PREDICTION OF PILE CAPACITY USING ARTIFICIAL NEURAL NETWORK

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CIVIL ENGINEERING

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By

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Dissertation submitted in partial fulfillment of
the requirements for the

Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

Prediction Of Pile Capacity Using Artificial Neural Network

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Nasrul Izzad Bin Ideris

A project dissertation submitted to the
Civil Engineering Programme
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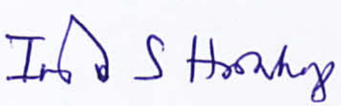
Approved by,



(A.P Dr. Indra Sati Hamonangan Harahap)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2010

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.

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NASRUL IZZAD BIN IDERIS

ABSTRACT

Soil is unpredictable and pile design usually depends on results of Soil Investigation (S.I) and Standard Penetration Test (S.P.T). Basically the main problem is how to derive the parameters from the early stages of construction in order to maximize benefits. Besides from load test results, parameters from the actual on-site results can be obtained. Therefore this study is to evaluate and perform an analysis to determine the reliability of soil properties toward pile bearing capacity and skin friction capacity. This project starts by collecting and summarized all soil data pertaining to the site and all pile load test results. Studying all driven pile and pile test results is essential along with the parameters as well as to analyse the results by the analytical method through the Microsoft Excel, Surfer and MATLAB 7.0.1 software by comparing the actual curve with S.I result. Furthermore, the findings that coincide with the project are the Load Settlement Curve which coincides with the Pile Dynamic Analysis (P.D.A) and the Maintained Load Test (M.L.T) results can be used to compare the result. Then, all data collected will be trained by using neural network under back propagation method. This tool is very useful to determine the hidden layer and determine locations which don't have sufficient data. The last finding would be that every pile has different soil characteristics which may increase or decrease the pile's bearing capacity and skin friction capacity. Other scopes would include finding out the parameters that are the most important and can be used as a reference for the same type of soil in future.

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LIST OF ABBREVIATIONS

PKK	Pusat Khidmat Kontraktor
CIDB	Construction Industry Development Board
M.L.T	Maintained Load Test
P.D.A	Pile Dynamic Analysis
RQD	Rock Quality Designation
SI	Site Investigation
SPT	Standard Penetration Test
FOS	Factor of Safety
BH	Bore Hole
CIDH	Cast-in-drilled-hole
fs	Unit shaft friction
fb	Unit base resistance
Qult	Ultimate Pile Capacity
Qs	Ultimate Skin Friction Capacity
Qb	Ultimate Bearing Capacity
CAPWAP	Case Pile Wave Analysis Program
ANN	Artificial Neural Network
RC	Reinforced Concrete

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background of Study

Brunsfield Construction has successfully undertaken residential and commercial properties, including some of the nation's most complex construction challenges. Brunsfield Construction Sdn Bhd is registered with the Governments under Pusat Khidmat Kontraktor (PKK) as a Class A' contractor, and with the Construction Industry Development Board (CIDB) under Grade 7, which allows Brunsfield to undertake construction projects of unlimited size and value. Therefore in collaboration with Brunsfield Construction Sdn Bhd, the author had obtained the data needed in his research of FYP title of evaluation of properties from pile load test responses. An important factor in the author research is that the ability to analyze and determine soil characteristic, pile bearing capacity, skin friction capacity and parameters that can be used for future references.

1.2 Problem Statement

The site which the author going to study consists of bored pile and reinforced concrete pile. Total bored pile points are 312 in 600 mm diameter. For reinforced concrete pile, total pile points are 1140 in square and the dimension is 400x400 mm. The piles are subjected to a series of test includes M.L.T and P.D.A test. A certain criteria such as maximum displacement under twice of working load and maximum residual displacement have been used as acceptance criteria for the pile.

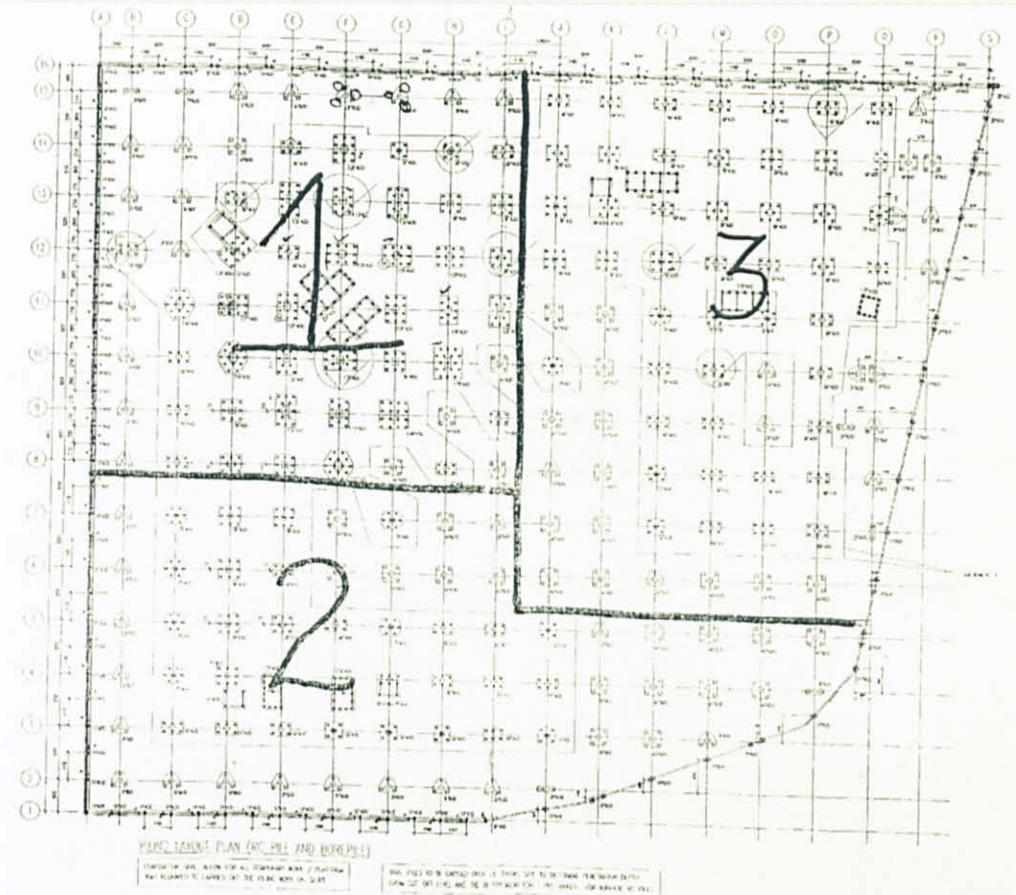

Figure 1: Pile Layout Plan

1.2.1 Problem Identification

The main problem while designing bored piles is that it is hard to predict the Bearing Capacity and Skin Friction Capacity each piles. Bored piles are designed normally according to soil strength as well as Rock Quality Designation (RQD). These two variables are normally very unpredictable as Soil Investigation can only give limited information and it is not encouraged to do too many S.I as it too costly and only companies which are capable financially can attempt it. In addition, pile foundation is very important structure since it is used to carry and transfer the load of the structure to the bearing ground located at some depth below ground surface.

1.2.2 Significance of Project

In the future, consultant and piling companies would be able to refer to this project as a benchmark and able to design piles which same soil characteristic with the data that is founded in this project. Companies as well as universities would be able to use this research to update the uncertainties when dealing with soil areas and be able to design piles with lesser Factor of Safety. Failure to design correct ultimate pile capacity will cause a problem such as settlements on the pile. Therefore it is important to evaluate the soil properties from Engineering Bore Hole site investigation, reinforced concrete driven pile result and study data from pile load test response.

1.3 Objectives and Scope of study

The main objective of this project is to evaluate and perform an analysis to determine the reliability of soil properties toward pile bearing capacity and skin friction capacity. The pile design will be compared to actual design parameters based on pile load test results.

The objectives to be achieved by the end of this project are:

a) To evaluate soil properties based on site investigation (Engineering Bore Logs) and compare with reinforced concrete driven pile data.
b) To determine the bearing capacity and skin friction capacity based on Maintained Load Test and Pile Dynamic Analysis Test.
c) To analyze and establish the correlations of each pile soil characteristics which may increase or decrease the pile's Bearing Capacity and Skin Friction from the results of pile load test responses.

The scopes of study involved would be towards on the various pile tests which include the M.L.T and P.D.A test. All driven pile and pile test results will be analyse by using Microsoft Excel software and MATLAB 7.0.1.

1.3.1 Relevancy of Project

This project is relevant to the study of foundation and earth structures as well as the study of underground soil structures. This project is also relevant to the recent constructions where people are paying more attention to the foundation of the buildings as to prevent any risk and disaster in future. A well design foundation structure is very essential to ensure sufficient pile bearing capacity and support structural loads of the buildings.

1.3.2 Feasibility of Project within Time Frame

The project is feasible as it utilizes and analyzes the data which can be obtained from the existing projects at Brunsfield Construction Sdn Bhd. This project is low in cost for analysis and can bring huge benefits for the future.

CHAPTER 2

LITERATURE REVIEW/THEORY

2.0 LITERATURE REVIEW/ THEORY

2.1 Bored Piles Theory and Methodology

According to Muni Budhu, (2007) Soil Mechanics and Foundations, a pile is a slender structural member installed in the ground to transfer the structural loads to soils at some significant depth below the base of structure. Structural loads include axial loads, lateral loads, and moments. Pile foundations are used when:-

a) The soil near the surface does not have sufficient bearing capacity to support the structural loads.
b) The estimated settlement of the soil exceeds tolerable limits (i.e., settlement greater than the serviceability limit state).
c) Differential settlement due to soil variability or non-uniform structural loads is excessive.
d) The structural loads consist of lateral loads and uplift forces.

Bored Piles are also called drilled piers or Cast-in-drilled-hole piles (CIDH piles). Rotary boring techniques offer larger diameter piles than any other piling method and permit pile construction through particularly dense or hard strata. Construction methods depend on the geology of the site.

Dry boring methods employ the use of a temporary casing to seal the pile bore through water-bearing or unstable strata overlying suitable stable material. Upon reaching the design depth, a reinforcing cage is introduced. Concrete is poured in the bore and brought up to the required level. The casing can be withdrawn or left in situ.

Wet boring also employs a temporary casing through unstable ground and is used when the pile bore cannot be sealed against water ingress. Boring is then undertaken using a digging bucket to drill through the underlying soils to design depth. The reinforcing cage is lowered into the bore and concrete is placed by tremmie pipe, following which, extraction of the temporary casing takes place.

Chean Sin Chen and Lee Ching Hiew (2006) describes that, bored piles generally have high capacity, easy length adjustment, and low noise and vibration during construction. They are commonly used to support heavy structures in the city areas in Malaysia. They are also very suitable in residual soil, where the hard soil layer or boulders may hinder penetration for most driven piles. The design of bored piles in residual soil is based on the empirical method. This is due to the difficulties in obtaining undisturbed soil samples in residual soil. The empirical approach makes use of the results of standard penetration tests (SPT-N) for assessment of the soil strength. Static pile load tests have been carried out on many fully instrumented bored piles.

The empirical correlations of the unit shaft friction (*fs*) and unit base resistance (*fb*) with the SPT-N values, established regardless of the construction method, are as follows:-

a) $f_s = K_s N$
b) $f_b = K_b N$
c) $Q_{ult} = Q_s + Q_b$

2.2 Pile Load Test

According to Muni Budhu, (2007) Soil Mechanics and Foundations, the purposes of pile load test are:-

a) to determine the axial load capacity of a single pile
b) to determine the settlement of a single pile at working loads
c) to verify estimated axial load capacity
d) to obtain information on load transfer in skin friction and end bearing

2.2.1 Maintained Load Test Methodology

Maintained Load Test (MLT) is to load the pile to twice the working load with specific load increments and used to determine its settlement while undertaking that load. The test is done for two cycles with the first cycle done to 100% working load of the pile. It is done at 12.5% working load increments at 15 minute intervals, after each load increase the operator has to look at the gauges to check the settlement of the pile. The operator has to use leveling to check the datum level and make sure that it is almost the same. If it is not, then there might be problems in the case of human errors or mechanical errors where the operator may have took the wrong level or the dial gauge may be experiencing mechanical failures. After the pile load reaches 100% working load the load is maintained for 12 hours and then only the load is released by 25% working load decrements until the load reaches zero again. After that the test is restarted for its second cycle, but this time the load is increased by 50% of working load increments until 200% of working load is reached. Then the load is also maintained for 24 hours before releasing it slowly again until it reaches zero again. If at any time the settlement of the pile exceeds 38mm then the pile is considered as failed and consultants have to be informed to set new points. The pile is done to a maximum of 200% load as the Factor of Safety (FOS) that the consultants used is 2. (Refer: **Appendix A** for details)

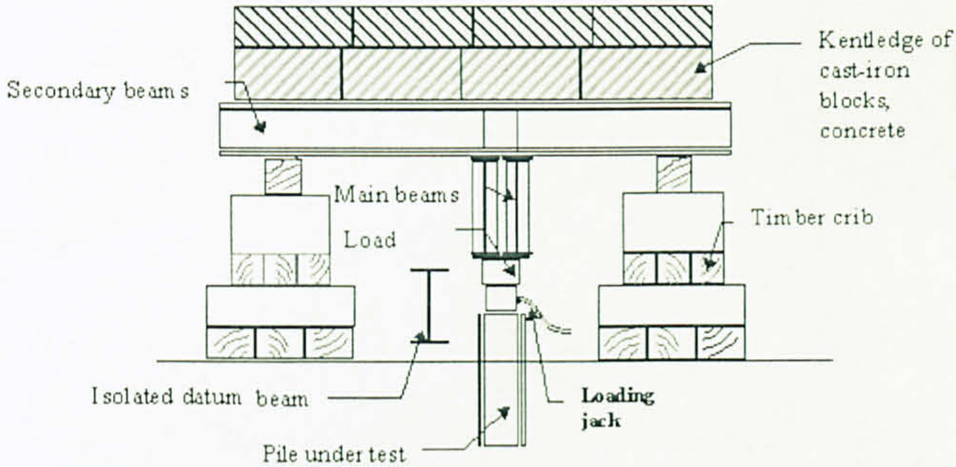

Figure 2: Maintained Load Test diagram Illustration

2.2.2 Pile Dynamic Analysis Test

According to Soil Dynamics PDA Test report (2009) a Pile Dynamic Incorporated Model PAK Pile Driving Analyser (PDA) and its associated pile top force and velocity transducers were used to conduct the dynamic pile test. Two strain transducers and two accelerometers were attached to the pile head. They were mounted opposite sides of the pile for cancellation of bending effects during each strike of the hammer. The signals of strain and acceleration were conditioned and processed by PDA. The PDA is a microprocessor based signal conditioner and digital computer. Signals of pile top force and velocity were measured and analysed during each strike of the pile driving hammer and stored in the analyser. The pile top force and velocity-time curves were displayed on the LCD screen. Real time analogue signals of pile top force and velocity were also recorded on the PDA static memory facilities as well as on a field unit for further analysis. The PDA uses a program based on the closed form Case-Goble solutions to compute static pile capacity from the pile top force and velocity data.

