Effect of Groundwater Level toward Slope Stability

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD ARIF BIN AHMAD

Abstract

It is well recognized that groundwater has important role on the slope failure. Slope failures are one of the serious hazards to the community. For example, the collapse of block of luxury condominium in Kuala Lumpur, the Genting Highland and Pos Dipang landslides tragedies as well as other landslides disaster have caused substantial loss of life and damage to property and infrastructure.

The purpose of this project is to examine the influence of rising groundwater on the engineering properties of soil. This study was base of laboratory model that allow control of groundwater by adding and releasing water into/from the model. The influence of the groundwater on man-made slope with a gradient of 34° was observed by determining the engineering properties of the soil at various depth and observing the slope behavior.

It was found that the slope was stable as long as the groundwater is lower than the toe of the slope. As the groundwater became higher than the toe, the moisture of the soil increase to level that can cause slope failure. Slope failure occur when the moisture in the soil reaching 40%.

ACKNOWLEDGEMENT

We would like to thank numerous individuals for their great support in executing this project. Deepest gratitude goes to my supervisor; Assoc. Prof. Dr Nasiman Sapari for his tremendous support and technical guidance throughout the entire whole year of my project progress and preparation of this report.

Special thanks to the lecturers of Civil Engineering Program of UTP, who have been very helpful and resourceful while guiding us. Especially to the Final Year Project Coordinators, the lecture series conducted were useful to us in manage the time to make the project finish successfully in time and preparing this report. Heartfelt appreciation also to all technicians from Civil Engineering Department and others who has provided us with helpful information and guidance regarding the preparation of the sample.

Finally yet importantly, we would like to thank all of our family and friends who have help us in their own way.

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INTRODUCTION

1.1 Background of Study

1.1.1 Groundwater

Groundwater flow through soils is the most common cause of instability problem on construction sites when excavating below the water table, earth structures retaining water and slope stability.

The fundamental law of groundwater flow in saturated soils is Darcy's law which relates the quantity of water flowing through a cross-sectional area to the hydraulic gradient causing flow by coefficient of permeability, k. Permeability is related to various soil properties, particularly the void sizes and shapes and the mass or macrostructure within a soil. Laboratory tests can be carried out to determine values of permeability and its properties towards instability issue.

1.1.2 Soil Stress

All soils have been subjected to a stress history, comprising loading, erosion or unloading and other environment processes. When a soil element is subjected to a change of stress it will undergo consolidation if loaded or swelling if unloaded. The change of pore pressure caused by change of total stress can be determined using the pore pressure parameter.

Below a water table there is a zone of full saturation where the surface tension in the pore water can sustain water in all the voids. Above this level the soil becomes partially saturated where the finest capillaries can sustain water up to the capillary fringe. The effective stresses are enhanced above the water table due to negative pore pressure.

CHAPTER 2

LITERATURE RIVIEW

2.1 Slope Stability

2.1.1 Slope Types and Failure Theories

Natural and man-made slopes are generally classified as either finite or infinite. The stability of a finite slope can be analyzed by considering the equilibrium of force acting on potential slope failure surface. The degree of complexity of the stability analysis of a finite slope depends on nature of the materials comprising the slope and the loading conditions associated with potential failure surface. An infinite slope is one with constant slope and with relatively shallow depth. In most cases the soil is assumed to be homogeneous, but an infinite slope may consist of non-homogeneous material.

There are several theories used to determine the stability of a slope, all of which assume that the soil mass is in a state of plastic equilibrium at failure. That is, once failure has occurred along a surface in the slope, the shear and normal stresses on this surface will not increase or decrease.

2.1.2 Cause of Instability

Failures of natural and man-made slopes are generally attributable to any activity that results in either an increase in soil stress or a decrease in soil strength. The specific causes of slope instability are varied and depend on the nature of the soil, pore water pressure, climate, and stress within the soil mass (static and dynamic). Specific examples that cause a net increase in stresses include an increase in the unit weight of the soil through rainfall, load imposed by fills or structures at the top of a slope or excavation at the toe of slope , movement of water levels, earthquakes and water pressure in crack within the slope.

2.2 Groundwater

2.2.1 Concentrated Water Sources

One of the most common causes of slope failure is water entering the ground from a concentrated water source during a storm. Some examples:

- Overflowing ditch on a highway that allows flood water to cross at a low point, causing failure of the outside slope.
- Broken culvert under fill causing internal erosion.
- Blocked culvert at the upstream end, causing ponding of water and blow out.
- Broken water pipes and storm sewers.
- Discharge of surface water.

2.2.2 Factor influencing Storage and Movement of Groundwater

Water soaks into the ground because bedrock, sediment, and soil contain countless voids, or openings. These opening are similar to those of a sponge and are often called pore spaces. The quantity of groundwater that can be stored depends on the **porosity** of the material, which is the percentage of total volume of rock or sediment that consists of pore spaces. Void most often are spaces between sedimentary particles, but also common are joints, faults, cavities formed by dissolving of soluble rocks such as limestone, and vesicles (voids left by gases escaping from lava).

Variation in **porosity** can be great. Sediment is commonly quite porous, and open spaces may occupy 10 to 50 percent of sediments total volume. Pore space depends on the size and shape of the grains, how they are packed together, the degree of sorting, and in sedimentary rocks, the amount of cementing material.

Where sediments of various sizes are mixed, the porosity is reduced because the finer particles tent to fill the opening among larger grains. Most igneous and metamorphic rocks, as well as some sedimentary rocks are composed of tightly interlocking crystals, so the voids between the grains may be negligible.

Porosity along cannot measure a material's capacity to yield groundwater. Rock or sediment might be very porous yet still not allow water to move through it. The pores must be connected to allow water flow, and they must be large enough to allow flow. Thus, the **permeability** of material, its ability to transmit a fluid, is also very important.

Groundwater moves by twisting and turning through interconnected small openings. The smaller the pore space, the slower the water moves. For example clay's ability to store water is great, owing to its high porosity, but its pore spaces are so small that water is unable to move through it. Thus, clay's porosity is high but permeability is poor.

2.3 Shear Strength of Soil

2.3.1 Introduction

The application of load or stress on soil below a foundation, or in a slope, until deformations become unacceptably large is describe as failure. For this reason the limiting value of shear stress is often based on a maximum allowable strain or deformation. Shear strength may be defined as the ability of a soil to sustain load without undue distortion or failure in the soil mass. The allowable deformation will often control the design of structures, because the usual factors of safety result in shear stresses much less than those that would cause collapse or failure.

