B: DATA SUMMARY AND GRAPHICAL OUTPUTS OF TEST RESULTS

Table B.1. Test 1-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-1	Cyclic 0%-50%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	88	0.86	1.11	1.23

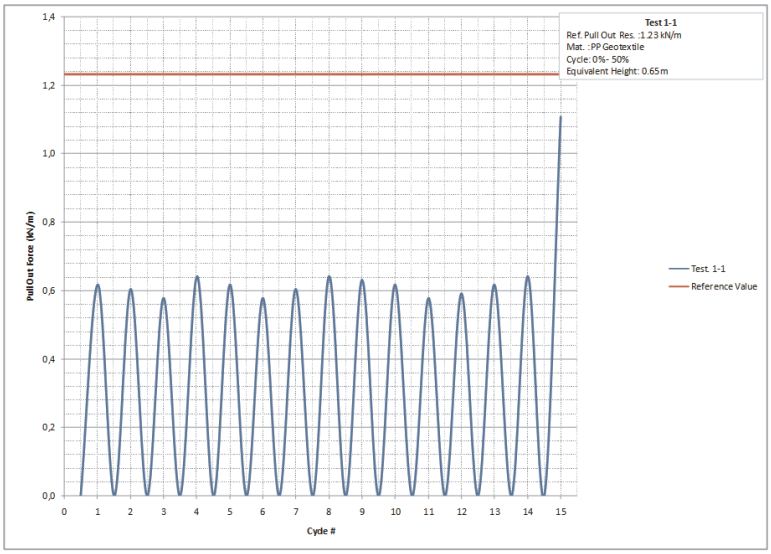


Figure B.1. Graphical Output of Test 1-1.

Table B.2. Test 1-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-2	Cyclic 0%-50%	Geotextile 120kN/120kN	155	1.52	1.95	0.67	90	0.88	1.13	1.27

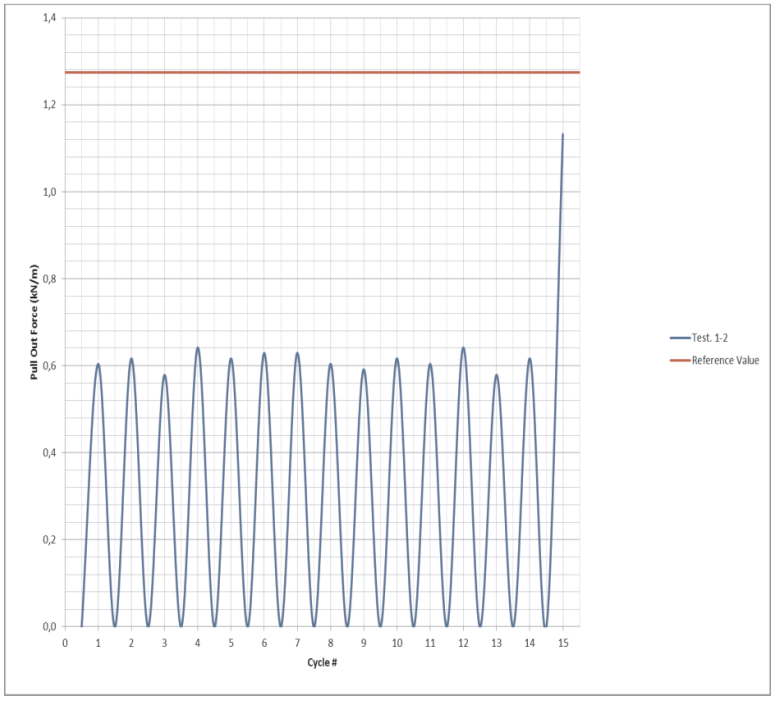


Figure B.2. Graphical Output of Test 1-2.

Table B.3. Test 1-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-3	Cyclic 25%-75%	Geotextile 120kN/120kN	145	1.42	1.82	0.63	87	0.85	1.09	1.19

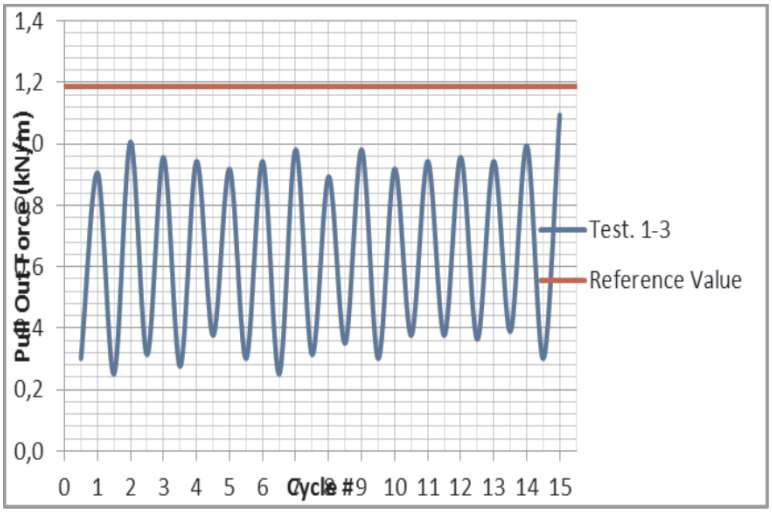


Figure B.3. Graphical Output of Test 1-3.

Table B.4. Test 1-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-4	Cyclic 25%-75%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	87	0.93	1.91	1.17

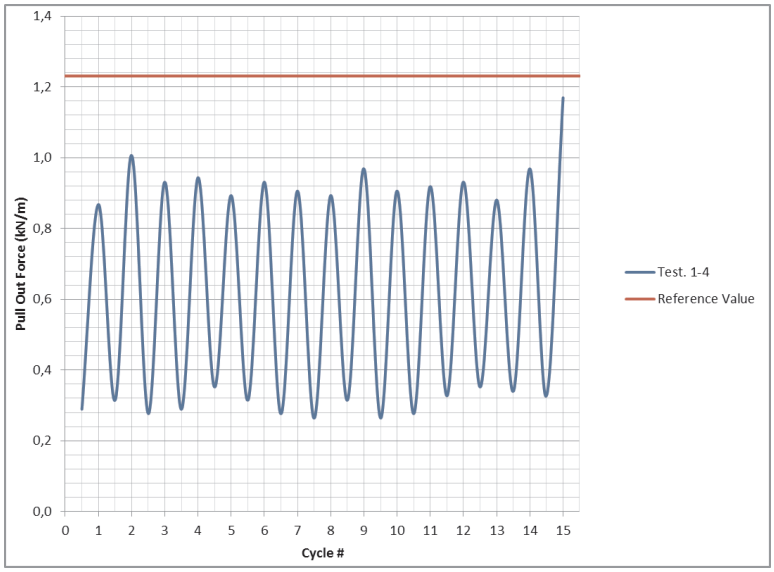


Figure B.4. Graphical Output of Test 1-4.

Table B.5. Test 1-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-5	Cyclic 50%-75%	Geotextile 120kN/120kN	155	1.52	1.95	0.67	90	0.88	1.13	1.27

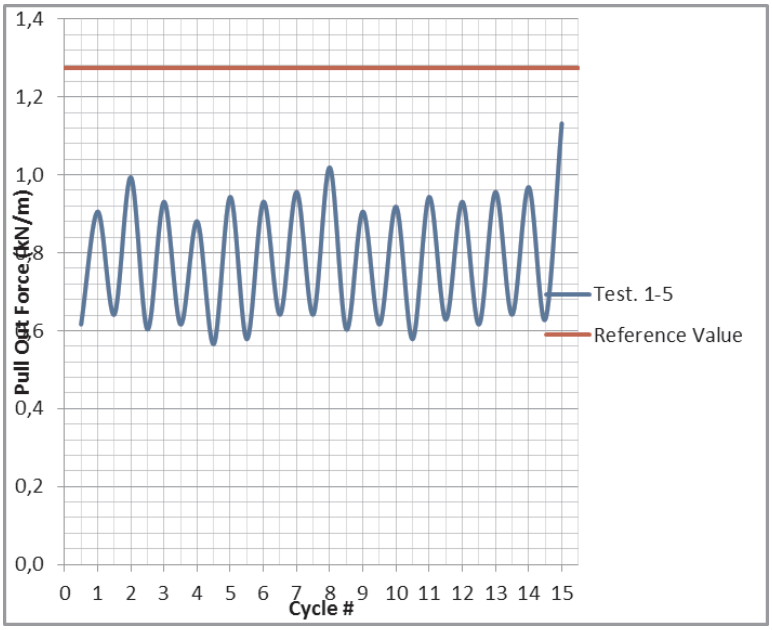


Figure B.5. Graphical Output of Test 1-5.

Table B.6. Test 1-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
1-6	Cyclic 50%-75%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	91	0.89	1.14	1.23

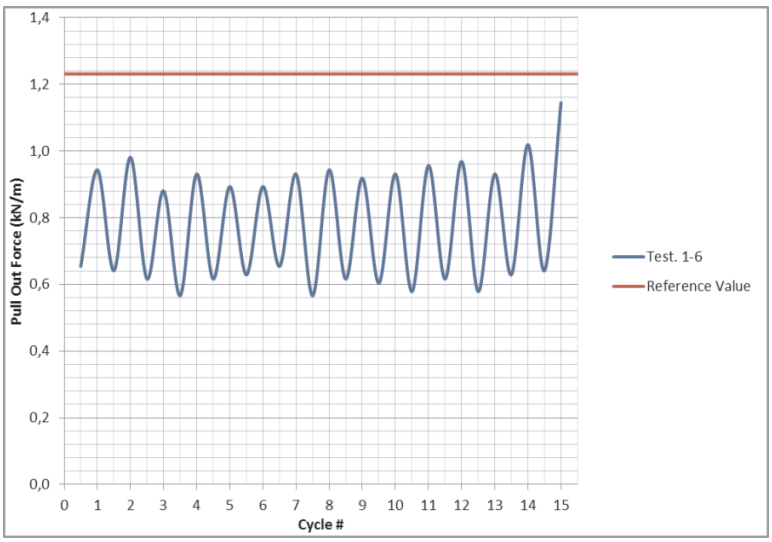


Figure B.6. Graphical Output of Test 1-6.

Table B.7. Test 2-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
2-1	Cyclic 0%-50%	Geotextile 120kN/120kN	350	3.43	4.40	1.51	216	2.12	2.72	2.96

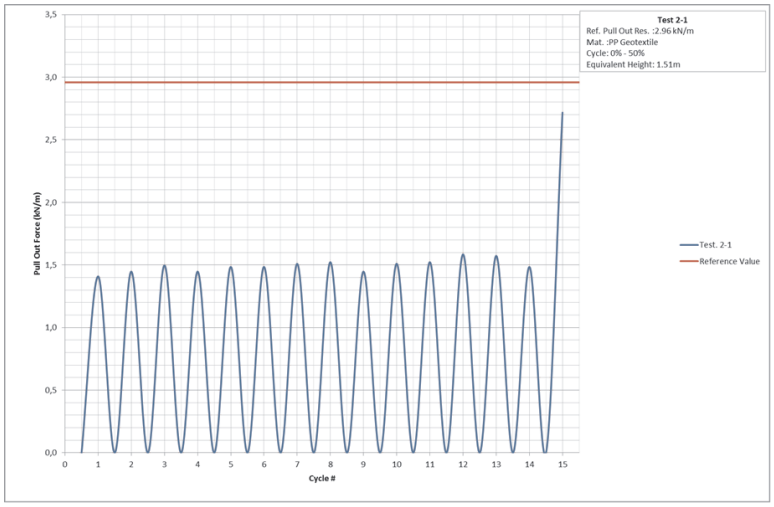


Figure B.7. Graphical Output of Test 2-1.

Table B.8. Test 2-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
2-2	Cyclic 0%-50%	Geotextile 120kN/120kN	355	3.48	4.46	1.53	222	2.18	2.79	3.0

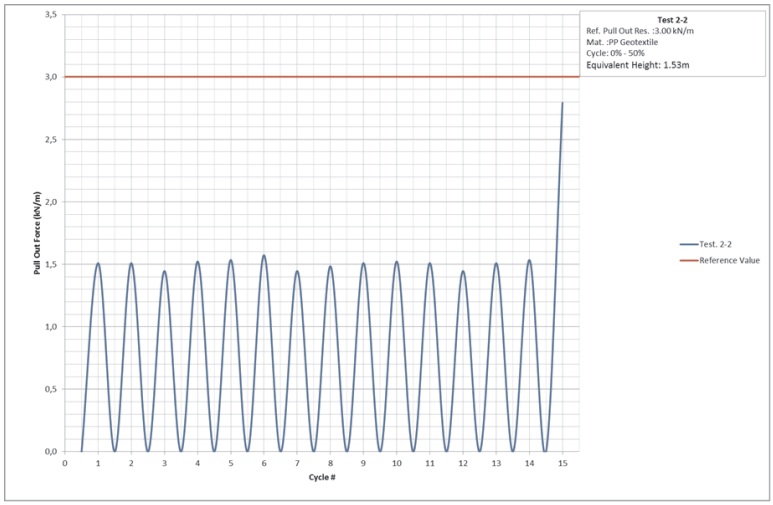


Figure B.8. Graphical Output of Test 2-2.

Table B.9. Test 2-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
2-3	Cyclic 25%-75%	Geotextile 120kN/120kN	350	3.43	4.40	1.51	219	2.15	2.75	2.96

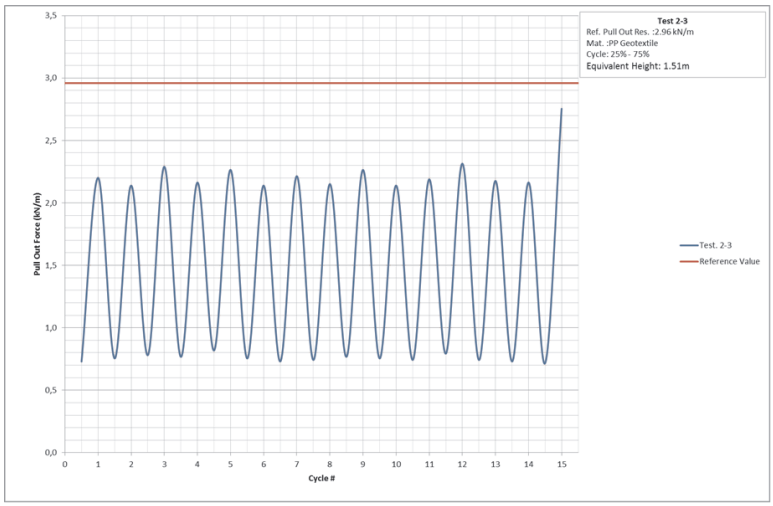


Figure B.9. Graphical Output of Test 2-3.

Table B.10. Test 2-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
2-4	Cyclic 25%-75%	Geotextile 120kN/120kN	360	3.53	4.53	1.55	225	2.21	2.83	3.05

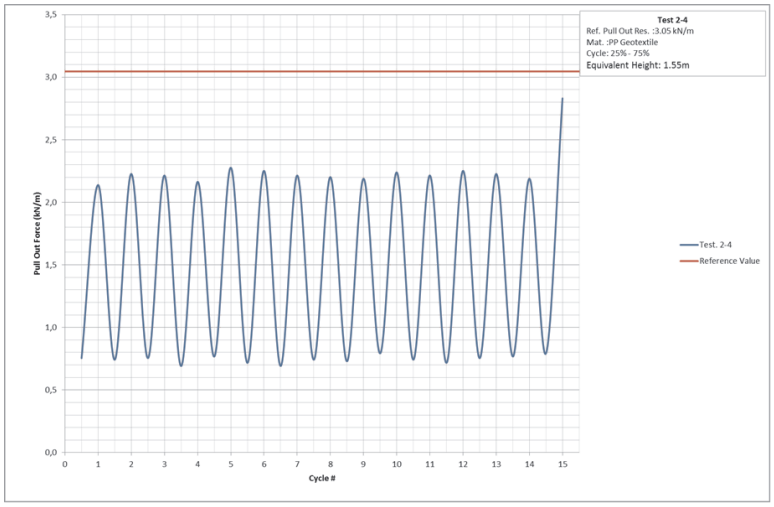


Figure B.10. Graphical Output of Test 2-4.

Table B.11. Test 2-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
2-5	Cyclic 50%-75%	Geotextile 120kN/120kN	345	3.38	4.34	1.49	215	2.11	2.70	2.92

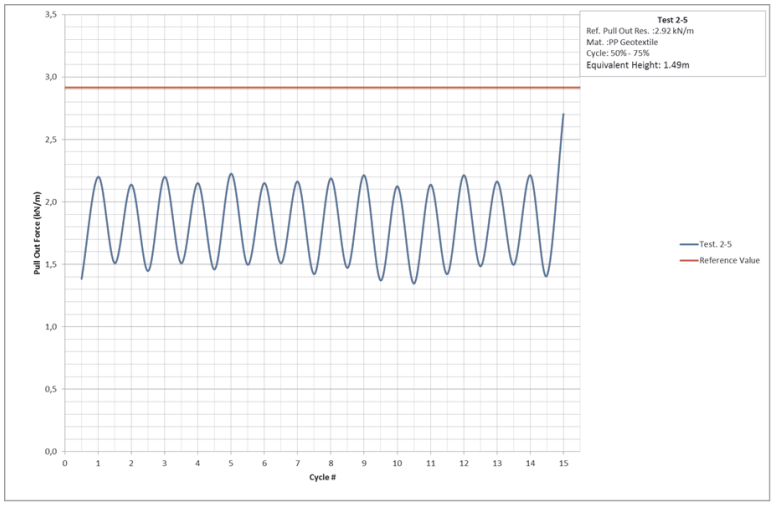


Figure B.11. Graphical Output of Test 2-5.

Table B.12. Test 2-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
2-6	Cyclic 50%-75%	Geotextile 120kN/120kN	340	3.34	4.28	1.47	215	2.11	2.70	2.87

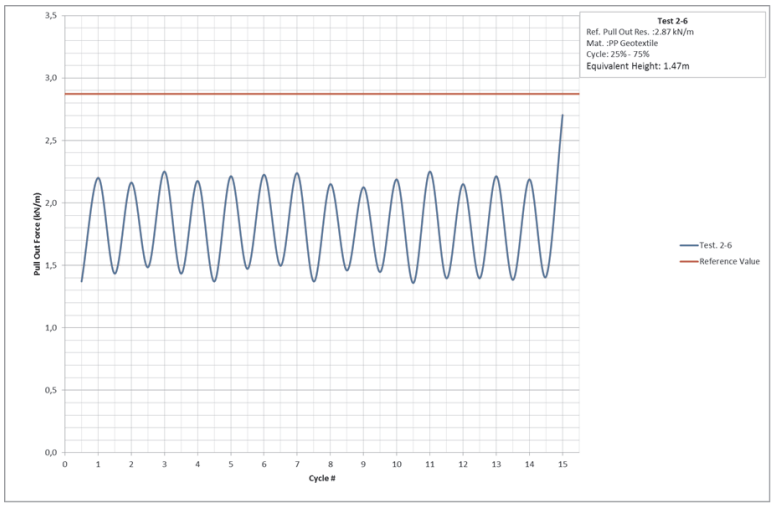


Figure B.12. Graphical Output of Test 2-6.

Table B.13. Test 3-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-1	Cyclic 0%-50%	Geotextile 120kN/120kN	550	5.40	6.92	2.38	347	3.40	4.36	4.69

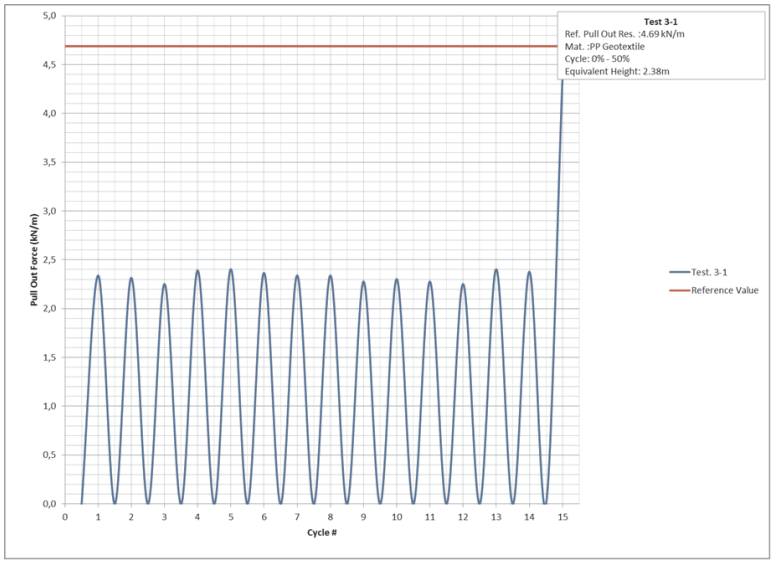


Figure B.13. Graphical Output of Test 3-1.

Table B.14. Test 3-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-2	Cyclic 0%-50%	Geotextile 120kN/120kN	550	5.40	6.92	2.38	346	3.39	4.35	4.69

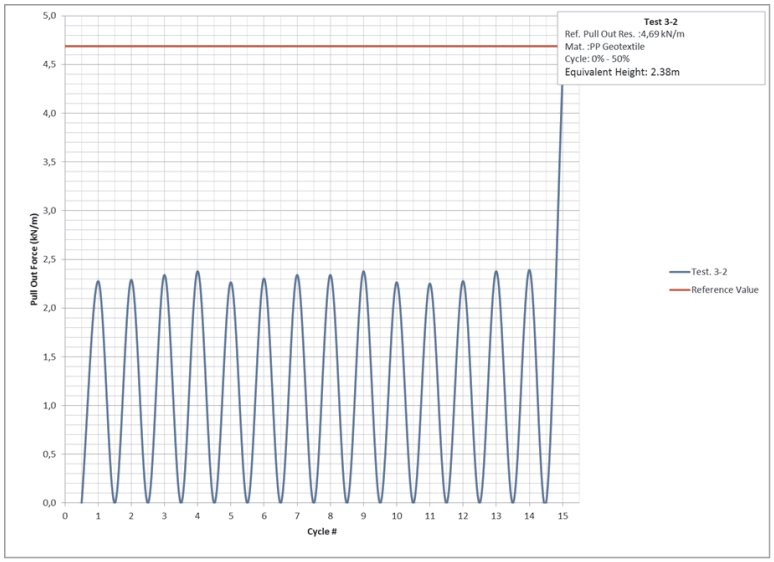


Figure B.14. Graphical Output of Test 3-2.

Table B.15. Test 3-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-3	Cyclic 25%-75%	Geotextile 120kN/120kN	560	5.49	7.04	2.42	351	3.44	4.41	4.77

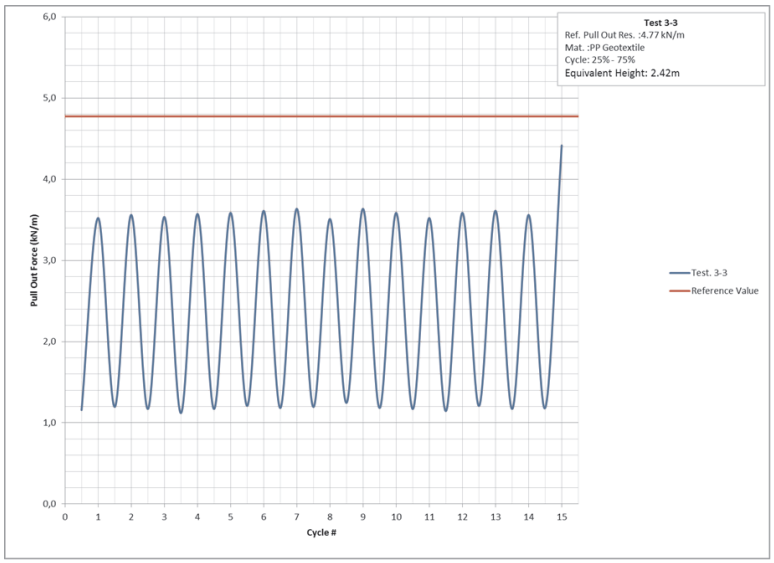


Figure B.15. Graphical Output of Test 3-3.

Table B.16. Test 3-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-4	Cyclic 25%-75%	Geotextile 120kN/120kN	555	5.44	6.98	2.40	349	3.42	4.39	4.73

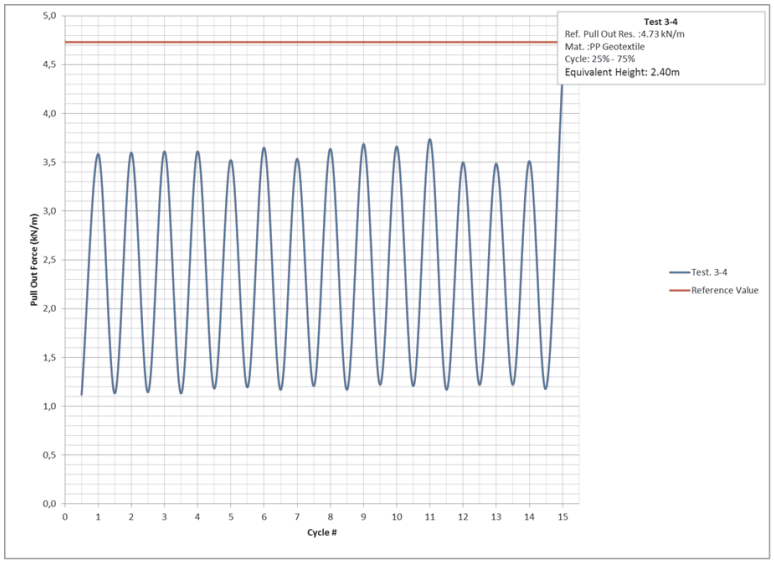


Figure B.16. Graphical Output of Test 3-4.

Table B.17. Test 3-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-5	Cyclic 25%-75%	Geotextile 120kN/120kN	545	5.35	6.85	2.35	341	3.35	4.29	4.64

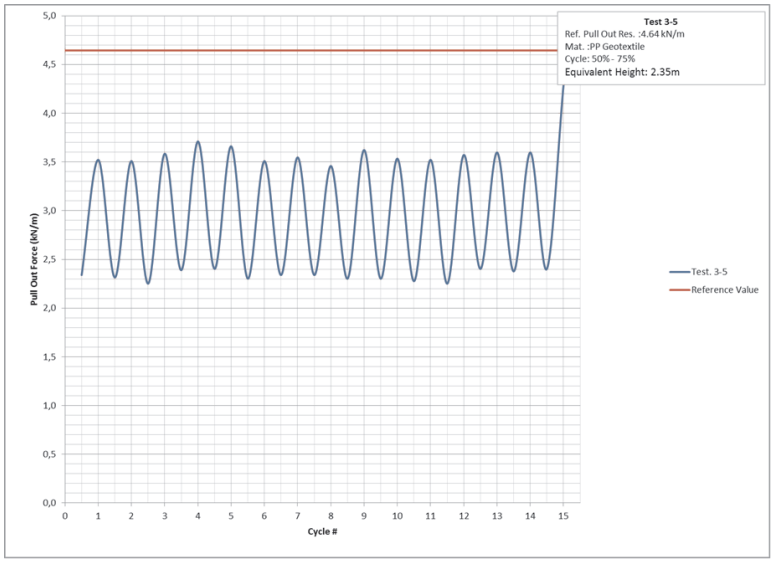


Figure B.17. Graphical Output of Test 3-5.

Table B.18. Test 3-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
3-6	Cyclic 50%-75%	Geotextile 120kN/120kN	555	5.44	6.98	2.40	390	3.83	4.91	4.73

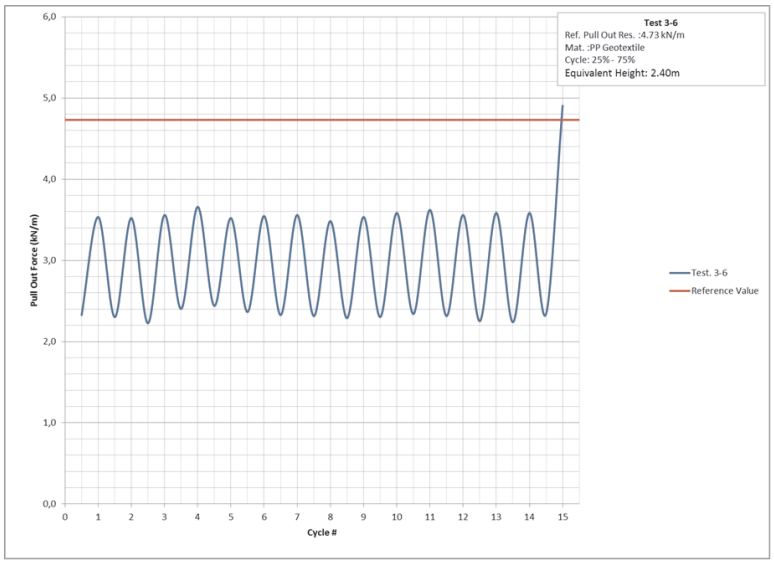


Figure B.18. Graphical Output of Test 3-6.

Table B.19. Test 4-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
4-1	Cyclic 0%-50%	Geotextile 120kN/120kN	750	7.36	9.43	3.24	475	4.66	5.97	6.42

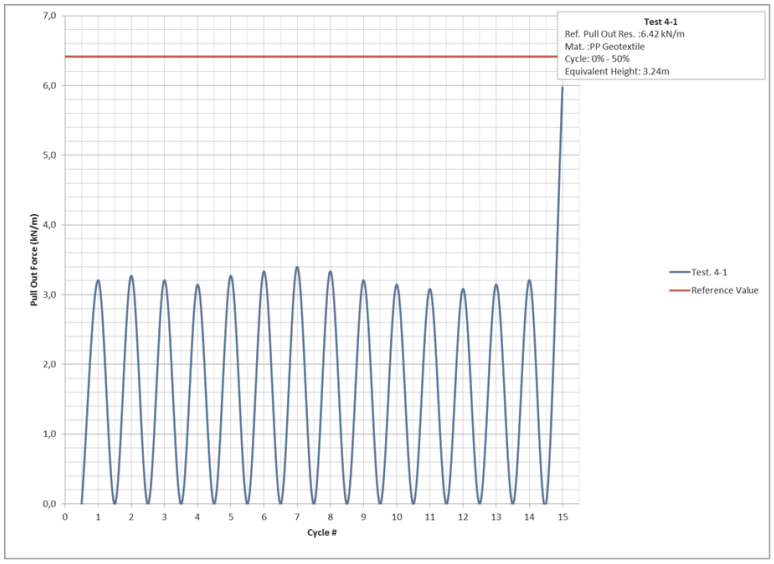


Figure B.19. Graphical Output of Test 4-1.