Dynamic pile test will be conducted on the cast-in-situ piles after a period where the concrete is allow to set or at re-strike for selected piles. The gauges are then attached to the pile using Ramset plugs. Prior pile head preparation during casting or before testing is required. This shall include a permanent steel casing of at least one pile diameter. Further details of the pile head preparation shall be submitted later. The client will supply and operate the crane to lift and drop hammer to induce a driving force on to the pile. Dynamic measurement of force and velocity will be collected by gauges attached to the pile. This data will be processes by the PDA to give immediate visual and permanent record onsite. The PDA will also provide onsite results such as:-

a) Mobilized static load capacity based on the CASE method
b) Pile integrity – location and extent of damage
c) Pile stresses – maximum compression forces at pile top/toe
d) Hammer Performance – maximum energy transferred to the pile

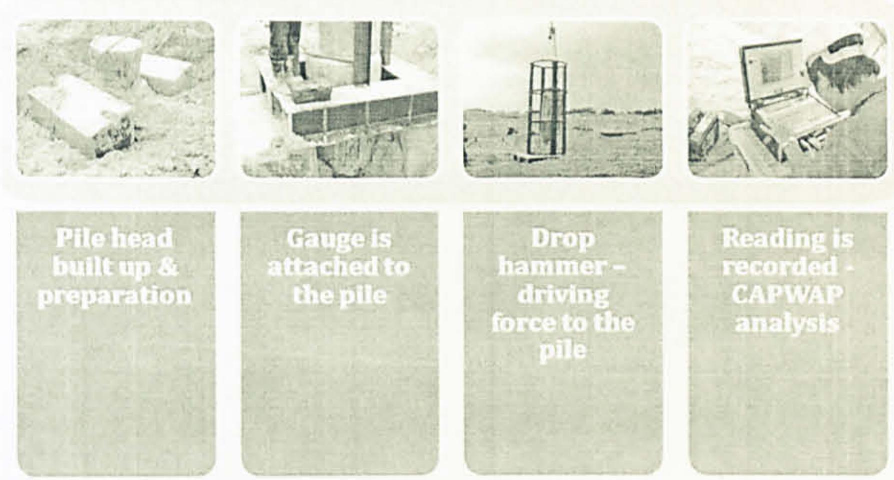

Figure 3: Processes for Pile Dynamic Analysis Test

2.3 Standard Penetration Test (SPT) and Rock Quality Designation (RQD)

The Standard Penetration Tests aims to determine the SPT N value which gives an indication of the soil stiffness and can be empirically related to many engineering properties.

The test is conducted inside a borehole. A 'split spoon' sampler is attached to the bottom of a core barrel and lowered into position at the bottom of the borehole. The sampler is driven into the ground by a drop hammer weighing 68 kg falling through a height of 76 cm. The number of hammer blows is counted. The number required to drive the sampler three successive 150mm increments is recorded. The first increment (0-150mm) is not included in the N value as it is assumed that the top of the test area has been disturbed by the drilling process. The SPT N is the number of blows required to achieve penetration from 150-450mm.

After the test, the sample remaining inside the split spoon is preserved in an airtight container for inspection and description. Besides that the SPT values enables engineer to know what type of soil is located underground from the disturbed samples collected in the split spoon and whether is it a hard or soft layer.

The recording of RQD has become virtually standard practice in drill core logging for a wide variety of geotechnical investigations. The RQD values provide a basis for making preliminary design decisions involving estimation of required depths of excavation for foundations of structures. The RQD values also can serve to identify potential problems related to bearing capacity, settlement, erosion, or sliding in rock foundations. The RQD can provide an indication of rock quality in quarries for concrete aggregate, rock fill, or large riprap.

The RQD has been widely used as a warning indicator of low-quality rock zones that may need greater scrutiny or require additional borings or other investigational work. The RQD is a basic component of many rock mass classification systems for engineering purposes. The RQD is sensitive to the orientation of joint sets with respect to the orientation of the core.

Core sizes from BQ to PQ with core diameters of 36.5 mm (1.44 in.) and 85 mm (3.35 in.) respectively are normally acceptable for measuring RQD as long as proper drilling techniques are used that do not cause excess core breakage or poor recovery. RQD value is very important to calculate skin friction and end bearing resistance in determine the socket length required for bored piles. From obtained RQD index we can classify rock mass:-

RQD	Rock Mass Quality
<25%	Very poor
25-50%	Poor
50-75%	Fair
75-90%	Good
90-100%	Excellent

Table 1: Rock Quality Designation classification

Eissa Elsayed A. and Zekaisen (1991) observed that when the core reaches rock layer, it would normally encounter a slime layer first, the starting cored rock may be quite fragile. The RQD will be used to test rock fragility, the higher the RQD, the better the rock quality. When taking RQD, any rock length which is less than 4 inches or 100mm would not be considered unless it is due to mechanical breaking which may happen when the workers try to pull out the rock or switch gear while rock coring. If the rock is less than 4 inches by causes such as normal rock weathering then that particular length of rock can be ignored. The percentage of

RQD obtained is determined by summation of total length of rock cored more than 100mm over the total core length (CL) for each 1.5-meter.

2.4 Case Pile Wave Analysis Program (CAPWAP) Method

According to Soil Dynamics PDA Test report (2009) the soil reaction forces are passive and up to now it have been found sufficiently accurate to express them as function of pile motion only. The soil reaction consists of a static (elastoplastic) and a dynamic (linear damping) component. In this way the soil model has at each point three unknowns (elasticity, plasticity and viscosity). A reasonable assumption is made regarding the soil parameters, and then the motion of the pile is assumed using the measured pile top acceleration as a boundary value. The results of the CAPWAP analysis then are the magnitude and location along the pile of both static and dynamic resistance forces. Static computations can be used to predict the static load test curve of the pile. (Refer: **Appendix B** for details)

2.6 Backpropagation– Function Approximation Method

According to **Simon Haykin, (2009),** ***Neural Networks and Learning Machine.*** **Pearson Prentice Hall company**, a neural network has a natural ability for pattern classification. The network is trained by presenting it with a number of different examples of the same object. In this case, pile bearing capacity data from M.L.T and P.D.A, soil characteristic data from site investigation and no of blows for reinforced concrete data will be trained by using function approximation to determine the hidden layer within the function. The training of the network is repeated for many examples in the set, until the network reaches a steady state where there are no further significant changes in the synaptic weights. Thus the network will learn from the data during training session.

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY/ PROJECT WORK

3.1 Methodology

The methodology is as follow:

Firstly, collect and summarized all soil data pertaining to the site and characterize soil layering system along the site. The entire soil stratum can be obtained from Engineering Bore Hole from Site Investigation. Secondly, all data from Reinforced Concrete pile driven result need to collect and will be summarized points which are near to Bore Hole only. Site Investigation and Reinforced Concrete data have relationship based on number of blows and both of data can be compared to determine the significant different. Thirdly, determine and summarized pile bearing and skin friction capacity based pile load test results. Ultimate, skin and bearing capacity can be determined from PDA and MLT. Fourthly, the Ultimate Load Capacity from Site Investigation can be compared with Load Test. Site variation of load significant different can be obtained by using Surfer software. Finally all the result obtained and analysed will be trained by using neural network under back propagation method in Matlab software. Ultimate load required can be predicted by using neural network based on data that have been trained. From the results, the author should be able to determine correlations between soil properties and pile bearing capacity as well as draw conclusions.

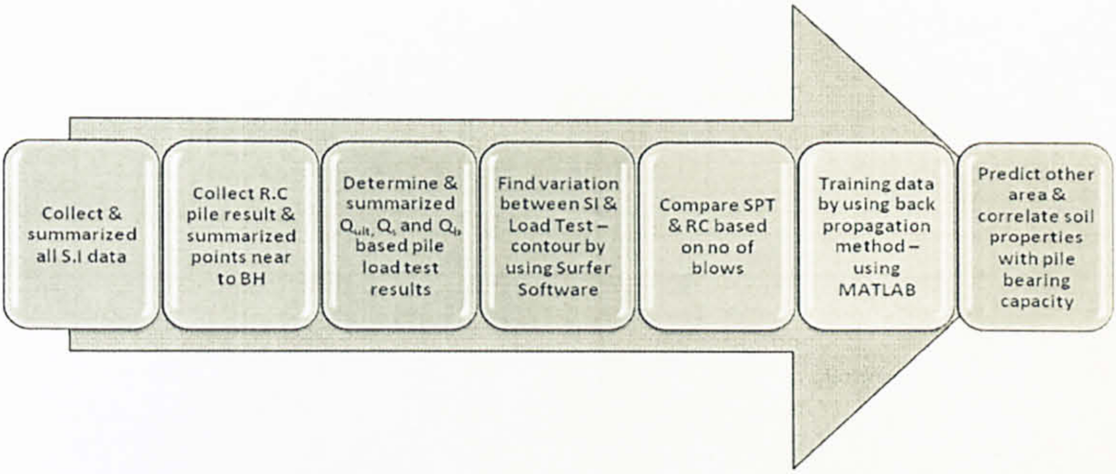

Figure 4: Methodology used in this project

3.2 Tools/Equipment Required

The tools and equipment which are required in this Final Year Project are Microsoft Office Excel, Surfer and MATLAB which is used to evaluate and analyse the data obtained. The driven pile data or reinforced concrete pile driven result, site investigation and pile load test response will be analysed in order to determine the correlation between soil properties and pile bearing capacity. Surfer software version 9 will be used by the author to plot the load distribution in contour format for comparison between Qu from load test and Qu from Site Investigation. By using this software, the pattern of load from actual can be compared with design parameters.

3.2.1 Artificial Neural Network (ANN) Training

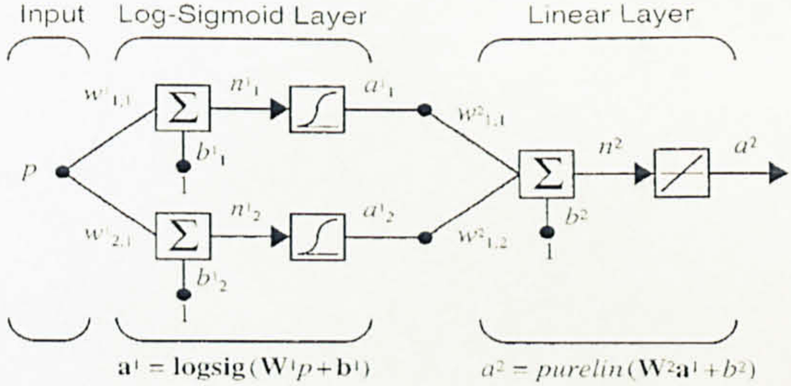

Figure 5: Example of Function Approximation Network

The training procedure will optimize the hidden layer size and also other parameters such as learning rate, momentum and training cycles. For example, initially by looking at the overall selected ANN, the hidden layer can be set to 5, momentum rate at 50% and then try to optimize the learning rate. The initial training parameters are set as in script in Matlab shown as below.

For example, here input P and targets T define a simple function which we can plot:-

```
p = [0 1 2 3 4 5 6 7 8];
t = [0 0.84 0.91 0.14 -0.77 -0.96 -0.28 0.66 0.99];
plot(p,t,'o')
```

Then, newff is used to create a two-layer feed-forward network. The network will have an input (ranging from 0 to 8), followed by a layer of 10 tansig neurons, and followed by a layer with 1 purelin neuron. Trainlm back propagation coding is used. The network is also simulated.

```
net = newff([0 8],[10 1],{'tansig' 'purelin'},'trainlm');
y1 = sim(net,p)
plot(p,t,'o',p,y1,'x')
```

Here the network is trained for up to 50 epochs to a error goal of 0.01, and then resimulated.

```
net.trainParam.epochs = 50;
net.trainParam.goal = 0.01;
net = train(net,p,t);
y2 = sim(net,p)
plot(p,t,'o',p,y1,'x',p,y2,'*')
```

Source: Neural Network Toolbox : Train a Neural Network (Matlab 7.0.1)

3.3 Gantt Chart and Key Milestone

3.3.1 Gantt Chart for FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	19
					14/8				11/9							30/10		30/11
1	Selection of Project Topic	■																
	- *Propose Topic*																	
	- *Confirmation of Topic Selection*																	
2	Preliminary Research Work		■	■														
	- *Data collection*																	
	- *Identifying software and tools required*																	
	- *Literature review on piles and load test*																	
3	Submission of Preliminary Report				●													
4	Project Work				■	■	■	■										
	- *Data analysis and interpretation*																	
5	Submission of Progress Report								●									
	- *Literature Review*																	
	- *Project Description*																	
6	Project work continue								■	■	■	■	■	■	■			
	- *Modelling data of load settlement curves*																	
7	Submission of Interim Report Final Draft															●		
8	Oral Presentation																	●

● Milestone

■ Process

3.3.2 Gantt Chart for FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue														
	-Study Surfer and Matlab														
2	Submission of Progress Report 2														
3	Project Work Continue														
	-Find variation between SI & Load Test														
4	-Compare SPT & RC based no of blows														
5	Project work continue														
	-Training data by using MATLAB														
6	Submission of Dissertation Final Draft														
7	Oral Presentation														
8	Submission of Project Dissertation														

CHAPTER 4

RESULTS

4.0 RESULTS

The data on the selected pile load test reports and site investigation were compiled. The information and data regarding the project, soil stratification and properties, pile characteristics, and load test data were processed and transferred from each load test report to tables, forms, and graphs. The following data and information below shown on how the author compiled, and analyzed each data that are going to use in this project.

4.1 Site Investigation Data

Data and graph shown below are regarding site investigation that had been carried out at the site. There are 10 engineering borehole points that can be observed and analyzed. This data is very essential for studying the soil condition and very important to refer for designing pile at certain location. The soil properties are mainly sand or clay layers which therefore explain the low N-values during SPT.

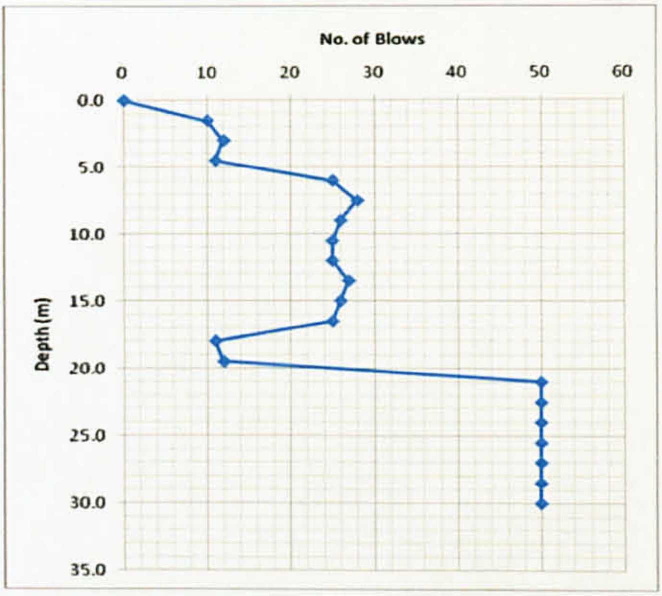

Figure 6: Engineering Bore Hole 1 (Refer: **Appendix C1** for details)

As it is observed through Figure 6, the SPT values for the first 3 meters are not relatively high and range from 0-10. From 0 until 7.5m depth, the soil properties were medium sand. After 7.5m, the properties were silt. When reached 21m, the SPT value was more than 50 and the properties was hard silt with some quartz gravel. The boring for BH1 end at 30.07m depth.