2.3.2 Direct Shear

A number of stress-strain tests are available for measuring the shear strength of soils. Laboratory tests are designed to permit application of stress to a soil sampling with measurement of the resulting deformation and pore water pressures. The most common methods is direct shear.

The direct shear test is applied a normal load to the soil sample in the shear box through a rigid loading cap. Next a shear load is applied while the horizontal displacement of the upper soil container and the vertical movement of loading cap are measured. The rate of shear displacement is about one percent per minutes except for drained test on cohesive soils, which require much slower rates. Shear resistance develops along the predetermined surface through the mechanism of internal friction within the soil.

CHAPTER 3

METHODOLOGY / PROJECT WORK

This project was conducted mainly in the laboratory using a model to examine the influence of water level on the engineering properties of soil. The sequences of the works involved are:

i. Soil sampling and determination of density and type of the soil using particle distribution test and bulk density.
ii. Liquid and plastic limit determination.
iii. Fabrication and development of slope model.
iv. Design and construction of man-made slope inside the slope model.
v. Shear strength determination by using shear box method.
vi. Determination of moisture content of sample.
vii. Interpretation of result and analysis data.

Table 3.0 below, show parameters and methods that being used to examine water level and engineering properties of soil.

Parameter	Method
Particle Distribution	Wet Sieve Analysis
Permeability Test	Falling Head
Plastic Limit	Dry-Oven
Liquid Limit	Cone Penetration
Moisture Content	Dry-Oven
Shear Strength	Shear Box

Table 3.0: Parameters & Methods

3.1 Particle Distribution

Objective:

To determine the size distribution of soil using the wet sieving method

Apparatus

- Test sieve having the following aperture sizes may be used
- Tray
- Drying Oven
- Sieve brushes

Methods

1. Weighted sieving tray of 2mm, 1.18mm, 0.6mm, 0.425mm, 0.3mm, 0.212mm, 0.15mm, 0.063mm and pan.
2. Sieving tray then was arranged based on their opening size from 2mm to 0.063mm.
3. Then, soil sample was weighted for 200g.
4. After that, 200g of soil sample was mixed with water and being stirred for 5 minutes to make sure that all particle of sample was mixed.
5. After all particles were mixed, the soil sample was quickly poured into the set of arranged sieving tray.
6. This set of arranged sieving tray then was left for 24 hours to allow gravity force separated soil particle according size opening of sieving tray.
7. Next 24 hours, all sieving tray was weighted once against and all reading was collected.
8. Water that left from wet sieving is taken. This water was put into beurette and allowed to settle. Then this soil was weighted and recorded as weighted inside the pan.
9. Data of mass retain is each of sieving tray was used to built the graph percentage passing Vs sieve size to determined type of the soil.

3.2 Permeability Test

Objective:

To determine the coefficient of permeability of the given soil sample by using falling head method.

Apparatus

- Soil specimen
- Permeameter with its accessories
- Cylinder container
- Stop watch
- Container for water

Methods

1. Weighted cylinder container which is diameter of 10cm and length of 13cm was used to collect soil sample at 5ft depth at actual site.
2. Then cylinder containing with soil sample was weighted and reading was recorded.
3. After that, cylinder container with soil sample was put inside the tank that filled with water. The water tank was connected to the pipe and also burette. The pipe was opened to create water flow inside the water tank.
4. After seven days, by using burette the height of head water was measured. For accuracy, this step was repeated for 3 times.
5. Different height of water was then used to determined hydraulic conductivity, k. By using Darcy law, hydraulic conductivity was then used to calculate flow rate, Q.

$$\boxed{K = \frac{2.3\, aL}{At} \text{ x } \log\frac{ho}{hi}}$$

$$\boxed{Q = KiA}$$

6. Weight and volume of cylinder container with soil sample was then used to calculate bulk density which is used to determine weight of soil needed to build man-made slope inside model.

Bulk density actual site = $\frac{Weight}{Volume}$

3.3 Plastic Limit Test

Objective

To determine the plastic limit and plasticity index of soil according to BS 1337 : Part 2

Apparatus

- A flat glass plate, 500mm square x 10mm thick
- Two spatulas
- A rod comparator, 3mm in diameter and 100mm long

Methods

1. Soil sample was put into oven for 24 hours.
2. Then dry soil sample was sieved using sieving tray with opening size of 425μm.
3. Dry soil sample that passed the opening size of 425μm was weighted for 200g.
4. After that, 200g of dry soil sample was mixed with water.
5. The glass plate was used to roll the paste of soil between palms of hand.
6. After partially dry, the paste was divided into four portion and continuously rolled with hand until crack appeared.
7. Then all portions were weighted and placed into hot oven (110°c) for 24 hours.
8. Next 24 hours, weight of portions reading were taken and determined the moisture content.

3.4 Liquid Limit Test

Objective

To determine the liquid limit of soil using cone penetration according to BS 1337 Part 2

Apparatus

- A flat glass plate 500mm square x 10mm thick
- Two spatulas
- A straightedge
- A cone penetration
- One metal cup not less 55mm diameter x 40mm deep
- An evaporating dish, of about 150mm diameter
- A wash bottle
- Automatic controller which release the plunger head and ensures free falling of the penetration device during the test.

Methods

1. The soil sample was put into dry oven (110°c) for 24 hours.
2. Dry soil sample was then sieve using sieving tray with opening of 425μm.
3. Then soil sample that passed 425μm opening size was weighted for 300g.
4. 300g of dry soil sample then was placed on glass plate and mixed with water.
5. Then cone penetration was used to determine depth of soil sample penetration through the soil within 5 sec.
6. The step was repeated until the depth of soil penetrated within range of 15mm – 28mm.
7. Then moisture content of the soil sample was measured by using dry-oven method.
8. Step 5, 6 and 7 was repeated twice by adding more water to the soil sample.
9. Data of moisture content was then used to build the graph.

3.5 Moisture Content

Objective:

To determine the moisture content in soil using the oven – drying method

Apparatus

- Drying oven
- Moisture content container
- Electronic balance

Methods

1. Three moisture containers were labeled and then weighted.
2. Then soil sample was put inside the moisture container and again weighted. The reading was taken.
3. Moisture containers with soil sample were then put into hot oven (110°c) for 24 hours.
4. After 24 hours, moisture container was weighted and reading was taken.
5. Dry and wet of soil reading was then used to calculated percentage of moisture content.

$$\% \text{ Moisture Content} = \left\{\frac{W_2 - W_3}{W_3 - W_1}\right\} x100$$

3.6 Shear Strength

Objective

To determine the shear strength of soil by using the shear box test.