Table B.20. Test 4-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
4-2	Cyclic 0%-50%	Geotextile 120kN/120kN	755	7.41	9.50	3.26	470	4.61	5.91	6.46

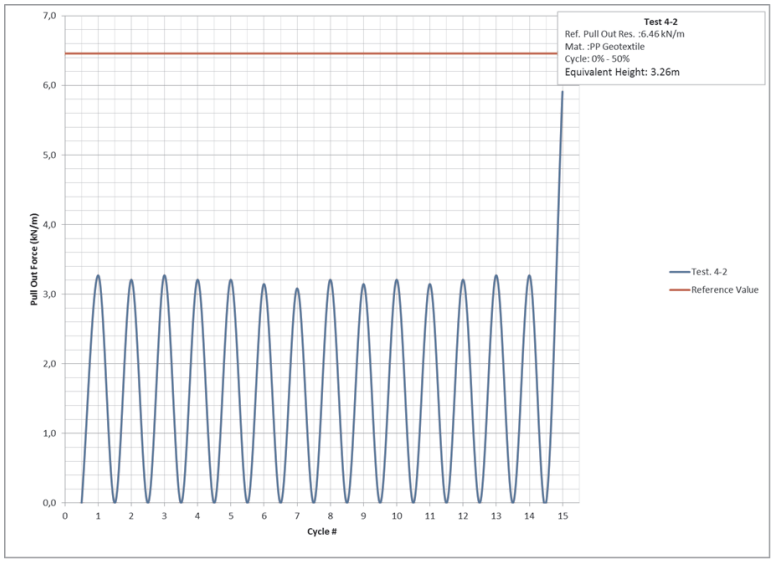


Figure B.20. Graphical Output of Test 4-2.

Table B.21. Test 4-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
4-3	Cyclic 25%-75%	Geotextile 120kN/120kN	760	7.46	9.56	3.28	480	4.71	6.04	6.50

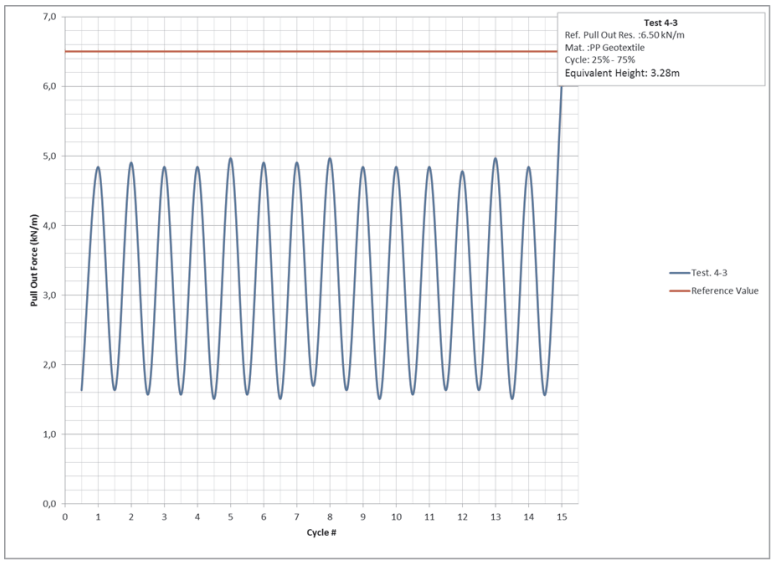


Figure B.21. Graphical Output of Test 4-3.

Table B.22. Test 4-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
4-4	Cyclic 25%-75%	Geotextile 120kN/120kN	750	7.36	9.43	3.24	475	4.66	5.97	6.42

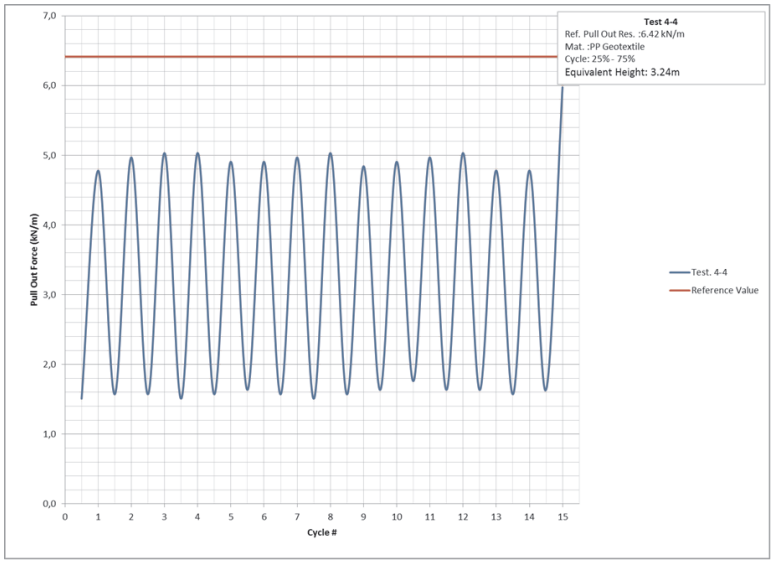


Figure B.22. Graphical Output of Test 4-4.

Table B.23. Test 4-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
4-5	Cyclic 50%-75%	Geotextile 120kN/120kN	750	7.36	9.43	3.24	470	4.61	5.91	6.42

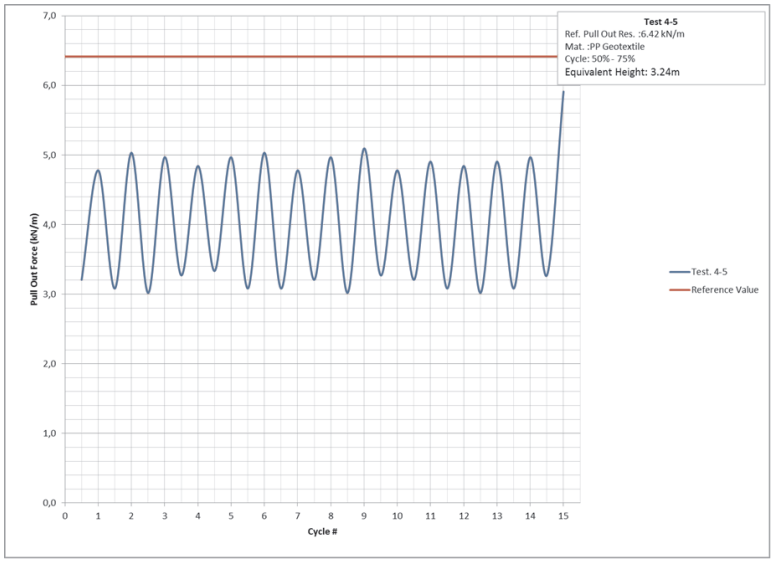


Figure B.23. Graphical Output of Test 4-5.

Table B.24. Test 4-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
4-6	Cyclic 50%-75%	Geotextile 120kN/120kN	745	7.31	9.37	3.22	465	4.56	5.85	6.37

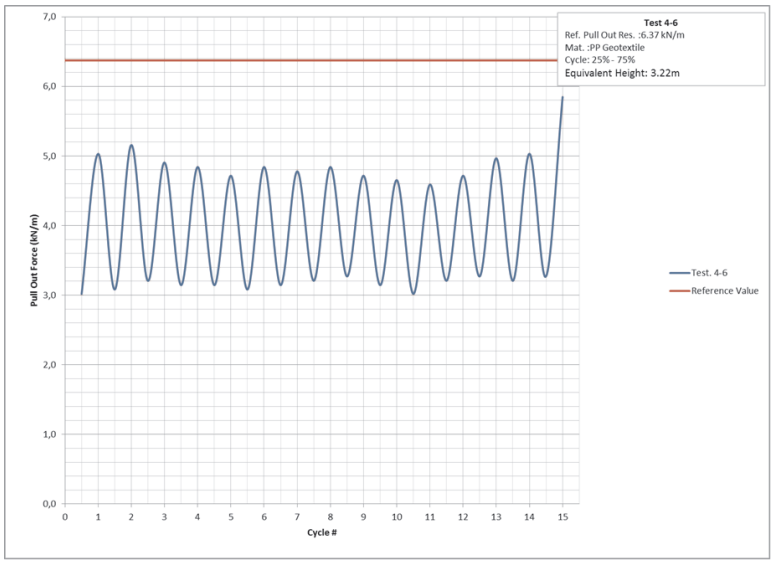


Figure B.24. Graphical Output of Test 4-6.

Table B.25. Test 5-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-1	Cyclic 0%-50%	Geotextile 120kN/120kN	950	9.32	11.95	4.10	615	6.03	7.73	8.14

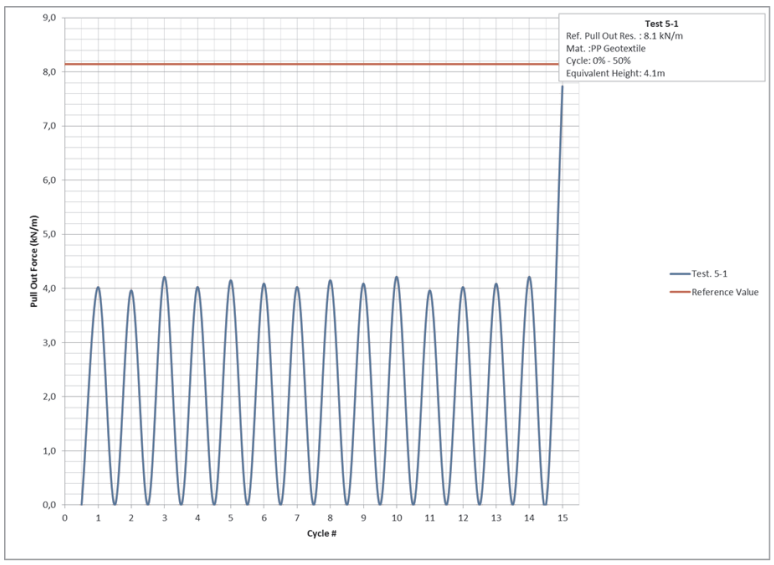


Figure B.25. Graphical Output of Test 5-1.

Table B.26. Test 5-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-2	Cyclic 0%-50%	Geotextile 120kN/120kN	950	9.32	11.95	4.10	605	5.94	7.61	8.14

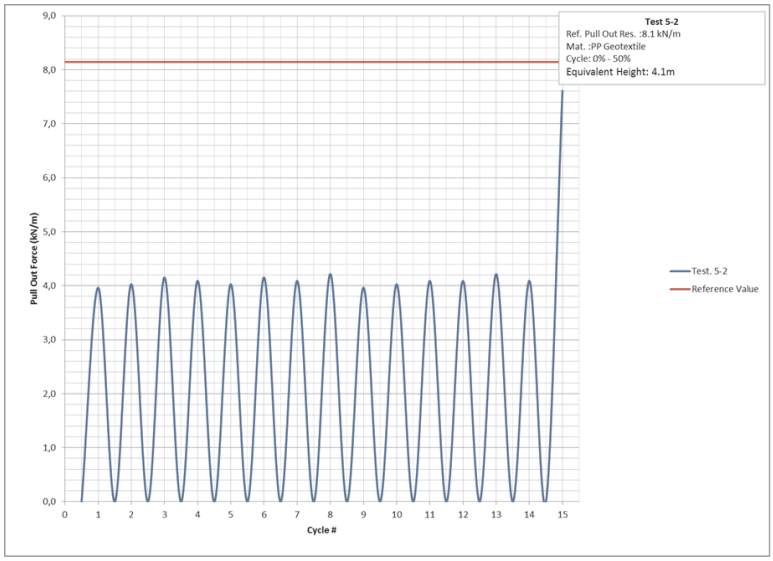


Figure B.26. Graphical Output of Test 5-2.

Table B.27. Test 5-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-3	Cyclic 25%-75%	Geotextile 120kN/120kN	960	9.42	12.07	4.15	610	5.98	7.67	8.23

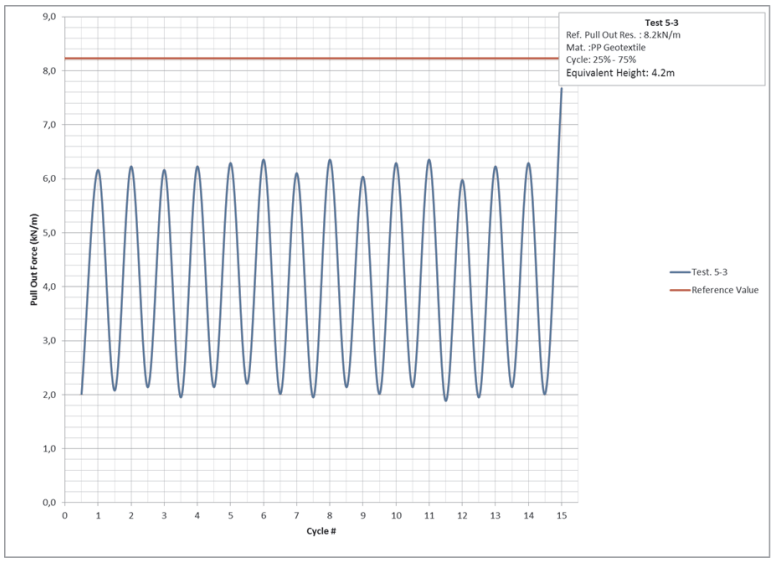


Figure B.27. Graphical Output of Test 5-3.

Table B.28. Test 5-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-4	Cyclic 25%-75%	Geotextile 120kN/120kN	940	9.22	11.82	4.06	595	5.84	7.48	8.06

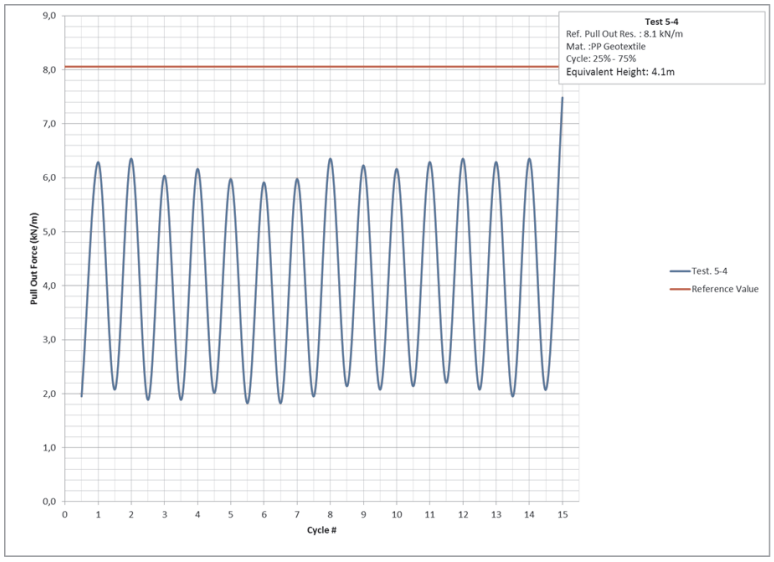


Figure B.28. Graphical Output of Test 5-4.

Table B.29. Test 5-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-5	Cyclic 50%-75%	Geotextile 120kN/120kN	950	9.32	11.95	4.10	600	5.89	7.55	8.14

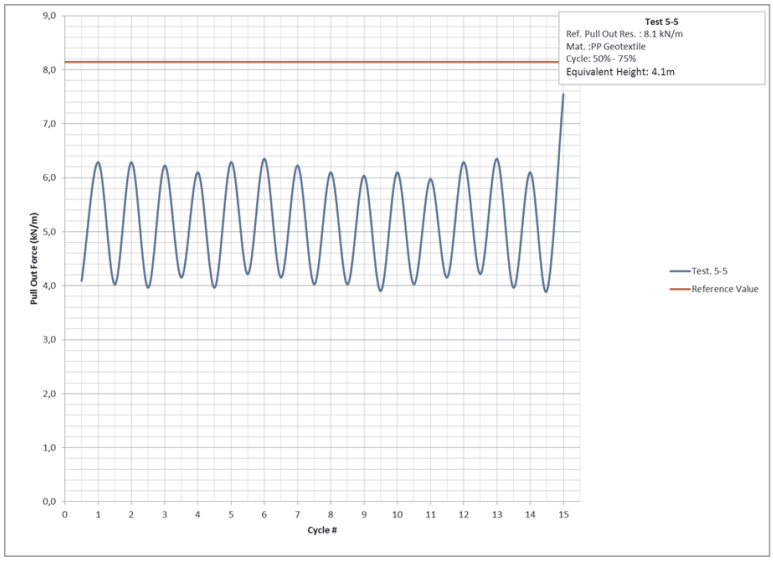


Figure B.29. Graphical Output of Test 5-5.

Table B.30. Test 5-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
5-6	Cyclic 50%-75%	Geotextile 120kN/120kN	960	9.42	12.07	4.15	605	5.94	7.61	8.23

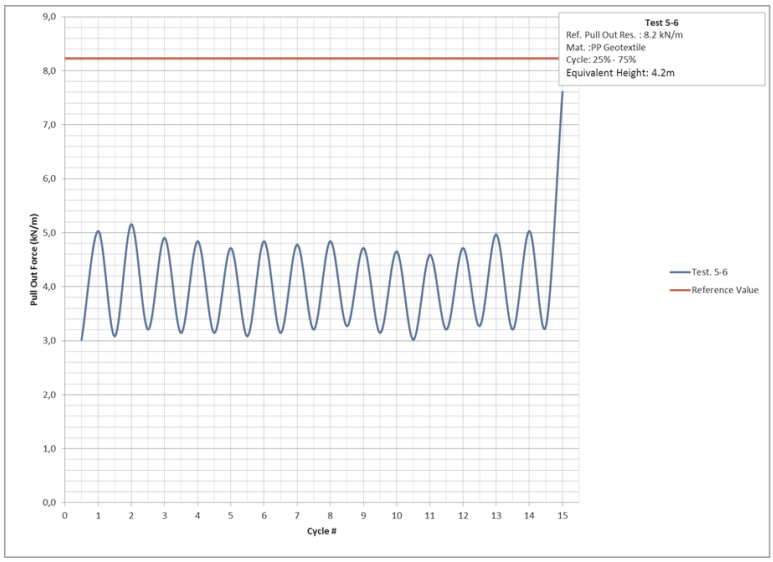


Figure B.30. Graphical Output of Test 5-6.

Table B.31. Test 6-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
6-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1150	11.28	14.46	4.97	740	7.26	9.31	9.87

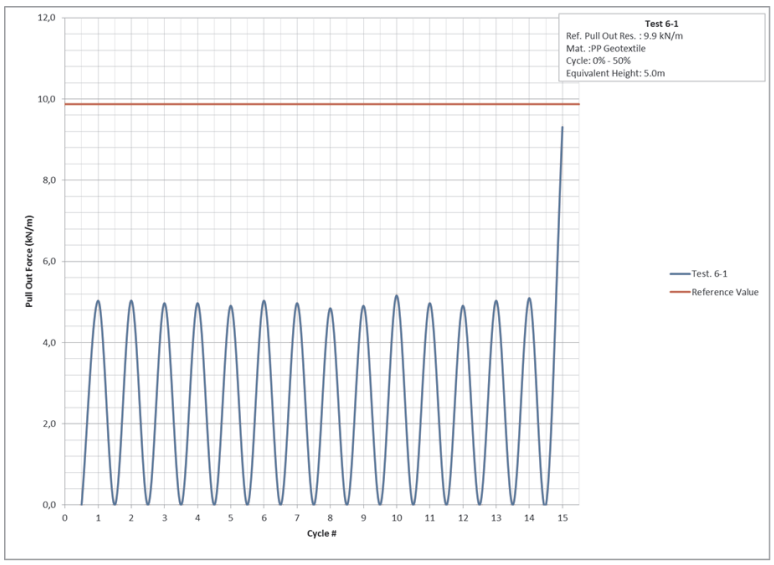


Figure B.31. Graphical Output of Test 6-1.

Table B.32. Test 6-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
6-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1160	11.38	14.59	5.01	735	7.21	9.24	9.96

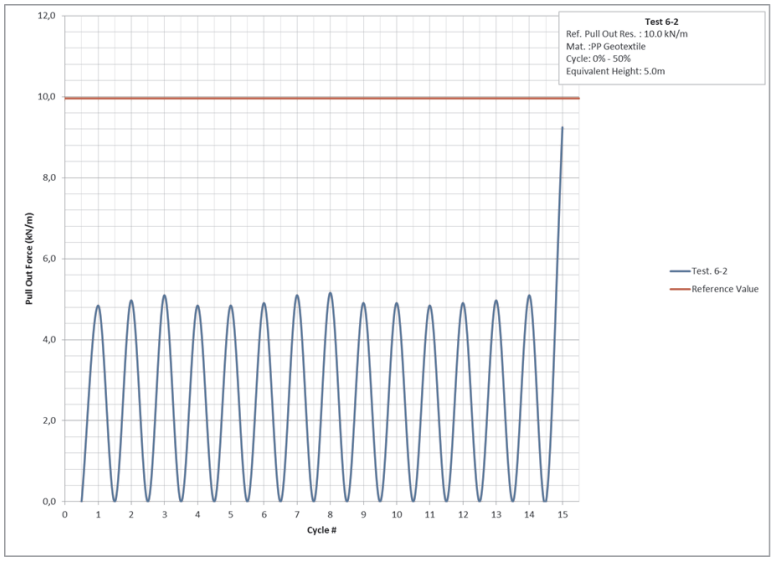


Figure B.32. Graphical Output of Test 6-2.

Table B.33. Test 6-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
6-3	Cyclic 25%-75%	Geotextile 120kN/120kN	1160	11.38	14.59	5.01	740	7.26	9.31	9.96

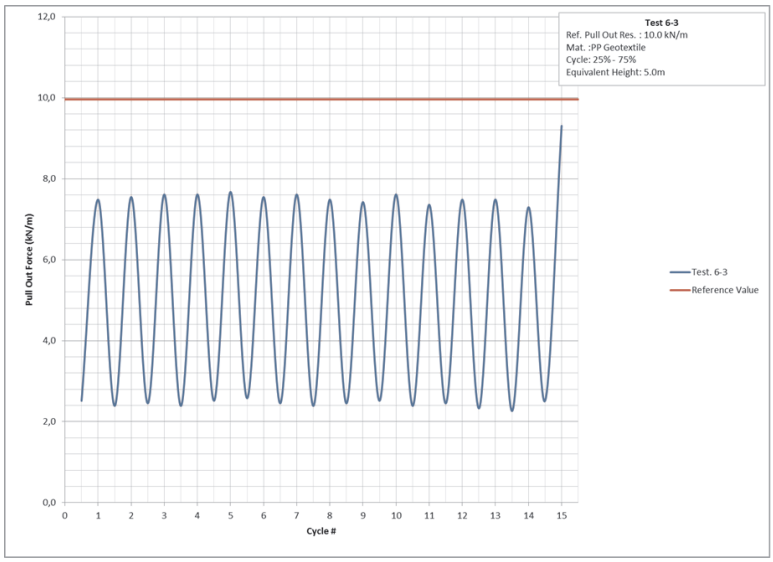


Figure B.33. Graphical Output of Test 6-3.

Table B.34. Test 6-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
6-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1150	11.28	14.45	4.97	790	7.75	9.94	9.87

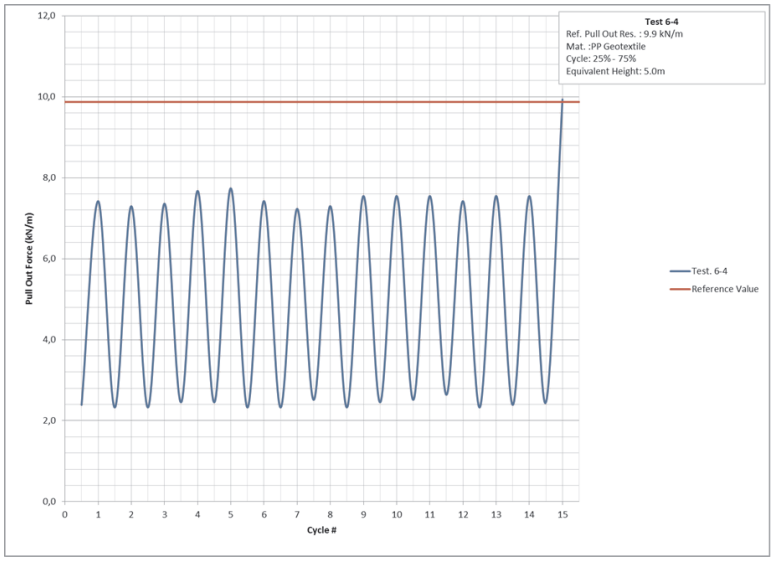


Figure B.34. Graphical Output of Test 6-4.

Table B.35. Test 6-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
6-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1150	11.28	14.45	4.97	725	7.11	9.12	9.87

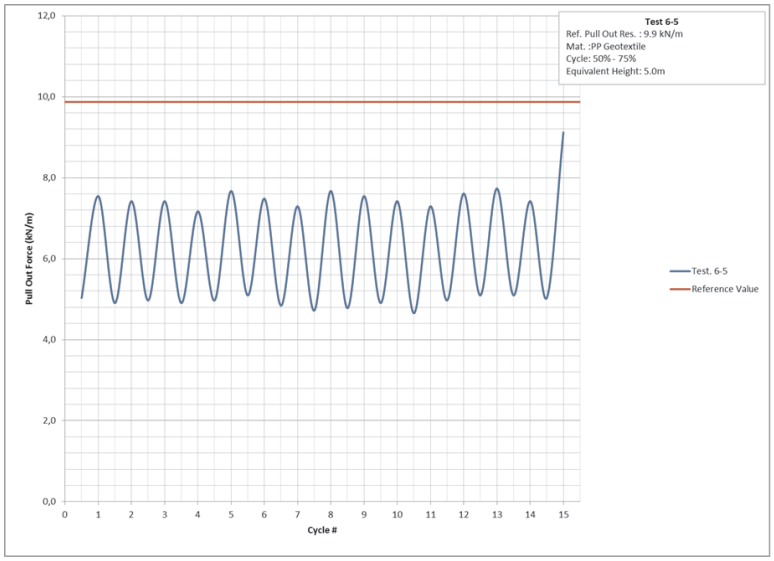


Figure B.35. Graphical Output of Test 6-5.

Table B.36. Test 6-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
6-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1150	11.28	14.46	4.97	720	7.06	9.06	9.87

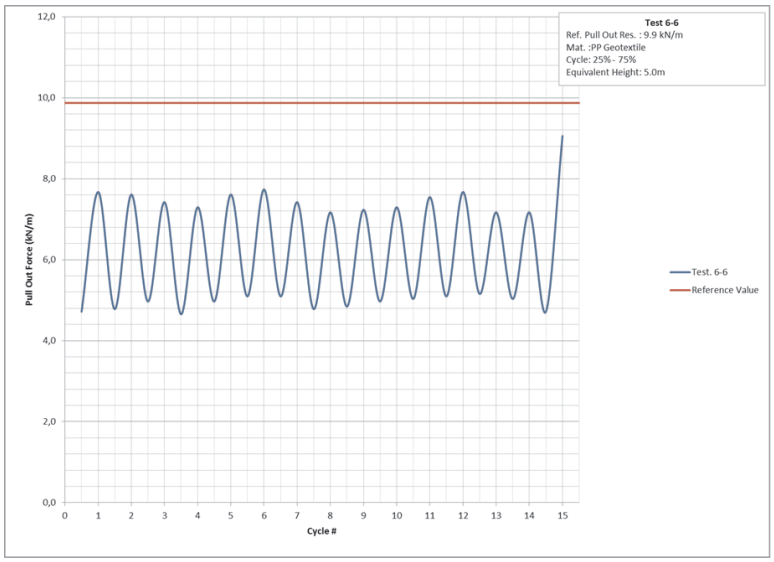


Figure B.36. Graphical Output of Test 6-6.

Table B.37. Test 7-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
7-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1500	14.72	18.87	6.48	935	9.17	11.76	12.90

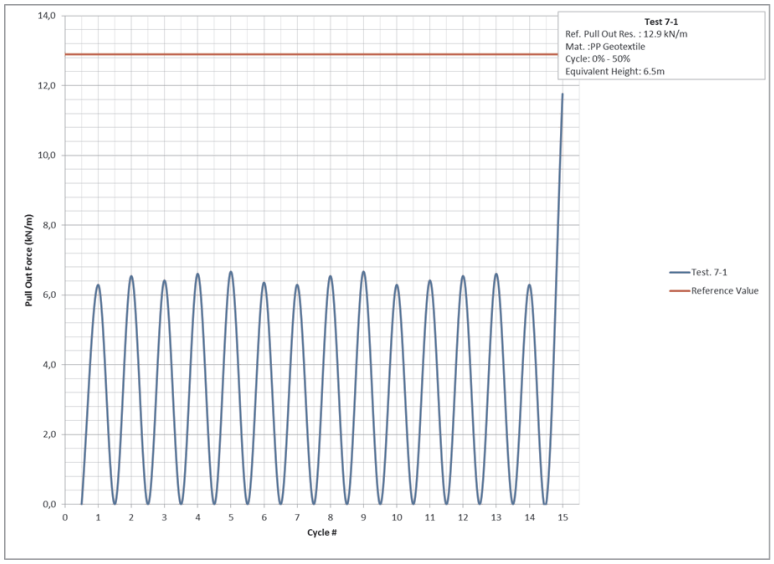


Figure B.37. Graphical Output of Test 7-1.

Table B.38. Test 7-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
7-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1450	14.22	18.24	6.26	940	9.22	11.82	12.46

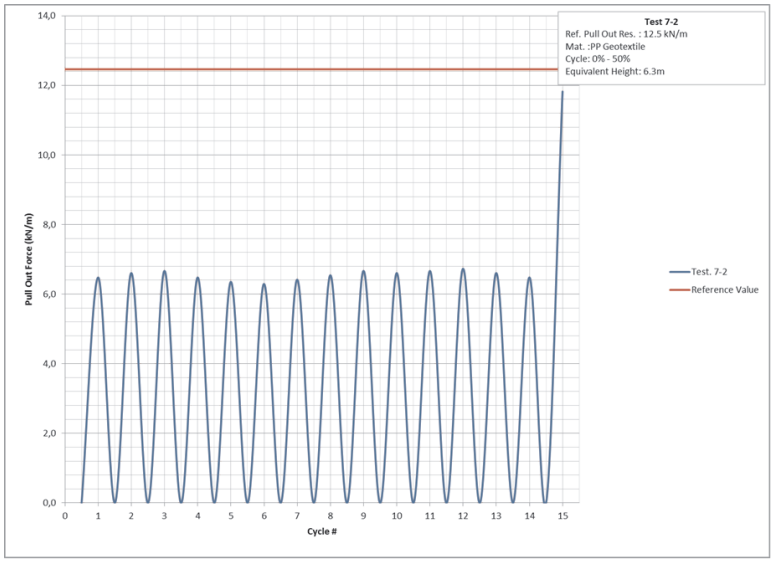


Figure B.38. Graphical Output of Test 7-2.