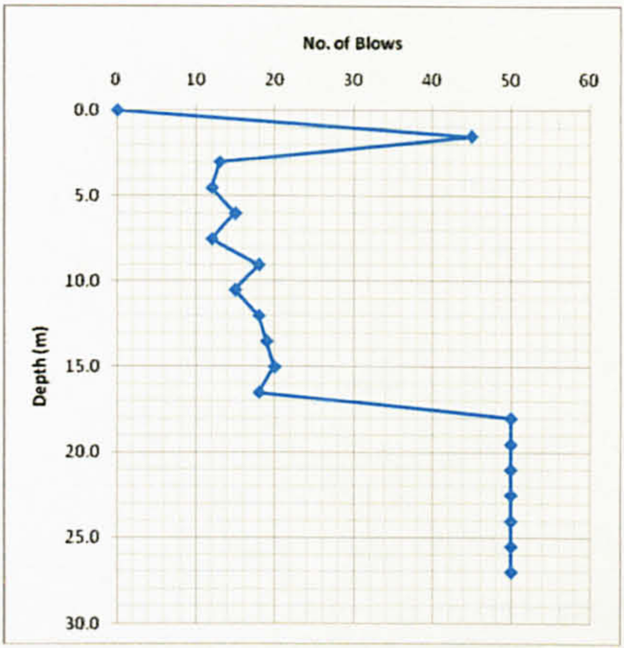

Figure 7 : Engineering Bore Hole 2 (Refer: **Appendix C2** for table)

Graph at Figure 7 shown that the soil properties were hard light brown sandy silt at 1.5m depth. This result is very essential in predicting the soil stratum of the area. From 4.5 to 12m the soil properties were medium sand. After 13.5m depth, silt can be found again. Hard light grey sandy silt with some quartz gravel can be found at 18m depth onwards. Furthermore, at this depth the SPT value was 50 and it can be concluded that the soil properties were hard. The boring for BH2 end at 27.06m depth.

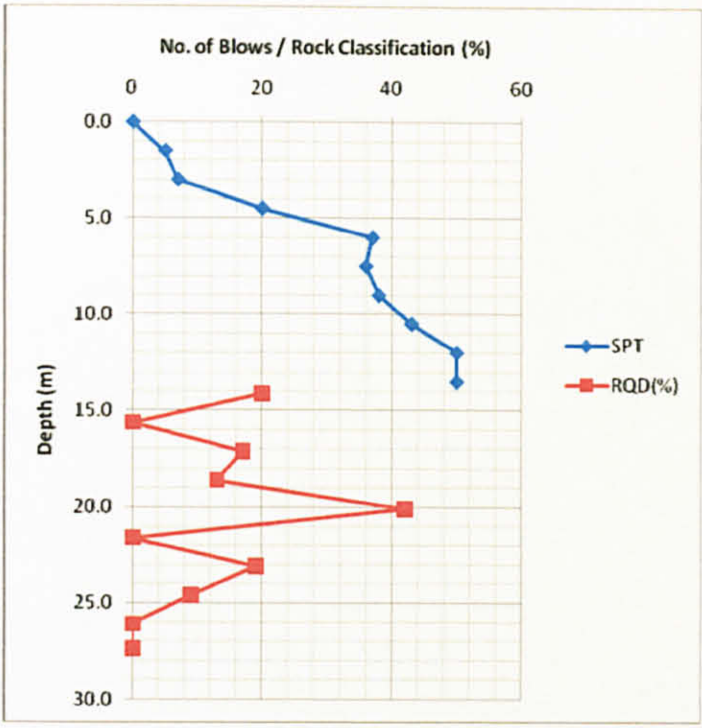

Figure 8 : Engineering Bore Hole 3 (Refer: **Appendix C3** for table)

As it is observed through Figure 8, the SPT values for the first 3 meters are not relatively high and range from 0-10. At this depth the soil properties were light grey medium sand. The silt can be found at 4.5m depth onwards. The SPT value already reached 50 at 12m depth. From 0 until Even the N 50 value at the end was due to the fact that the SI machine had hit the rock layer and therefore it cannot be considered as a potential pile sitting zone. The RQD values in the site are founded to be quite high ranging from 13% to 42%. This fact encourages the consultants to go forward with their plan of designing the piles to sit on the rock surface. Rocks in the site are mostly granite and range from in colour to whitish or greyish in colours. The whitish and greyish rocks are normally the better ones and produce higher RQD normally. The boring for BH3 end at 27.4m depth.

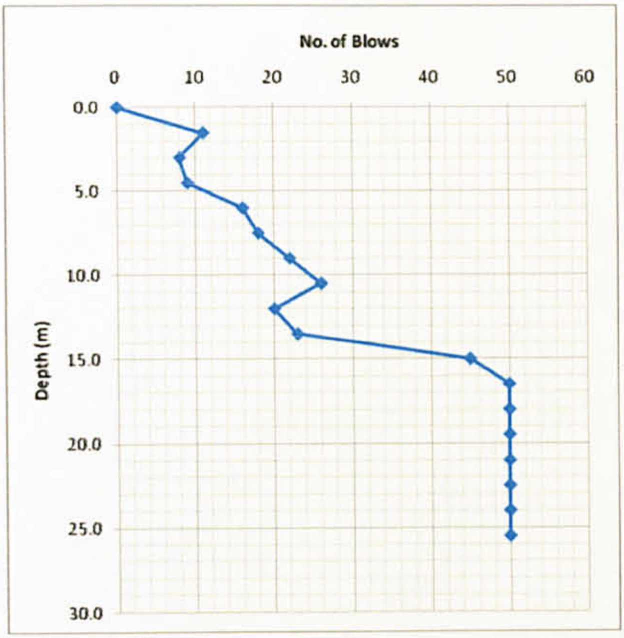

Figure 9 : Engineering Bore Hole 4 (Refer: **Appendix C4** for table)

Graph at Figure 9 shown that the soil properties were light grey silty medium sand at 1.5m depth. At 6m depth, the properties changed to light grey clayey silt with some gravel until 10.5m. After 15m onwards, the soil properties were hard light grey fine sandy silt with some quartz gravel. At this depth, the value of SPT already reached 50. The boring for BH4 end at 25.59m depth.

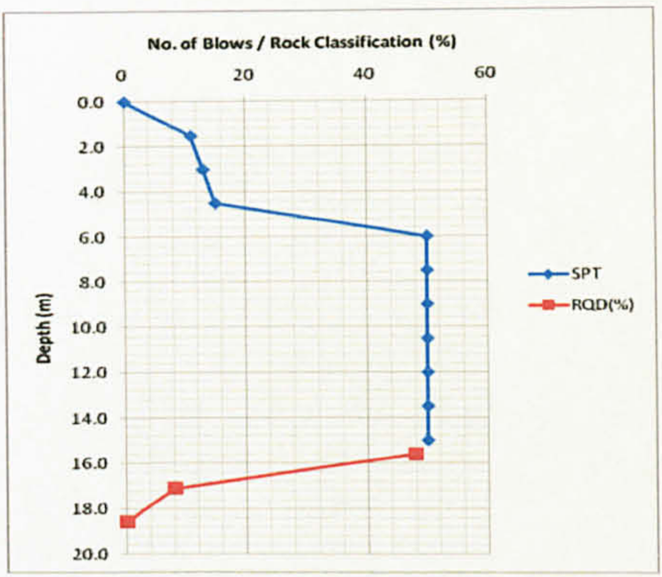

Figure 10 : Engineering Bore Hole 5 (Refer: **Appendix C5** for table)

As it is observed through Figure 10, the SPT values for the first 3 meters are not relatively high and range from 0-15. At this range of depth the soil properties were light grey sandy silt with some gravel. At 6m depth onwards, the properties were hard light grey fine sandy SILT with some quartz gravel. At this point, the SPT value already reached 50. Even the N 50 value at the end was due to the fact that the SI machine had hit the rock layer and therefore it cannot be considered as a potential pile sitting zone. The RQD values in the site are founded to be quite high ranging from 8% to 48%. The soil properties were light grey moderately weak & weathered highly fractured granite. The boring for BH5 end at 18.6m depth.

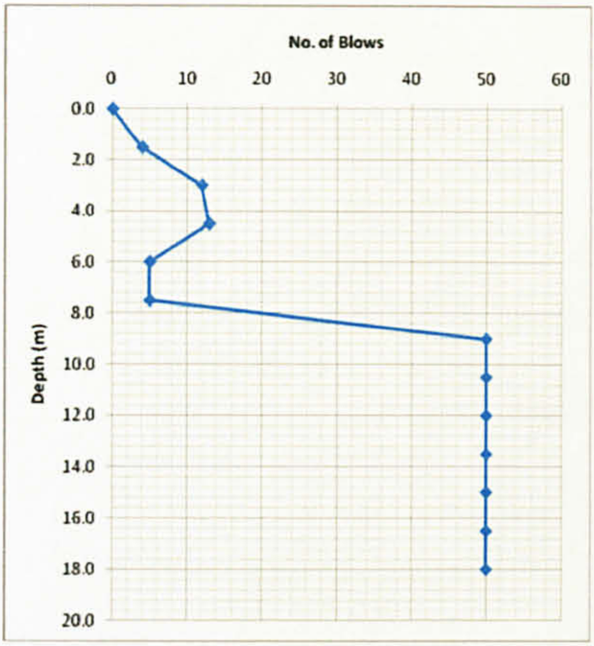

Figure 11 : Engineering Bore Hole 6 (Refer: **Appendix C6** for table)

Site investigation at Bore Hole 6 shown that the soil properties were firm light grey gravelly sandy silt from 1.5 to 7.5m depth. The SPT value were range from 4-13. At 9m depth, the result of SPT was more than 50. This is because the soil properties at this stage were hard layer. While boring, the soil properties were hard yellowish reddish brown sandy silt and hard light grey gravelly sandy silt. The boring for BH6 end at 18.295m depth.

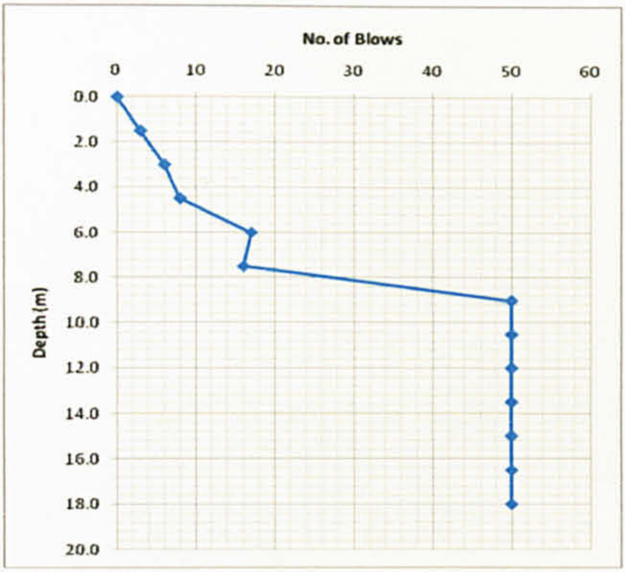

Figure 12 : Engineering Bore Hole 7 (Refer: **Appendix C7** for table)

Graph at Figure 12 shown that the soil properties were firm light grey sandy silt until 7.5m depth. The SPT value were range from 3-17. At 9m depth, the properties changed to hard light grey reddish sandy. At this point, the SPT value already reached 50. At 12m onwards, the soil properties were hard yellowish brown sandy silt. At this depth, conclusion can be made that the stratum was in hard layer. The boring for BH7 end at 18.05m depth.

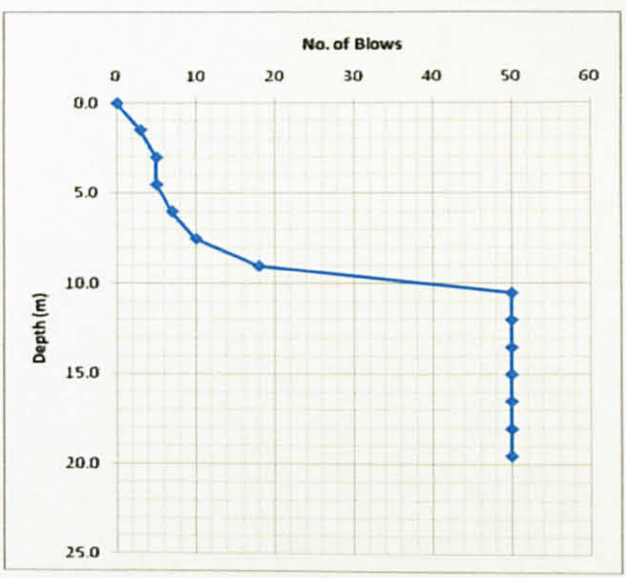

Figure 13 : Engineering Bore Hole 8 (Refer: **Appendix C8** for table)

As it is observed through Figure 13, the SPT values for the first 6 meters are not relatively high and range from 0-7. At 7.5 to 9m depth, the soil properties changed to stiff light grey yellow sandy silt. From 10.5m onwards, the SPT values were more than 50. At 10.5 to 12m the properties were hard light grey yellow sandy silt. At 13.5m onwards the properties were hard light grey gravelly sandy silt. The boring for BH8 end at 19.785m depth.

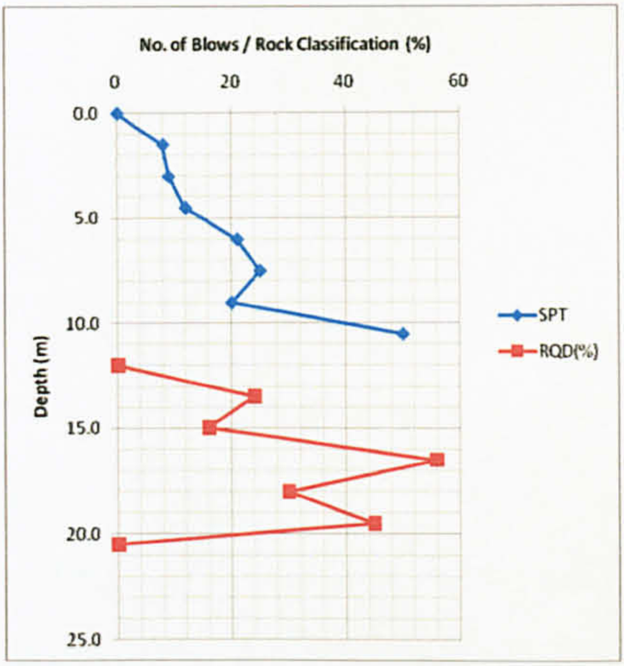

Figure 14 : Engineering Bore Hole 9 (Refer: **Appendix C9** for table)

As it is observed through Figure 14, the SPT values for the first 3 meters are not relatively high and range from 0-9. At this range of depth the soil properties were firm to stiff light grey sandy silt with traces of gravel. At 6 to 9m depth the soil properties were very stiff light grey sandy silt with traces of gravel. The value of SPT reached 50 at 10.5m depth and the properties were hard light grey sandy SILT with traces of gravel. At this point, the SPT value already reached 50. Even the N 50 value at the end was due to the fact that the SI machine had hit the rock layer and therefore it cannot be considered as a potential pile sitting zone. The RQD values in the site are founded to be quite high ranging from 16% to 56%. The soil properties were light grey, strong, moderately weathered, moderately fractured granite. The boring for BH5 end at 20.5m depth.

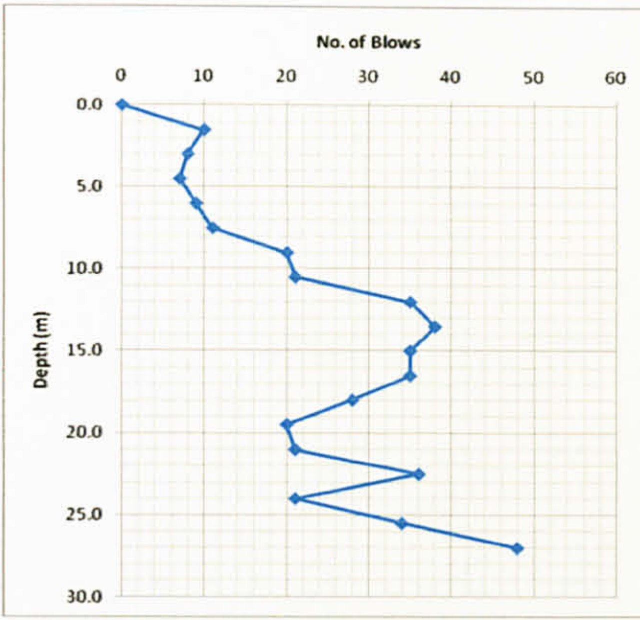

Figure 15 : Engineering Bore Hole 10 (Refer: **Appendix C10** for table)

Site investigation at Bore Hole 10 shown that the soil properties were loose to medium dense light brown-silty medium SAND from 1.5 to 7.5m depth. The SPT value were range from 7-11. At 9 to 21m depth, the result of SPT were range from 20-38. The soil properties were hard light grey fine sandy SILT with quartz gravel. After 22.5m onward, the stratum was hard layer. The soil properties were hard light grey sandy SILT with traces of gravel. The boring for BH6 end at 43.85m depth.