Apparatus

- Direct shear box apparatus
- Loading frame
- Dial gauge
- Proving ring
- Tamper
- Straight edge
- Balance to weight

Methods

1. The inner of the shear box was measured.
2. Then the container volume and its weight were also measured.
3. After that, wet soil sample was put into the shear box container. Then the shear box container was placed in the machine.
4. The weight of 10kg was applied as vertical force.
5. The vertical and horizontal displacement gauge was set at 0.
6. After that, test was started and reading of force, vertical and displacement vs taken once the soil was fail.
7. The data was then used to build the graph.

3.7 Slope Model

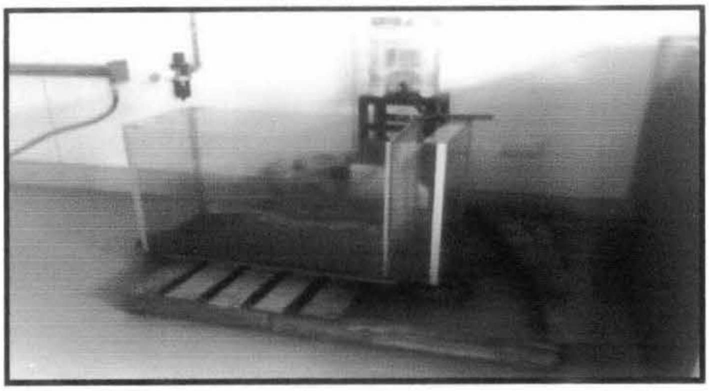


Figure 3.1 : Slope Model

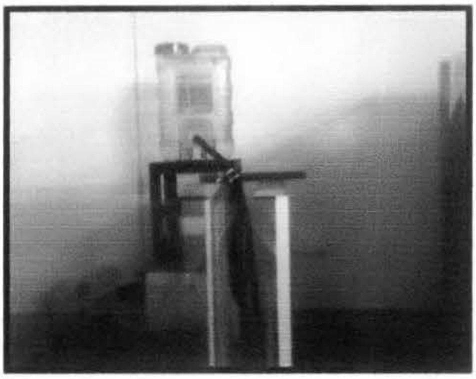


Figure 3.2 : Inflow Section

(This section consist of water tank to store water, Pin to control flow of water and pipe as medium to water flow inside the model)

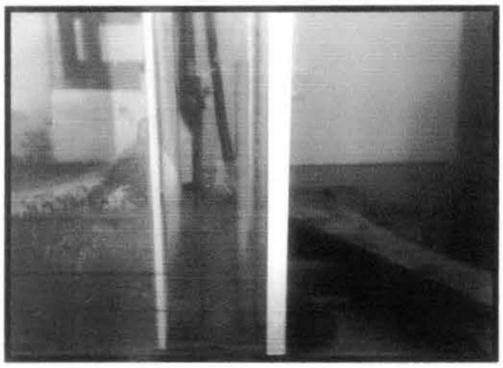


Figure 3.3 : Water Level Section

(This section consist of one pipe that have 3 opening (7cm, 14cm & 21cm). Purpose of this section is to control level of water)

Figure 3.4 : Slope Section

(This section is for construct the slope. This slope is marked by three line (7cm, 14cm & 21cm) for layer)

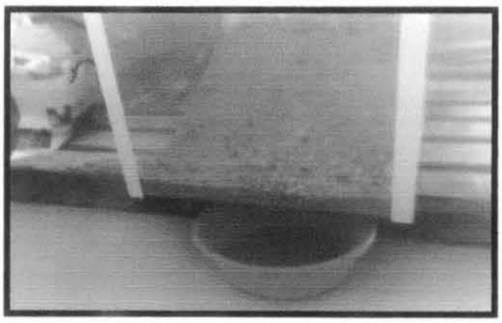


Figure 3.5 : Outflow Section

(This section consist container to collect the outflow water)

3.8 Draft of Slope Model at Different Water Level

This draft showed how the experiment was conducted. Figure 3.6 showed the condition when the water at 1st level. When the soil was saturated, sample from each layer of soil will be tested for moisture content and soil strength. Figure 3.7 and Figure 3.8 showed the condition when water level were increased to 2nd level and 3rd level. Then the procedure for 1st water level will be repeated.

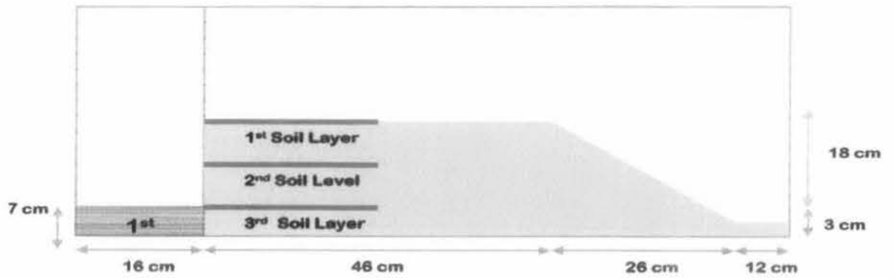


Figure 3.6 : Draft of First Water Level

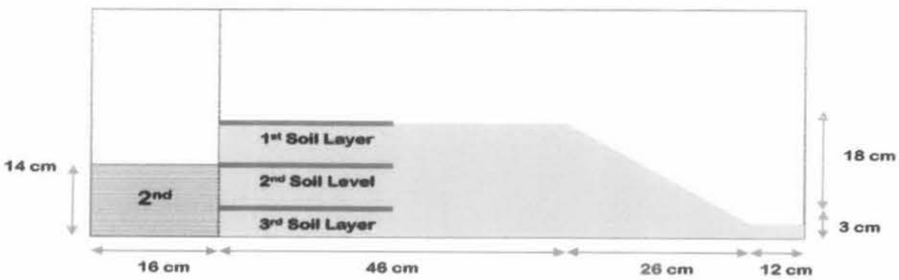


Figure 3.7 : Draft of Second Water Level

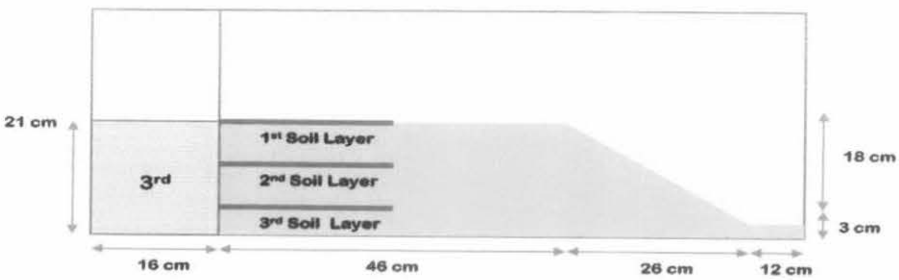


Figure 3.8: Draft of Third Water Level

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Experiment Results

4.1.1 Particle Size Distribution

Result particle size distribution are showed in table 4.0 below.