Table B.39. Test 7-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
7-3	Cyclic 25%-75%	Geotextile 120kN/120kN	1450	14.22	18.24	6.26	1000	9.81	12.58	12.46

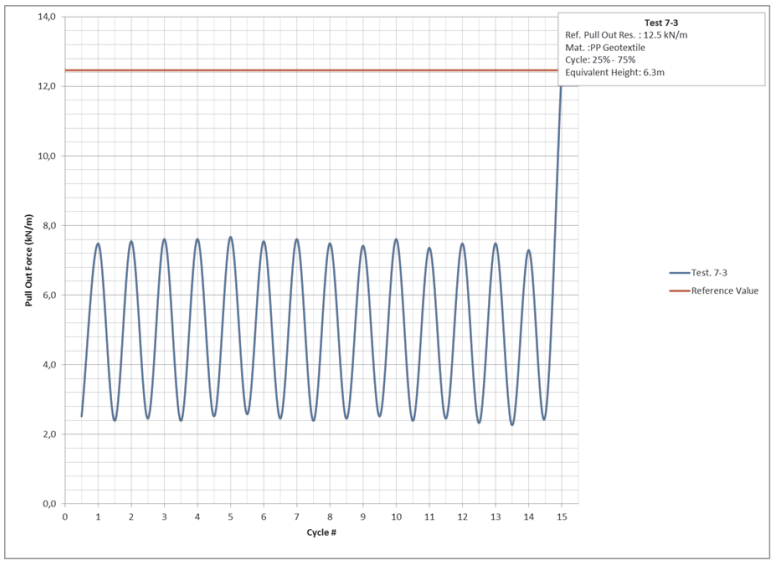


Figure B.39. Graphical Output of Test 7-3.

Table B.40. Test 7-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
7-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1500	14.72	18.87	6.48	925	9.07	11.63	12.90

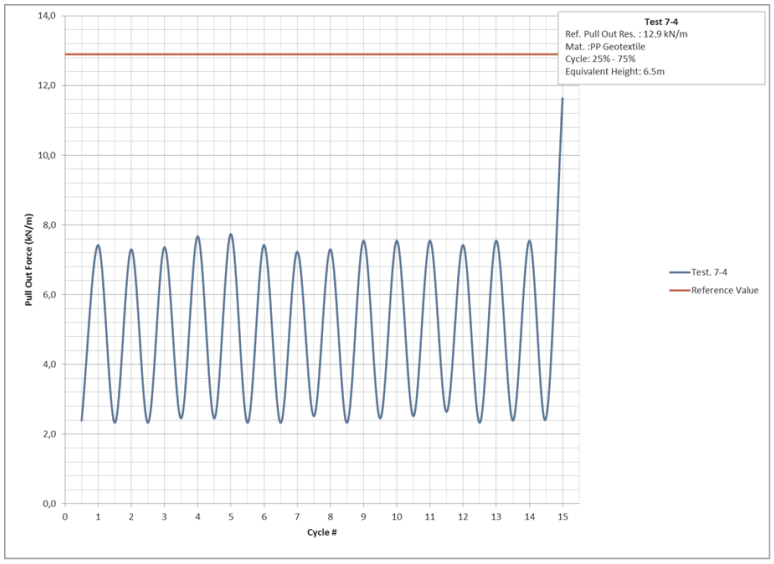


Figure B.40. Graphical Output of Test 7-4.

Table B.41. Test 7-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
7-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1450	14.22	18.24	6.26	945	9.27	11.89	12.46

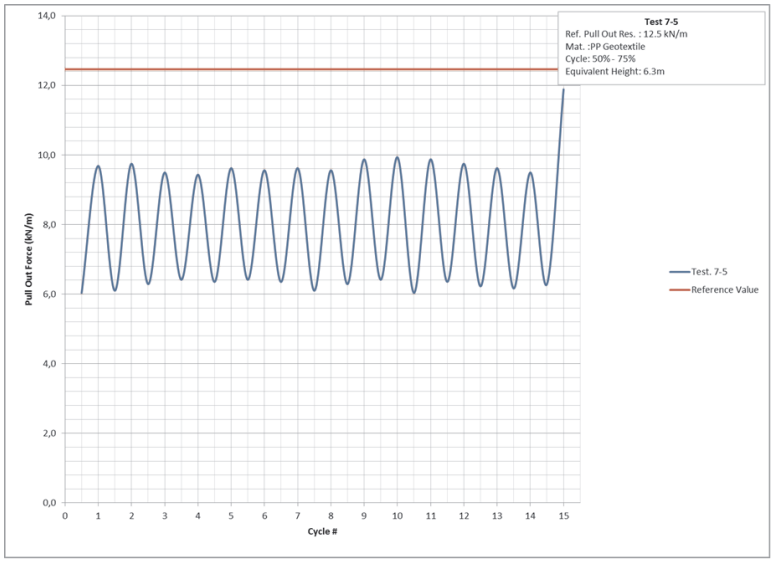


Figure B.41. Graphical Output of Test 7-5.

Table B.42. Test 7-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
7-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1500	14.72	18.87	6.48	960	9.42	12.07	12.90

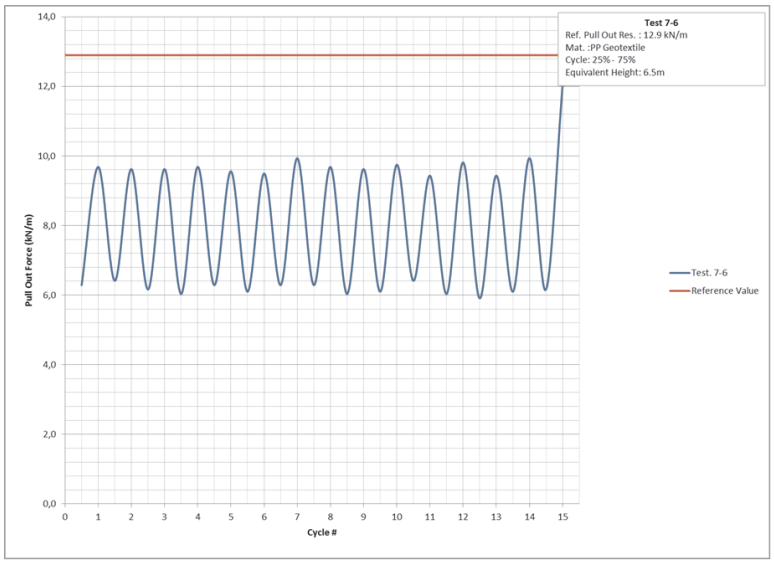


Figure B.42. Graphical Output of Test 7-6.

Table B.43. Test 8-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
8-1	Cyclic 0%-50%	Geotextile 120kN/120kN	1800	17.66	22.64	7.77	1145	11.23	14.40	15.49

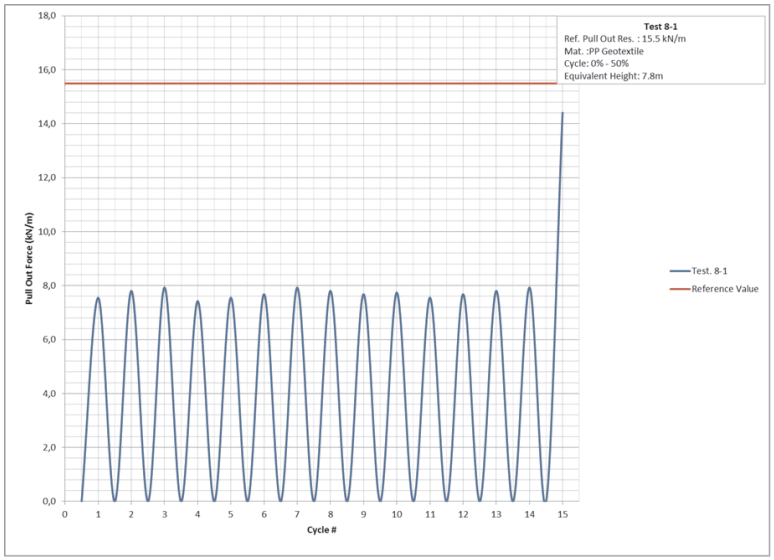


Figure B.43. Graphical Output of Test 8-1.

Table B.44. Test 8-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
8-2	Cyclic 0%-50%	Geotextile 120kN/120kN	1750	17.17	22.01	7.56	1120	10.99	14.09	15.06

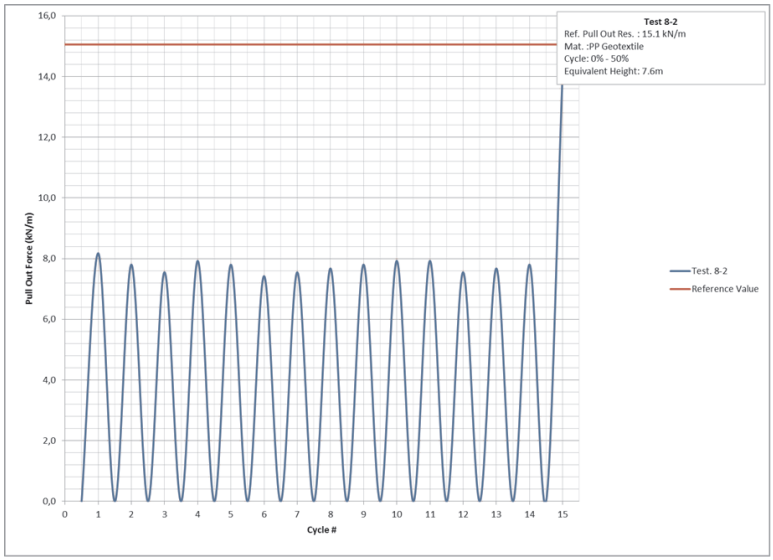


Figure B.44. Graphical Output of Test 8-2.

Table B.45. Test 8-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
8-4	Cyclic 25%-75%	Geotextile 120kN/120kN	1750	17.17	22.01	7.56	1125	11.04	14.15	15.06

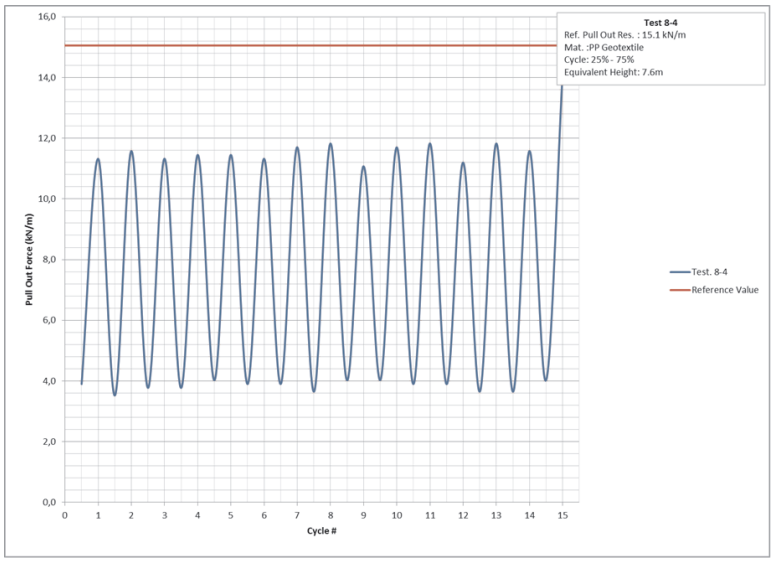


Figure B.45. Graphical Output of Test 8-4.

Table B.46. Test 8-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
8-5	Cyclic 50%-75%	Geotextile 120kN/120kN	1750	17.17	22.01	7.56	1120	10.99	14.09	15.06

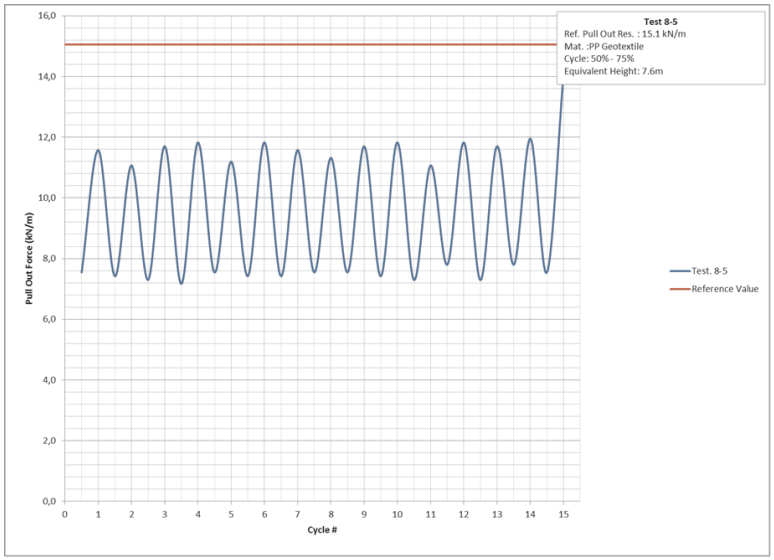


Figure B.46. Graphical Output of Test 8-5.

Table B.47. Test 8-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
8-6	Cyclic 50%-75%	Geotextile 120kN/120kN	1700	16.68	21.38	7.34	1100	10.79	13.83	14.62

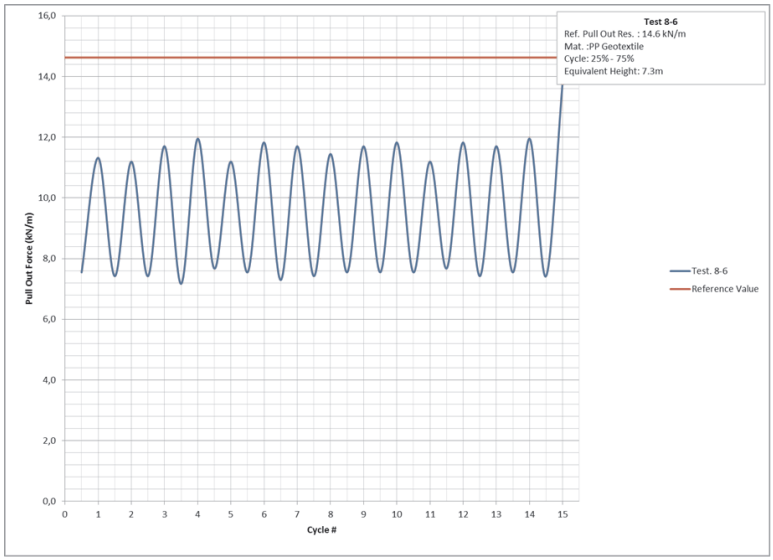


Figure B.47. Graphical Output of Test 8-6.

Table B.48. Test 9-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1250	12.26	15.72	17.65

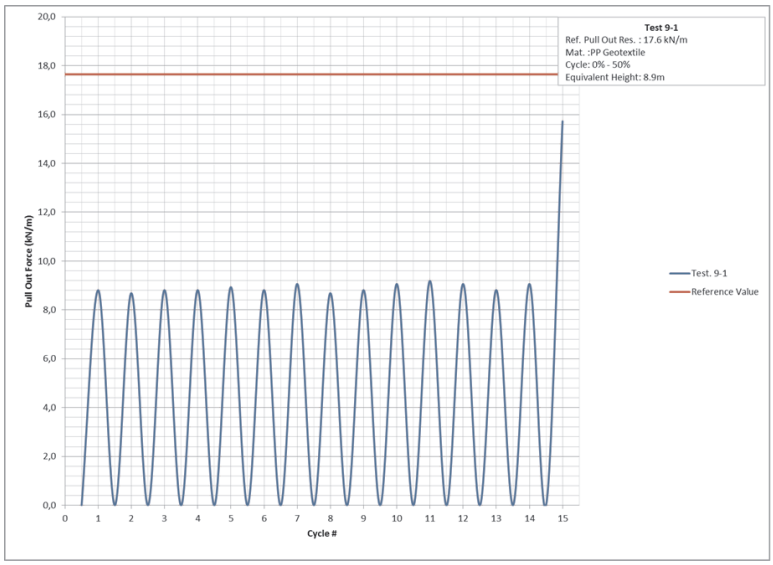


Figure B.48. Graphical Output of Test 9-1.

Table B.49. Test 9-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1315	12.90	16.54	17.65

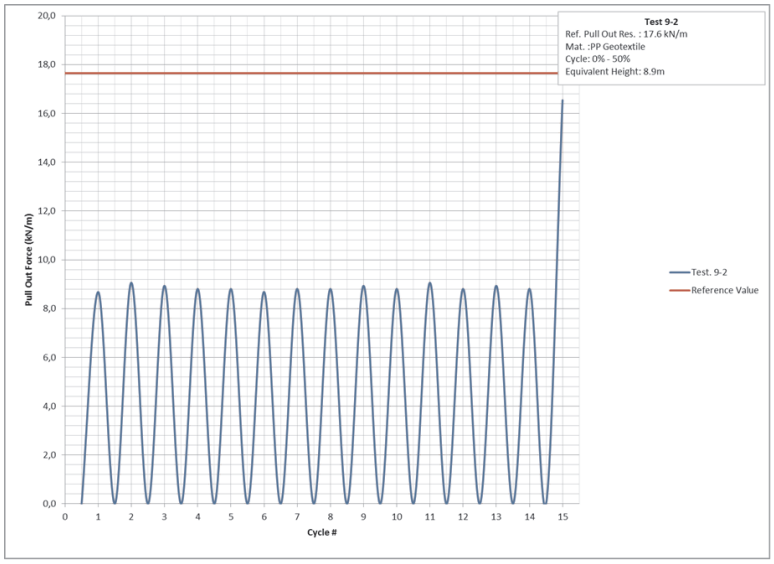


Figure B.49. Graphical Output of Test 9-2.

Table B.50. Test 9-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2100	20.60	26.41	9.07	1450	14.32	18.36	18.08

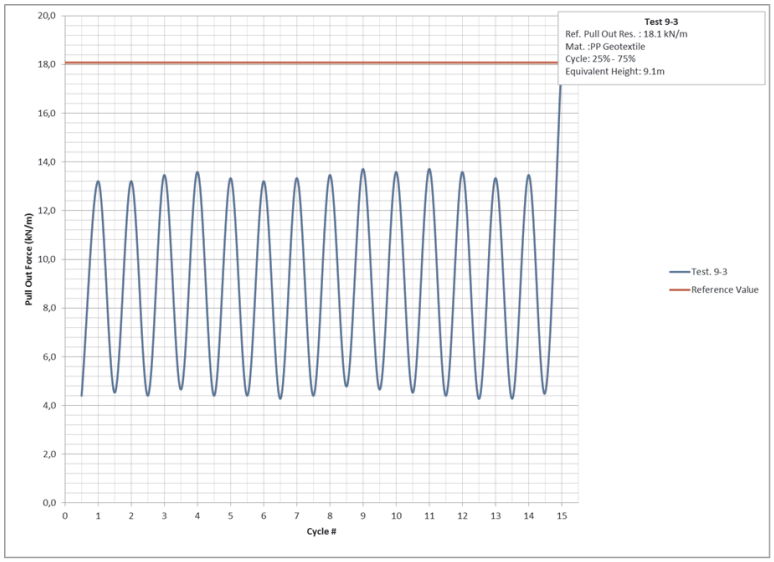


Figure B.50. Graphical Output of Test 9-3.

Table B.51. Test 9-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1290	12.65	16.22	17.65

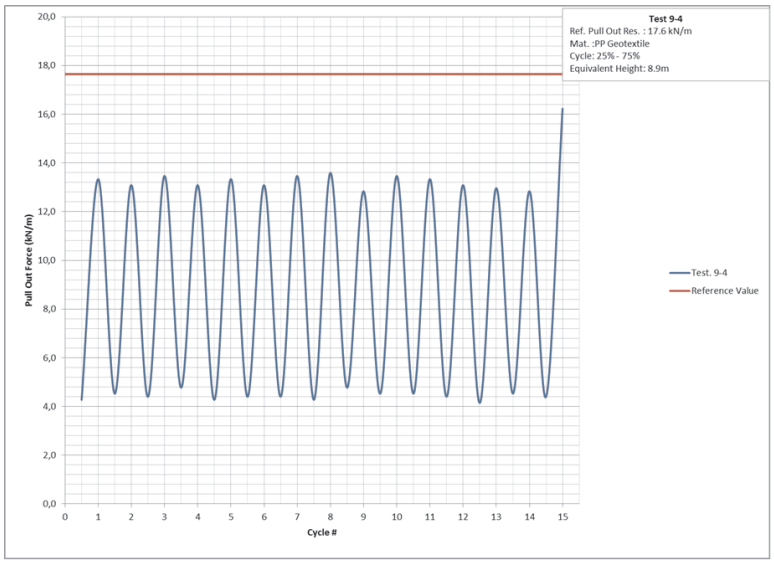


Figure B.51. Graphical Output of Test 9-4.

Table B.52. Test 9-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1300	12.75	16.35	17.65

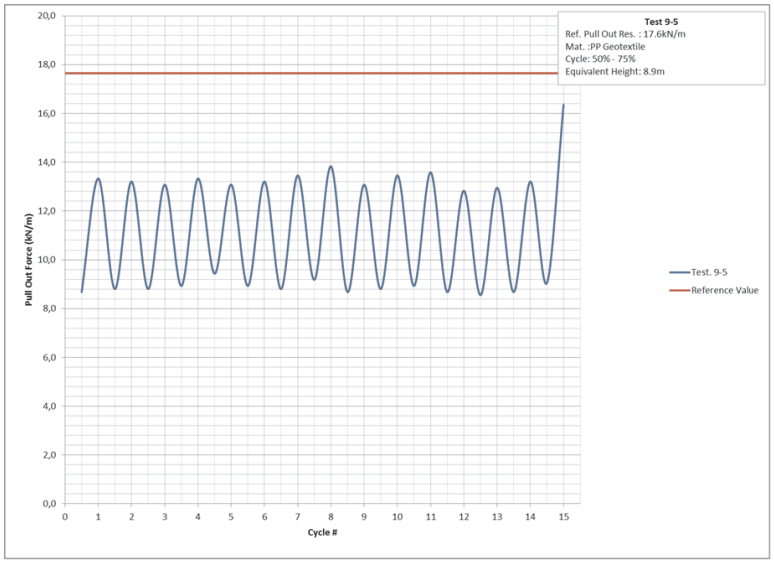


Figure B.52. Graphical Output of Test 9-5.

Table B.53. Test 9-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
9-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2050	20.11	25.78	8.85	1280	12.56	16.10	17.65

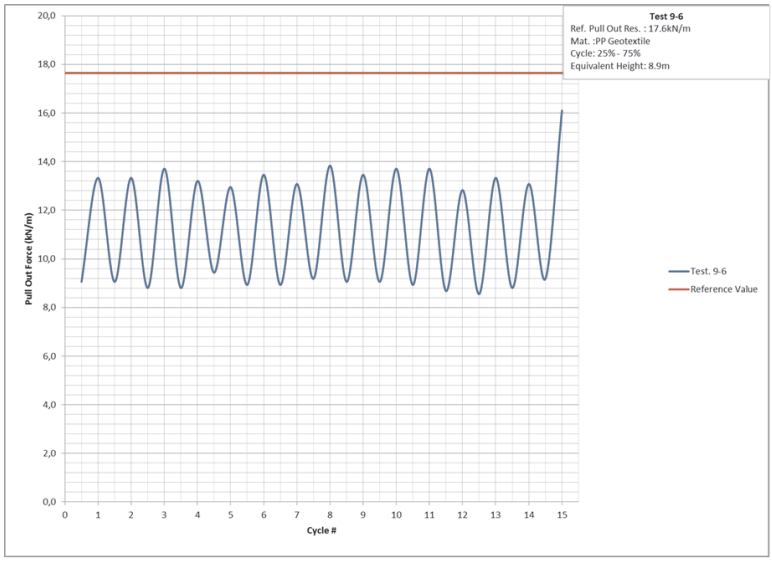


Figure B.53. Graphical Output of Test 9-6.

Table B.54. Test 10-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
10-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2350	23.05	29.56	10.15	1470	14.42	18.49	20.24

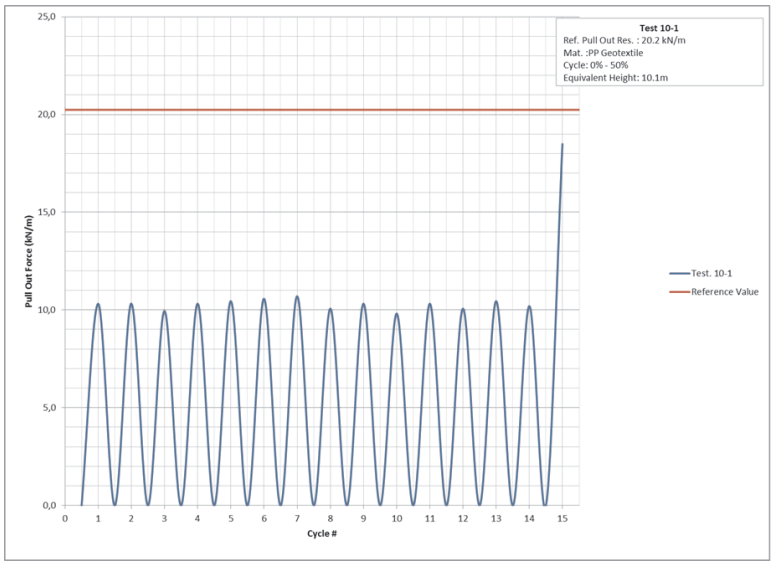


Figure B.54. Graphical Output of Test 10-1.

Table B.55. Test 10-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
10-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2350	23.05	29.56	10.15	1540	15.11	19.37	20.24

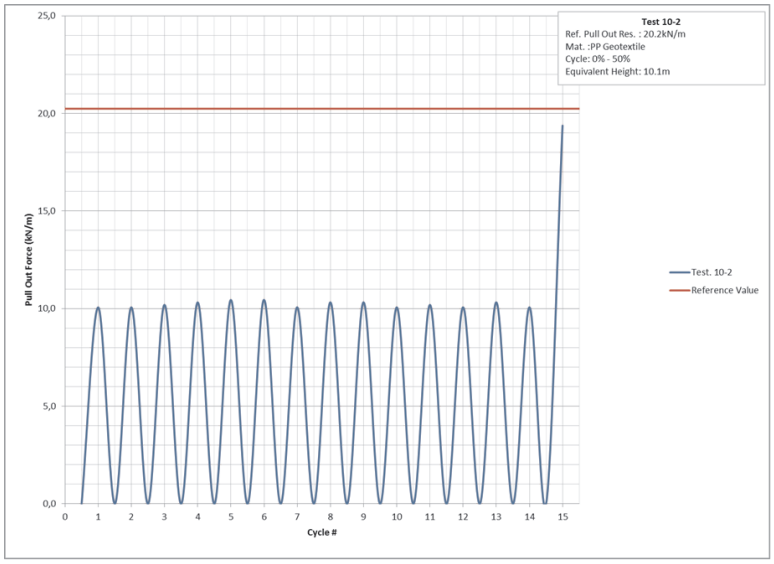


Figure B.55. Graphical Output of Test 10-2.

Table B.56. Test 10-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
10-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2300	22.56	28.93	9.93	1420	13.93	17.86	19.81

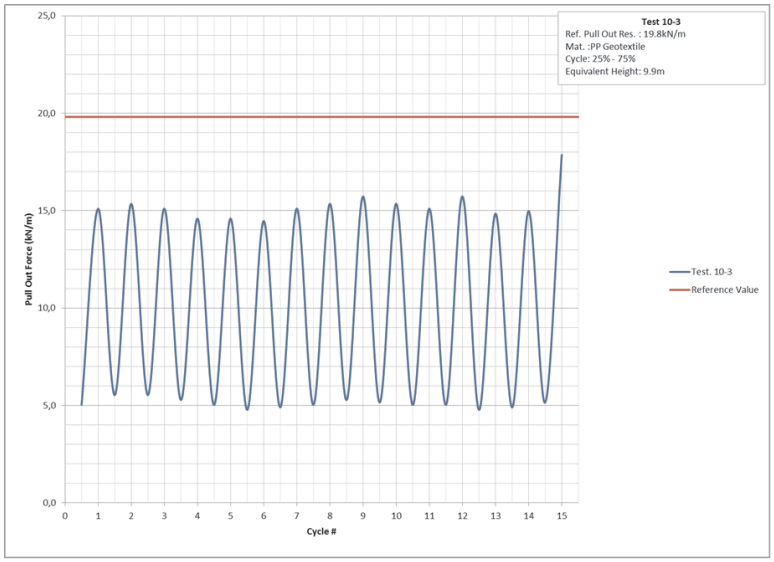


Figure B.56. Graphical Output of Test 10-3.

Table B.57. Test 10-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
10-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2300	22.56	28.93	9.93	1650	16.19	20.75	19.81

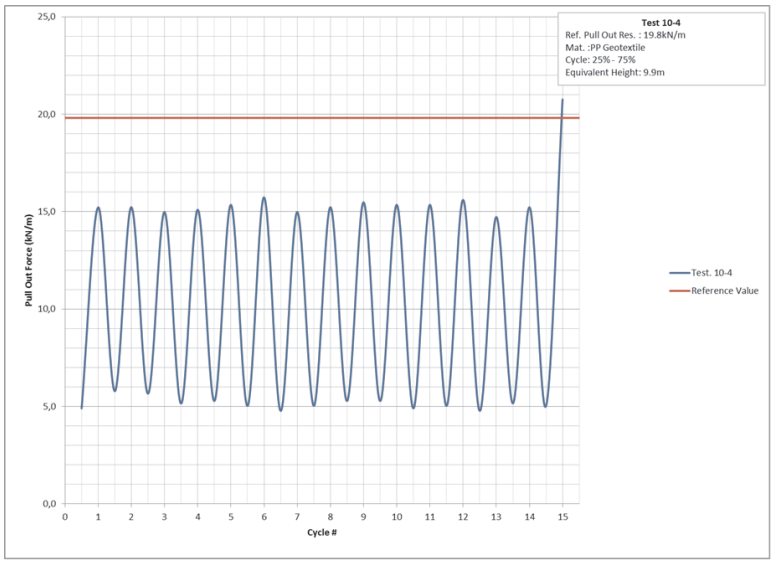


Figure B.57. Graphical Output of Test 10-4.