4.2 Reinforced Concrete Driven Pile Result

There are 1,140 reinforced concrete pile points at this site. From reinforced concrete driving record, the author can determined the effective depth of location and no of blows required. The analysis is essential to points which are near to each Engineering Bore Hole area. The result obtained will be compared to engineering Bore Hole data to determine the accuracy of soil properties. In addition, there is constraint in this analysis because the maximum numbers of blows are range from 80-90. Based on Standard Penetration Test (S.P.T), when the number of blows ever reached 50, the test will be terminated and corresponding penetration will be recorded. This is because number of blows more than 50 is considered as hard layer, very dense soil or rock. Therefore, the number of blows at 50 from SPT will be compared with RC driving record and find the correlation between this data. Referring to RC pile data, points which are near to Engineering Bore Hole are as below:-

a) **BH1** : 3/G-1, 3/G-2, 3/G-5, 1/G-1, 3/F-1, and 3/F-2

b) **BH2** : 3/H-3

c) **BH3** : 7a/A-1, 6a/A-1, 8/A-1, 6/C-1, 6/C-2, 6/C-3, 6/C-5,7/C-1, 7/C-6, and 7/C-7

d) **BH 4** : 7/L-1, 7/L-5, 5/J-1, 5/J-2, 5/J-3, 5/J-4, and 5/J-5

e) **BH 5** : 8/F-3, 8/F-6, 8/F-8, 9/F-5, 9/F-8, 8/E-1, 8/E-3, 8/E-7, 9/E-13 and 9/E-16

f) **BH 6** : 10/L-1, 10/L-2, 10/L-4, 10/L-6, 10/M-2, 10/M-5, 11/L-1, 11/L-7, 9/L-2, and 9/L-5,

g) **BH 7** : 13/J-1, 13/J-2, 13/J-3, 13/J-5, 13/J-9, 14/J-2, 14/J-6, 12/J-3, 12/J-8, and 13/I-3

h) **BH 8** : 15/A-1, 16/A-1, 14a/A-1 and 16/B-1

i) **BH 9** : 11/A-1, 11/C-2, 11/C-6, 11/C-9, 11/C-12, 12/B-1, 12/B-3, and 12/B-5

j) **BH 10** : 1/B-1, 2/A-1, 3/C-1, 3/C-2, 3/C-3, 3/C-5 and 3/C-6

(Refer: **Appendix D** for details)

4.3 Data comparison between RC Pile and Engineering Bore Hole

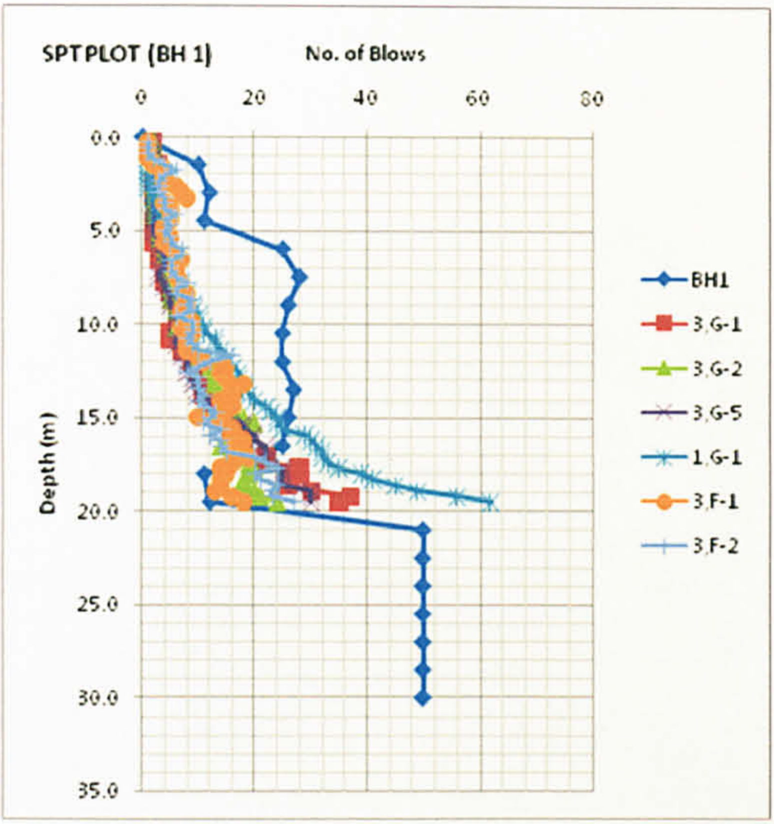

Figure 16 : Comparison between BH1 and RC pile points

Based on Engineering Bore Hole from Figure 16, soil properties at 1.5m is light brown-medium sand and before reach SPT 50 the properties change to light grey sandy silt with some gravel. Actual result from RC pile data shown consistent value number of blows compare to SPT. Comparison between RC pile points and BH1 are significant different esspecially from depth 1.5m until 15m. Number of blows from SPT are high probably because of high underground water table at the site location. Furthermore, weathering process can also be consider as a factor affected the significant different of soil particle at the location. During installation of RC pile, the soil was totally compacted. Therefore the void size of soil particles structure was totally compacted compare to SPT.

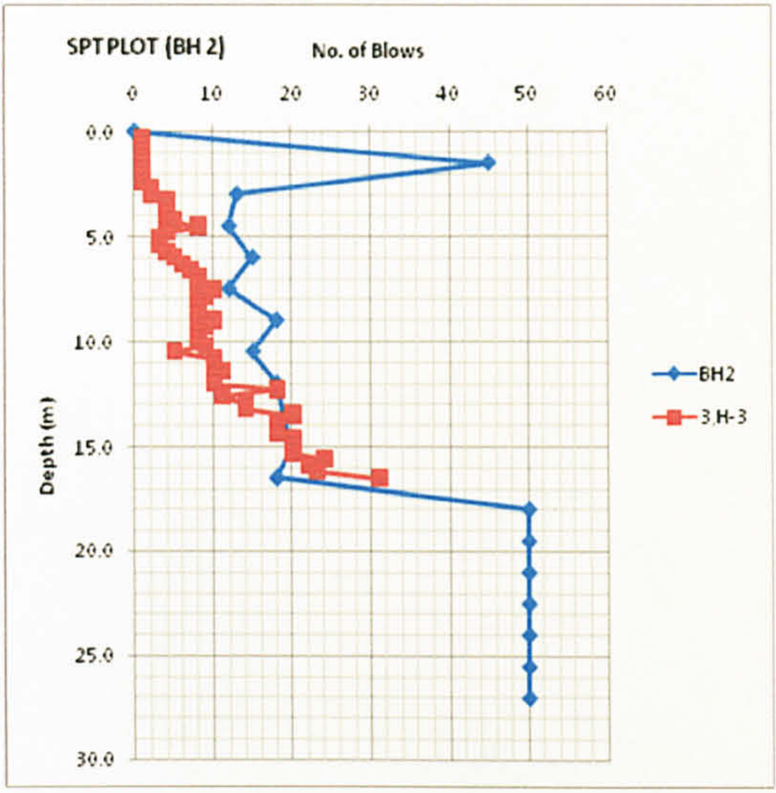

Figure 17 : Comparison between BH2 and RC pile points

Based on Engineering Bore Hole from Figure 17, soil properties at 1.5m is hard light brown sandy silt and before reach SPT 50 the properties change to very stiff light grey fine sandy silt with some quartz gravel. This location consist more Bore Pile than RC pile. Only one actual result of RC pile can be obtained and analyzed based on site condition. Comparison between RC pile point and BH2 are significant different esspecially from depth 1.5m until 11m. Number of blows from SPT are high probably because of high density of soil structure and weathering process of soil particle at the location.

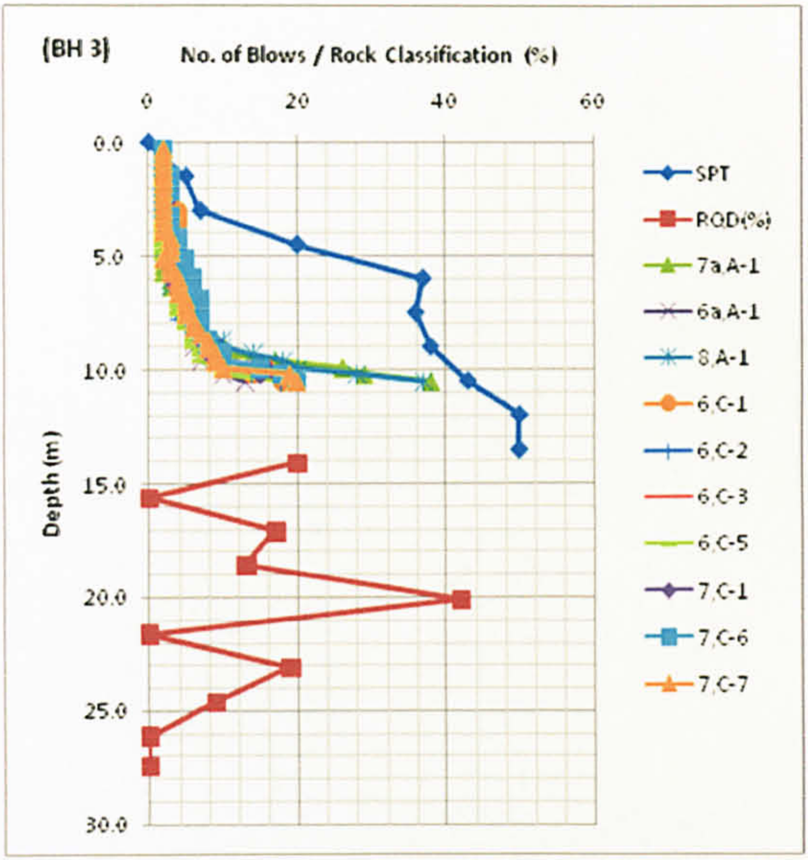

Figure 18 : Comparison between BH3 and RC pile points

Based on Engineering Bore Hole from Figure 18, soil properties at 1.5m is loose light grey silty medium sand and before reach SPT 50 the properties change to hard light grey fine sandy Silt with some quartz gravel. Actual result from RC pile data shown consistent tabulation value number of blows compare to SPT. Comparison between RC pile points and BH3 are significant different esspecially from depth 1.5m until 10.5m. Number of blows from SPT result are high probably because of high density of soil particles. In addition, weathering process can also be consider as a factor affected the significant result between SPT and RC pile points.

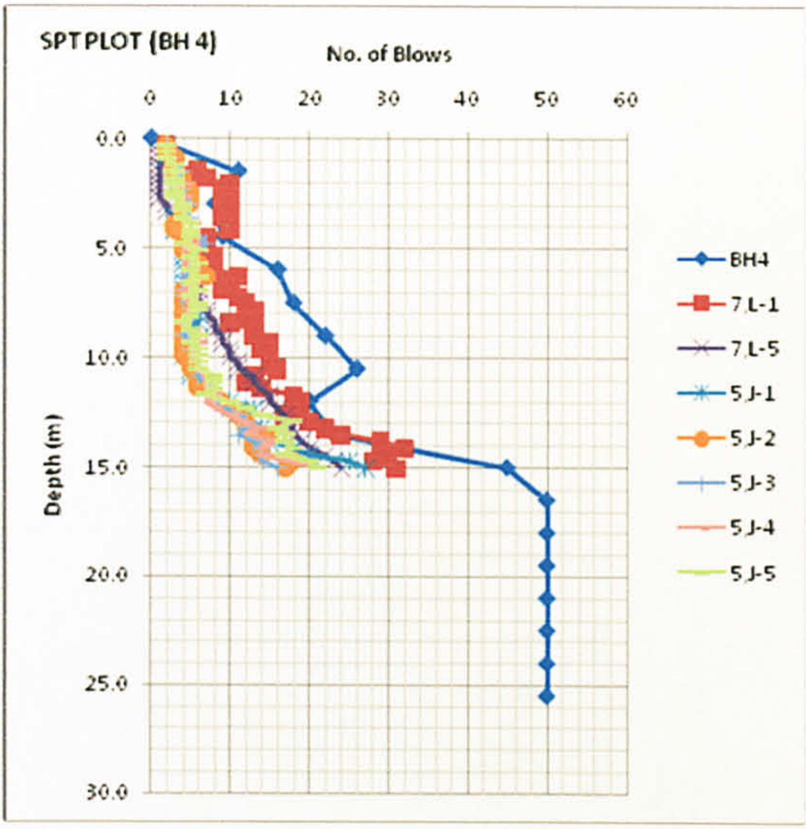

Figure 19 : Comparison between BH4 and RC pile points

Based on Figure 19, soil properties at 1.5m is medium dense light grey silty medium Sand and before reach SPT 50 the properties change to hard light grey fine sandy Silt with some quartz gravel. Actual result from RC pile and SPT data shown consistent value. The most significant different between RC pile points and BH4 are at depth 6m to 11m. At 15m depth, the value of SPT already reached 50 and already consider reached hard layer.

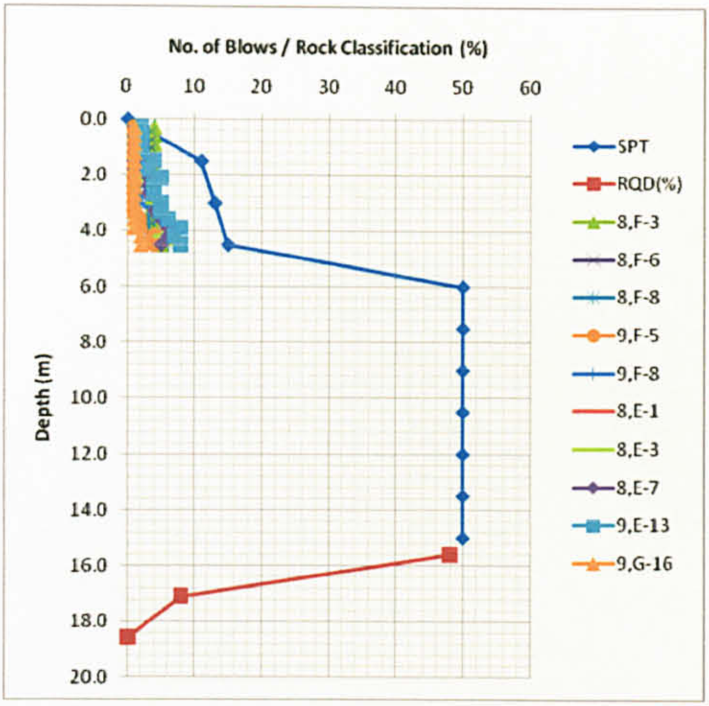

Figure 20 : Comparison between BH5 and RC pile points

Based on Engineering Bore Hole from Figure 20, soil properties at 1.5m is medium dense, light grey silty medium Sand with some gravel and before reach SPT 50 the properties change to hard light grey fine sandy Silt with some quartz gravel. Actual result from RC pile data shown unconsistent value number of blows compare to SPT. Comparison between RC pile points and BH5 are significant different esspecially from depth 1.5m until 5m. Number of blows from SPT are high probably because of the soil condition and properties. Furthermore, N 50 value at depth 6.0m was due to the fact that the SI machine had hit the rock layer and therefore it cannot be considered as a potential pile sitting zone. The RQD values in the site are founded to be quite high ranging from 8% to 48%. The rock properties were light grey moderately weak & weathered highly fractured granite.