Sieve No	Opening (mm)	Mass of Empty Sieve (g)	Mass Sieve + Soil Retained (g)	Mass Retained (g)	% Retained	Cummulative % Retained	% Passing
1	2.00	454.95	457.22	2.27	1.14	1.14	98.87
2	1.180	425.68	427.00	1.32	0.66	1.80	98.21
3	0.600	406.58	412.98	6.40	3.20	5.00	95.01
4	0.425	378.86	399.10	20.24	10.12	15.12	84.89
5	0.300	366.87	425.95	59.08	29.54	44.66	55.35
6	0.212	346.20	387.20	41.00	20.50	65.16	34.85
7	0.150	337.18	361.35	24.17	12.09	77.24	22.76
8	0.063	329.26	364.78	35.52	17.76	95.00	5.00
pan	0.00	396.28	406.26	9.98	4.99	99.99	0.01
Total				**199.98**	**99.99**		

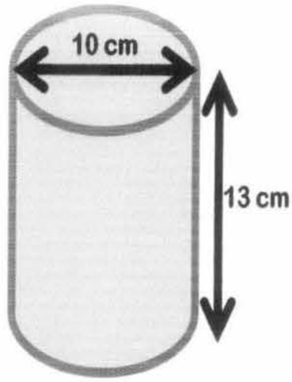
Table 4.0 : Particle size distribution

Discussion

From the graph of particle distribution, we can see that the curve is well-graded soil. Also from the graph, the soil sample was determined as fine sand.

4.1.2 Permeability Test

Diameter of cylinder container : 10cm
Length of cylinder container : 13cm
Area of cylinder container : 78.54cm^2
Specific Gravity : 9.81
Volume of specimen : 1021.02cm3
Weight of wet specimen : 1.94kg
Weight of dry specimen : 1.84kg
Moisture content : 5%



Hydraulic Conductivity, k

$K_1 = \mathbf{3.63 \times 10^{-3}}$ **cm/sec**

$K_2 = \mathbf{3.12 \times 10^{-3}}$ **cm/sec**

$K_{ave} = (K_1 + K_2) / 2$

$K_{average} = \mathbf{3.375 \times 10^{-3}}$ **cm/sec**

Flow rate, Q

The flow rate result in table 4.1 was used to determine amount of water that flow through the soil at different layer in one hour.

SECTION	FLOWRATE (Q)
First Water Level	28.34 ml/hr
Second Water Level	113.4 ml/hr
Third Water Level	255.15 ml/hr

Table 4.1 : Flow rate at different water level

Bulk Density

Bulk density actual site = $\frac{Weight}{Volume}$

$= \frac{1.94\ kg}{1.0215 kg}$

= 1.9 kg/L

Volume of model = (0.1 x 0.35 x 0.4) + (0.5x0.7x0.35x0.4)

= 0.063m^3

= 63L

Weight of soil sample based on Bulk density of actual site

= 1.9 x 63

= 119.7 kg

Discussion

From Falling Head Permeability Test, the hydraulic conductivity, k, from hydraulic conductivity, the flow rate of groundwater was determined.

The bulk density was used to determine weight of soil sample needed for the slope model so that the compaction of the slope model similar to the actual site.

4.1.3 Plastic Limit

Table of 4.2 below showed the percentage of moisture content from plastic limit test by using dry oven method.

Container no.	Unit	1	2	3
Mass of wet soil + container	g	22.14	20.35	22.72
Mass of dry soil + container	g	21.89	20.05	22.37
Mass of container	g	20.97	18.98	21.07
Mass of moisture	g	0.25	0.3	0.35
Mass of dry soil + container	g	0.92	1.09	1.31
Moisture content	%	**27.2**	**27.5**	**26.7**

Table 4.2 : Plastic limit test

The average moisture content = 27.13%

Discussion

From table of 4.2, the percentage of moisture content was determined for soil sample at the time crack appeared. The average of moisture content was 27.13%.

4.1.4 Liquid Limit

Table below showed percentage of moisture content for liquid limit of soil sample.

Container no.	unit	1	2	3
Average penetration	mm	15.5	16.5	24.5
Mass of wet soil + container	g	70.9	71.1	85.1
Mass of dry soil + container	g	56.28	58.98	70.34
Mass of container	g	20.78	29.67	38.31
Mass of moisture	g	14.62	12.12	14.76
Mass of dry soil	g	35.5	29.31	32.03
Moisture content	%	41.2	41.35	46.1

Table 4.3: Liquid Limit

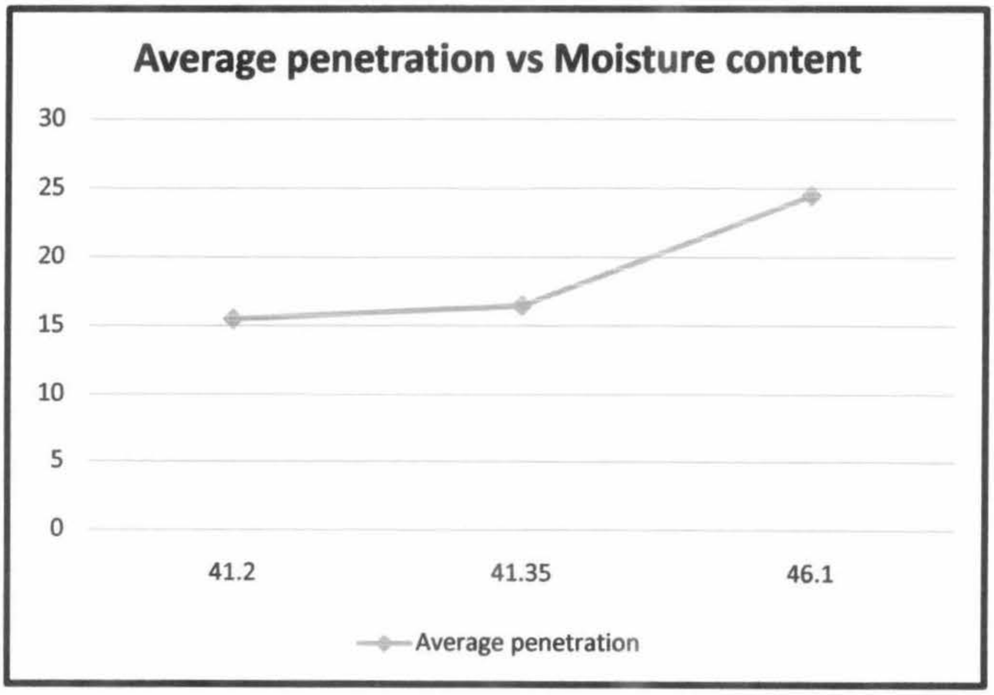


Figure 4.1: Penetration vs. Moisture content

Discussion

From the table of 4.3, the average of liquid limit of soil sample was found to be 42%. From the graph of penetration vs. moisture content, it was found that as moisture content increase the penetration depth also will increase.