Table B.58. Test 10-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
10-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2400	23.54	30.18	10.36	1510	14.81	18.99	20.67

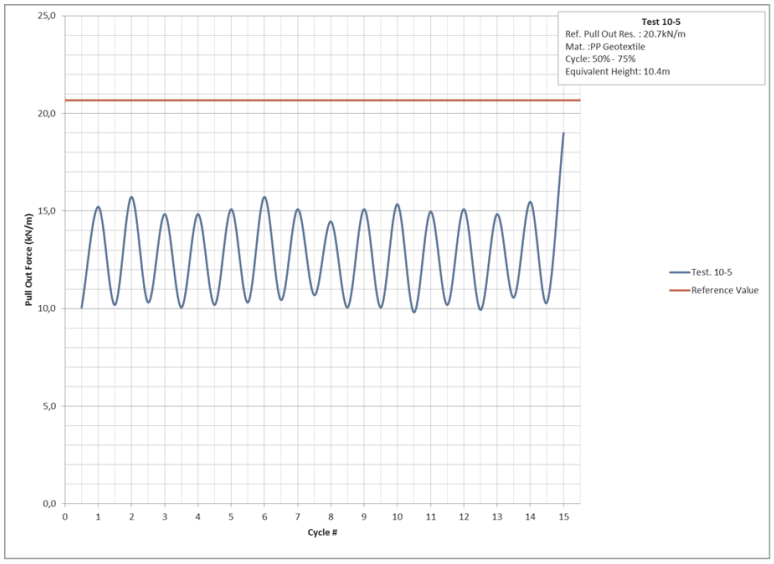


Figure B.58. Graphical Output of Test 10-5.

Table B.59. Test 10-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
10-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2400	23.54	30.18	10.36	1550	15.21	19.49	20.67

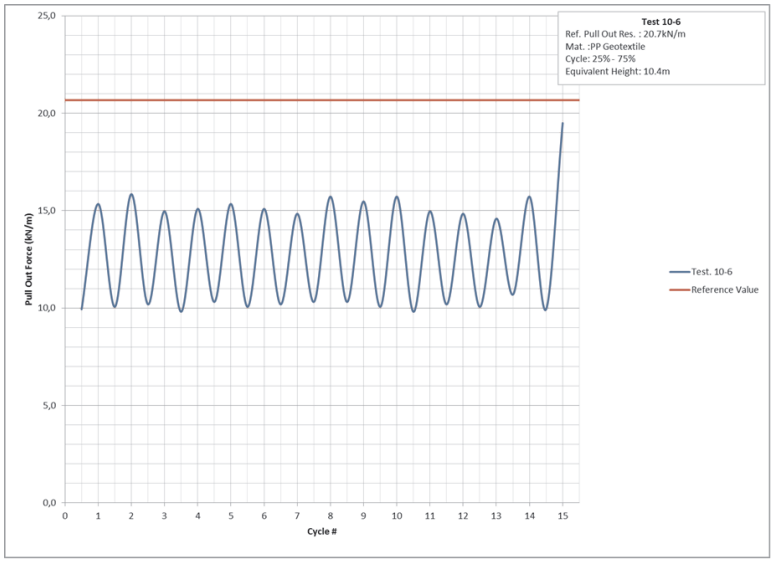


Figure B.59. Graphical Output of Test 10-6.

Table B.60. Test 11-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
11-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1600	15.70	20.12	22.83

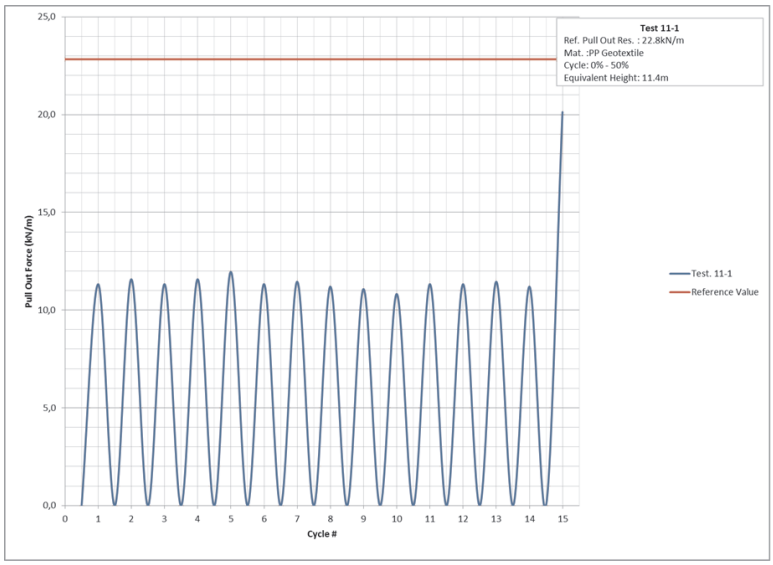


Figure B.60. Graphical Output of Test 11-1.

Table B.61. Test 11-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
11-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1680	16.48	21.13	22.83

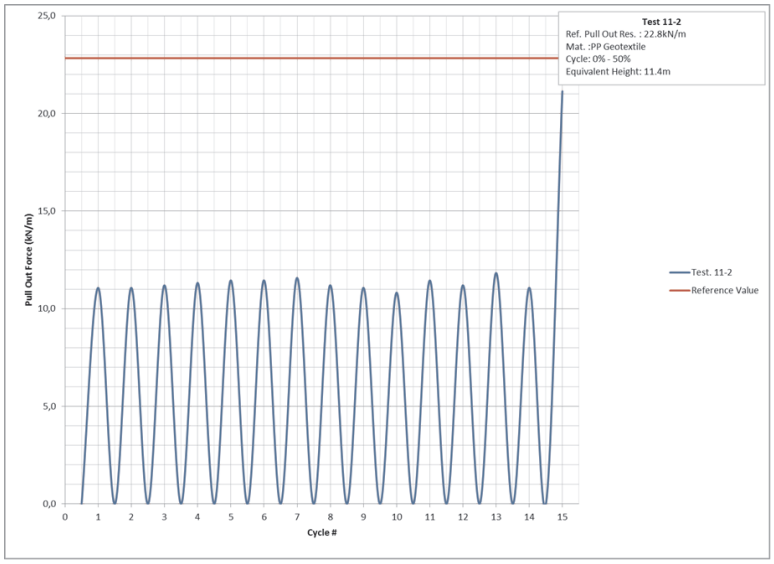


Figure B.61. Graphical Output of Test 11-2.

Table B.62. Test 11-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
11-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1720	16.87	21.63	22.83

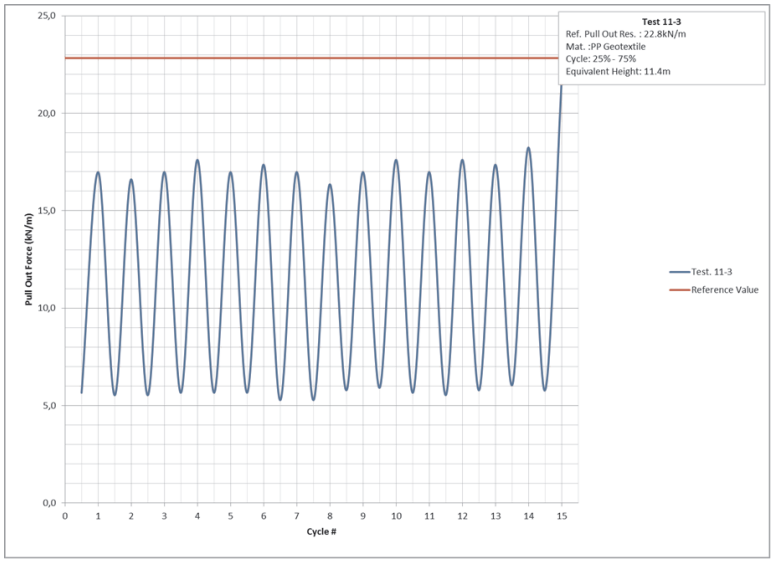


Figure B.62. Graphical Output of Test 11-3.

Table B.63. Test 11-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
11-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2600	25.51	32.70	11.23	1700	16.68	21.38	22.40

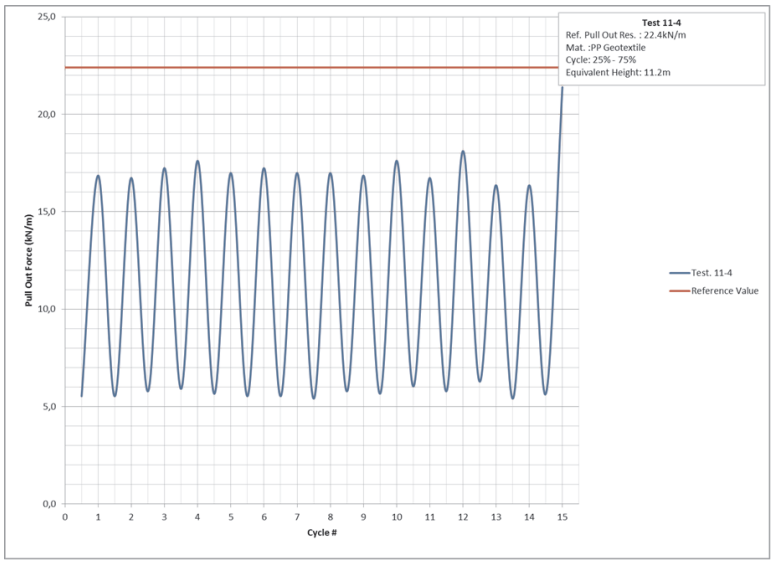


Figure B.63. Graphical Output of Test 11-4.

Table B.64. Test 11-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
11-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2600	25.51	32.70	11.23	1720	16.87	21.63	22.40

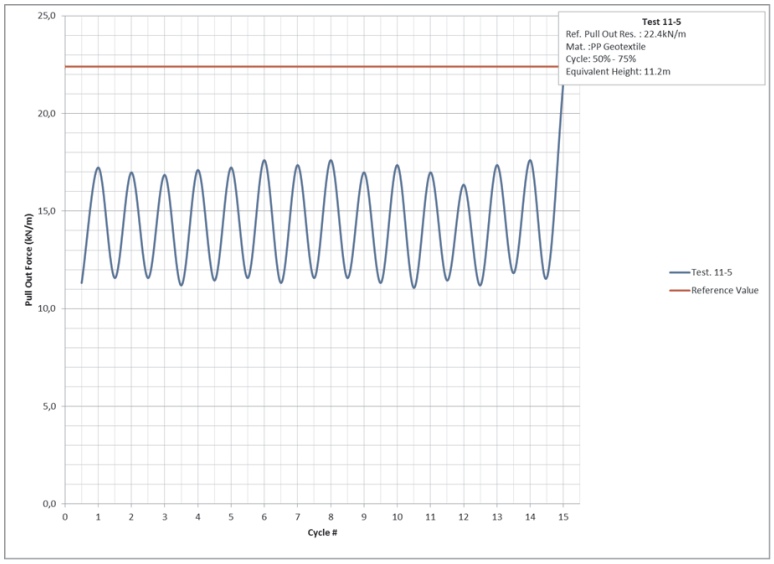


Figure B.64. Graphical Output of Test 11-5.

Table B.65. Test 11-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
11-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2650	26.00	33.33	11.44	1670	16.38	21.00	22.83

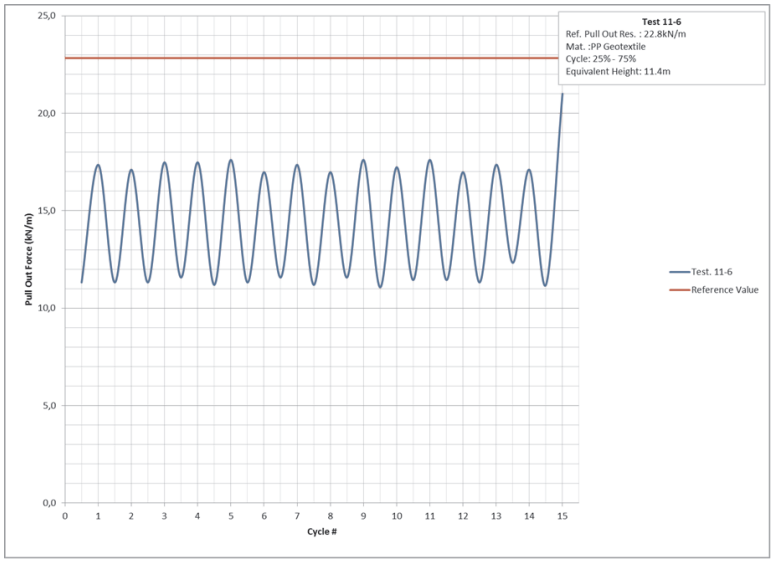


Figure B.65. Graphical Output of Test 11-6.

Table B.66. Test 12-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
12-1	Cyclic 0%-50%	Geotextile 120kN/120kN	2900	28.45	36.47	12.52	1870	18.34	23.52	24.99

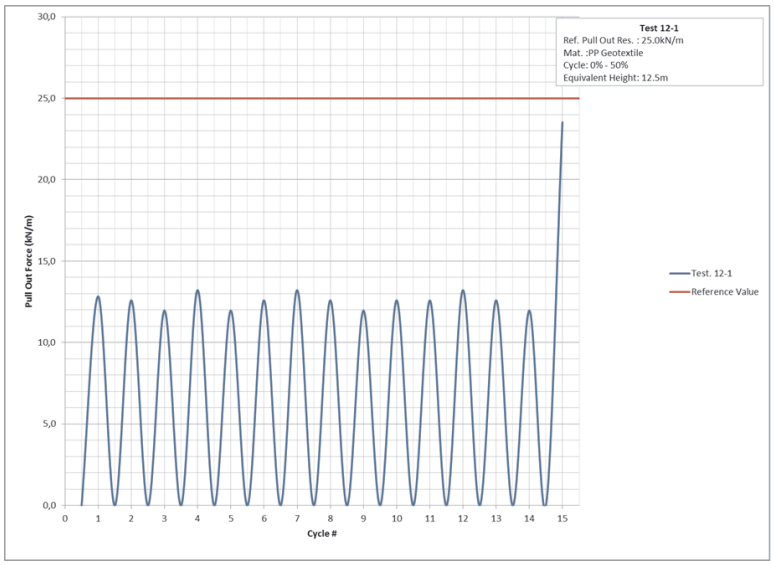


Figure B.66. Graphical Output of Test 12-1.

Table B.67. Test 12-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
12-2	Cyclic 0%-50%	Geotextile 120kN/120kN	2900	28.45	36.47	12.52	1750	17.17	22.01	24.99

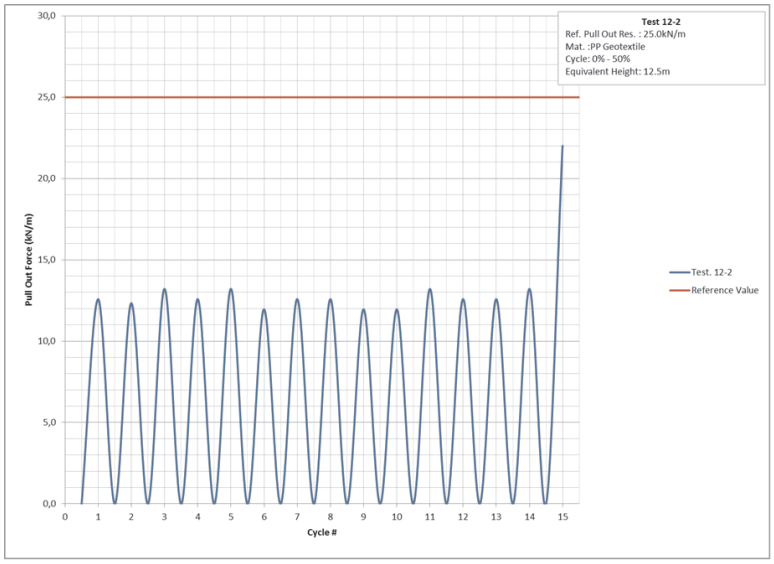


Figure B.67. Graphical Output of Test 12-2.

Table B.68. Test 12-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
12-3	Cyclic 25%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	1890	18.54	23.77	25.42

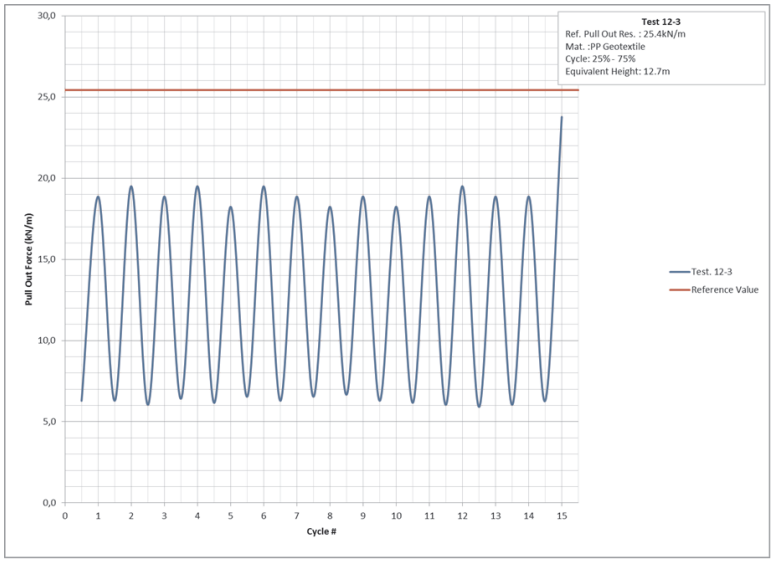


Figure B.68. Graphical Output of Test 12-3.

Table B.69. Test 12-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
12-4	Cyclic 25%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	2050	20.11	25.78	25.42

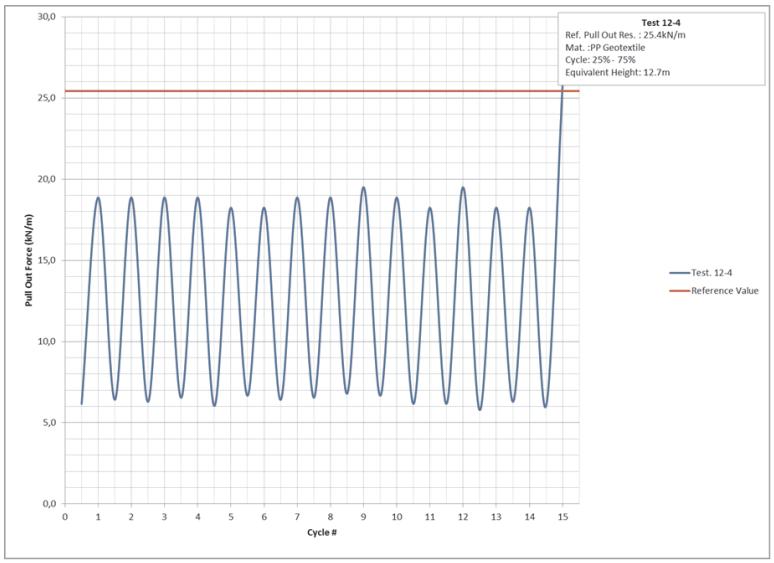


Figure B.69. Graphical Output of Test 12-4.

Table B.70. Test 12-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
12-5	Cyclic 50%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	1880	18.44	23.64	25.42

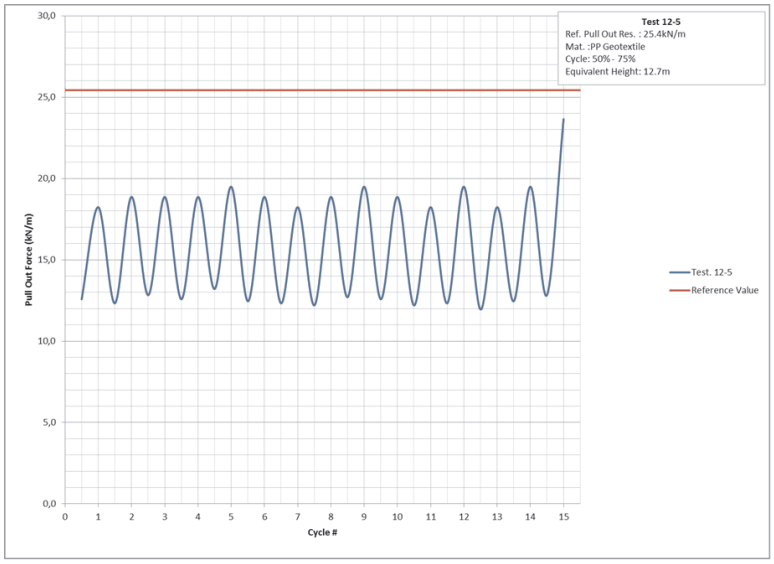


Figure B.70. Graphical Output of Test 12-5.

Table B.71. Test 12-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
12-6	Cyclic 50%-75%	Geotextile 120kN/120kN	2950	28.94	37.10	12.74	1900	18.64	23.90	25.42

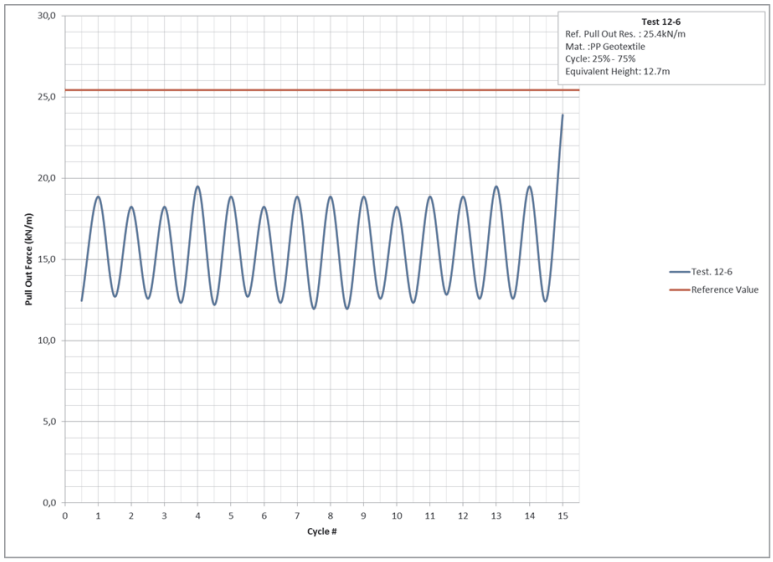


Figure B.71. Graphical Output of Test 12-6.

Table B.72. Test 13-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-1	Cyclic 0%-50%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2300	22.56	28.93	28.02

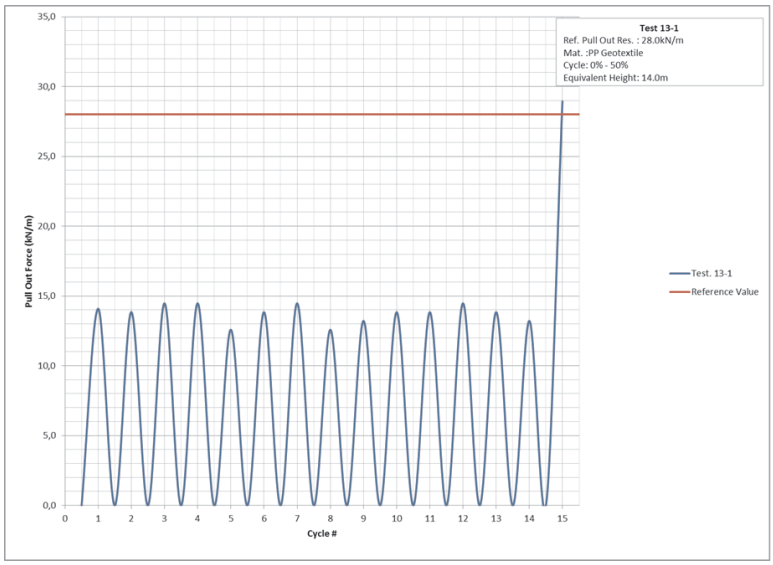


Figure B.72. Graphical Output of Test 13-1.

Table B.73. Test 13-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-2	Cyclic 0%-50%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2040	20.01	25.66	28.02

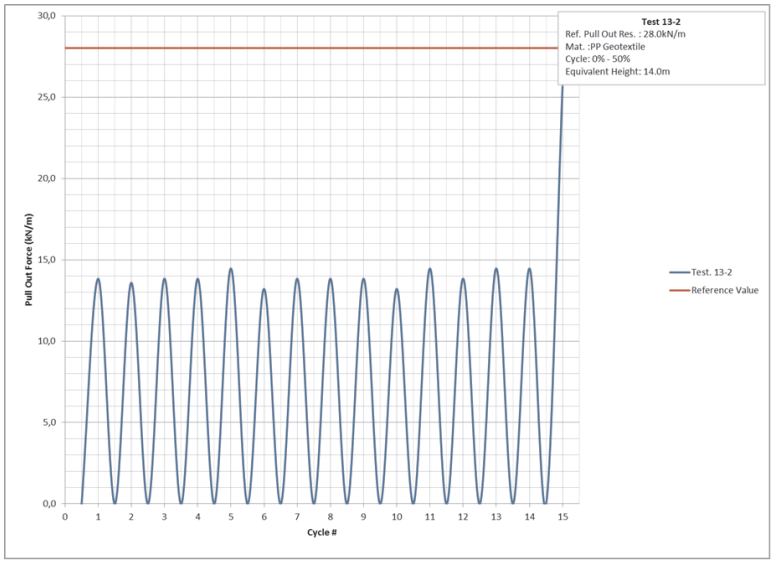


Figure B.73. Graphical Output of Test 13-2.

Table B.74. Test 13-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-3	Cyclic 25%-75%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2150	21.09	27.04	28.02

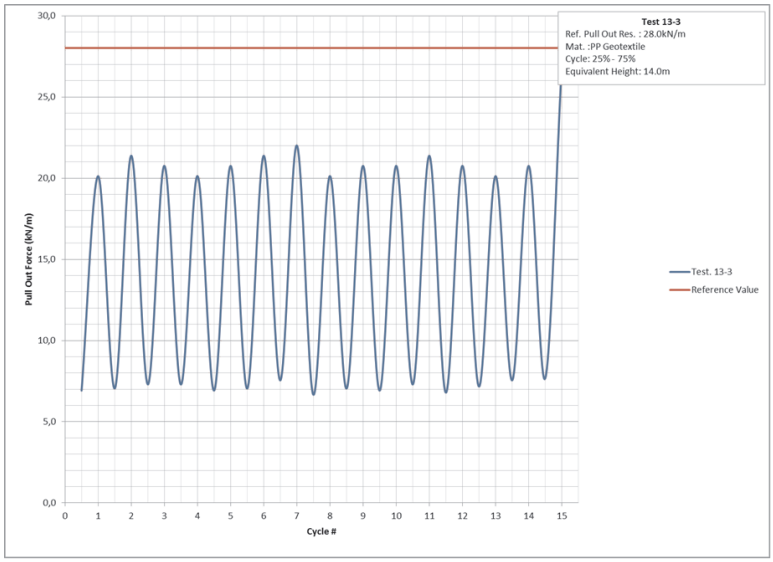


Figure B.74. Graphical Output of Test 13-3.

Table B.75. Test 13-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-4	Cyclic 25%-75%	Geotextile 120kN/120kN	3250	31.88	40.88	14.03	2060	20.21	25.91	28.02

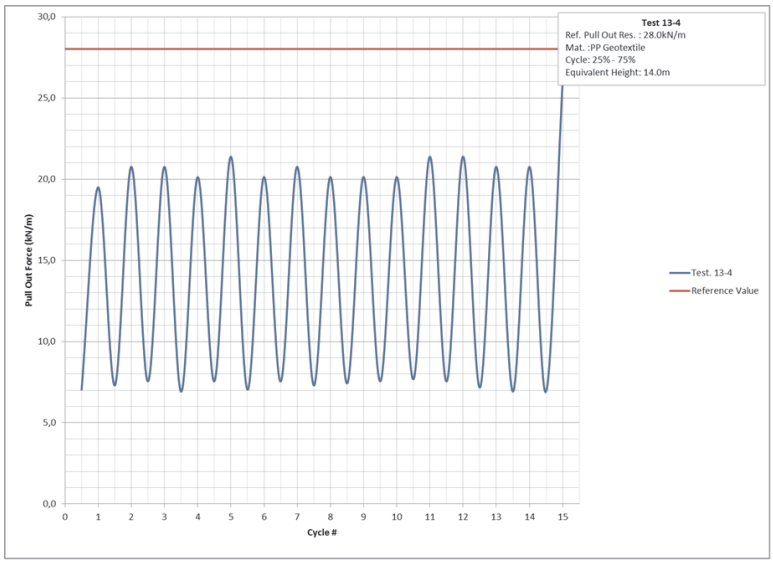


Figure B.75. Graphical Output of Test 13-4.

Table B.76. Test 13-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-5	Cyclic 50%-75%	Geotextile 120kN/120kN	3200	31.39	40.25	13.82	2030	19.91	25.53	27.58

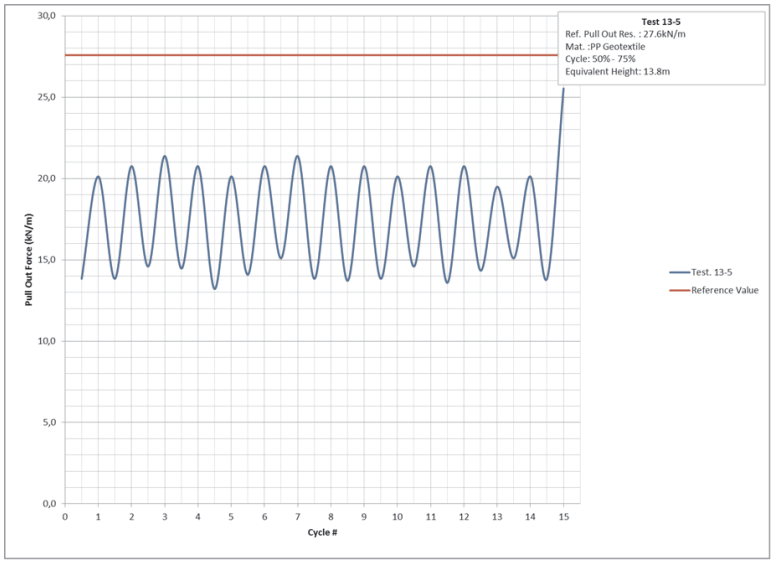


Figure B.76. Graphical Output of Test 13-5.