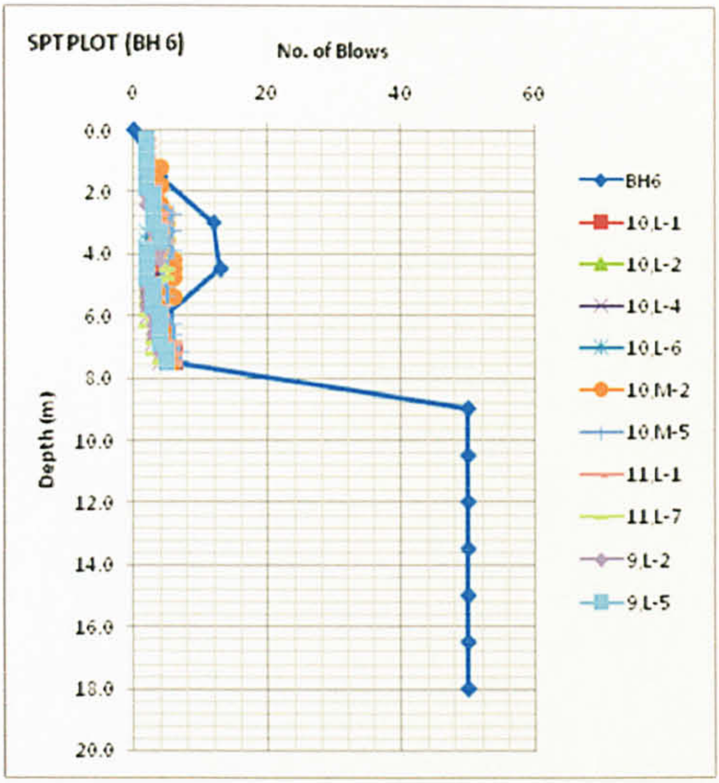

Figure 21 : Comparison between BH6 and RC pile points

Based on Engineering Bore Hole from Figure 21, soil properties at 1.5m is soft to firm brownish grey sandy Silt and before reach SPT 50 the properties change to hard light grey yellow sandy Silt. Actual result from RC pile data shown consistent value number of blows compare to SPT. Comparison between RC pile points and BH6 are significant different esspecially from depth 1.5m until 6m. Number of blows from SPT are high probably because of high underground water table at the site location. Furthermore, weathering process can also be consider as a factor affected the significant different of soil particle at the location. During installation of RC pile, the soil was totally compacted. Therefore the void size of soil particles structure during RC pile installation was totally compacted compare to SPT.

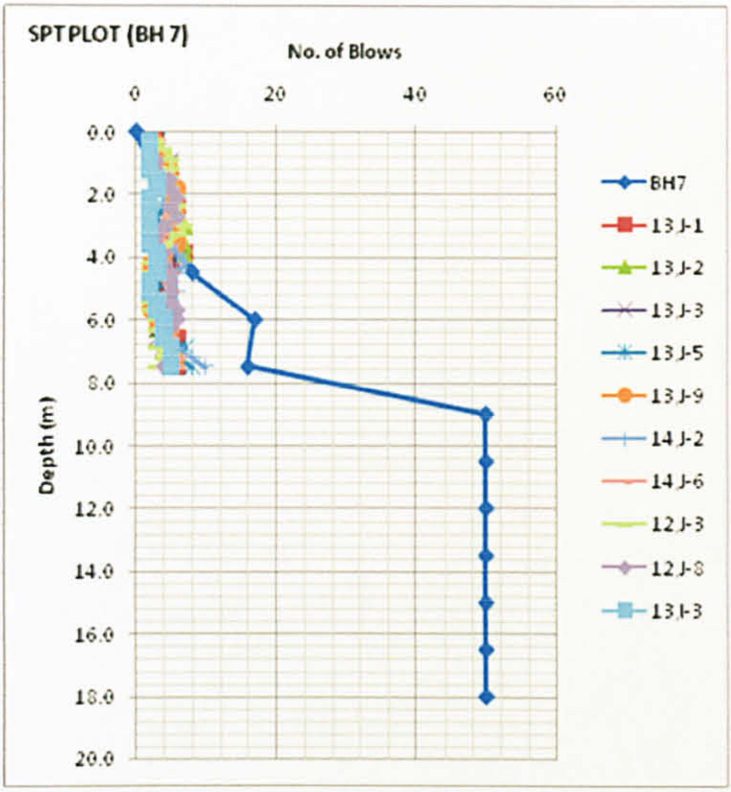

Figure 22 : Comparison between BH7 and RC pile points

Based on Engineering Bore Hole from Figure 22, soil properties at 1.5m is very loose light grey, silty coarse Sand and before reach SPT 50 the properties change to hard light grey reddish sandy Silt. Actual result from RC pile data shown consistent value number of blows compare to SPT. From 1m until 4m depth, the soil properties are consistent and the tabulation of data from RC pile and SPT are not much dfferent. Comparison between RC pile points and BH7 are significant different when reached depth 4m until 7.5m. Number of blows from RC pile are low at this stage probably because of weathering process effect. Thus, during SPT the soil were probably in high density and totally compacted compare during installation of RC pile. Therefore the void size of soil particles structure will also be considered as factor for significant different of data from 4m until 7.5m depth.

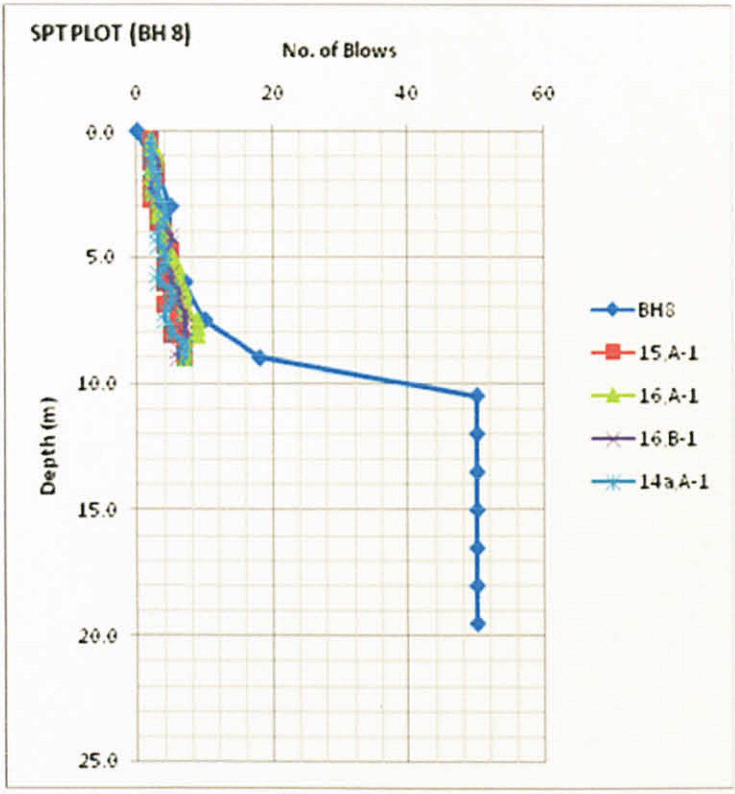

Figure 23 : Comparison between BH8 and RC pile points

Based on Engineering Bore Hole from Figure 23, soil properties at 1.5m is soft light grey sandy Silt and before reach SPT 50 the properties change to very stiff yellowish brown sandy Silt. Actual result from RC pile data shown consistent value number of blows compare to SPT. The soil properties are consistent and the tabulation of data from RC pile and SPT are not much dfferent. At 10.5m depth, the value of SPT already reached 50 and already consider reached hard layer.

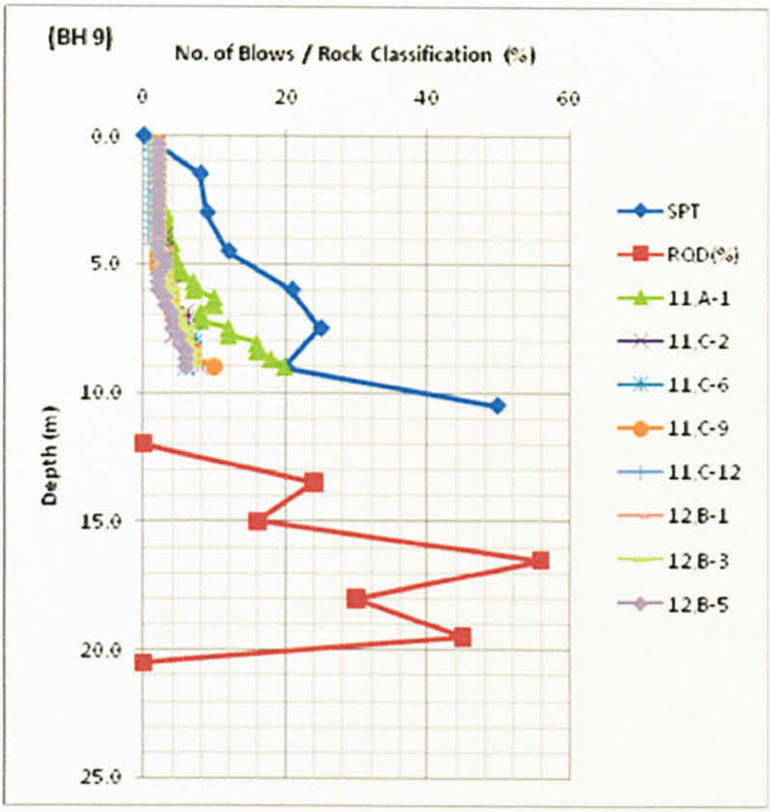

Figure 24 : Comparison between BH9 and RC pile points

Based on Engineering Bore Hole from Figure 24, soil properties at 1.5m is firm to stiff light grey sandy Silt with traces of gravel and before reach SPT 50 the properties change to very stiff light grey sandy Silt with traces of gravel. Actual result from RC pile data shown unconsistent value number of blows compare to SPT. Comparison between RC pile points and BH9 are significant different esspecially from depth 1.5m until 9m. Number of blows from SPT are high probably because of high underground water table at the site location and weathering process can also be consider as a factor. Even the N 50 value at 10.5m depth was due to the fact that the SI machine had hit the rock layer and therefore it cannot be considered as a potential pile sitting zone. The RQD values in the site are founded to be quite high ranging from 16% to 56%. The rock properties were light grey, strong, moderately weathered, moderately fractured granite.

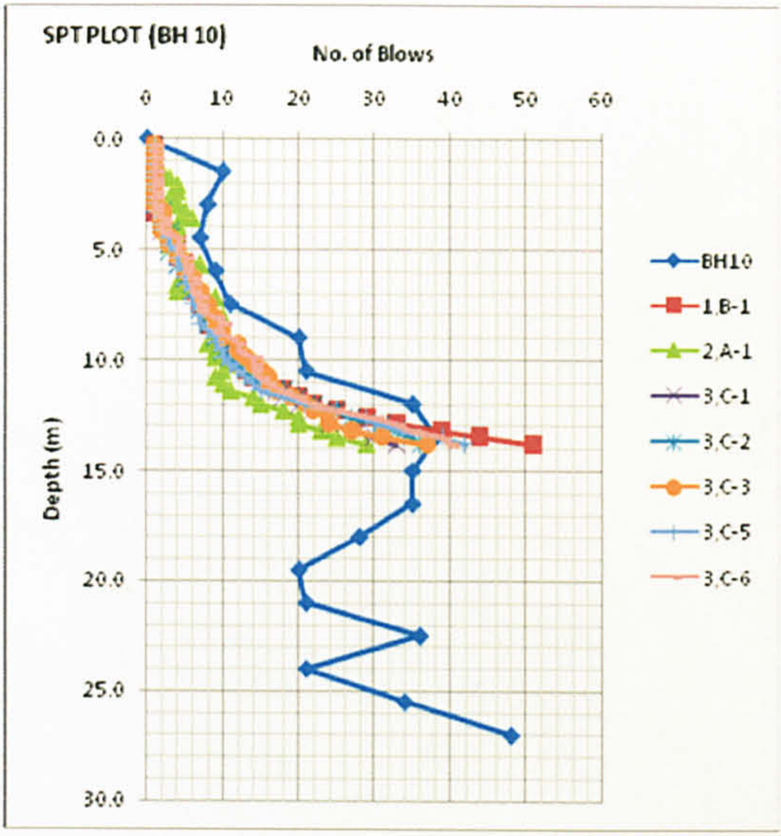

Figure 25 : Comparison between BH10 and RC pile points

Based on Engineering Bore Hole from Figure 25, soil properties at 1.5m is firm to stiff light grey sandy Silt with traces of gravel and before reach SPT 50 the properties change to very stiff light grey sandy Silt with traces of gravel. Actual result from RC pile data shown consistent value number of blows compare to SPT. The soil properties are consistent and the tabulation of data from RC pile and SPT are not much dfferent. At 21m depth, the value of SPT already reached 50 and already consider reached hard layer.

4.4 Pile Load Test Responses Summary

In this section the author will discussed regarding Maintained Load Test and Pile Dynamic Analysis Test. The pile bearing, skin friction and ultimate bearing capacity can be determined from both tests. For PDA, bearing and skin friction can be determined from CAPWAP Analysis. For MLT, the bearing and skin friction capacity can be determined by using Chin's Plot analysis. Chin Plot analysis enable us to detemine pile bearing capcity, skin friction and ultimate pile capacity. 1st cycle data represent ultimate skin friction capacity and 2nd cycle data represent ultimate pile capacity. Bearing capcity can be determined by below equation:-

$$Q_{ult} = Q_s + Q_b$$

Therefore, $Q_b = Q_{ult} - Q_s$

The summary of Maintained Load Test is shown as table below:-

Pile Location	11/G-10	9/C-4	6/I-1
Date of Testing	22/04/09	5/5/2009	8/6/2009
Pile Type	RC	RC	BP
Total Length (m)	12	12	19.9
1st cycle Settlement	7.395mm	6.735mm	3.13mm
Residual Settlement	3.65mm	2.363mm	1.65mm
2nd cycle Settlement	21.71mm	20.855mm	7.92mm
Residual Settlement	5.445mm	9.408mm	0.62mm
Skin Friction Q_f	192	150	420
End Bearing Q_b	158	270	116
Ultimate Load Capacity Q_{ult}	350	420	536

Table 2: Summary of Maintained Load Test

(Refer: **Appendix E** for details)

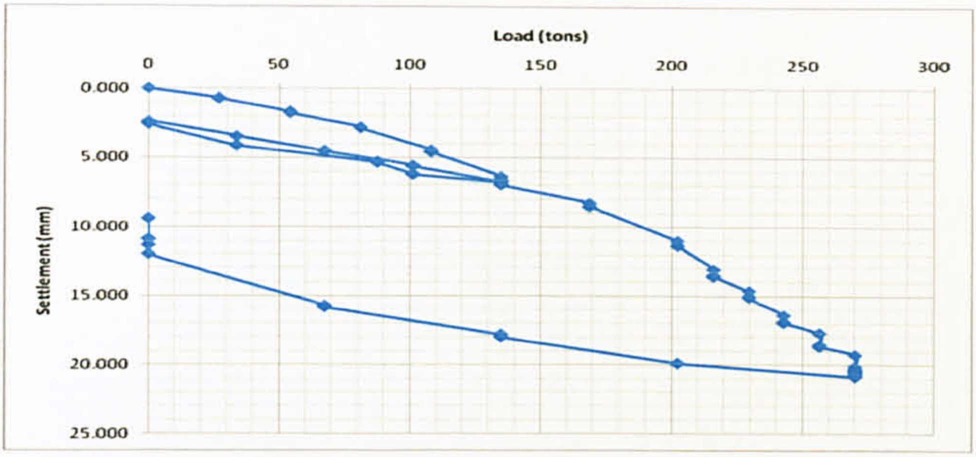

Figure 26: Settlement graph for grid line 9/C-4

Based on Figure 26, the M.L.T the working load is 135 tons and the ultimate load is 2 times working load which is 270 tons. The 1st cycle result of settlement until 135 tons is **6.735mm**. After released to 0 tons, the residual settlement is **2.363mm** and the rebound is 4.372mm. For the 2nd cycle, the settlement is **20.855mm** at 270 tons and the residual settlement is **9.408mm** after released to 0 tons. The rebound for 2nd cycle is 11.447mm.