4.1.5 Moisture Content

Table below showed the reading of moisture content taken as water level increase by using dry oven method.

Type of Soil	% Moisture
Actual Site	
All Layer	**11.44**
First Water Level	
1st Soil Layer	**13.27**
2nd Soil Layer	**21.56**
3rd Soil Layer	**35.57**
Second Water Level	
1st Soil Layer	**37.34**
2nd Soil Layer	**40.48**
3rd Soil Layer	**40.64**
Third Water Level	
1st Soil Layer	**40.71**
2nd Soil Layer	**41.72**
3rd Soil Layer	**42.33**

Table 4.4: Moisture Content

Discussion

Table 4.4 showed that as the water level increases, the moisture content for each soil layer also increases. Also from the table, we can say that moisture content at saturated soil is 40-50% for this soil sample.

4.1.6 *Shear Strength*

Results from shear strength determination are presented in Figure 4.2 to Figure 4.7.

First Water Level

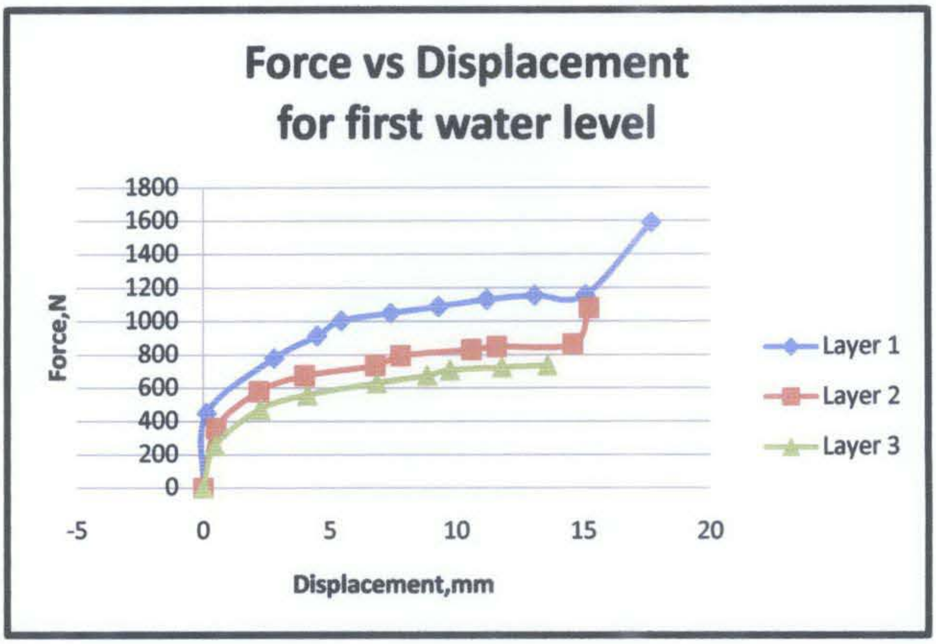


Figure 4.2: Force vs. Displacement for first water level

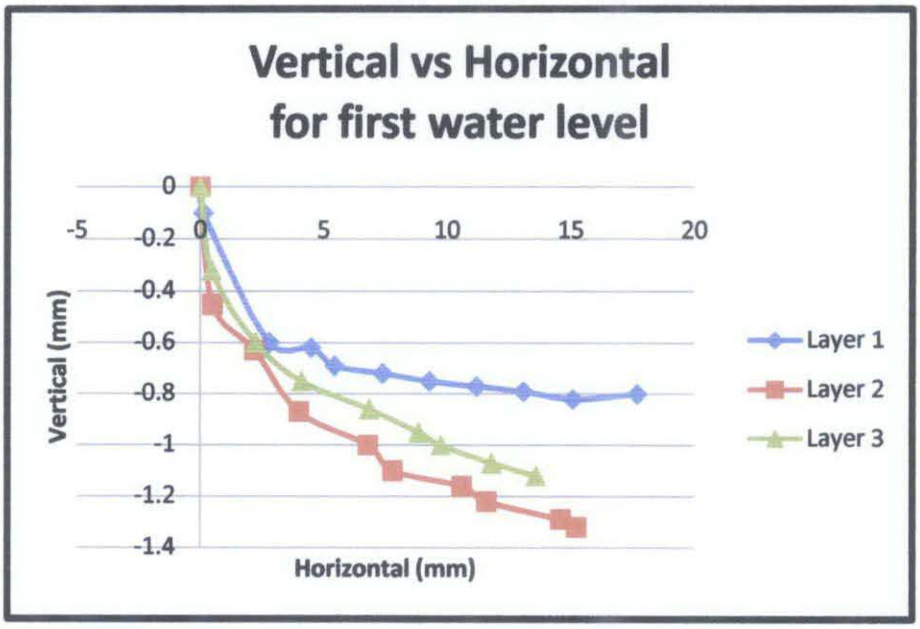


Figure 4.3 : Vertical vs. Horizontal for first water level

Second Water Level

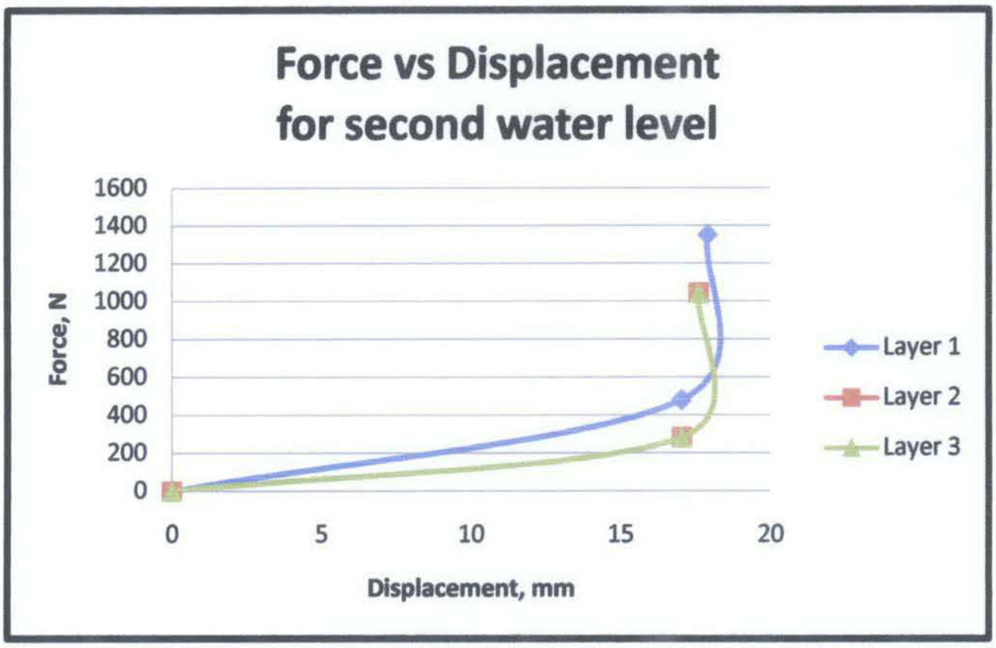


Figure 4.4: Force vs. Displacement for second water level