Table B.77. Test 13-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
13-6	Cyclic 50%-75%	Geotextile 120kN/120kN	3200	31.39	40.25	13.82	2000	19.62	25.15	27.58

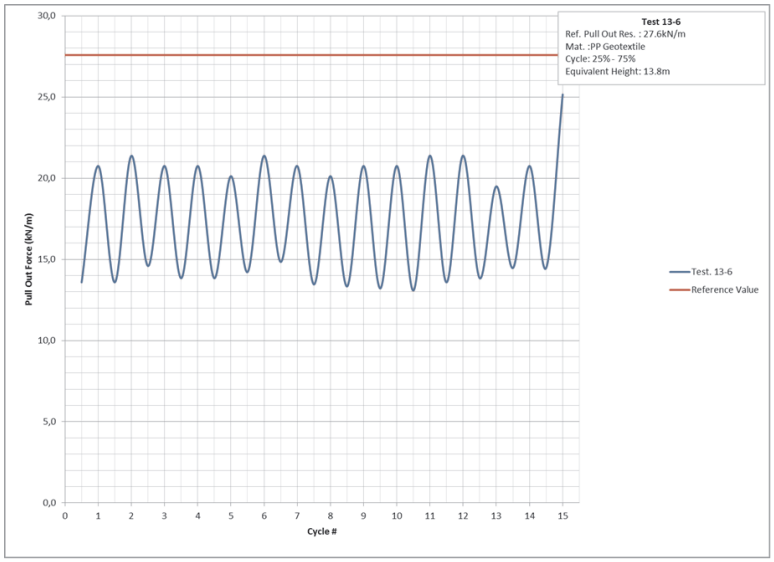


Figure B.77. Graphical Output of Test 13-6.

Table B.78. Test 14-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
14-1	Cyclic 0%-50%	Geotextile 120kN/120kN	150	1.47	1.89	0.65	160	1.57	2.01	2.16

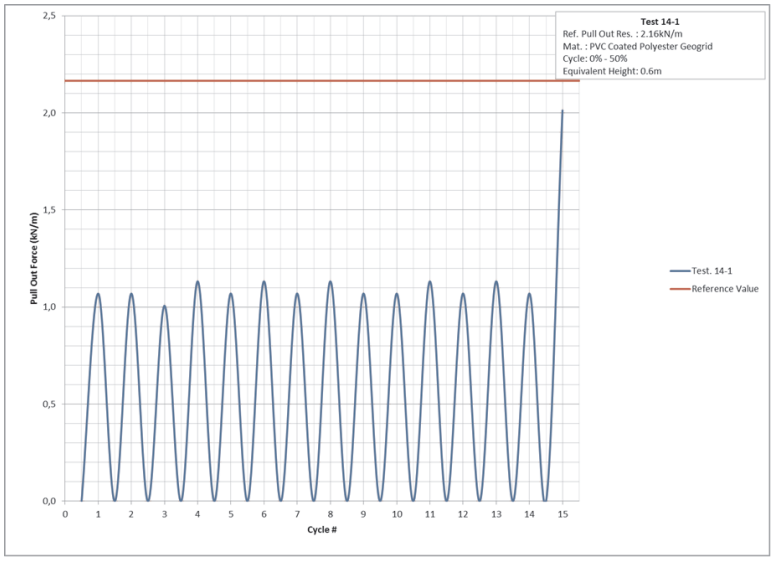


Figure B.78. Graphical Output of Test 14-1.

Table B.79. Test 14-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
14-2	Cyclic 0%-50%	Geotextile 300kN/60kN	150	1.47	1.89	0.65	165	1.62	2.08	2.16

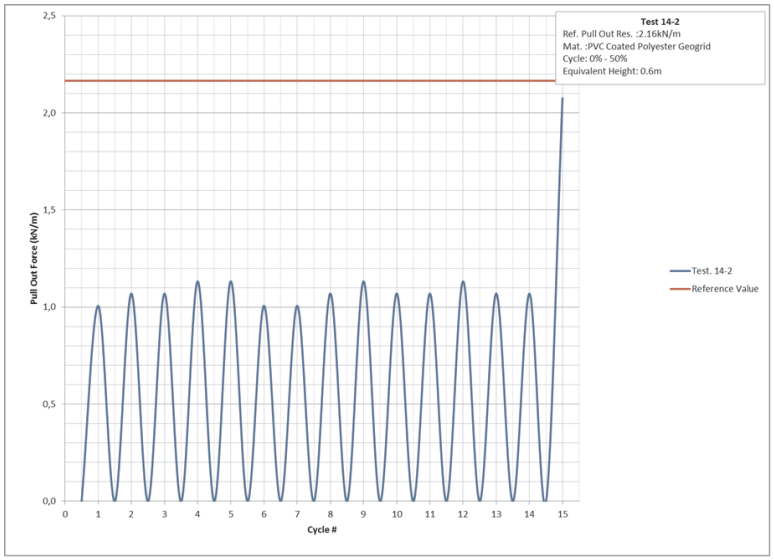


Figure B.79. Graphical Output of Test 14-2.

Table B.80. Test 14-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
14-3	Cyclic 25%-75%	Geotextile 300kN/60kN	150	1.47	1.89	0.65	162	1.59	2.04	2.16

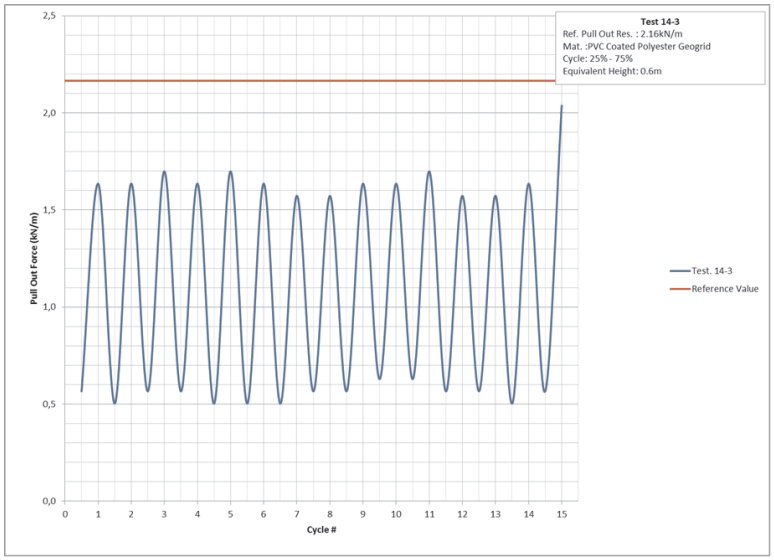


Figure B.80. Graphical Output of Test 14-3.

Table B.81. Test 14-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
14-4	Cyclic 25%-75%	Geotextile 300kN/60kN	150	1.47	1.89	0.65	160	1.57	2.01	2.16

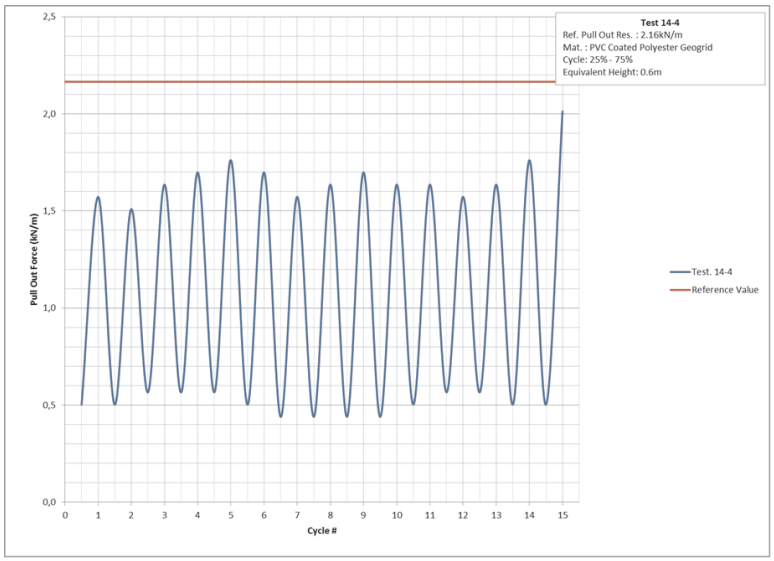


Figure B.81. Graphical Output of Test 14-4.

Table B.82. Test 14-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
14-5	Cyclic 50%-75%	Geotextile 300kN/60kN	160	1.57	2.01	0.69	195	1.91	2.45	2.33

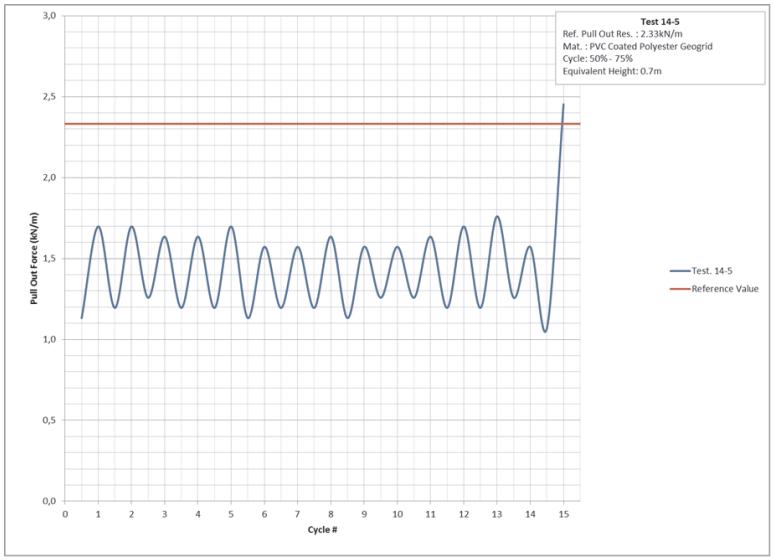


Figure B.82. Graphical Output of Test 14-5.

Table B.83. Test 14-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
14-6	Cyclic 50%-75%	Geotextile 300kN/60kN	160	1.57	2.01	0.69	170	1.67	2.14	2.33

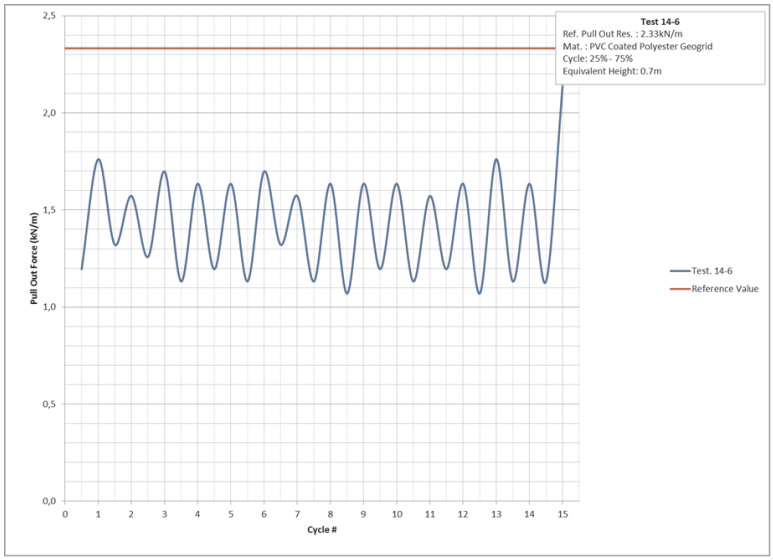


Figure B.83. Graphical Output of Test 14-6.

Table B.84. Test 15-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
15-1	Cyclic 0%-50%	Geotextile 300kN/60kN	350	3.43	4.40	1.51	420	4.12	5.28	5.51

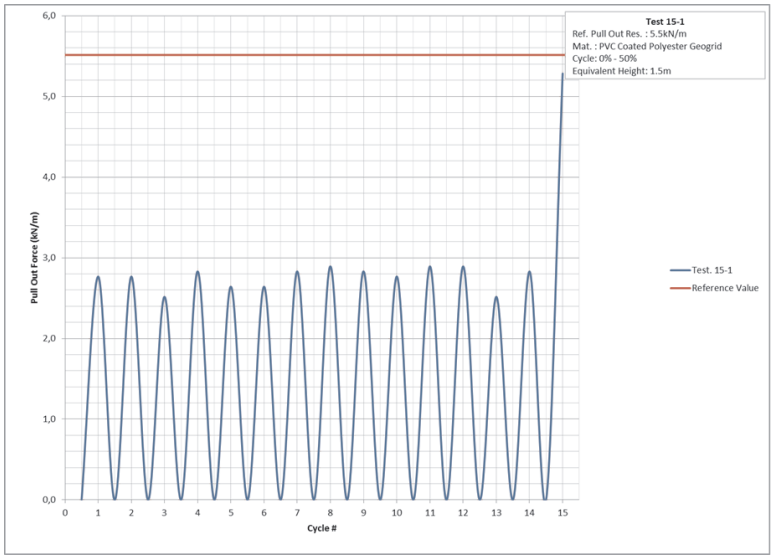


Figure B.84. Graphical Output of Test 15-1.

Table B.85. Test 15-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
15-2	Cyclic 0%-50%	Geotextile 300kN/60kN	350	3.43	4.40	1.51	480	4.71	6.04	5.51

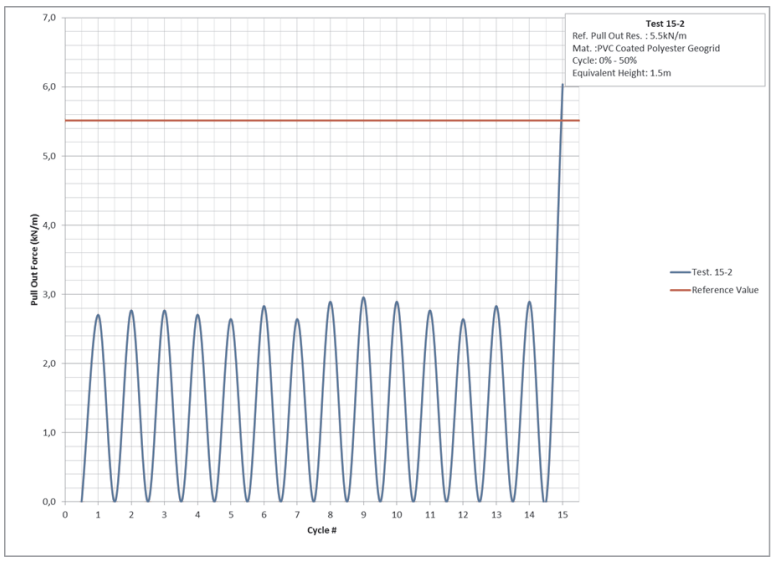


Figure B.85. Graphical Output of Test 15-2.

Table B.86. Test 15-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
15-3	Cyclic 25%-75%	Geotextile 300kN/60kN	350	3.43	4.40	1.51	415	4.07	5.22	5.51

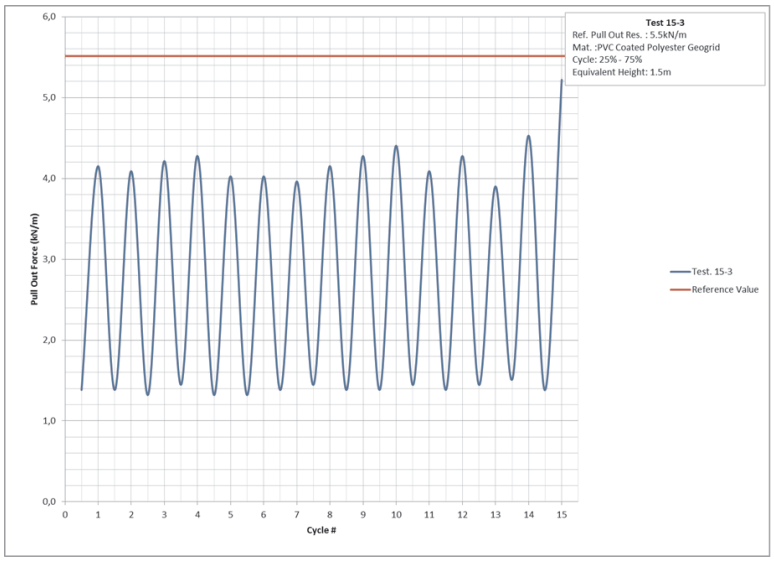


Figure B.86. Graphical Output of Test 15-3.

Table B.87. Test 15-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
15-4	Cyclic 25%-75%	Geotextile 300kN/60kN	350	3.43	4.40	1.51	420	4.12	5.28	5.51

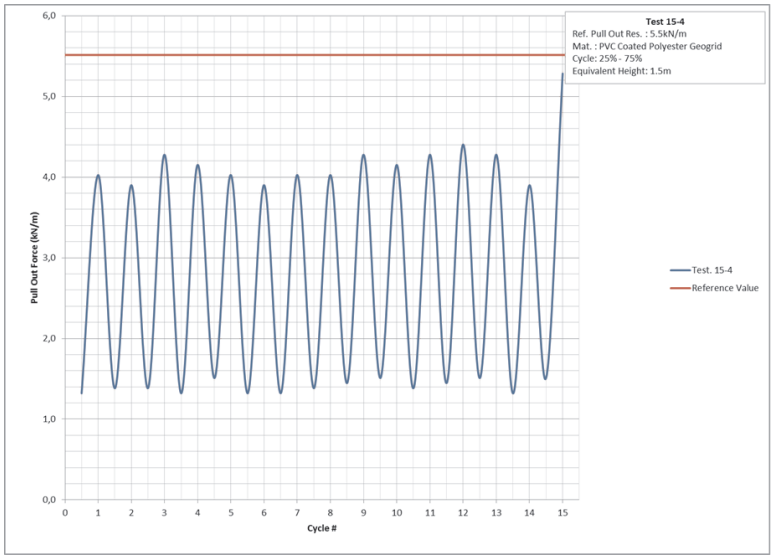


Figure B.87. Graphical Output of Test 15-4.

Table B.88. Test 15-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
15-5	Cyclic 50%-75%	Geotextile 300kN/60kN	350	3.43	4.40	1.51	430	4.22	5.41	5.51

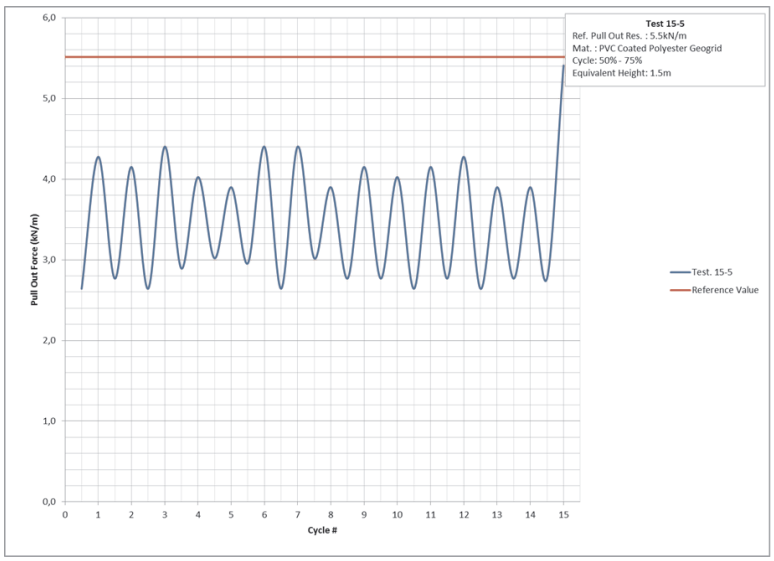


Figure B.88. Graphical Output of Test 15-5.

Table B.89. Test 15-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
15-6	Cyclic 50%-75%	Geotextile 300kN/60kN	350	3.43	4.40	1.51	410	4.02	5.16	5.51

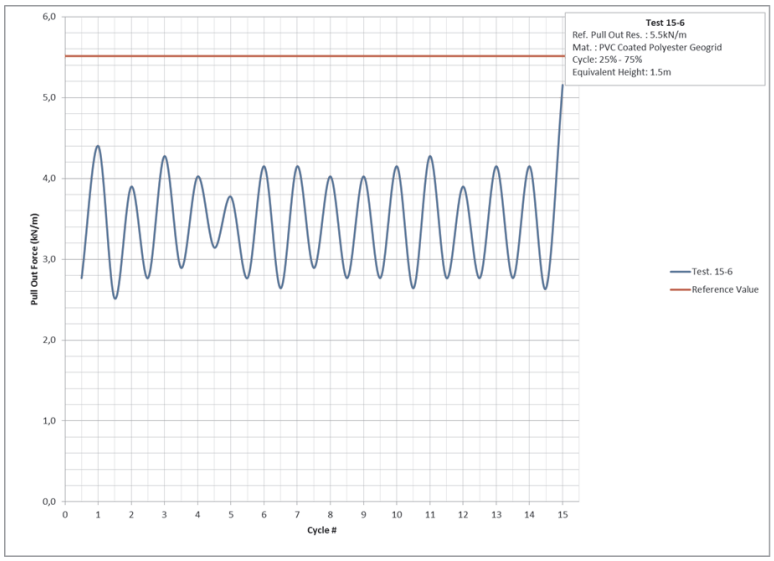


Figure B.89. Graphical Output of Test 15-6.

Table B.90. Test 16-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
16-1	Cyclic 0%-50%	Geotextile 300kN/60kN	550	5.40	6.92	2.38	670	6.57	8.43	8.86

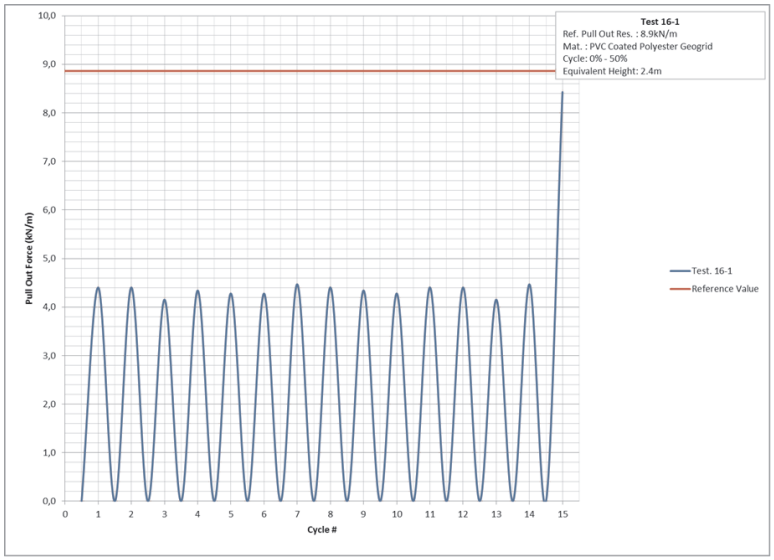


Figure B.90. Graphical Output of Test 16-1.

Table B.91. Test 16-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
16-2	Cyclic 0%-50%	Geotextile 300kN/60kN	550	5.40	6.92	2.38	680	6.67	8.55	8.86

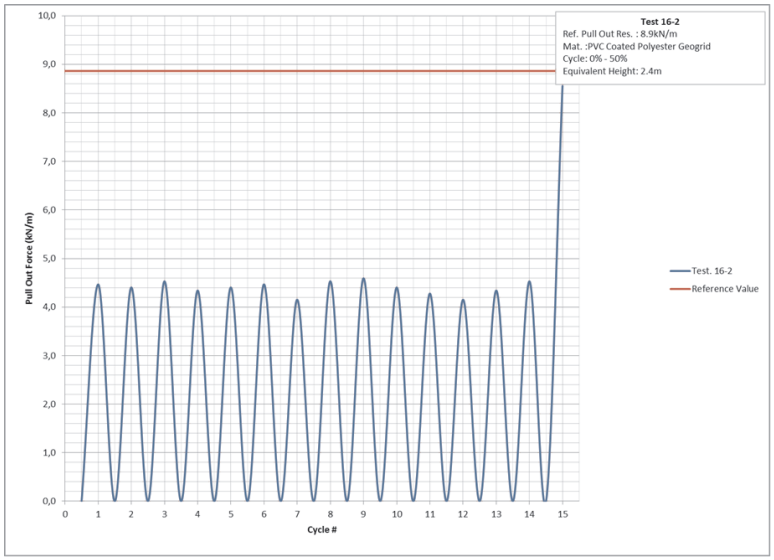


Figure B.91. Graphical Output of Test 16-2.

Table B.92. Test 16-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
16-3	Cyclic 25%-75%	Geotextile 300kN/60kN	560	5.49	7.04	2.42	660	6.47	8.30	9.03

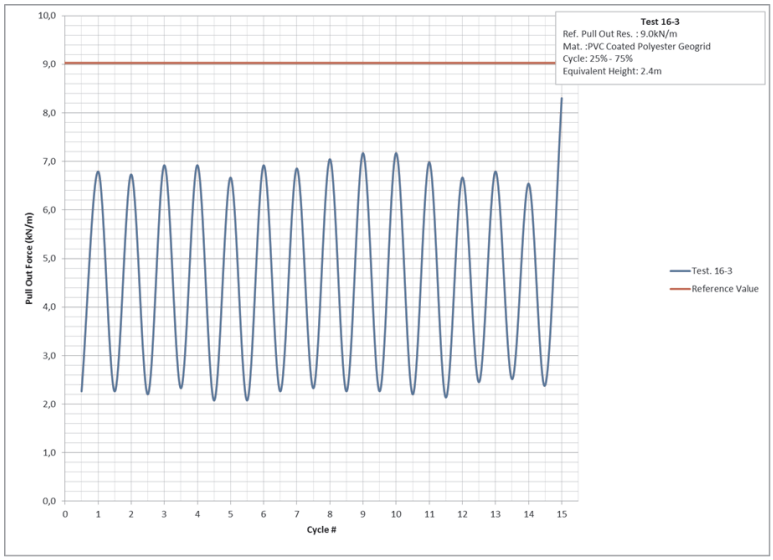


Figure B.92. Graphical Output of Test 16-3.

Table B.93. Test 16-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
16-4	Cyclic 25%-75%	Geotextile 300kN/60kN	560	5.49	7.04	2.42	690	6.77	8.68	9.03

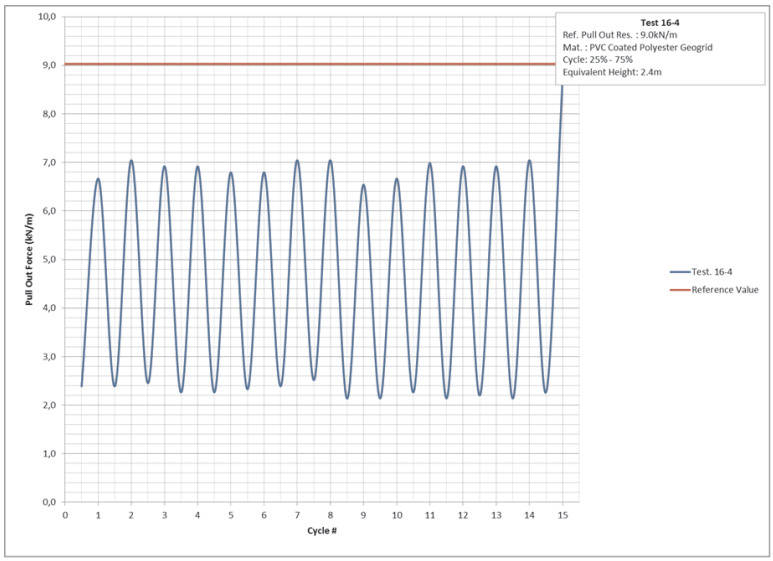


Figure B.93. Graphical Output of Test 16-4.

Table B.94. Test 16-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
16-5	Cyclic 50%-75%	Geotextile 300kN/60kN	550	5.40	6.92	2.38	690	6.77	8.68	8.86

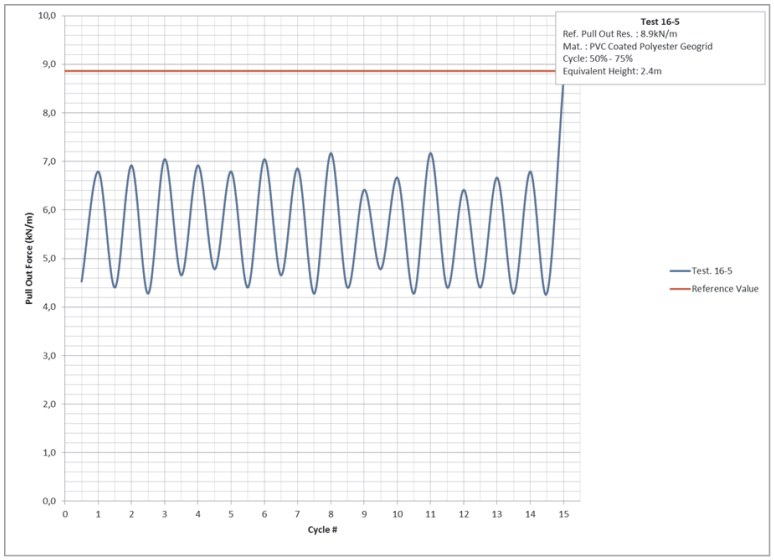


Figure B.94. Graphical Output of Test 16-5.

Table B.95. Test 16-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
16-6	Cyclic 50%-75%	Geotextile 300kN/60kN	550	5.40	6.92	2.38	660	6.47	8.30	8.86

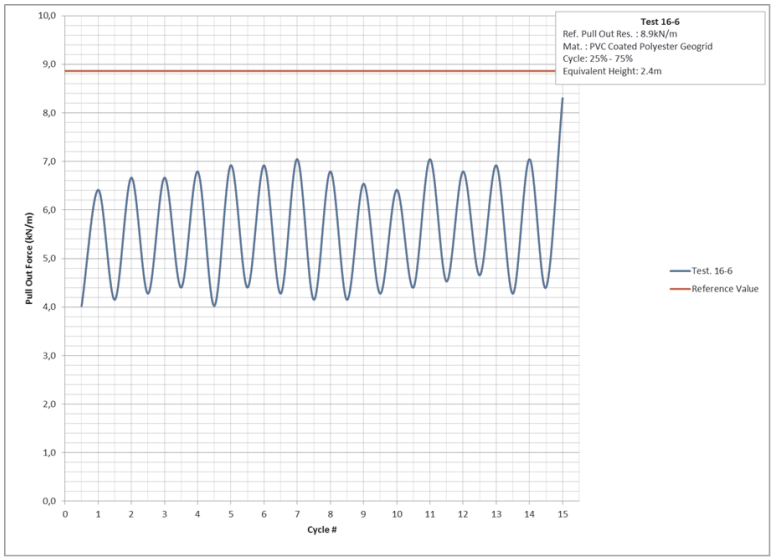


Figure B.95. Graphical Output of Test 16-6.