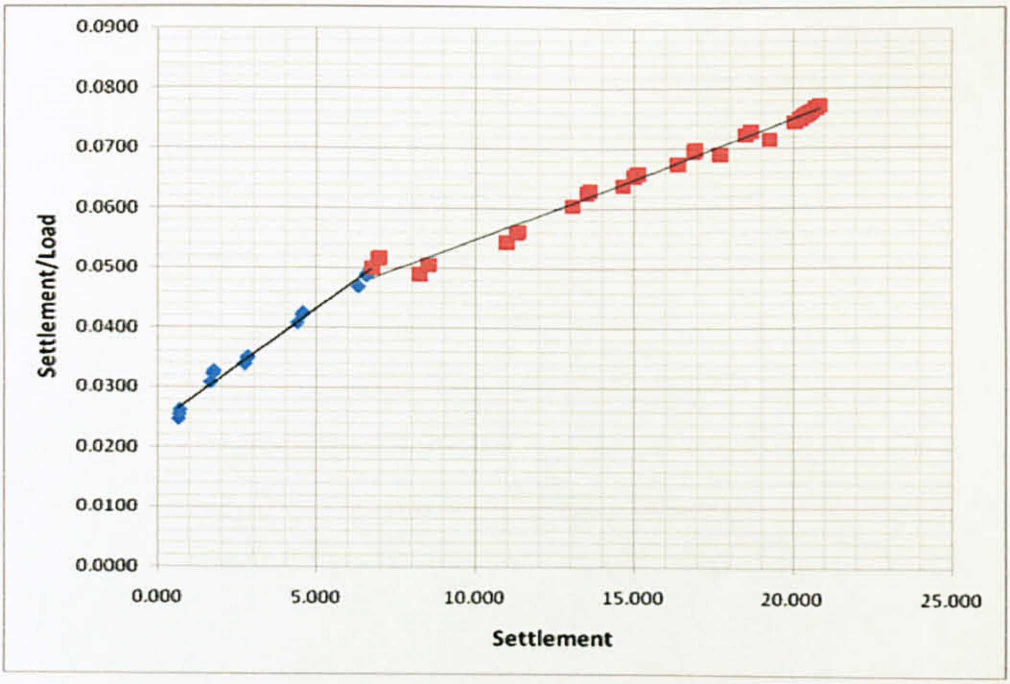

Figure 27: Chin's Plot for grid line 9/C-4

Based on Chin's Plot analysis the 1st cycle gradient represent ultimate skin friction capacity while 2nd cycle represent ultiamate pile capacity. Based on Figure 27, the ultimate pile capacity (**Q_{ult}**) is 350 tons, ultimate skin friction capacity (**Q_s**) is 192 tons and ultimate bearing capacity (**Q_b**) is 158 tons (after 0.7 correction factor).

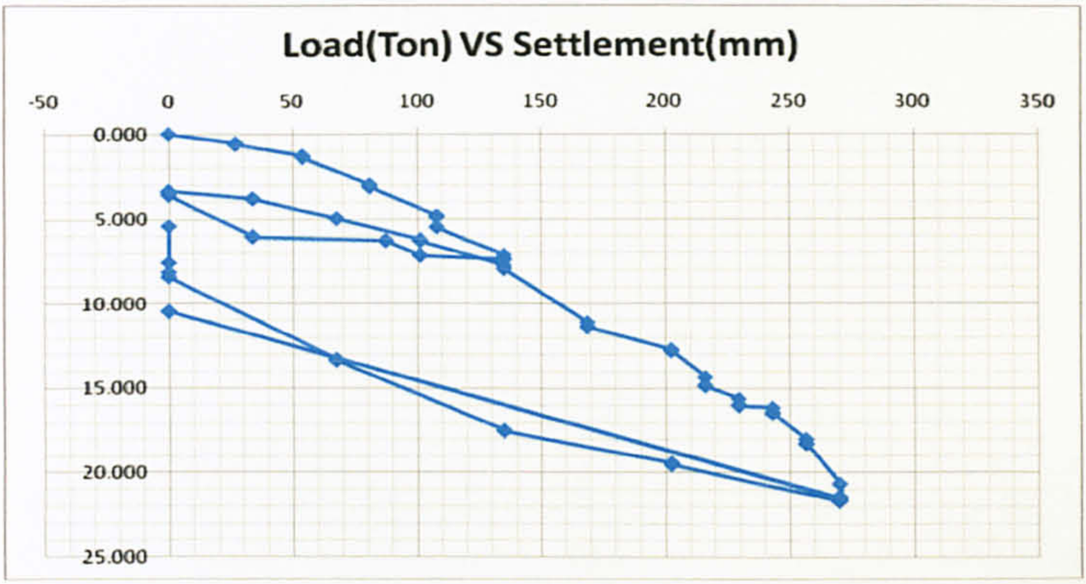

Figure 28: Settlement graph for grid line 11/G-10

Based on Figure 28, the M.L.T the working load is 135 tons and the ultimate load is 2 times working load which is 270 tons. The 1st cycle result of settlement until 135 tons is **7.395mm**. After released to 0 tons, the residual settlement is **3.365mm** and the rebound is 4.03mm. For the 2nd cycle, the settlement is **21.710mm** at 270 tons and the residual settlement is **5.445mm** after released to 0 tons. The rebound for 2nd cycle is 16.265mm.

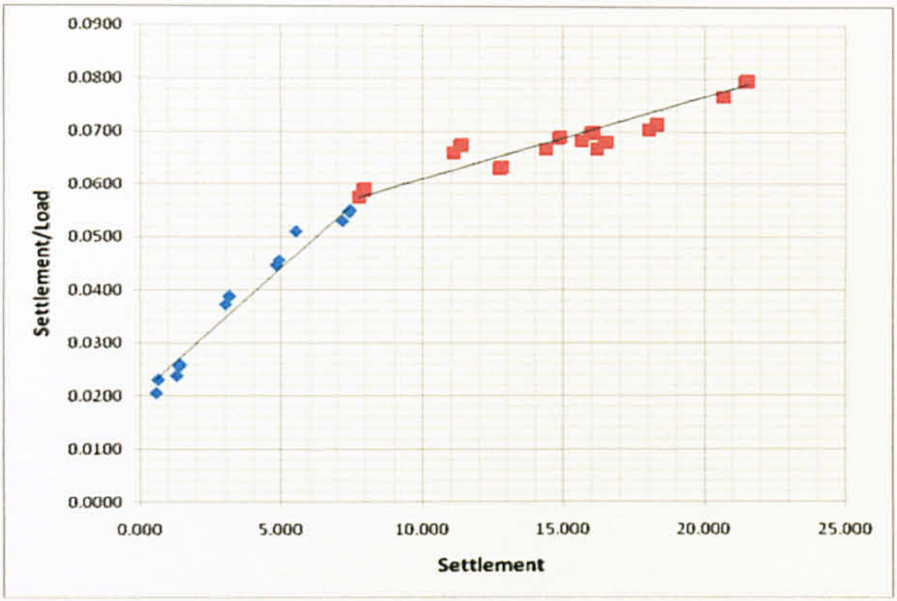

Figure 29: Chin's Plot for grid line 11/G-10

Based on Chin's Plot analysis 11/G-10, the ultimate pile capacity (**Q_{ult}**) is 420 tons, ultimate skin friction capacity (**Q_s**) is 150 tons and ultimate bearing capacity **(Q_b)** is 270 tons (after 0.7 correction factor).

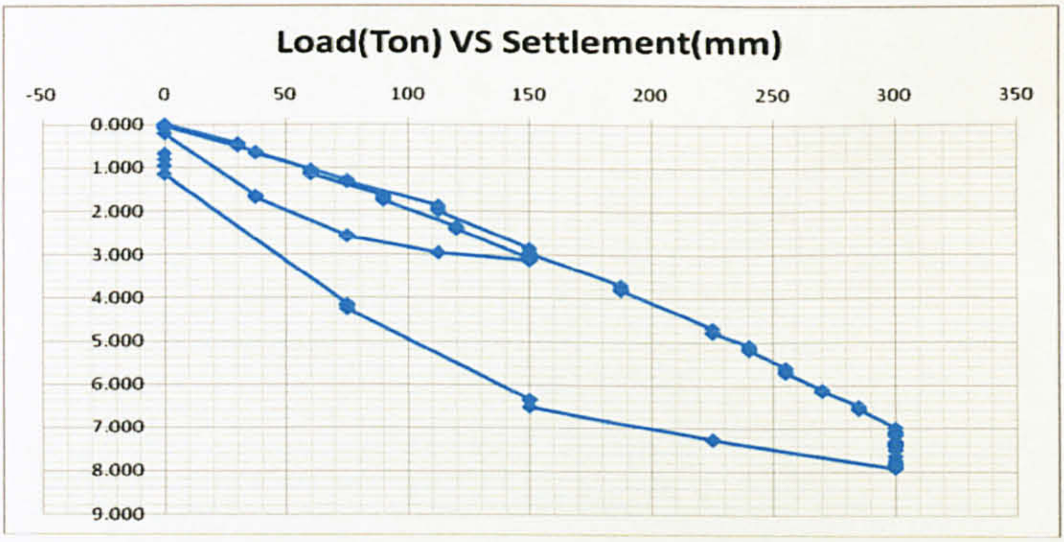

Figure 30: Settlement graph for grid line 6/I-1

Based on Figure 30, the M.L.T the working load is 150 tons and the ultimate load is 2 times working load which is 300 tons. The 1st cycle result of settlement until 150 tons is **3.13mm**. After released to 0 tons, the residual settlement is **0.04mm** and the rebound is 3.09mm. For the 2nd cycle, the settlement is **7.92mm** at 300 tons and the residual settlement is **0.67mm** after released to 0 tons. The rebound for 2nd cycle is 7.25mm.

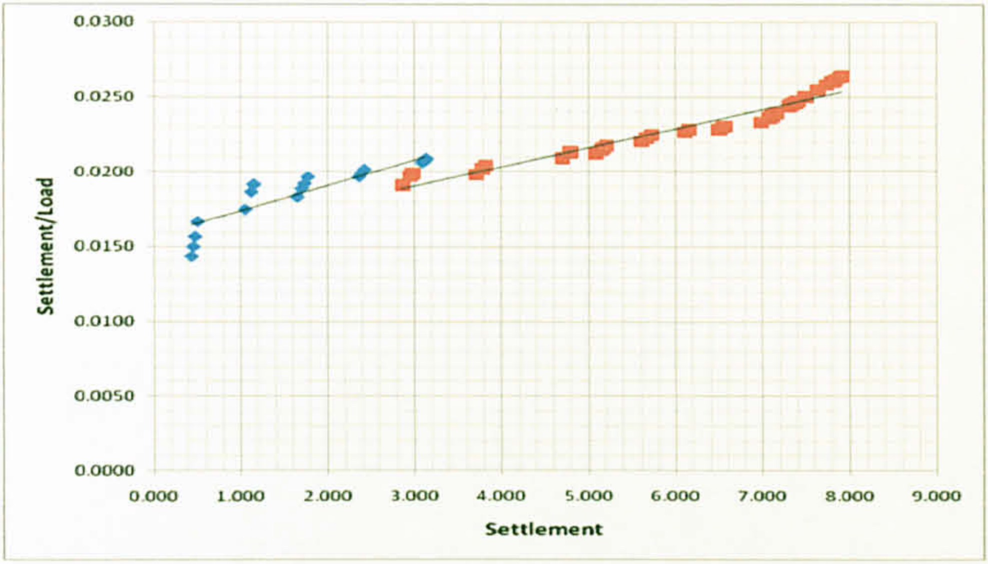

Figure 31: Chin's Plot for grid line 6/I-1

Based on Chin's Plot analysis 11/G-10, the ultimate pile capacity (**Q_{ult}**) is 536 tons, ultimate skin friction capacity (Q_s) is 420 tons and ultimate bearing capacity (**Q_b**) is 116 tons (after 0.7 correction factor).

The summaries of Pile Dynamic Analysis test are as below:-

Pile Location	5/H-2	4/C-2	7/E-2	10/E-7	11/I-7	13/I-3	13/G-5	12/D-7	15/E-2	13/B-1	14/C-3	12/C-1
Pile Type	RC	RC	RC	RC	RC	RC	RC	RC	BP	BP	BP	BP
Skin Friction Q_f	276	145	91	90	250	144	287	172	206	165	132	268
End Bearing Q_b	212	234	268	259	135	215	79	268	112	166	176	92
Ultimate Load Capacity Q_{ult}	488	379	359	349	385	359	366	440	318	331	308	360
Settlement at WL (mm)	4	4	4	4	2	4	3	4	3	3	5	3
Settlement at UL (mm)	10	11	10	9	6	11	7	9	9	7	11	6

Table 2 Pile Dynamic Analysis Test Summary

Pile Location	10/B-2	2/B-1	8/G-4	5/B-3	6/B-1	3/K-3	6/M-1	4/O-1	9/O-P(2)	12/Q-3	14/P-Q(3)
Pile Type	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP
Skin Friction Q_f	255	165	257	231	190	336	289	257	276	184	353
End Bearing Q_b	224	142	51	94	129	58	56	64	119	160	41
Ultimate Load Capacity Q_{ult}	479	307	308	325	319	394	345	321	395	344	394
Settlement at WL (mm)	2	2	3	3	3	2	3	4	2	3	2
Settlement at UL (mm)	3	9	10	7	7	5	6	9	4	7	5

Table 3 Pile Dynamic Analysis Test Summary

4.5 Comparison between Ultimate Load Capacity (Q_u) from Load Test and SI

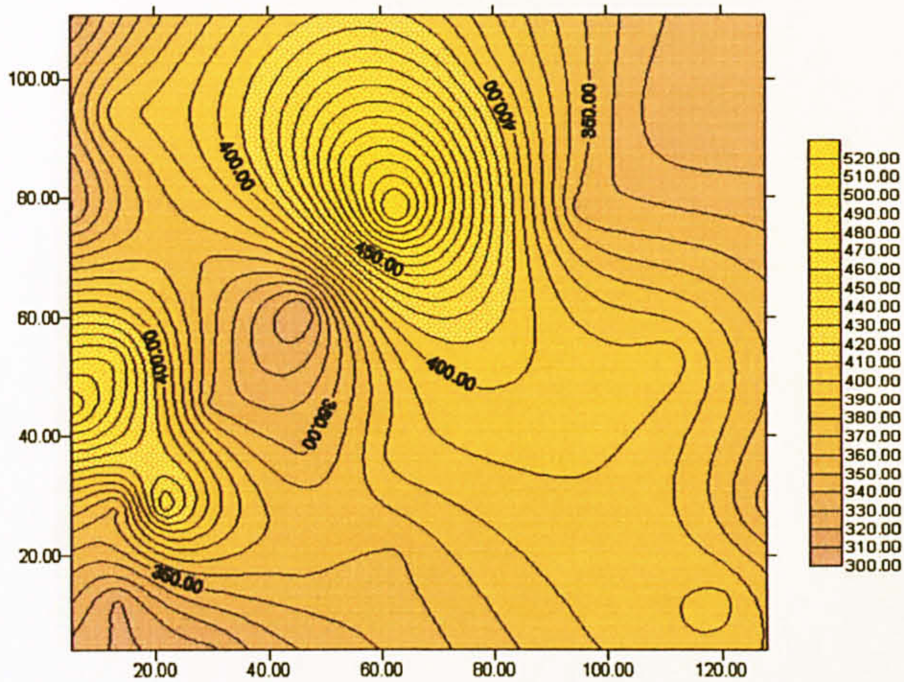

Figure 32: contour lines represent Q_u from Load Test (PDA & MLT)