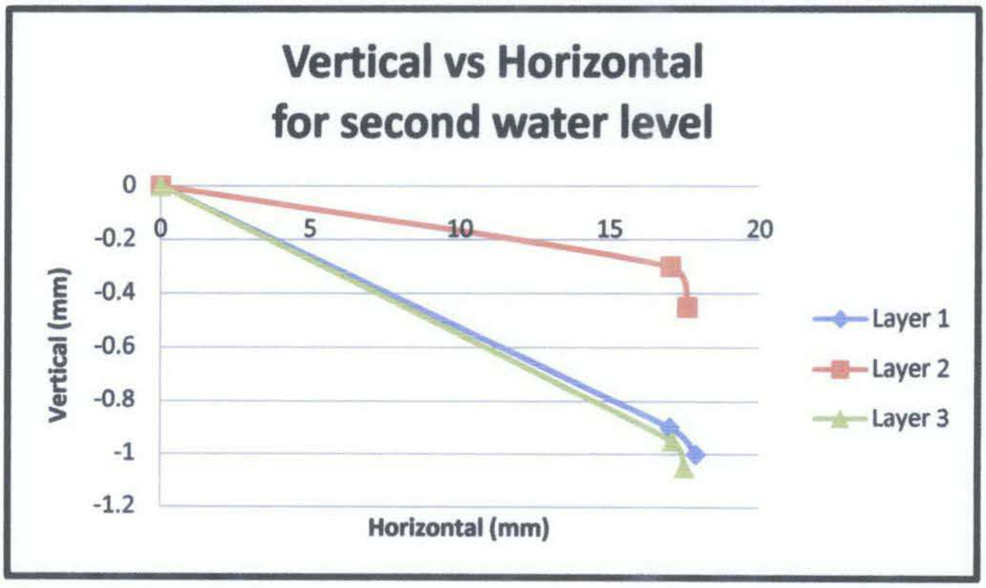


Figure 4.5: Vertical vs. Horizontal for second water level

Third Water Level

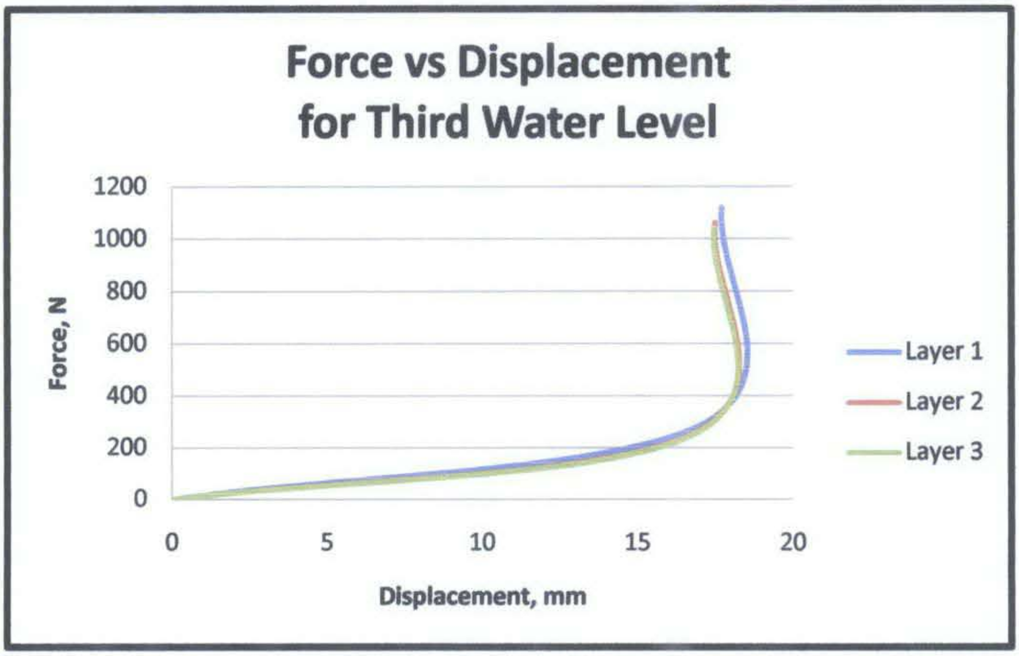


Figure 4.6: Force vs. Displacement for third water level

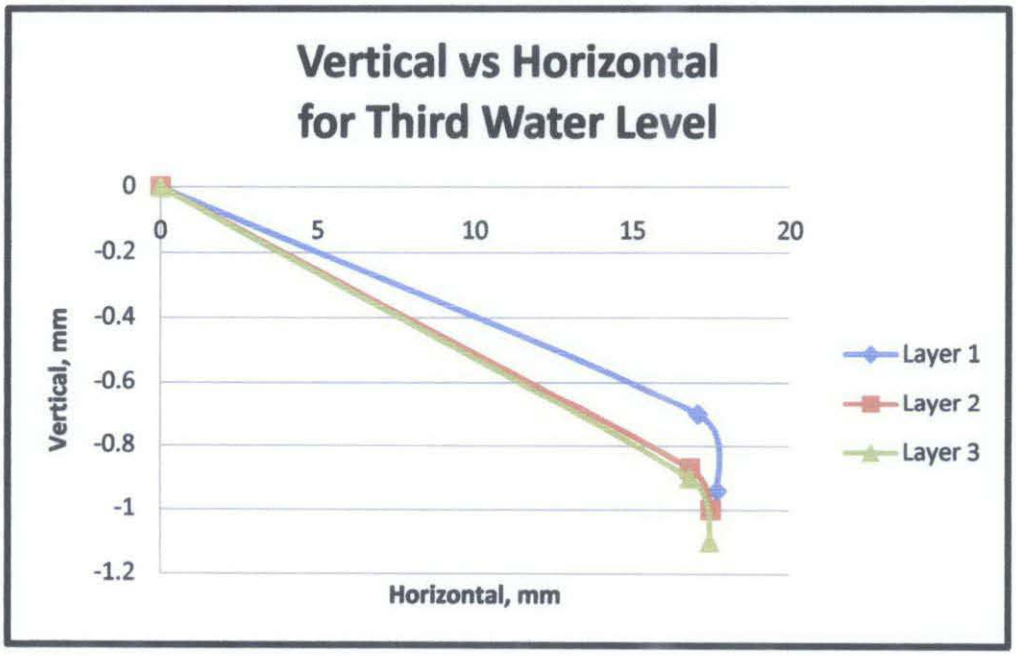


Figure 4.7: Vertical vs. Horizontal for third water level

Discussion

From graph of Force vs. Displacement, it was clear that less force is taken to displace the soil when the moisture content of the soil increasing. That why as the water level increase, the force to displace the soil was decreasing.

From graph of Vertical vs. Horizontal, the condition of soil was determined whether it dense or loose in the soil box. From the graph above, the condition of soil found to be loose because the line was in negative value.

4.2 Slope Failure

Figure below was showing the slope failure.

Figure 4.8: Slope Failure

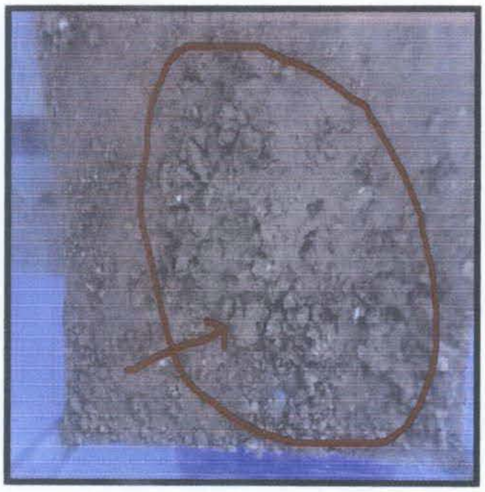


Figure 4.9: Slope Failure

Discussion

The figure above shows the slope failure when the water level was increasing. This failure occurred when the soil was saturated and moisture content was from 40% to 45%.