Table B.96. Test 17-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-1	Cyclic 0%-50%	Geotextile 300kN/60kN	740	7.26	9.31	3.20	920	9.03	11.57	12.04

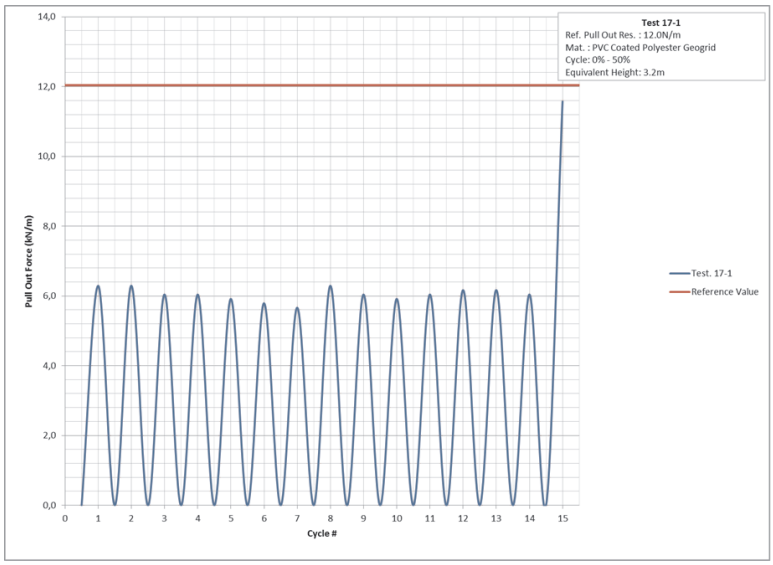


Figure B.96. Graphical Output of Test 17-1.

Table B.97. Test 17-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-2	Cyclic 0%-50%	Geotextile 300kN/60kN	740	7.26	9.31	3.20	910	8.93	11.45	12.04

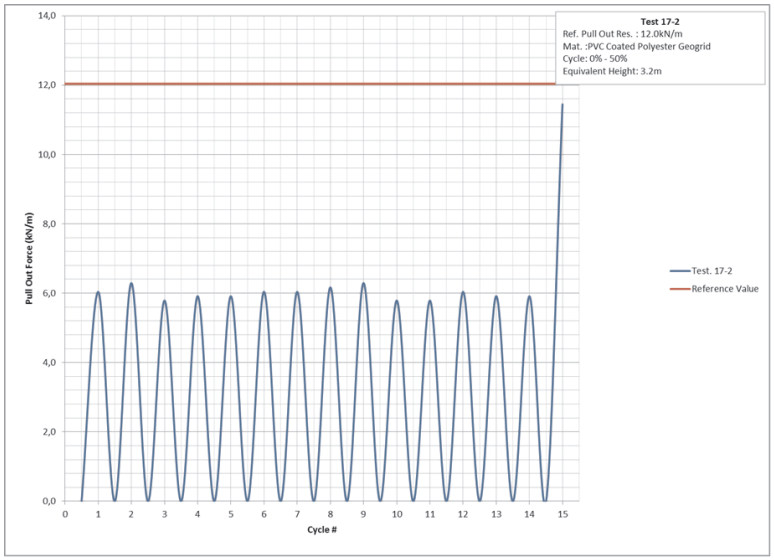


Figure B.97. Graphical Output of Test 17-2.

Table B.98. Test 17-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-3	Cyclic 25%-75%	Geotextile 300kN/60kN	750	7.36	9.43	3.24	910	8.93	11.45	12.21

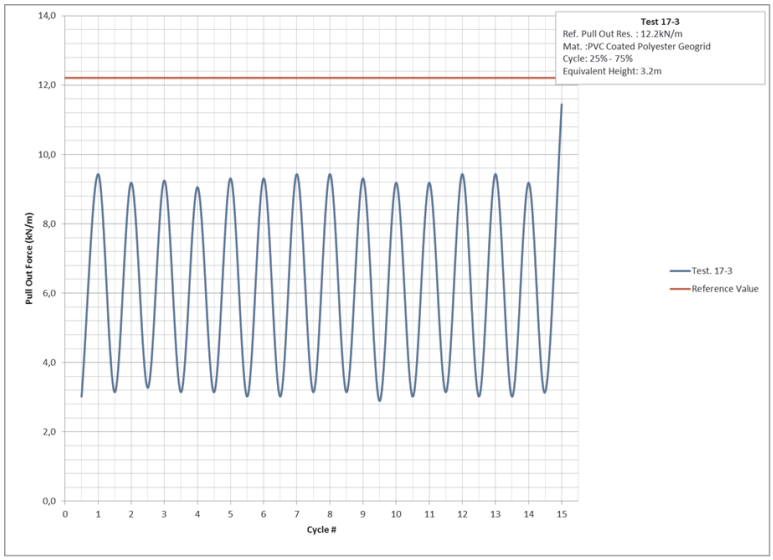


Figure B.98. Graphical Output of Test 17-3.

Table B.99. Test 17-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-4	Cyclic 25%-75%	Geotextile 300kN/60kN	750	7.36	9.43	3.24	910	8.93	11.45	12.21

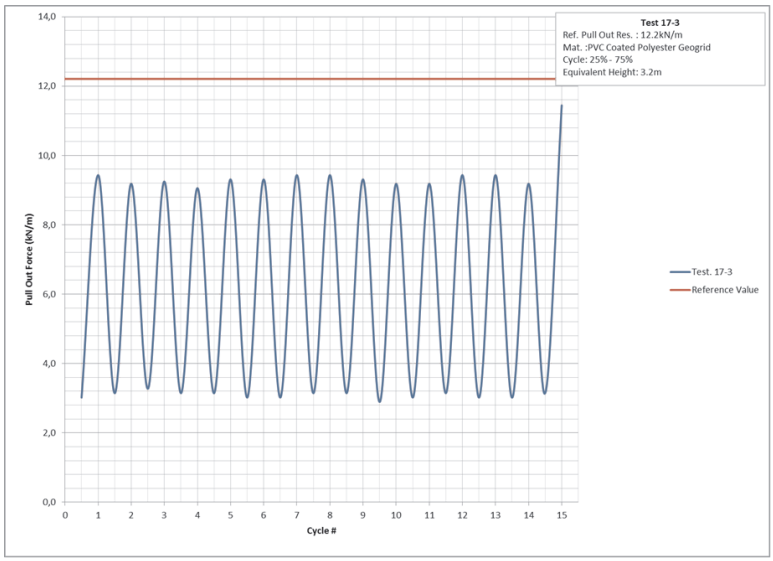


Figure B.99. Graphical Output of Test 17-4.

Table B.100. Test 17-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-5	Cyclic 50%-75%	Geotextile 300kN/60kN	740	7.36	9.31	3.20	920	9.03	11.57	12.04

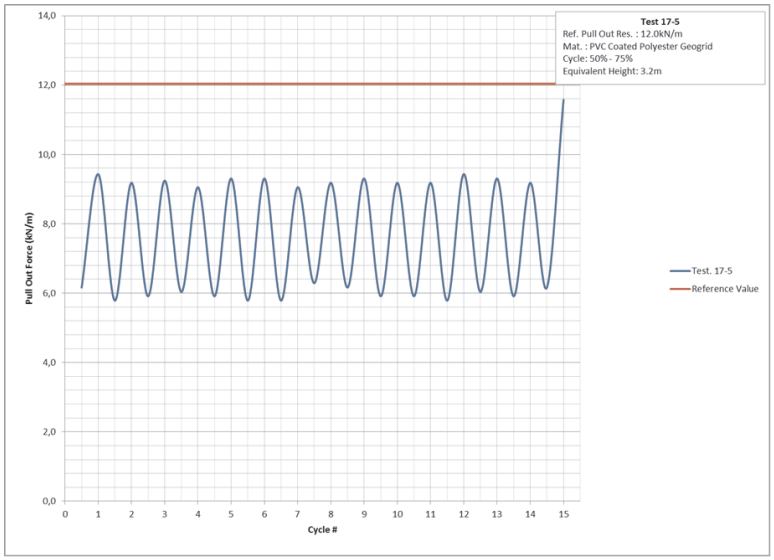


Figure B.100. Graphical Output of Test 17-5.

Table B.101. Test 17-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
17-6	Cyclic 50%-75%	Geotextile 300kN/60kN	740	7.26	9.31	3.20	910	8.93	11.45	12.04

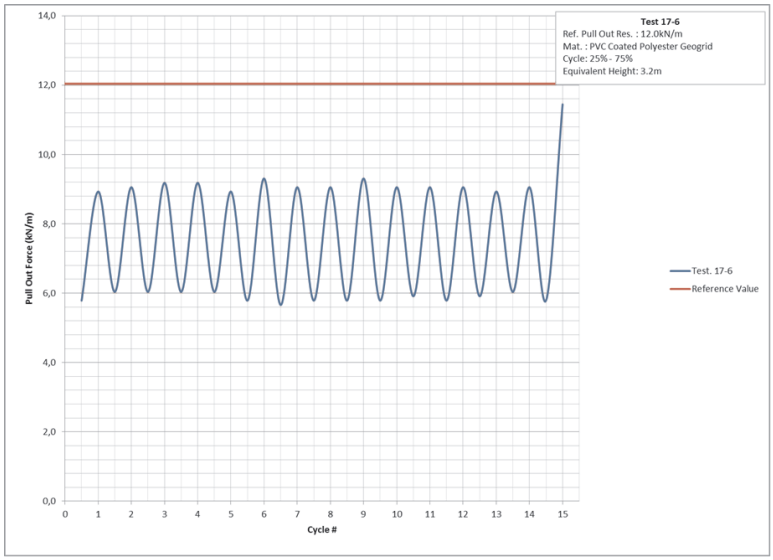


Figure B.101. Graphical Output of Test 17-6.

Table B.102. Test 18-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-1	Cyclic 0%-50%	Geotextile 300kN/60kN	950	9.32	11.95	4.10	1190	11.67	14.97	15.56

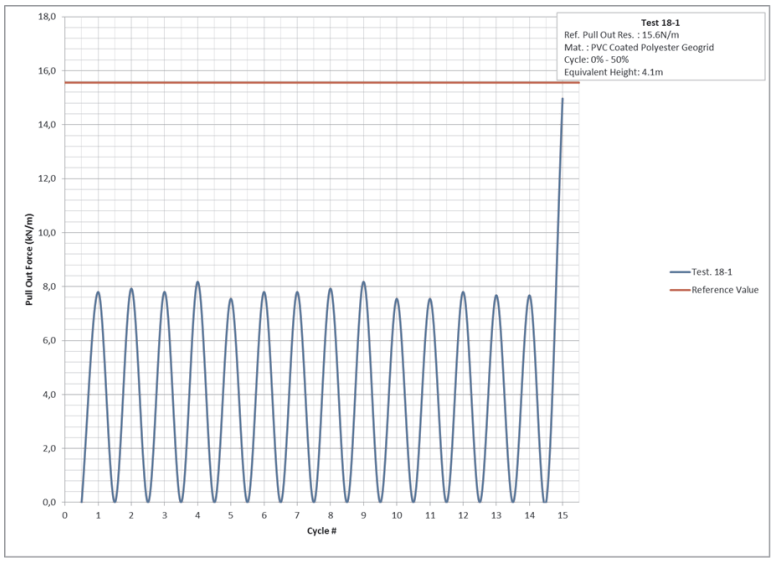


Figure B.102. Graphical Output of Test 18-1.

Table B.103. Test 18-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-2	Cyclic 0%-50%	Geotextile 300kN/60kN	950	9.32	11.95	4.10	1180	11.58	14.84	15.56

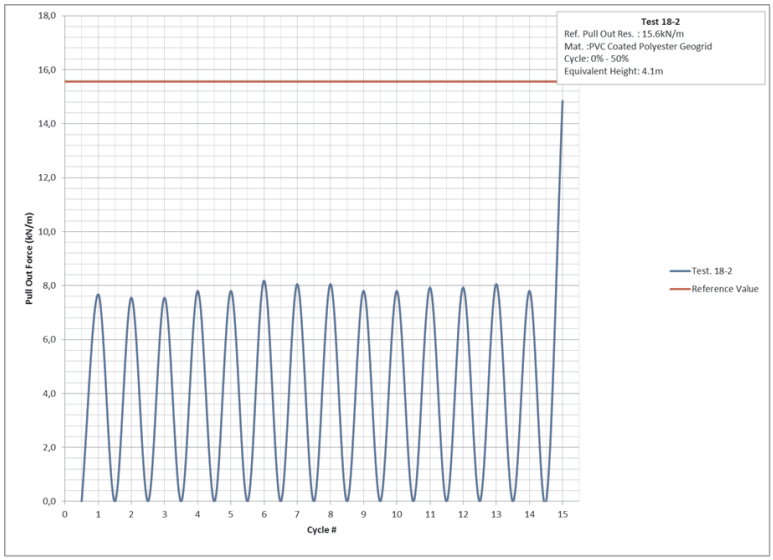


Figure B.103. Graphical Output of Test 18-2.

Table B.104. Test 18-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-3	Cyclic 25%-75%	Geotextile 300kN/60kN	950	9.32	11.95	4.10	1170	11.48	14.72	15.56

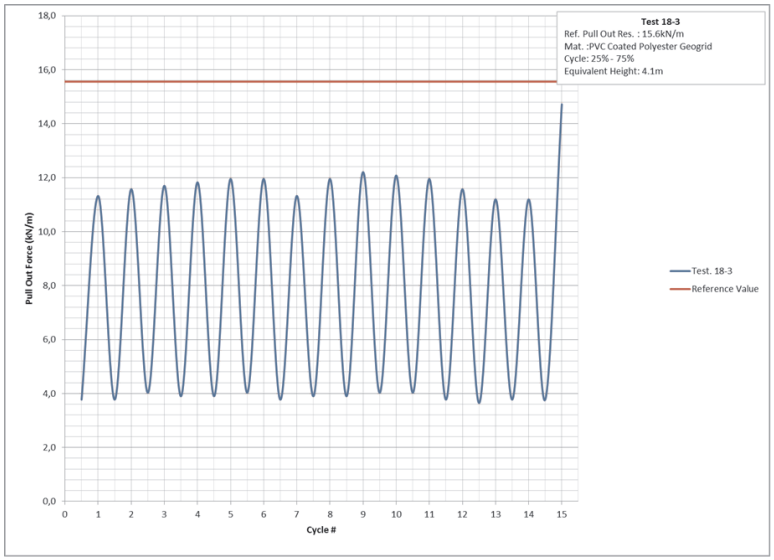


Figure B.104. Graphical Output of Test 18-3.

Table B.105. Test 18-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-4	Cyclic 25%-75%	Geotextile 300kN/60kN	950	9.32	11.95	4.10	1150	11.28	14.46	15.56

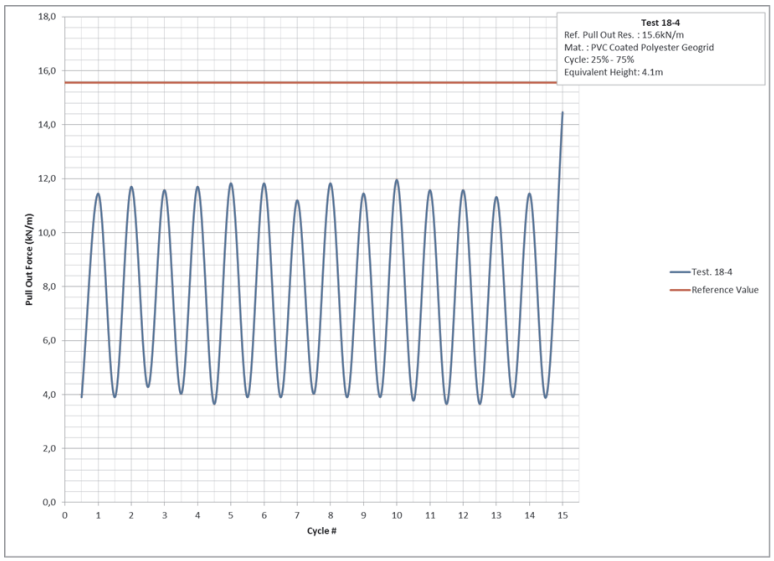


Figure B.105. Graphical Output of Test 18-4.

Table B.106. Test 18-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-5	Cyclic 50%-75%	Geotextile 300kN/60kN	950	9.32	11.95	4.10	1170	11.48	14.72	15.56

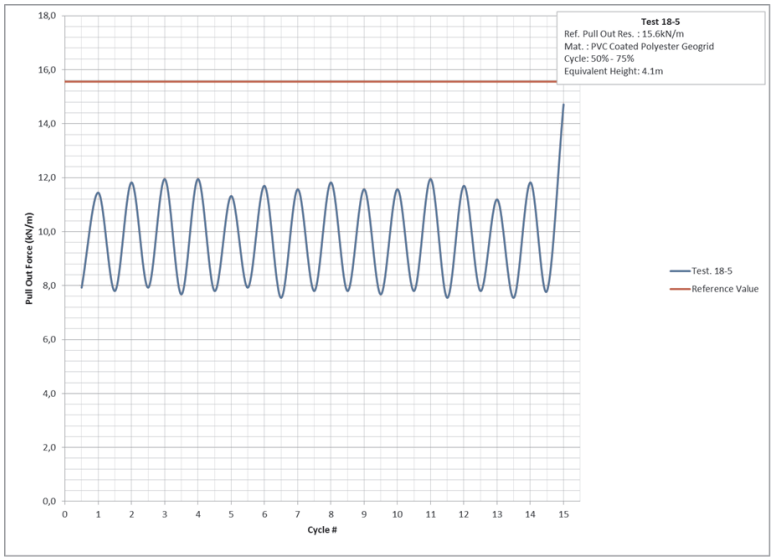


Figure B.106. Graphical Output of Test 18-5.

Table B.107. Test 18-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
18-6	Cyclic 50%-75%	Geotextile 300kN/60kN	950	9.32	11.95	4.10	1180	11.58	14.84	15.56

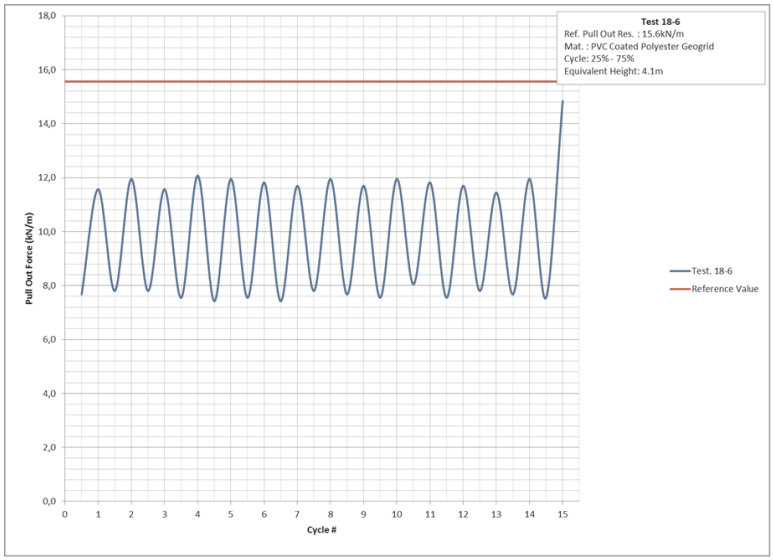


Figure B.107. Graphical Output of Test 18-6.

Table B.108. Test 19-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
19-1	Cyclic 0%-50%	Geotextile 300kN/60kN	1150	11.28	14.46	4.97	1420	13.93	17.86	18.90

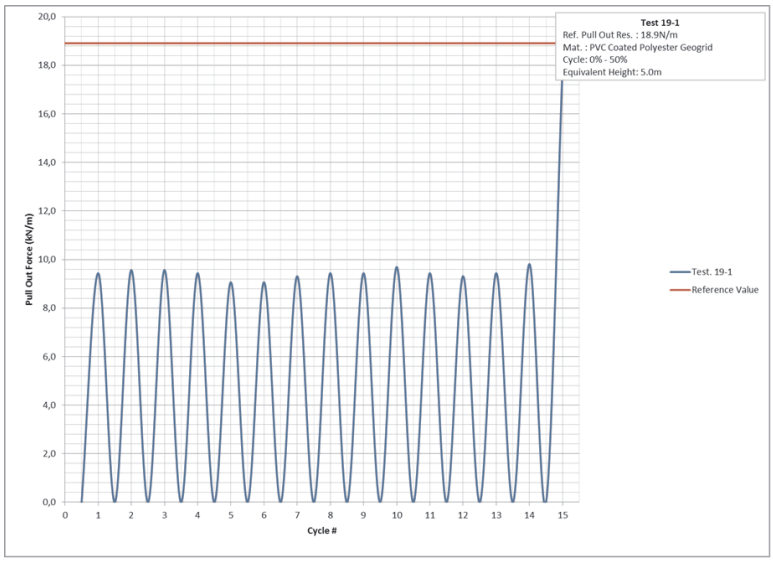


Figure B.108. Graphical Output of Test 19-1.

Table B.109. Test 19-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
19-2	Cyclic 0%-50%	Geotextile 300kN/60kN	1150	11.28	14.45	4.97	1450	14.22	18.24	18.90

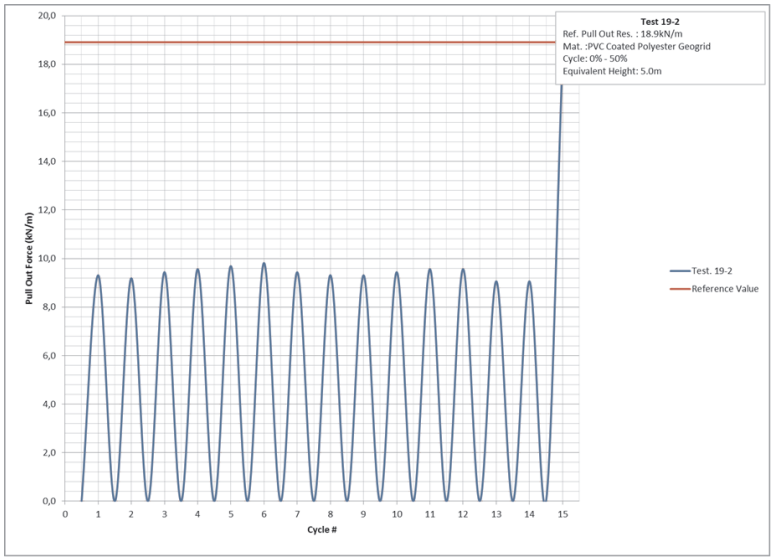


Figure B.109. Graphical Output of Test 19-2.

Table B.110. Test 19-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
19-3	Cyclic 25%-75%	Geotextile 300kN/60kN	1100	11.79	13.83	4.75	1370	13.44	17.23	18.07

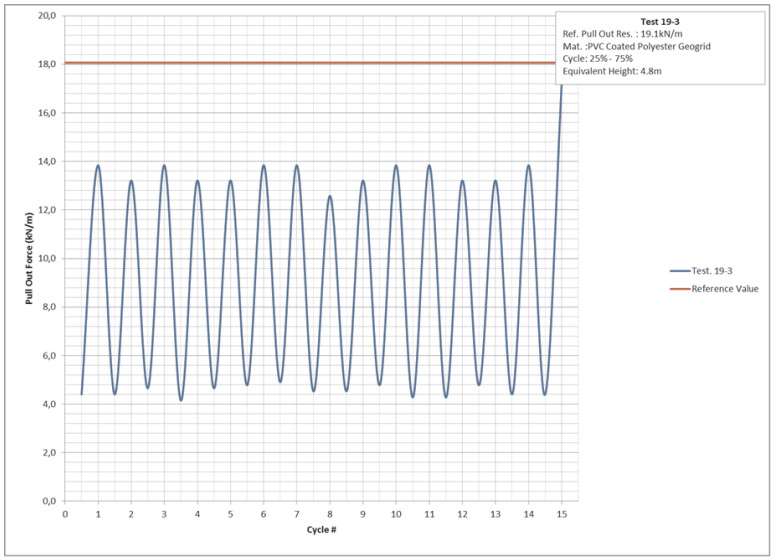


Figure B.110. Graphical Output of Test 19-3.

Table B.111. Test 19-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
19-4	Cyclic 25%-75%	Geotextile 300kN/60kN	1100	11.79	13.83	4.75	1380	13.54	17.36	18.07

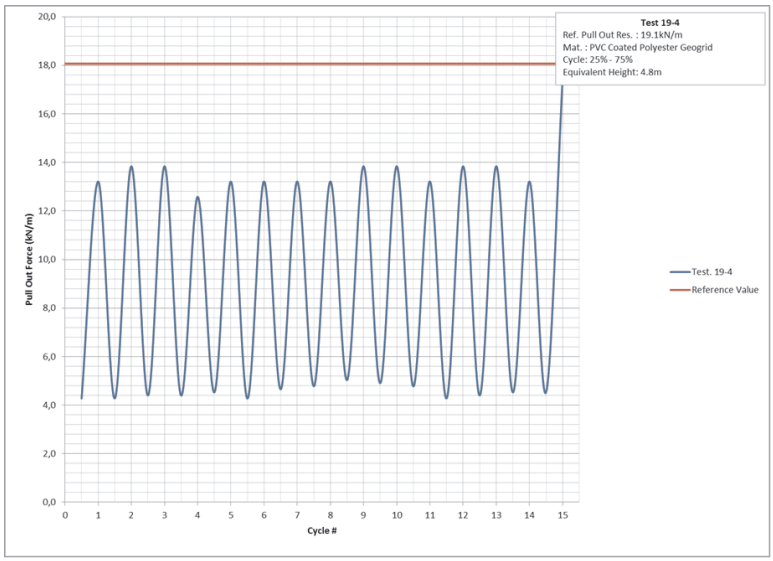


Figure B.111. Graphical Output of Test 19-4.

Table B.112. Test 19-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
19-5	Cyclic 50%-75%	Geotextile 300kN/60kN	1150	11.28	14.46	4.97	1400	13.73	17.61	18.90

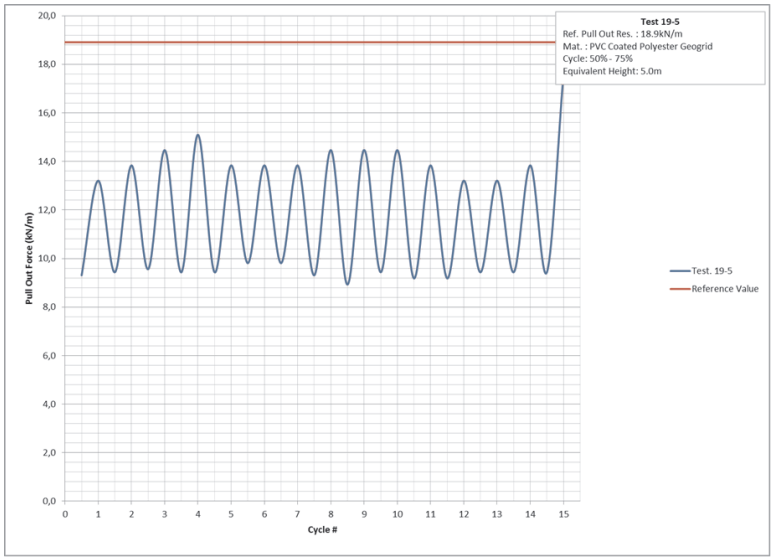


Figure B.112. Graphical Output of Test 19-5.

Table B.113. Test 19-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
19-6	Cyclic 50%-75%	Geotextile 300kN/60kN	1150	11.28	14.46	4.97	1450	14.22	18.24	18.90

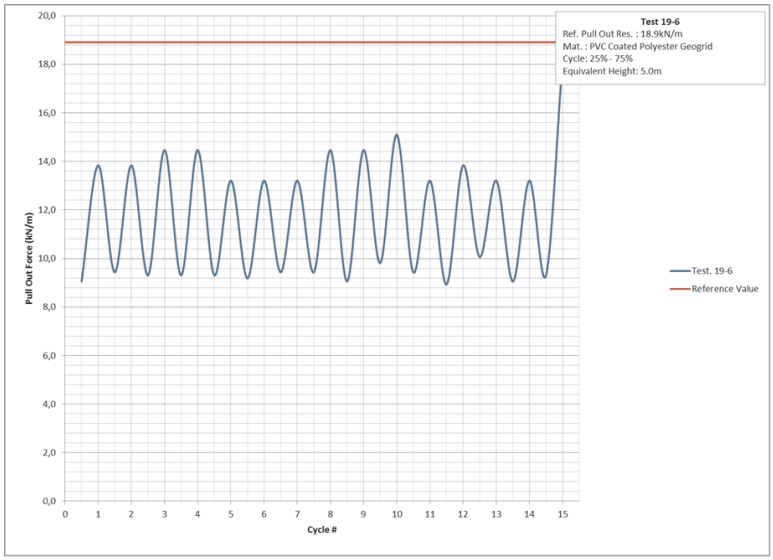


Figure B.113. Graphical Output of Test 19-6.

Table B.114. Test 20-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
20-1	Cyclic 0%-50%	Geotextile 300kN/60kN	1450	14.22	18.24	6.26	1820	17.85	22.89	23.93

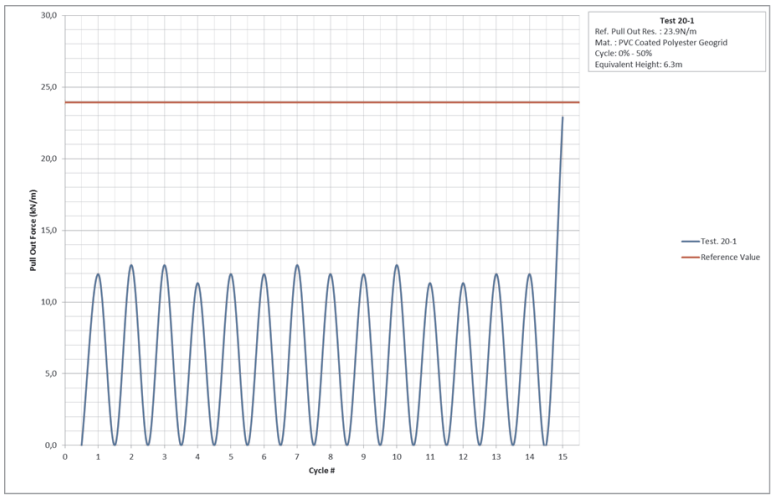


Figure B.114. Graphical Output of Test 20-1.