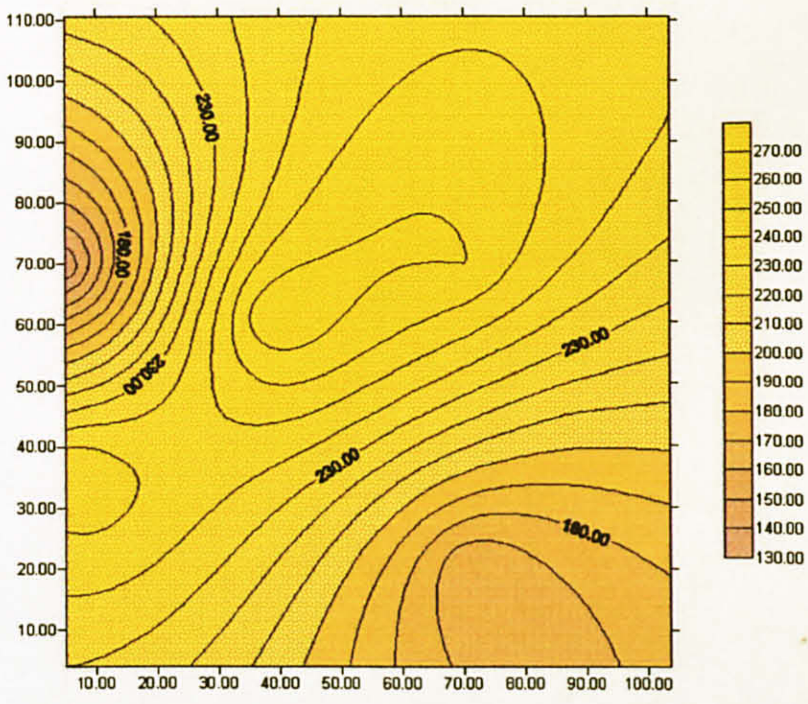

Figure 33: contour lines represent Q_u from Site Investigation

Based on Figure 32 and 33, the contour had been plotted by using Surfer software version 9. The X and Y axis represent the distance of the site location and Z axis represent Ultimate Pile Capacity (Q_u). By plotting this contour line, the author is able to differentiate the different between actual Q_u actual from Load Test and compare with Q_u from Site Investigation. The different of load pattern can be determined by comparing both patterns of contour lines. From figure 34, there are significant different between actual and design parameters. Therefore, the author should be able to determine factors that affect huge significant by using back propagation method in Matlab.

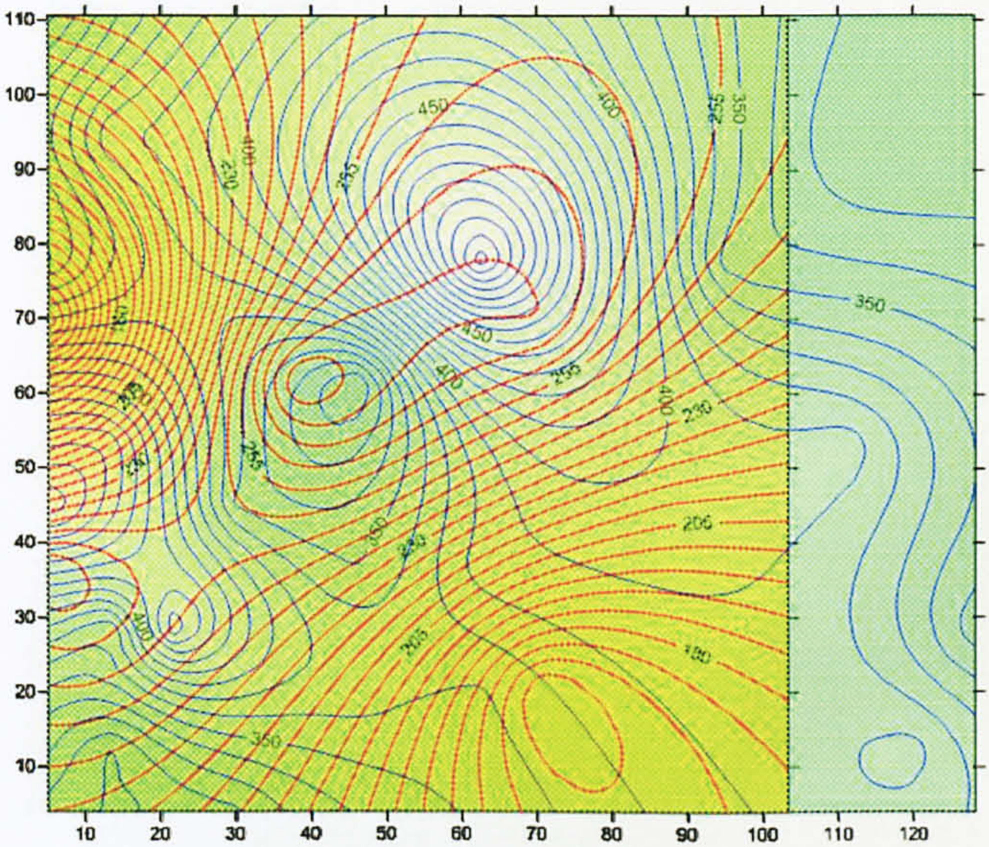

Figure 34: contour lines represent Q_u from SI & Load Test

4.6 Training data by using neural network - back propagation method

Furthermore, training data by using back propagation method will be used to determine the hidden layer and location which don't have sufficient data. According to **Mohd Nasir, Ramli Adnan & Mohd Hezri Fazalul (2007), *Practical System Identification***, hidden layer is named because the network can be regarded as a black box with inputs and outputs that can be seen but seen but the hidden layers cannot be seen. This network is very powerful and has been shown in many cases the ability to learn any arbitrarily complex non-linear input-output mapping. It also has a capacity much greater than the dimensionality of its input and output layers.

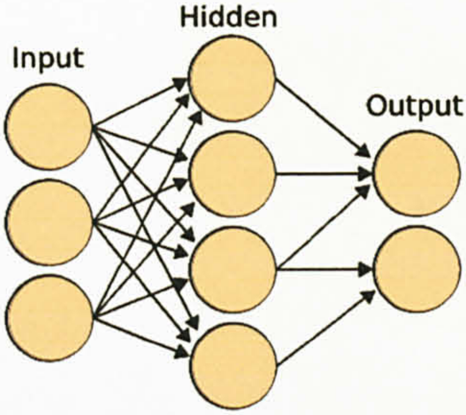

Figure 35: General structure of a multilayer neural network

The data from Load Test and Site Investigation will be trained and hidden area can be predicted later. Once the network weights and biases have been initialized, the network is ready for training. The network can be trained for function approximation (nonlinear regression), pattern association, or pattern classification. The training process requires a set of examples of proper network behaviour. The sample of coding that the author obtains from Neural network Toolbox are as below:-

```
load data1.mat

net=newff(minmax(input1),[10,1],{'logsig','purelin'},'trainlm');
net=init(net);
net.IW{1,1} = [0 0; 0 0; 0 0; 0 0; 0 0; 0 0; 0 0; 0 0; 0 0; 0 0];
net.b{1} = [0; 0; 0; 0; 0; 0; 0; 0; 0; 0];

net.trainParam.show = 50;
net.trainParam.lr = 0.2;
net.trainParam.epochs = 2000;
net.trainParam.goal = 1e-5;
[net,tr]=train(net,input1,output1);

a= sim(net,input1);
plot(a,'r');
hold on;
plot(output1,'b');
```

In batch mode the weights and biases of the network are updated only after the entire training set has been applied to the network. The gradients calculated at each training example are added together to determine the change in the weights and biases. The performance and errors can be reduced by testing or trial an error of each training code using several different sets of initial weights and biases. The example of data training result can be referred as below:-

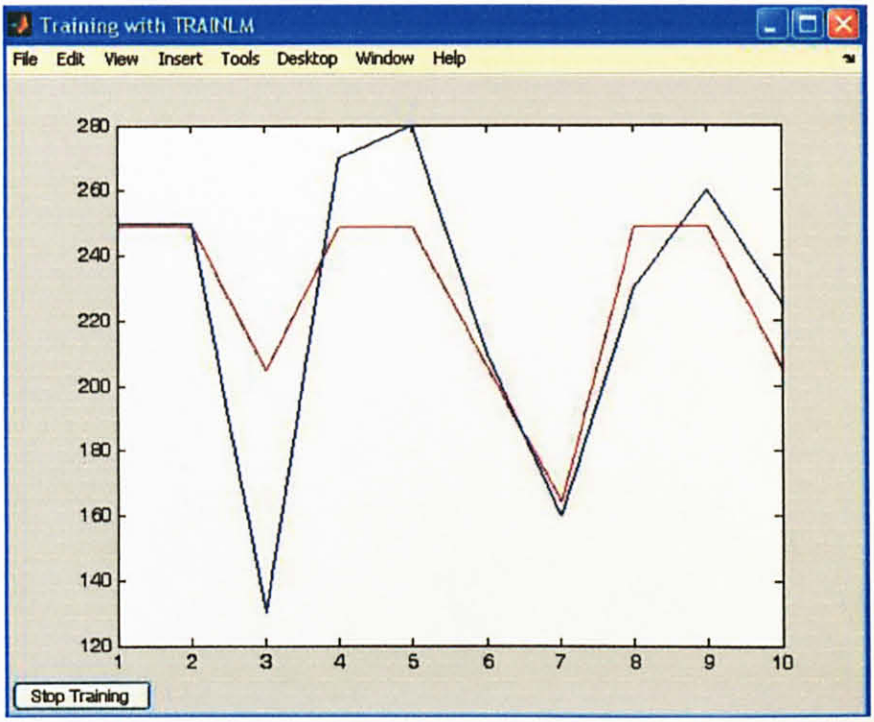

Figure 36: Training of Qu from SI by using back propagation method

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.0 CONCLUSION

In a nutshell, the methodology which is used in this project can support the objectives in the project which are to evaluate soil properties, determine pile bearing capacity, skin friction capacity and compare pile design with actual design parameters based on pile load test results. The outcome of this project is that in future, consultant or piling companies able to reduce Site Investigation experiment at site location because S.I is very expensive. Therefore by using tools which are found in this project, consultant as well as university students able to design piles with same soil characteristic with lesser factor of safety. In addition, data which are found in this project can be as benchmark and the parameters are useful for future references.

5.1 RECOMMENDATIONS

Even though the project has achieved its goals and objectives, it still has some room for improvement that can be worked on so that a better product or modeling can be achieved.

These are the recommendation work that can add into the current project to enhance the project even further. Among the improvement suggestions are:

- To improve the accuracy of programming in neural network. The current network function still can be improved by adjusting the number of neurons and epochs. The prediction will be more accurate if the learning and training process in the network are consistent to design data.
- Test the accuracy of prediction network by comparing with actual parameters.
- To create a Graphical User Interface (GUI) for user friendly and who are not familiar with Matlab programming. By having GUI, the product founded in this project probably can be widespread used and commercialized.

CHAPTER 6

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CHAPTER 7

ECONOMIC BENEFITS

7.1 Capital Cost Considerations

This project is low in cost for analysis and brings huge benefits for the future reference. Capital cost that the author had spent is more on photocopy of raw data from his collaboration company. All site investigation data, reinforced concrete pile driven record, maintained load test and pile dynamic analysis data are very essential in accomplish the objectives of project. Cost for analysis is low because required skills of using Matlab software and the software can be obtained easily from laboratory. The modelling the author had studied and designed by using Matlab 7.0.1 is relevant to the study of foundation & earth structures.

In addition, the author had also spent cost on travelling for meeting and to get advice from contractor firm. Current costs that the author had spent are as below:-

No	Description	Amount (RM)
1	Photostat and binding data or raw materials	88.60
2	Printing A1 poster	35.00
3	Transportation cost	47.00
	Total	**170.60**

Table 5: Total cost used to analyze the project

7.2 Business Element and Others

Soil is very unpredictable and site investigation is very expensive to study. In common practice, site investigation is not encouraged to do too many because it is costly and only companies which have good financial are able to attempt it. Soil properties or stratum is very important to get sufficient information in order to design good foundation. Site Investigation is essential to design and know sufficient pile capacity to support structural loads of the buildings.

Therefore by using modelling which founded in this project, consultants and piling companies are able to reduce cost and design pile with sufficient ultimate pile capacity and pile bearing capacity. Site investigation still need to be conducted at site but require less investigation of points in order to use the modelling founded in this project. Moreover, piling companies can reduce cost in site investigation and this project can bring huge benefits in Geotechnical field.

CHAPTER 8

APPENDICES

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APPENDIX A:

Loading Cycle and Holding Time for Maintained Load Test

Loading Cycle for Maintained Load Test at Sime Plantation

Project : Sime Plantation, DBI Engineering S/B
Pile Location : 9/C-4
Pile Size : 400mm x 400mm
Working Load : 135 Tons
Ultimate Load (2.0 times w.l.) : 270 tons
Hydraulic jack model : CLS 5006 (500 tons)

Cycle	Test Load (Ton)	Pressure (PSI)	Holding Time (hours)	Frequency of Readings
1	0	0	0	every 15 minutes
	27	525	1	every 15 minutes
	54	1051	1	every 15 minutes
	81	1576	1	every 15 minutes
	108	2102	1	every 15 minutes
	135	2627	12	every 60 minutes
	101.25	1970	1	every 15 minutes
	67.75	1319	1	every 15 minutes
	33.75	657	1	every 15 minutes
2	0	0	1	every 15 minutes
	33.75	657	1	every 15 minutes
	67.75	1319	1	every 15 minutes
	101.25	1970	1	every 15 minutes
	135	2627	1	every 15 minutes
	168.75	3284	1	every 15 minutes
	202.5	3941	1	every 15 minutes
	216	4204	1	every 15 minutes
	229.5	4466	1	every 15 minutes
	243	4729	1	every 15 minutes
	256.5	4992	1	every 15 minutes
	270	5255	24	every 60 minutes
	202.5	3941	1	every 15 minutes
	135	2627	1	every 15 minutes
	67.5	1314	1	every 15 minutes
	0	0	1	every 15 minutes

Formula for conversion from Metric Ton to PSI

$$\frac{\text{Metric Ton} \times 2204}{\text{Cylinder EFF. Area}}$$

Note : Cylinder effective area for hydraulic jack Enerpac model CLS 5006 is 113.25 square inch

APPENDIX B:

CAPWAP Analysis Using the Continuous Pile Segments

CAPWAP/C

(Capwap Analysis using the Continuous Pile Segments)

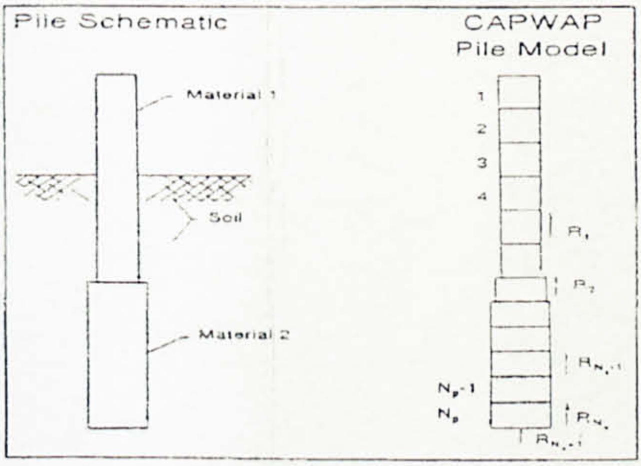
CAPWAP/C is a program that in general works like CAPWAP, except that it uses the characteristics method rather than the lumped mass approach for analysis. The characteristics method divides the pile into Np segments which are of uniform cross-section. Each element, i, has a length, dti, equals the analysis time increments, dt. Thus for variable pile properties Ei, Wi (elastic modulus, specific weight), the wave speed of a segment is

$$C_i = (E_i\, g/W_i)^{1/2}$$

Where Ci, Ei, and Wi, may be average properties over a segments length if the properties change within the corresponding length increment, dLi, and g is the earth gravitational constant.

$$dL_i = (dt)\, c_i$$

Note that the segments are not of equal length. Resistance forces Rk may act at the bottom of any segment. They are the sum of the usual elasto-plactic and linearly viscous resistance values.