4.3 Comparing Soil Layer at Different Water Level

1st Soil Layer

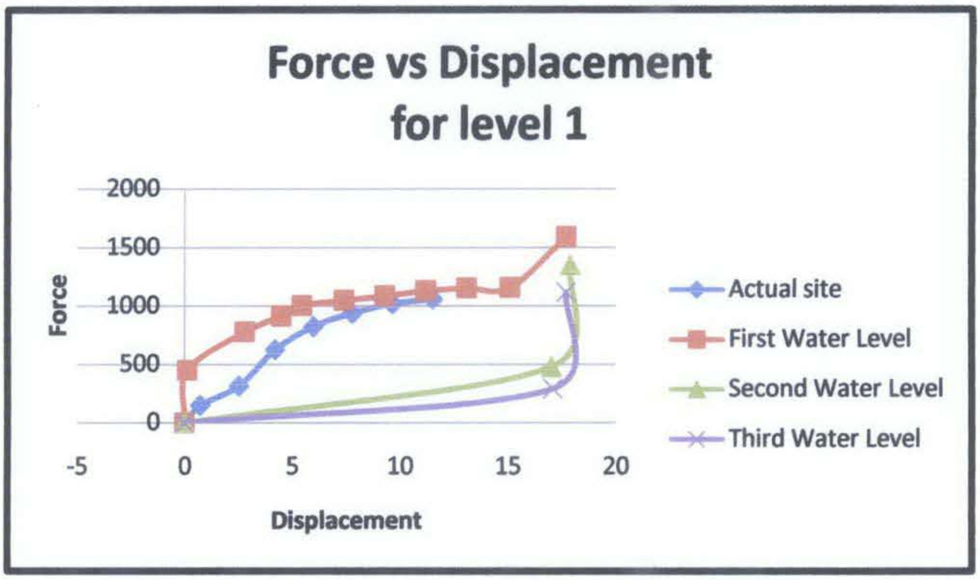


Figure 4.10: Force vs. Displacement for first soil layer

2nd Soil Layer

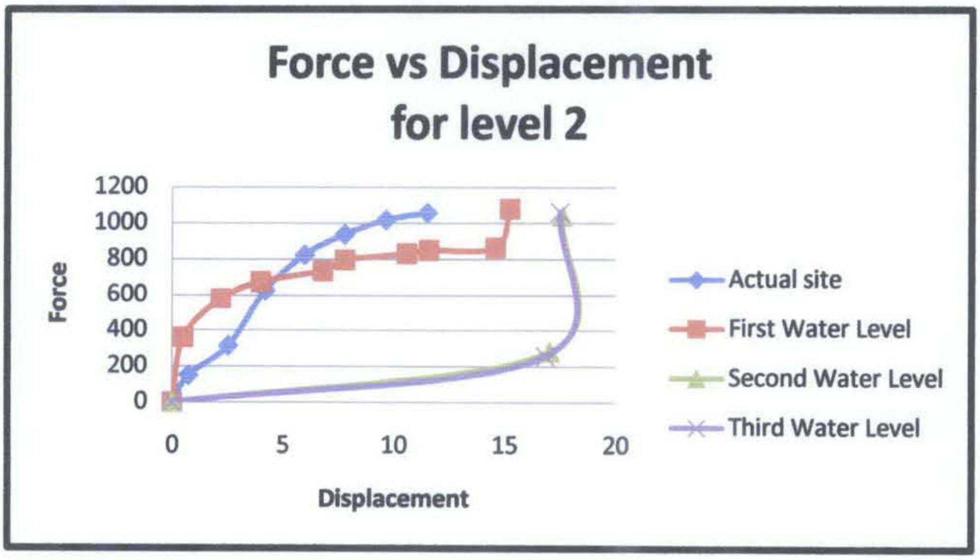


Figure 4.11: Force vs. Displacement for second soil layer

3rd Soil Layer

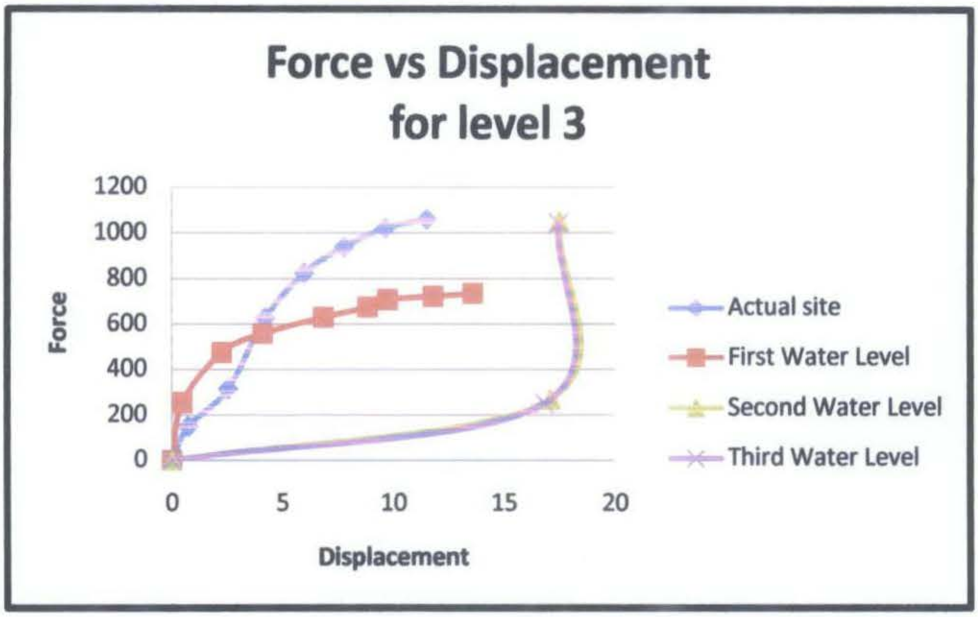


Figure 4.12: Force vs. Displacement for third soil layer

Discussion:

From the graph of Force vs. Displacement, it was found that at same soil layer less force was required to displace the soil as the moisture content increase. The increasing moisture content at the soil layer was caused by increasing water level.

CHAPTER 5

CONCLUSION & RECCOMENDATION

5.1 Conclusion

From the graph of Force vs. Displacement, we can see that as the moisture content increases due to water level increase, the force needed to displace the soil decreases. This showed that as the moisture content increases, the shear strength of the soil reduces. The shear strength reduce until the slope fail. This was shown in the laboratory work; when the percentage of moisture content in the range of 40% to 45%, the slope failed.

The slope fails when the soil layer was in saturated condition which is 40% to 45% of moisture content. This percentage o moisture content was same with the liquid limit of the soil sample. This means that when the slope reach it liquid limit, there was possibility of the slope to fail.

Different soil layer at same water level showed different percentage of moisture content because of location of soil layer toward the water level. This showed that as the soil closed to the water or groundwater the moisture content increased.

5.2 Recommendation

- To prevent the slope from failure, the groundwater level must be below the toe of the slope.
- The percentage of moisture content must always be monitor from time to time to avoid it from reaching liquid limit which can caused slope to fail.
- Increasing of water level can be prevented by reducing water accumulation in the ground. This can be done by installing good drainage system.

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APPENDIX

Permeability Test (Raw Data)

Experiment No	Burette 1				Burette 2			
	1	2	3	ave	1	2	3	ave
Length Specimen (cm)	13	13	13	13	13	13	13	13
Diameter burette (cm)	0.478	0.478	0.478	0.478	0.287	0.287	0.287	0.287
Area of burette (cm^2)	0.18	0.18	0.18	0.18	0.06	0.06	0.06	0.06