Table B.115. Test 20-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
20-2	Cyclic 0%-50%	Geotextile 300kN/60kN	1450	14.22	18.24	6.26	1770	17.36	22.26	23.93

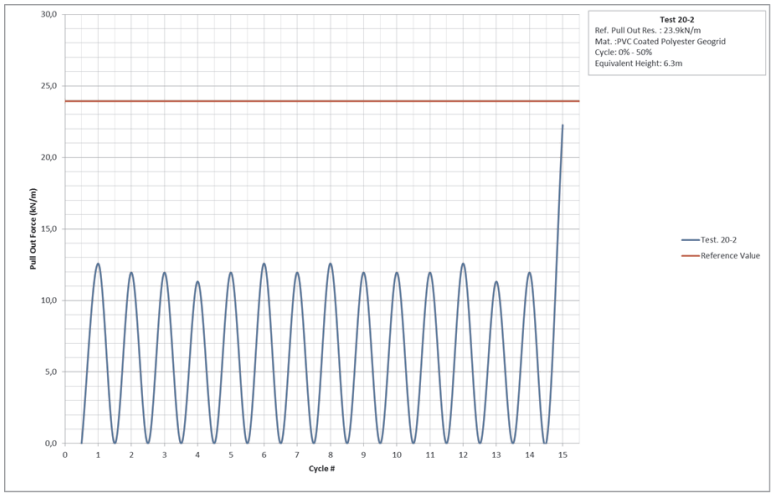


Figure B.115. Graphical Output of Test 20-2.

Table B.116. Test 20-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
20-3	Cyclic 25%-75%	Geotextile 300kN/60kN	1450	14.22	18.24	6.26	1830	17.95	23.02	23.93

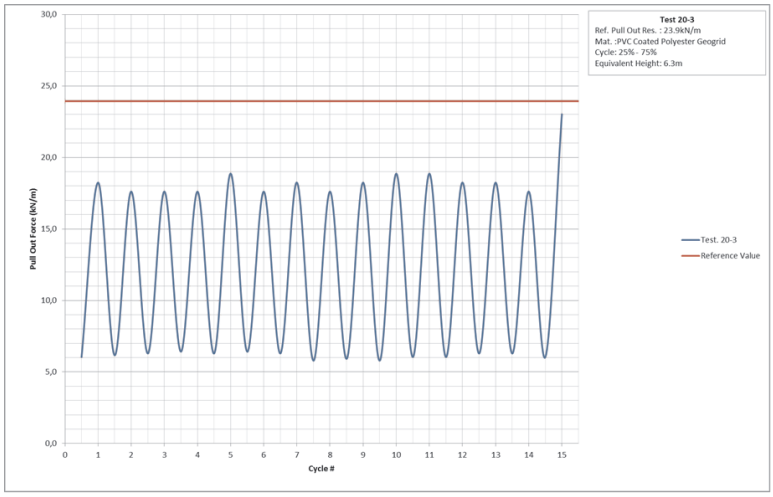


Figure B.116. Graphical Output of Test 20-3.

Table B.117. Test 20-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
20-4	Cyclic 25%-75%	Geotextile 300kN/60kN	1450	14.22	18.24	6.26	1750	17.17	22.01	23.93

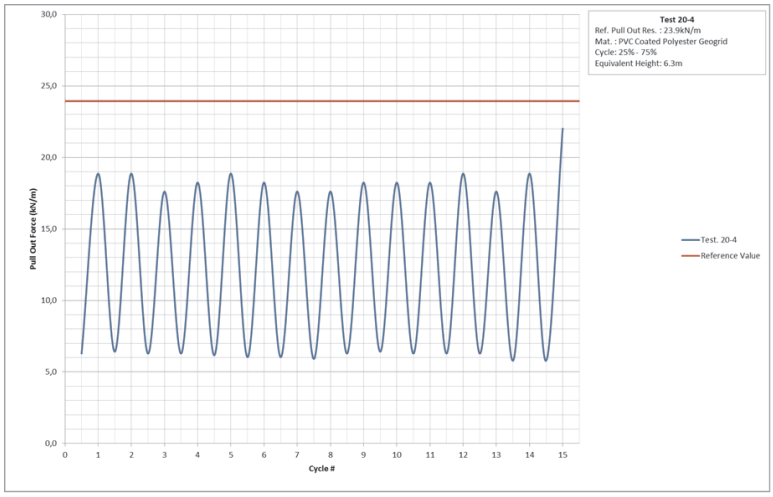


Figure B.117. Graphical Output of Test 20-4.

Table B.118. Test 20-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
20-5	Cyclic 50%-75%	Geotextile 300kN/60kN	1450	14.22	18.24	6.26	1820	17.85	22.89	23.93

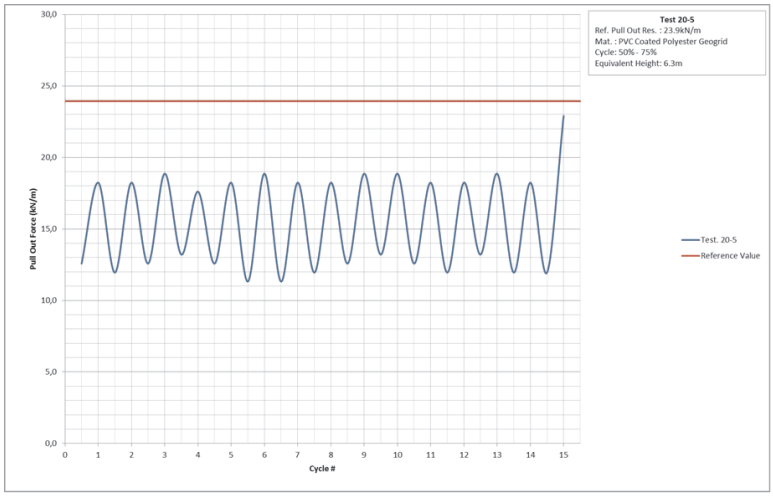


Figure B.118. Graphical Output of Test 20-5.

Table B.119. Test 20-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
20-6	Cyclic 50%-75%	Geotextile 300kN/60kN	1450	14.22	18.24	6.26	1920	18.84	24.15	23.93

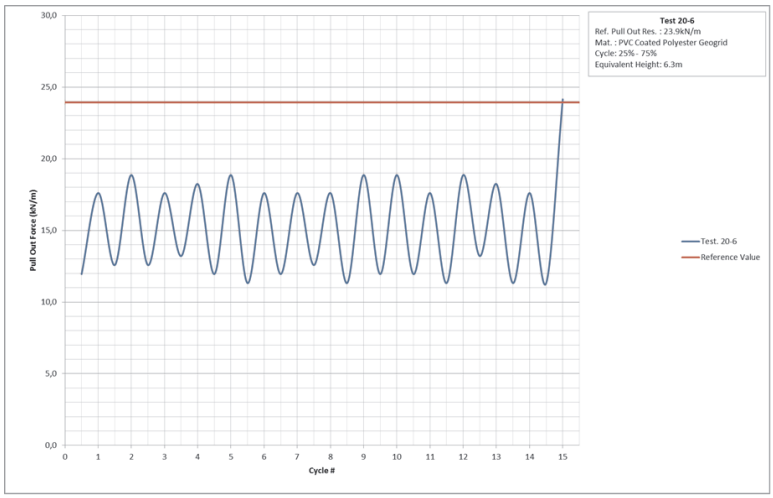


Figure B.119. Graphical Output of Test 20-6.

Table B.120. Test 21-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-1	Cyclic 0%-50%	Geotextile 300kN/60kN	1750	17.17	22.01	7.56	2290	22.46	28.80	28.95

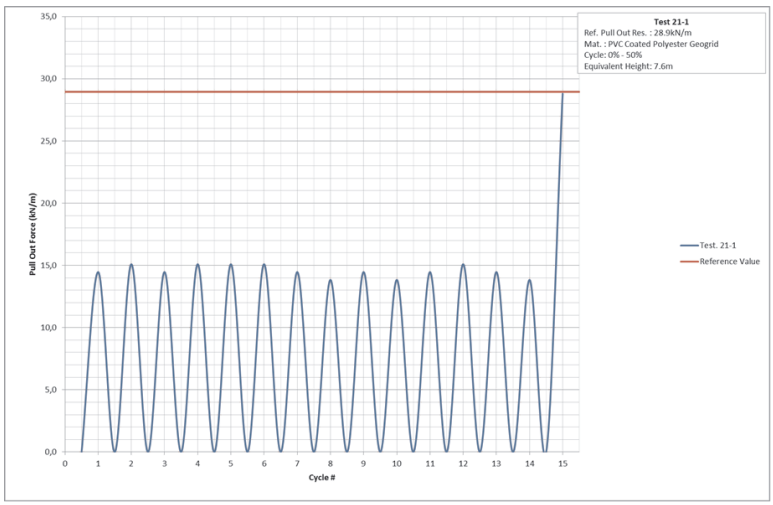


Figure B.120. Graphical Output of Test 21-1.

Table B.121. Test 21-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-2	Cyclic 0%-50%	Geotextile 300kN/60kN	1750	17.17	22.01	7.56	2210	21.68	27.80	28.95

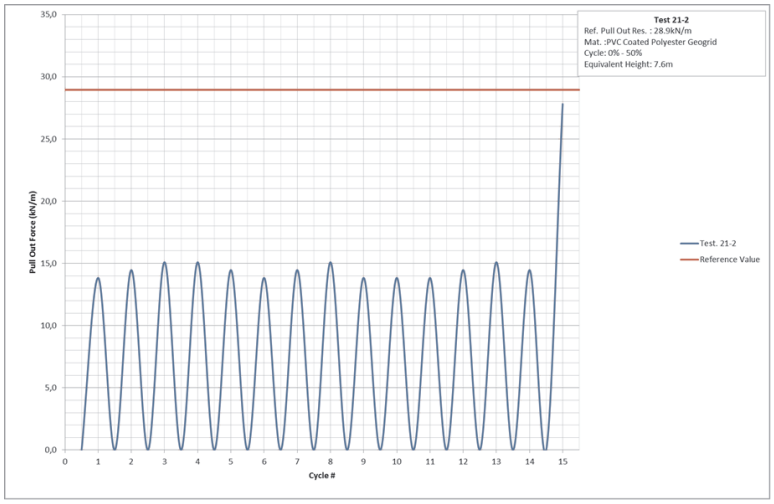


Figure B.121. Graphical Output of Test 21-2.

Table B.122. Test 21-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-3	Cyclic 25%-75%	Geotextile 300kN/60kN	1800	17.66	22.64	7.77	2200	21.58	27.67	29.79

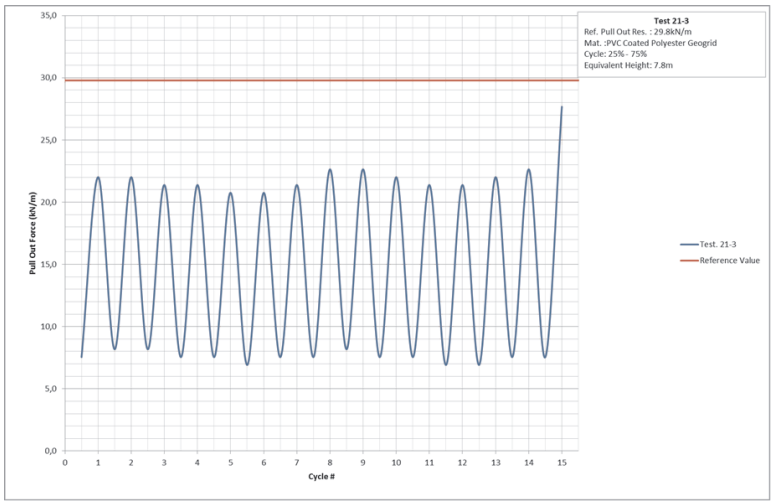


Figure B.122. Graphical Output of Test 21-3.

Table B.123. Test 21-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-4	Cyclic 25%-75%	Geotextile 300kN/60kN	1800	17.66	22.64	7.77	2250	22.07	28.30	29.79

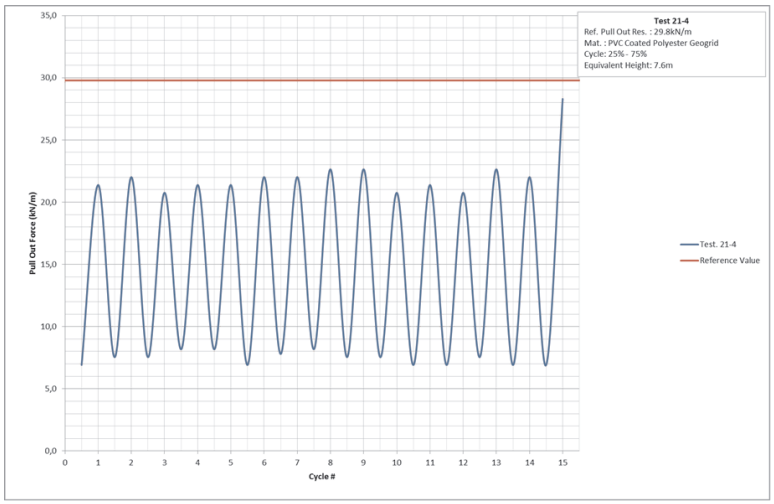


Figure B.123. Graphical Output of Test 21-4.

Table B.124. Test 21-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-5	Cyclic 50%-75%	Geotextile 300kN/60kN	1750	17.17	22.01	7.56	2200	21.58	22.67	28.95

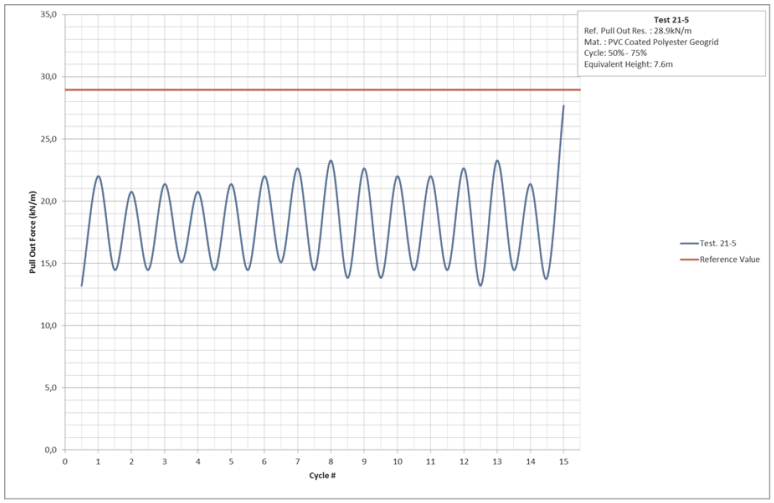


Figure B.124. Graphical Output of Test 21-5.

Table B.125. Test 21-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
21-6	Cyclic 50%-75%	Geotextile 300kN/60kN	1750	17.17	22.01	7.56	2200	21.58	22.67	28.95

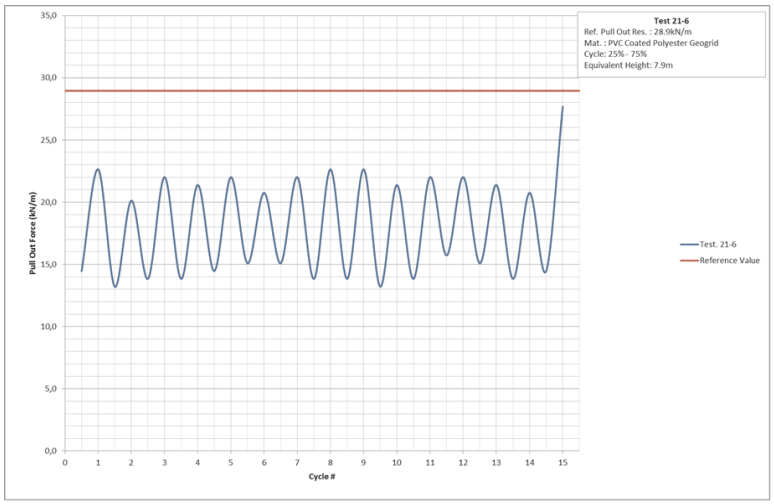


Figure B.125. Graphical Output of Test 21-6.

Table B.126. Test 22-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
22-1	Cyclic 0%-50%	Geotextile 300kN/60kN	2100	20.60	26.41	9.07	2670	26.19	33.58	34.81

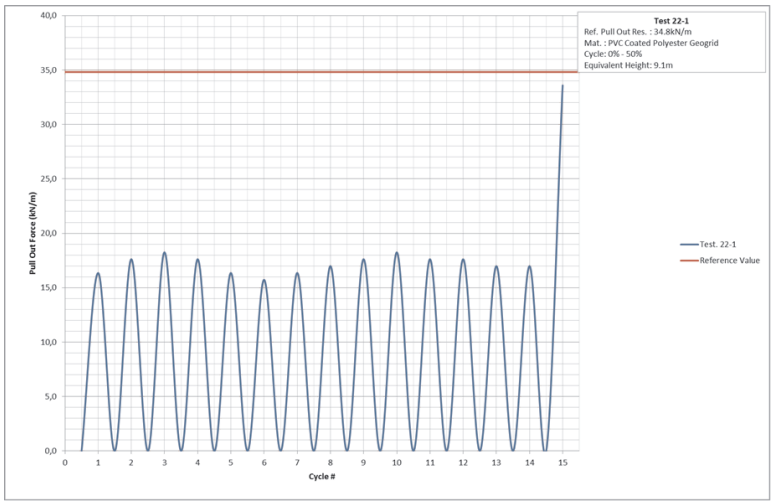


Figure B.126. Graphical Output of Test 22-1.

Table B.127. Test 22-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
22-2	Cyclic 0%-50%	Geotextile 300kN/60kN	2100	20.60	26.41	9.07	2600	25.51	32.70	34.81

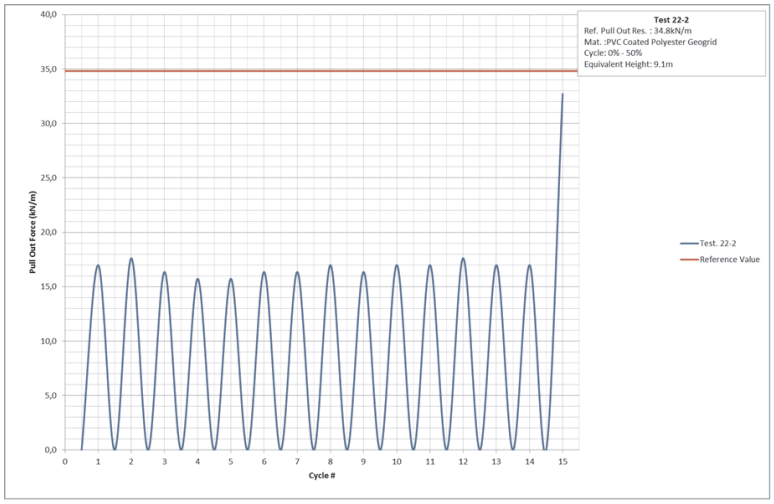


Figure B.127. Graphical Output of Test 22-2.

Table B.128. Test 22-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
22-3	Cyclic 25%-75%	Geotextile 300kN/60kN	2050	20.11	25.78	8.85	2600	25.51	32.70	33.97

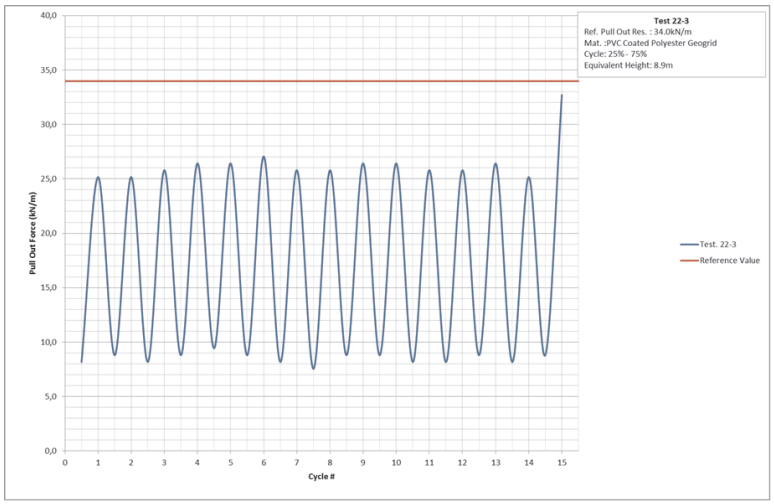


Figure B.128. Graphical Output of Test 22-3.

Table B.129. Test 22-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
22-4	Cyclic 25%-75%	Geotextile 300kN/60kN	2050	20.11	25.78	8.85	2550	25.02	32.07	33.97

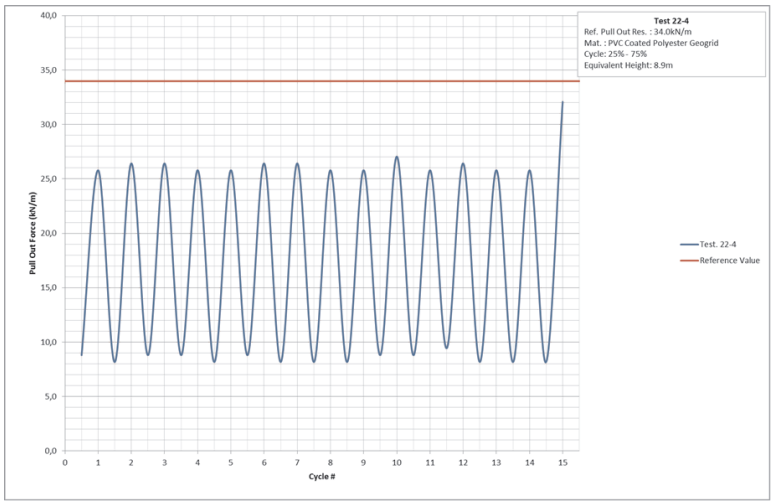


Figure B.129. Graphical Output of Test 22-4.

Table B.130. Test 22-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
22-5	Cyclic 50%-75%	Geotextile 300kN/60kN	2050	20.11	25.78	8.85	2600	25.51	32.70	33.97

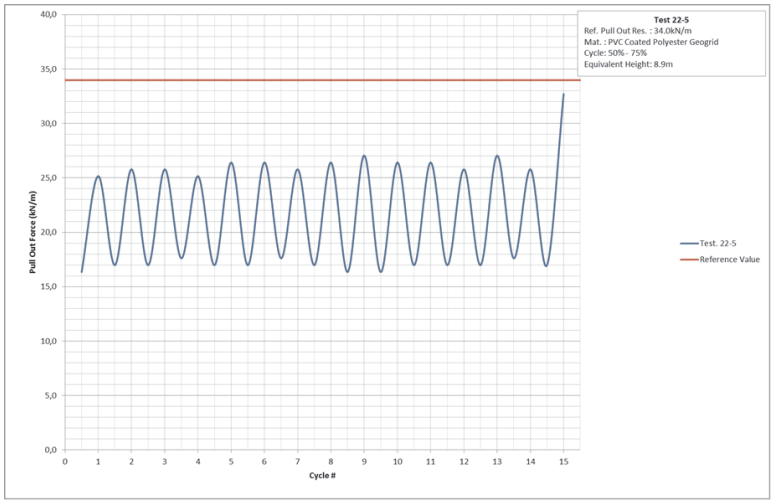


Figure B.130. Graphical Output of Test 22-5.

Table B.131. Test 22-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
22-6	Cyclic 50%-75%	Geotextile 300kN/60kN	2050	20.11	25.78	8.85	2600	25.51	32.70	33.97

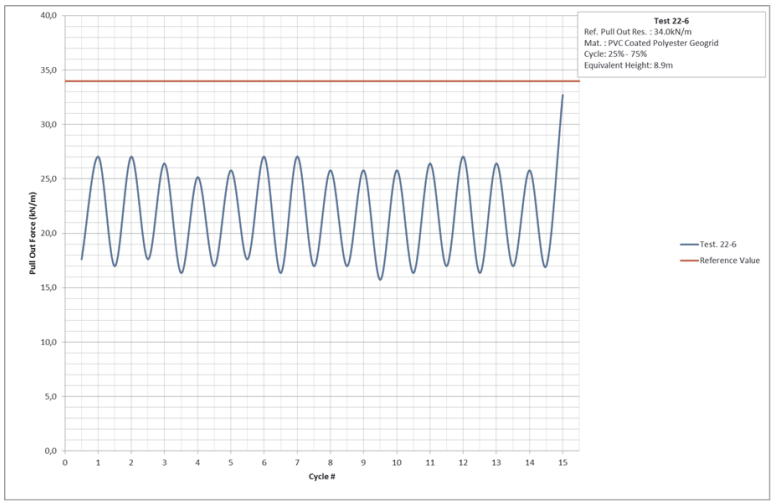


Figure B.131. Graphical Output of Test 22-6.

Table B.132. Test 23-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
23-1	Cyclic 0%-50%	Geotextile 300kN/60kN	2350	23.05	29.56	10.15	3150	30.90	39.62	38.99

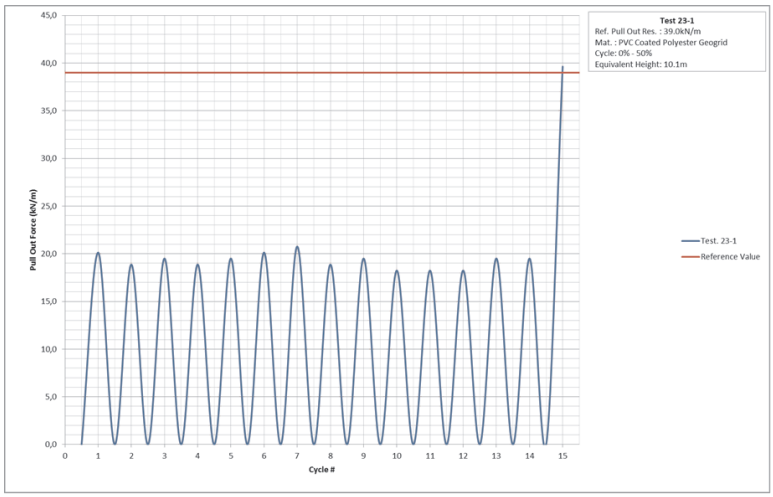


Figure B.132. Graphical Output of Test 23-1.

Table B.133. Test 23-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
23-2	Cyclic 0%-50%	Geotextile 300kN/60kN	2350	23.05	29.56	10.15	2950	28.94	37.10	38.99

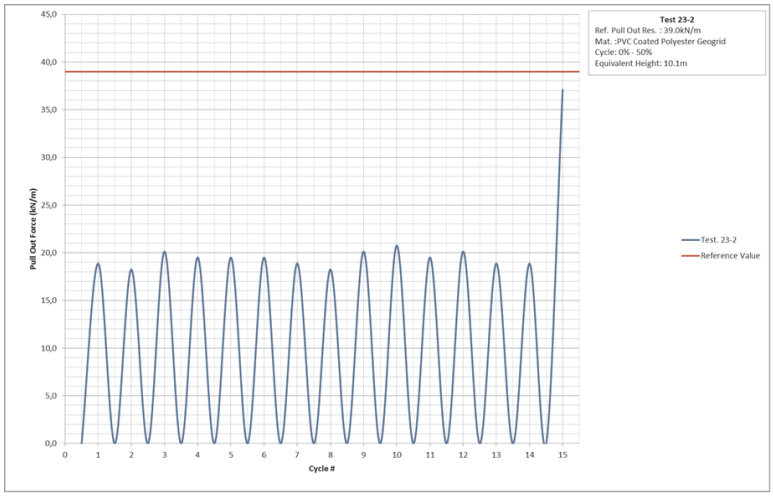


Figure B.133. Graphical Output of Test 23-2.

Table B.134. Test 23-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
23-3	Cyclic 25%-75%	Geotextile 300kN/60kN	2350	23.05	29.56	10.15	2900	28.45	36.47	38.99

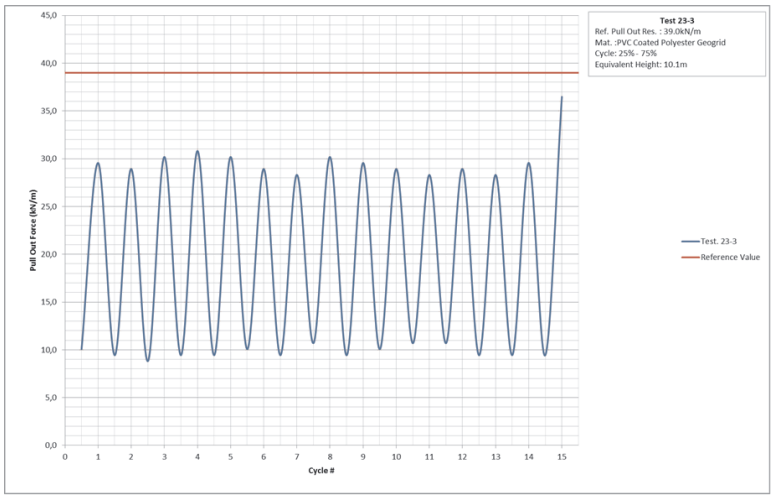


Figure B.134. Graphical Output of Test 23-3.

Table B.135. Test 23-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
23-4	Cyclic 25%-75%	Geotextile 300kN/60kN	2350	23.05	29.56	10.15	2950	28.94	37.10	38.99

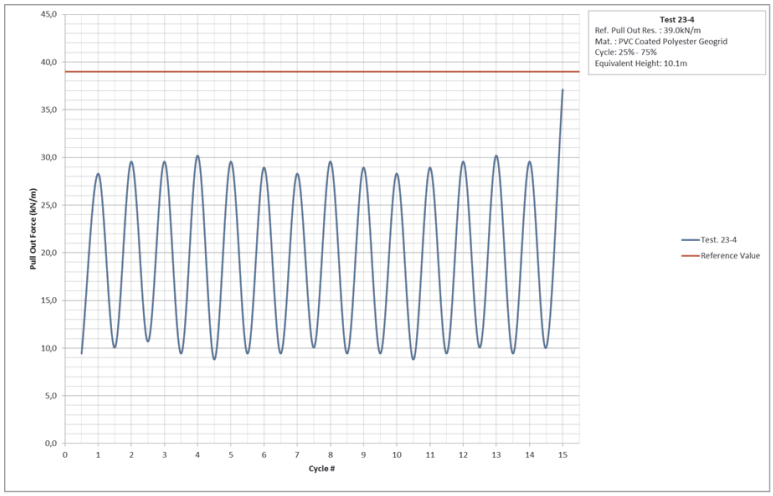


Figure B.135. Graphical Output of Test 23-4.

Table B.136. Test 23-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
23-5	Cyclic 50%-75%	Geotextile 300kN/60kN	2400	23.54	30.18	10.36	3000	29.43	37.73	39.83

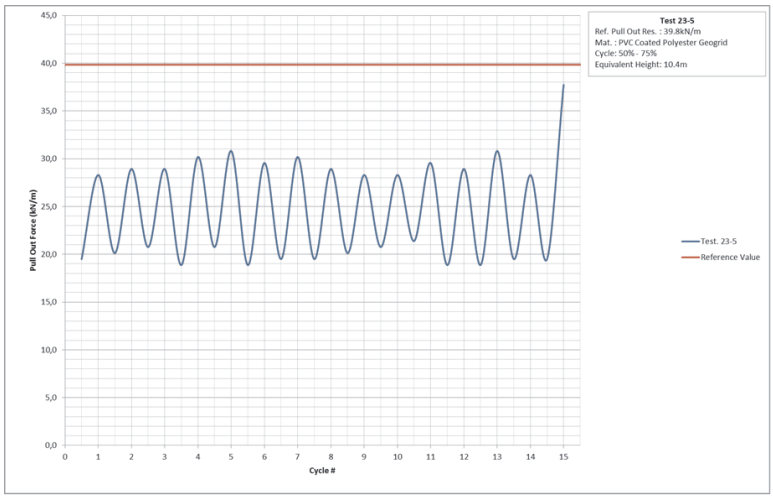


Figure B.136. Graphical Output of Test 23-5.

Table B.137. Test 23-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
23-6	Cyclic 50%-75%	Geotextile 300kN/60kN	2400	23.54	30.18	10.36	3100	30.41	38.99	39.83

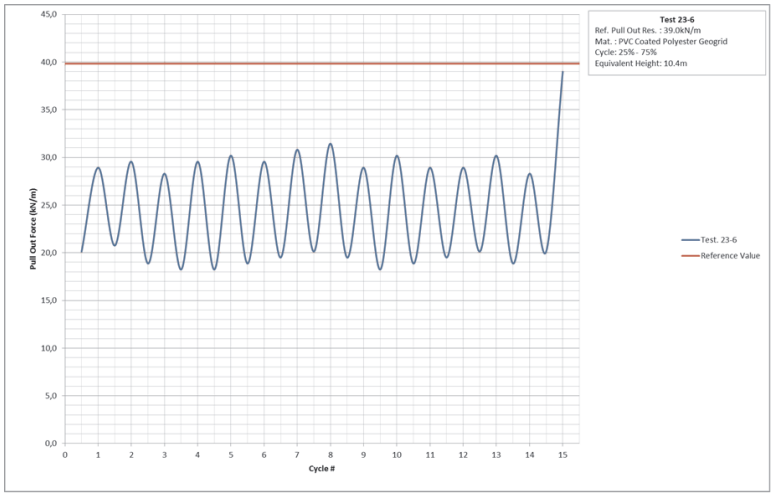


Figure B.137. Graphical Output of Test 23-6.

Table B.138. Test 24-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
24-1	Cyclic 0%-50%	Geotextile 300kN/60kN	2650	26.00	33.33	11.44	3100	30.41	38.99	41.88

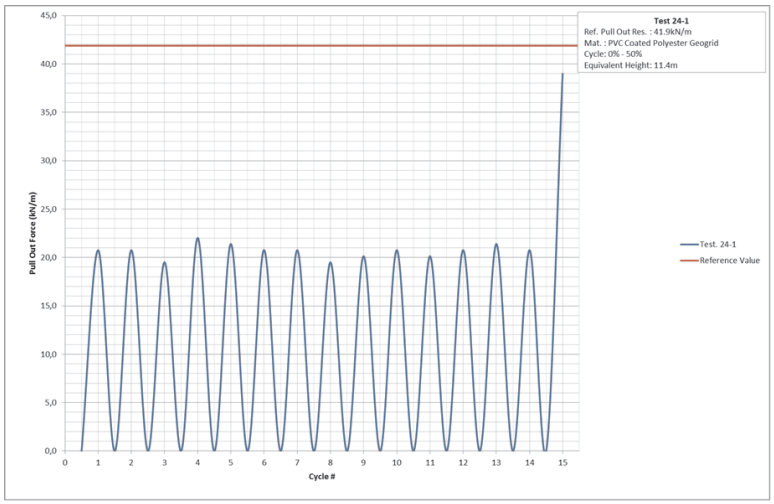


Figure B.138. Graphical Output of Test 24-1.

Table B.139. Test 24-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
24-2	Cyclic 0%-50%	Geotextile 300kN/60kN	2650	26.00	33.33	11.44	3200	31.39	40.25	41.88

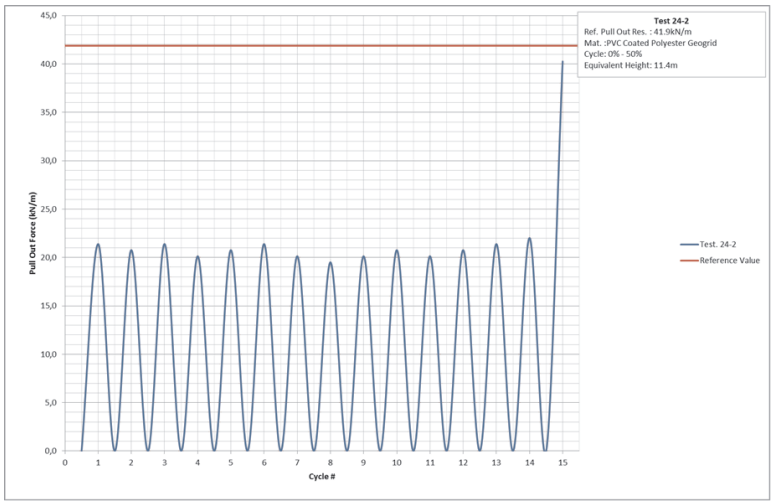


Figure B.139. Graphical Output of Test 24-2.

Table B.140. Test 24-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
24-3	Cyclic 25%-75%	Geotextile 300kN/60kN	2650	26.00	33.33	11.44	3050	29.92	38.36	41.88

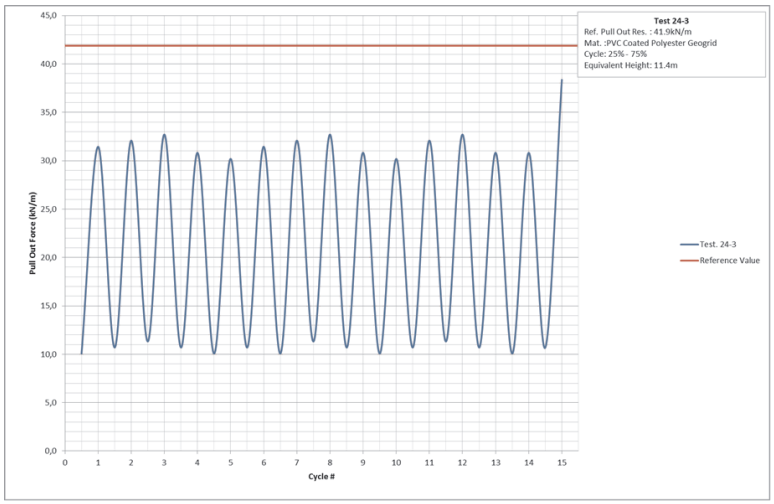


Figure B.140. Graphical Output of Test 24-3.

Table B.141. Test 24-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
24-4	Cyclic 25%-75%	Geotextile 300kN/60kN	2650	26.00	33.33	11.44	3050	29.92	38.36	41.88

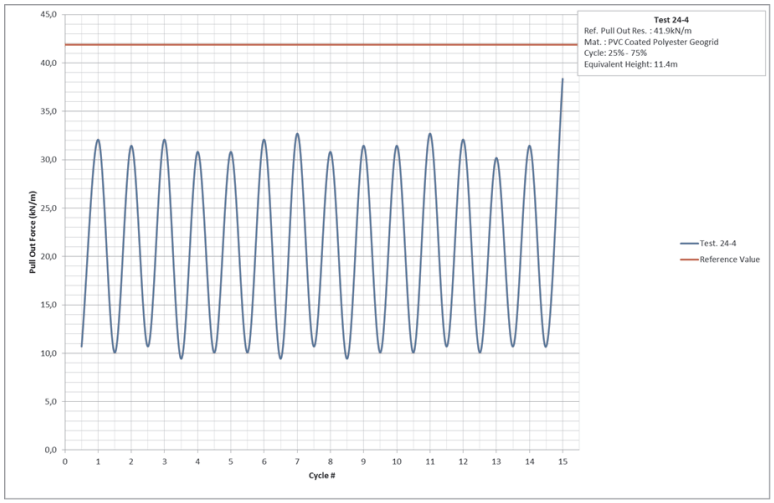


Figure B.141. Graphical Output of Test 24-4.

Table B.142. Test 24-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
24-5	Cyclic 50%-75%	Geotextile 300kN/60kN	2650	26.00	33.33	11.44	3150	30.90	39.62	41.88

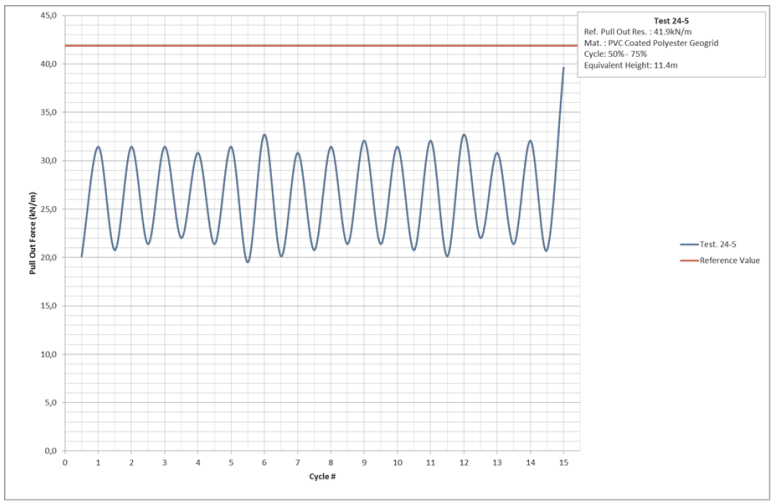


Figure B.142. Graphical Output of Test 24-5.

Table B.143. Test 24-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
24-6	Cyclic 50%-75%	Geotextile 300kN/60kN	2650	26.00	33.33	11.44	3150	30.90	39.62	41.88

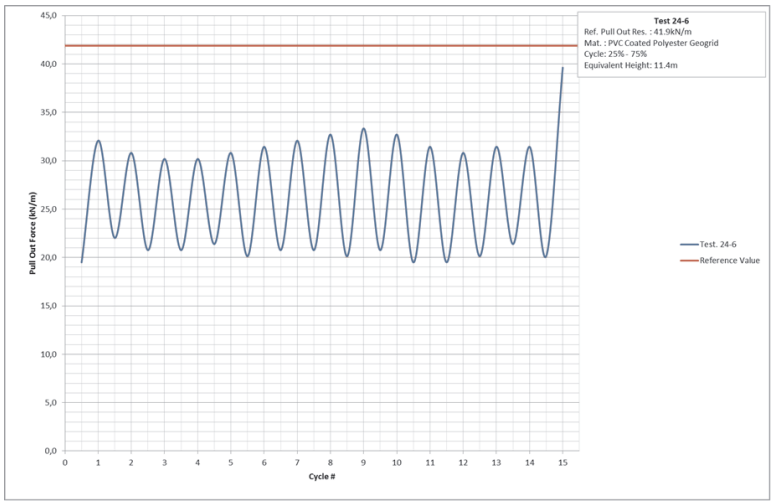


Figure B.143. Graphical Output of Test 24-6.

Table B.144. Test 25-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-1	Cyclic 0%-50%	Geotextile 300kN/60kN	2950	28.94	37.10	12.74	3100	30.41	38.99	42.63

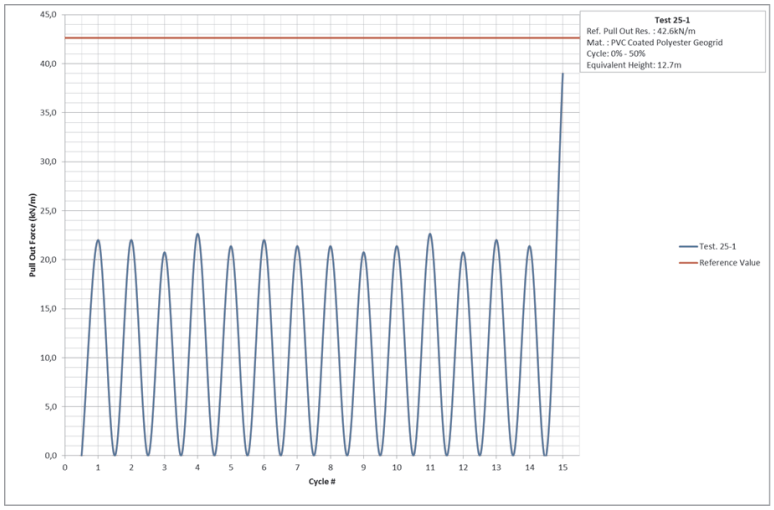


Figure B.144. Graphical Output of Test 25-1.

Table B.145. Test 25-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-2	Cyclic 0%-50%	Geotextile 300kN/60kN	2950	28.94	37.10	12.74	3200	31.39	40.25	42.63

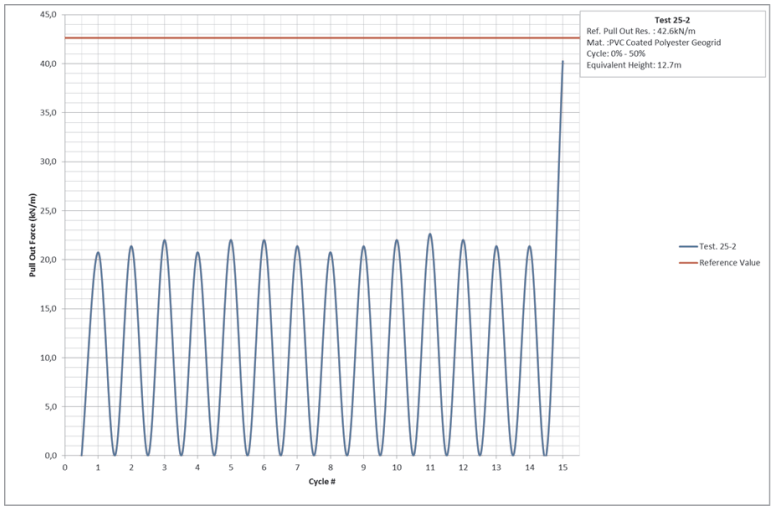


Figure B.145. Graphical Output of Test 25-2.

Table B.146. Test 25-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-3	Cyclic 25%-75%	Geotextile 300kN/60kN	2950	28.94	37.10	12.74	3050	29.92	38.36	42.63

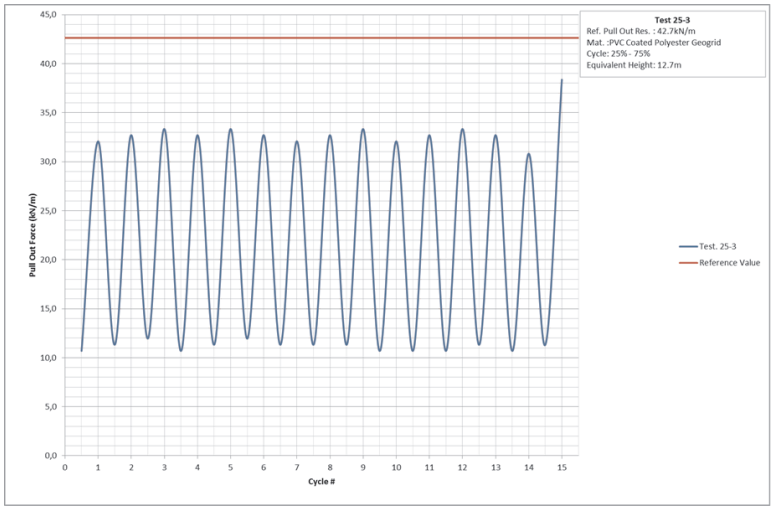


Figure B.146. Graphical Output of Test 25-3.

Table B.147. Test 25-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-4	Cyclic 25%-75%	Geotextile 300kN/60kN	2950	28.94	37.10	12.74	3050	29.92	38.36	42.63

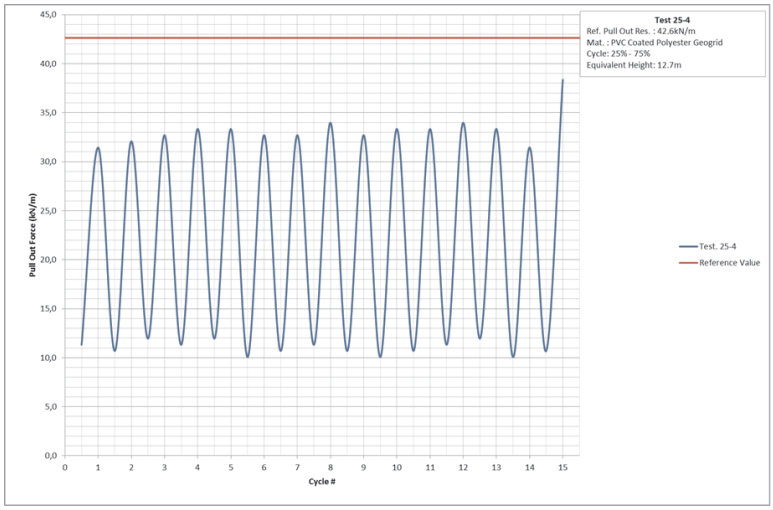


Figure B.147. Graphical Output of Test 25-4.

Table B.148. Test 25-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-5	Cyclic 50%-75%	Geotextile 300kN/60kN	2950	28.94	37.10	12.74	3150	30.90	39.62	42.63

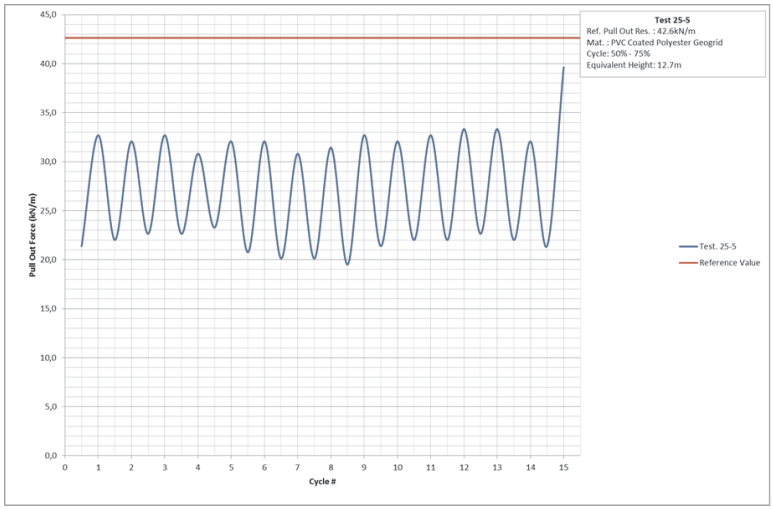


Figure B.148. Graphical Output of Test 25-5.

Table B.149. Test 25-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
25-6	Cyclic 50%-75%	Geotextile 300kN/60kN	2950	28.94	37.10	12.74	3150	30.90	39.62	42.63

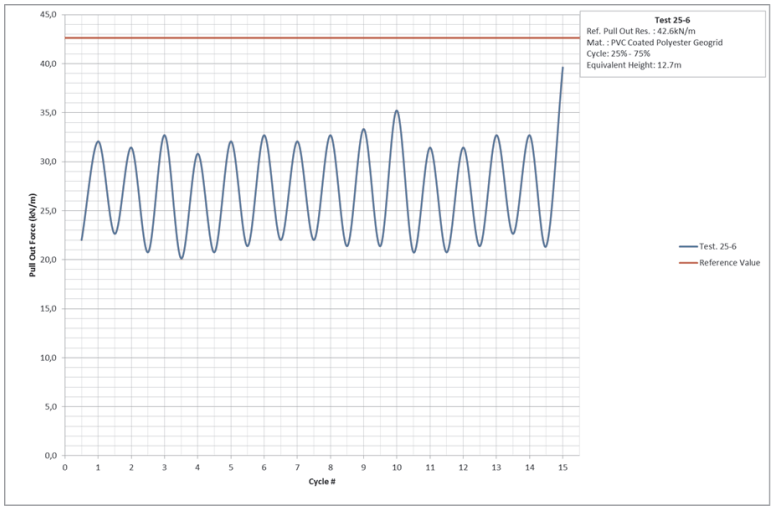


Figure B.149. Graphical Output of Test 25-6.

Table B.150. Test 26-1 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
26-1	Cyclic 0%-50%	Geotextile 300kN/60kN	3250	31.88	40.88	14.03	3300	32.37	41.50	43.39

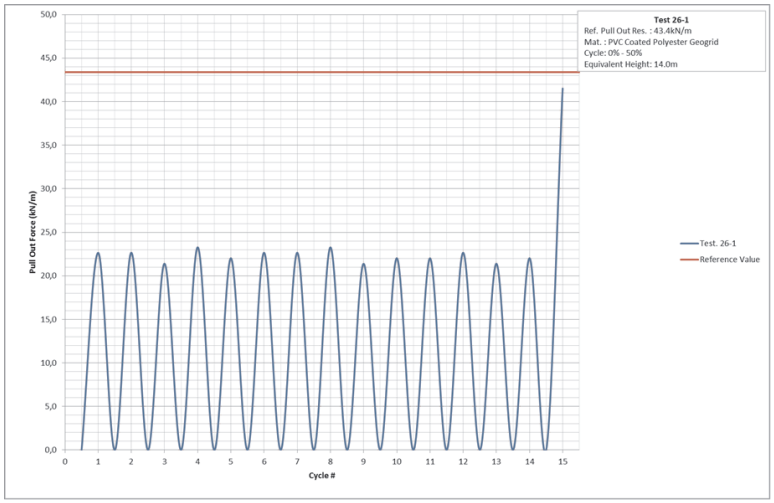


Figure B.150. Graphical Output of Test 26-1.

Table B.151. Test 26-2 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
26-2	Cyclic 0%-50%	Geotextile 300kN/60kN	3250	31.88	40.88	14.03	3250	31.88	40.88	43.39

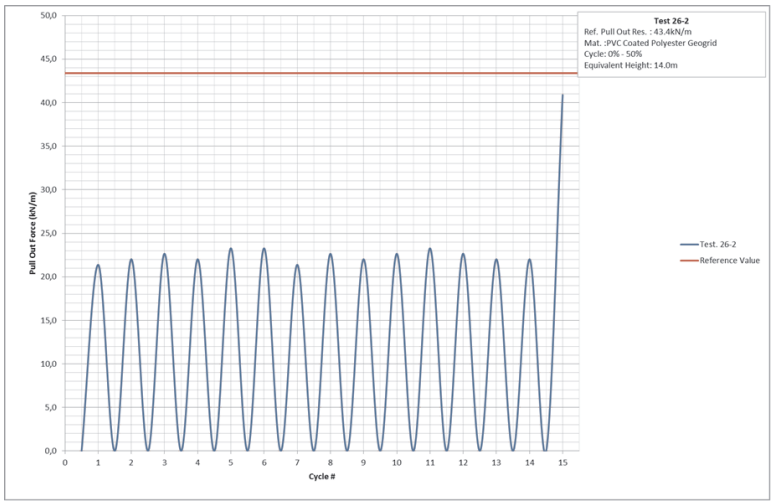


Figure B.151. Graphical Output of Test 26-2.

Table B.152. Test 26-3 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
26-3	Cyclic 25%-75%	Geotextile 300kN/60kN	3300	32.37	41.50	14.25	3350	32.86	42.13	43.51

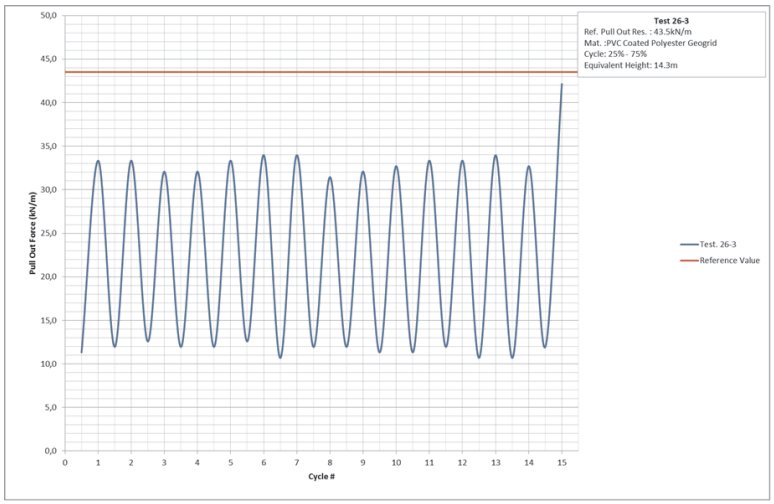


Figure B.152. Graphical Output of Test 26-3.

Table B.153. Test 26-4 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
26-4	Cyclic 25%-75%	Geotextile 300kN/60kN	3300	32.37	41.50	14.25	3300	32.37	41.50	43.51

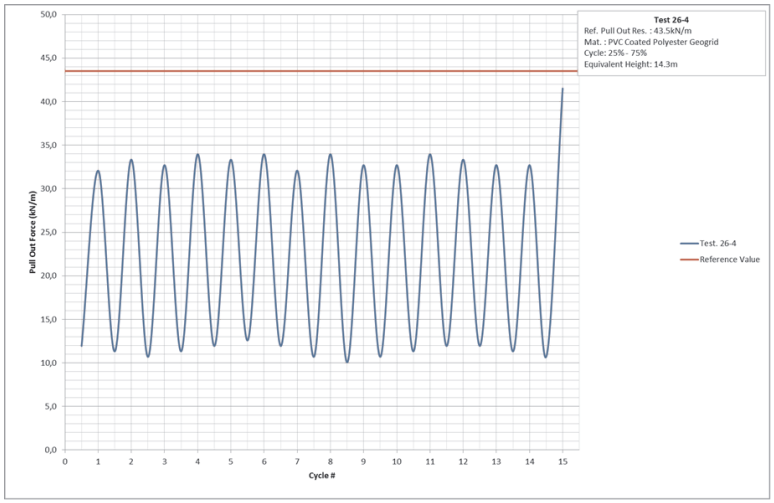


Figure B.153. Graphical Output of Test 26-4.

Table B.154. Test 26-5 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
26-5	Cyclic 50%-75%	Geotextile 300kN/60kN	3300	32.37	41.50	14.25	3250	31.88	40.88	43.51

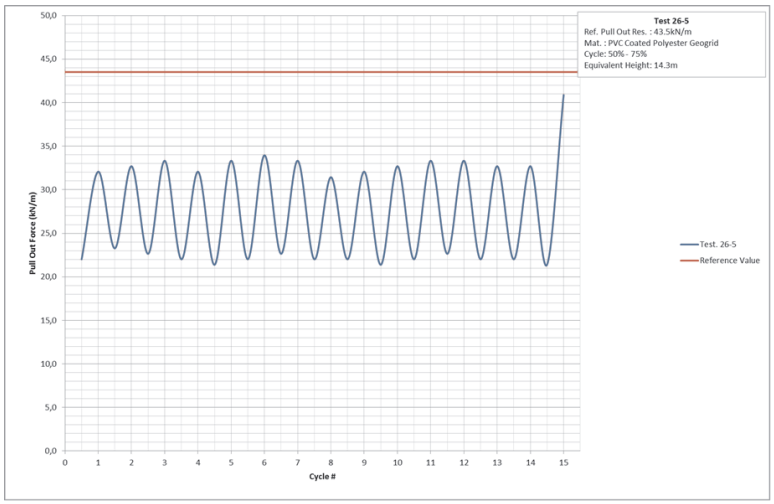


Figure B.154. Graphical Output of Test 26-5.

Table B.155. Test 26-6 Data Summary.

Test #	Experiment Type	Material	Total Normal Load	Total Normal Load	Unit Normal Load	Equivalent Height	Total Pullout Resistance		Unit Pullout Resistance	Reference Value
			kg	kN	kN/m	m	kg	kN	kN/m	kN/m
26-6	Cyclic 50%-75%	Geotextile 300kN/60kN	3300	32.37	41.50	14.25	3400	33.35	42.75	43.51

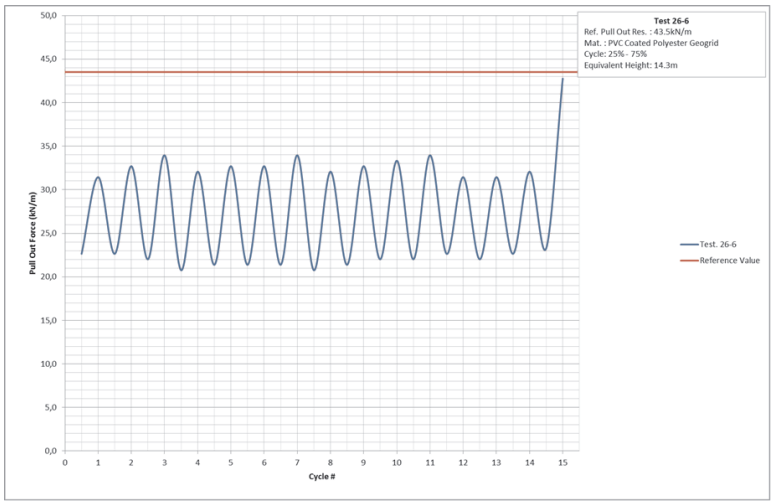


Figure B.155. Graphical Output of Test 26-6.

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