Time (sec)	18	19	18	18	7	6	7	7
Height water (cm)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Temperature	27	27	27	27	27	27	27	27

Shear Strength (Raw Data)

Actual Site

All Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
2	50	150	73.5	0.735	-20	-0.2
4	105	315	253.5	2.535	-33	-0.33
6	209	627	421.5	4.215	-29	-0.29
8	275	825	598.5	5.985	-27	-0.27
10	313	939	779.5	7.795	-10	-0.1
12	340	1020	965.5	9.655	-1	-0.01
14	353	1059	1152.5	11.525	8	0.08
15.33	**355**	**1065**				
16	345	1035	1357.5	13.575	15	0.15

First Water Level

1st Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
2	150	450	13	0.13	-10	-0.1
4	260	780	280	2.8	-60	-0.6
6	305	915	450	4.5	-62	-0.62
8	335	1005	545	5.45	-69	-0.69
10	350	1050	740	7.4	-72	-0.72
12	363	1089	930	9.3	-75	-0.75
14	377	1131	1120	11.2	-77	-0.77
16	385	1155	1310	13.1	-79	-0.79
18	386	1158	1510	15.1	-82	-0.82
20	530	1590	1770	17.7	-80	-0.8

2nd Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
2	120	360	50	0.5	-45	-0.45
4	193	579	220	2.2	-63	-0.63
6	225	675	400	4	-87	-0.87
8	245	735	680	6.8	-100	-1
10	265	795	780	7.8	-110	-1.1
12	277	831	1060	10.6	-116	-1.16
14	283	849	1160	11.6	-122	-1.22
16	288	864	1460	14.6	-129	-1.29
18	360	1080	1524	15.24	-132	-1.32

3rd Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
2	85	255	46	0.46	-32	-0.32
4	158	474	225	2.25	-60	-0.6
6	186	558	410	4.1	-75	-0.75
8	210	630	685	6.85	-86	-0.86
10	225	675	885	8.85	-95	-0.95
12	236	708	975	9.75	-100	-1
14	241	723	1180	11.8	-107	-1.07
16	245	735	1360	13.6	-112	-1.12
18						

Second Water Level

1st Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
1.83	160	480	1703	17.03	-90	-0.9
2	450	1350	1790	17.9	-100	-1
		0		0		0

2nd Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
1.75	94	282	1704	17.04	-30	-0.3
2	347	1041	1760	17.6	-45	-0.45
		0		0		0

3rd Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
1.67	90	270	1710	17.1	-95	-0.95
2	350	1050	1750	17.5	-105	-1.05
		0		0		0

Third Water Level

1st Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
1.6	97	291	1710	17.1	-70	-0.7
2	373	1119	1771	17.71	-94	-0.94

2nd Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
1.54	86	258	1685	16.85	-87	-0.87
2	354	1062	1750	17.5	-100	-1

3rd Layer (10kg)

Time	Force Gauge	Force Gauge (x3.0)	Horizontal	Horizontal (x0.01)	Vertical	Vertical (x0.01)
0	0	0	0	0	0	0
1.51	84	252	1682	16.82	-90	-0.9
2	347	1041	1746	17.46	-110	-1.1