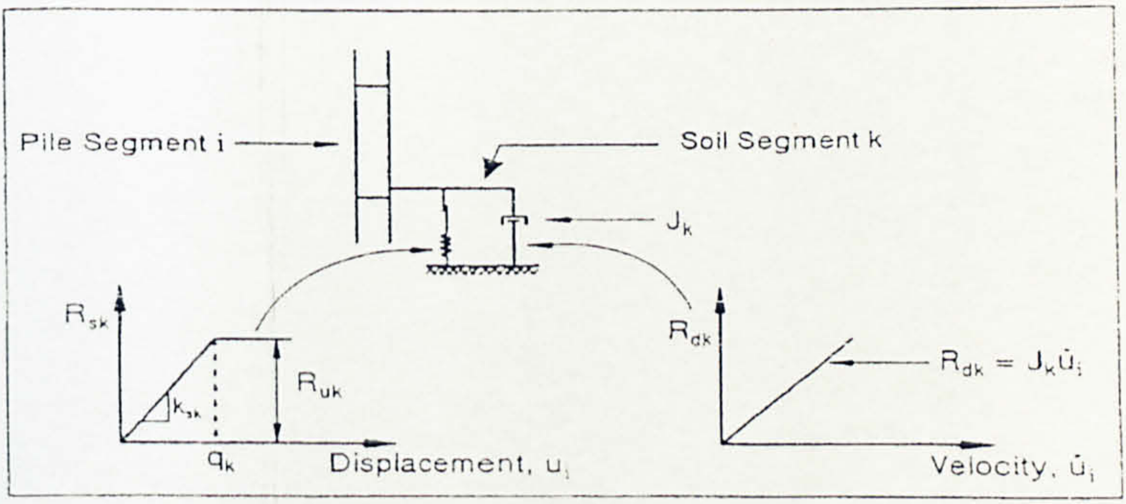
For variable pile properties E_i, ρ_i (elastic modulus, mass density), the wave speed c_i, of segment i is

$$c_i = \sqrt{\frac{E_i}{\rho_i}}$$

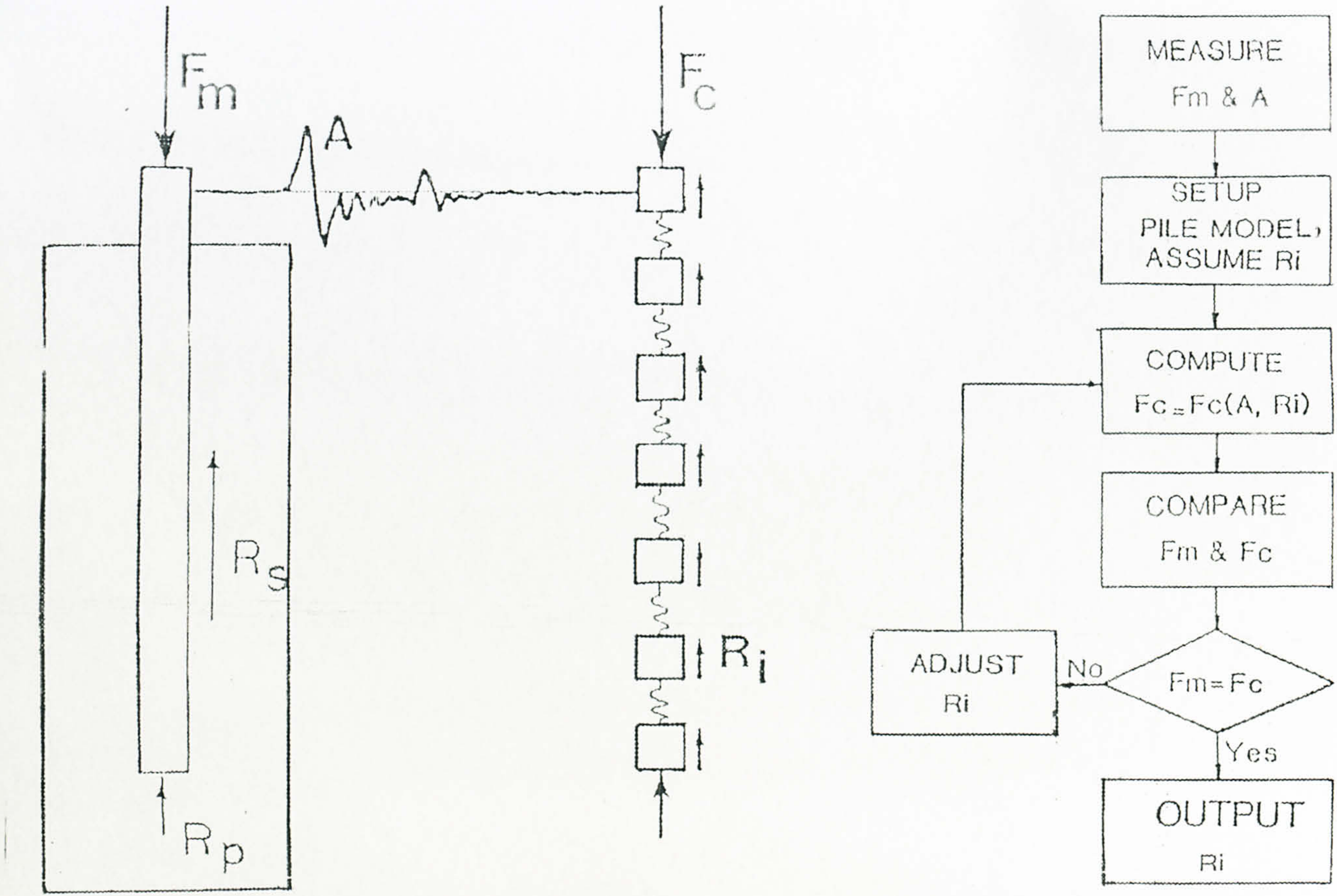
Note that c_i, E_i and ρ_i may be average properties over a segment's length if the properties change within the segment. Each segment, i, has a length ΔL_i, such that its wave travel time, Δt, equals the analysis time increment, Δt.

$$\Delta L_i = \Delta t\, c_i$$

The sum of all ΔL_i equals the total pile length L and $N_p(\Delta t)$ is equal to the total wave travel time (L/c for piles of uniform material). Since each pile segment is uniform and linearly elastic, the magnitude of a downward traveling wave, F_{ij}, at time j at the top of a segment i, is equal to the wave at the bottom of the same segment at time j + 1



(Viscous damping model instead of a strict Smith damping is shown)



Fm
A
Fc
Rs
Ri
Rp
MEASURE
Fm & A
SETUP
PILE MODEL,
ASSUME Ri
COMPUTE
Fc = Fc(A, Ri)
COMPARE
Fm & Fc
Fm = Fc
No
Yes
ADJUST
Ri
OUTPUT
Ri

APPENDIX C:

Site Investigation table for:-

- BH1
- BH2
- BH3
- BH4
- BH5
- BH6
- BH7
- BH8
- BH9
- BH10

Appendix C1: BH1

Drill Method : Rotary Wash
Ground Level : 15.250 m
Water Level : 3.0 m

Depth (m)	Description of Strata	SPT	RQD
0.0	light brown-medium SAND	0	-
1.5	loose to medium dense light brown-medium SAND	10	-
3.0	light grey silty-medium SAND	12	-
4.5	Ditto	11	-
6.0	Ditto	25	-
7.5	Ditto	28	-
9.0	very stiff, light grey fine SILT with some quartz gravel	26	-
10.5	Ditto	25	-
12.0	very stiff, light grey fine sandy SILT with some gravel	25	-
13.5	Ditto	27	-
15.0	Ditto	26	-
16.5	Ditto	25	-
18.0	stiff, light grey sandy SILT with some gravel	11	-
19.5	Ditto	12	-
21.0	hard, light grey fine sandy SILT with some gravel	50	-
22.5	hard, light grey fine sandy SILT with some quartz gravel	50	-
24.0	Ditto	50	-
25.5	Ditto	50	-
27.0	Ditto	50	-
28.5	Ditto	50	-
30.0	Ditto	50	-

End of BH1 at depth 30.07m

Appendix C2: BH2

Drill Method : Rotary Wash
Ground Level : 17.160 m
Water Level : 5.0 m

Depth	Description of Strata	SPT	RQD
0.0	light brown-medium SAND	0	-
1.5	hard light brown sandy SILT	45	-
3.0	medium dense, dark brown light grey silty fine SAND	13	-
4.5	Medium dense, light grey silty medium SAND	12	-
6.0	Ditto	15	-
7.5	Ditto	12	-
9.0	Ditto	18	-
10.5	Ditto	15	-
12.0	Ditto	18	-
13.5	very stiff, light grey fine sandy SILT with some quartz gravel	19	-
15.0	Ditto	20	-
16.5	Ditto	18	-
18.0	hard, light grey fine sandy SILT with some quartz gravel	50	-
19.5	Ditto	50	-
21.0	hard, light grey sandy SILT with some quartz gravel	50	-
22.5	hard, light grey sandy SILT with some gravel	50	-
24.0	Ditto	50	-
25.5	Ditto	50	-
27.0	Ditto	50	-

End of BH2 at depth 27.06m

Appendix C3: BH3

Drill Method : Rotary Wash
Ground Level : 9.20m
Water Level : Full

Depth	Description of Strata	SPT	RQD(%)
0.0	light grey-medium SAND	0	-
1.5	loose light grey silty medium SAND	5	-
3.0	Ditto	7	-
4.5	medium dense, light grey silty medium SAND	20	-
6.0	hard light grey sandy SILT with some gravel	37	-
7.5	Ditto	36	-
9.0	hard light grey fine sandy SILT with some quartz gravel	38	-
10.5	Ditto	43	-
12.0	Ditto	50	-
13.5	Ditto	50	-
14.1	light grey, moderately weak & weathered, highly fractured; GRANITE	-	20
15.6	light grey, very weak, moderately weathered, highly fractured; GRANITE	-	0
17.1	light grey, moderately weak & weathered, highly fractured; GRANITE	-	17
18.6	Ditto	-	13
20.1	light grey, strong, moderately weathered, moderately fractured; GRANITE	-	42
21.6	light grey, very weak, moderately weathered, highly fractured; GRANITE	-	0
23.1	light grey, moderately weak & weathered, highly fractured; GRANITE	-	19
24.6	Ditto	-	9
26.1	light grey, very weak, moderately weathered, highly fractured; GRANITE	-	0
27.4	Ditto	-	0

End of BH3 at depth 27.40m

Appendix C4: BH4

Drill Method : Rotary Wash
Ground Level : 9.53 m
Water Level : 1.0 m

Depth	Description of Strata	SPT	RQD
0.0	light grey medium SAND	0	-
1.5	medium dense light grey silty medium SAND	11	-
3.0	Ditto	8	-
4.5	Ditto	9	-
6.0	very stiff, light grey clayey SILT with some gravel	16	-
7.5	Ditto	18	-
9.0	Ditto	22	-
10.5	Ditto	26	-
12.0	very stiff, light grey fine sandy SILT with some quartz gravel	20	-
13.5	Ditto	23	-
15.0	hard light grey fine sandy SILT with some quartz gravel	45	-
16.5	Ditto	50	-
18.0	Ditto	50	-
19.5	Ditto	50	-
21.0	Ditto	50	-
22.5	Ditto	50	-
24.0	Ditto	50	-
25.5	Ditto	50	-

End of BH4 at depth 25.59m

Appendix C5: BH5

Drill Method : Rotary Wash
Ground Level : 9.35 m
Water Level : 0.0m

Depth	Description of Strata	SPT	RQD(%)
0.0	light grey-medium SAND	0	-
1.5	medium dense, light grey silty medium SAND with some gravel	11	-
3.0	stiff light grey sandy SILT with some gravel	13	-
4.5	Ditto	15	-
6.0	hard light grey fine sandy SILT with some quartz gravel	50	-
7.5	Ditto	50	-
9.0	Ditto	50	-
10.5	Ditto	50	-
12.0	Ditto	50	-
13.5	Ditto	50	-
15.0	Ditto	50	-
15.6	light grey, strong, moderately weathered, moderately fractured; GRANITE	-	48.0
17.1	light grey, moderately weak & weathered, highly fractured; GRANITE	-	8.0
18.6	Ditto	-	0.0

End of BH5 at depth 18.6m

Appendix C6: BH6

Drill Method : Rotary Wash
Ground Level : 9.86 m
Water Level : 1.6 m

Depth	Description of Strata	SPT	RQD
0.0	light grey medium SAND	0	-
1.5	soft to firm brownish grey sandy SILT	4	-
3.0	stiff light grey sandy SILT	12	-
4.5	Ditto	13	-
6.0	firm light grey gravelly sandy SILT	5	-
7.5	Ditto	5	-
9.0	hard light grey yellow sandy SILT	50	-
10.5	hard yellowish reddish brown sandy silt	50	-
12.0	Ditto	50	-
13.5	Ditto	50	-
15.0	hard light grey gravelly sandy SILT	50	-
16.5	Ditto	50	-
18.0	Ditto	50	-

End of BH6 at depth 18.295m

Appendix C7: BH7

Drill Method : Rotary Wash
Ground Level : 9.60 m
Water Level : 1.6 m

Depth	Description of Strata	SPT	RQD
0.0	very loose light grey, silty coarse SAND	0	-
1.5	Ditto	3	-
3.0	firm light grey sandy SILT	6	-
4.5	firm to stiff light grey reddish sandy SILT	8	-
6.0	very stiff light grey yellow gravelly sandy SILT	17	-
7.5	Ditto	16	-
9.0	hard light grey reddish sandy SILT	50	-
10.5	hard light grey sandy SILT	50	-
12.0	hard yellowish brown sandy SILT	50	-
13.5	Ditto	50	-
15.0	Ditto	50	-
16.5	hard dark grey, gravelly sandy SILT	50	-
18.0	Ditto	50	-

End of BH7 at depth 18.05m

Appendix C8: BH8

Drill Method : Rotary Wash
Ground Level : 9.79 m
Water Level : 0.9 m

Depth	Description of Strata	SPT	RQD
0.0	soft light grey sandy SILT	0	-
1.5	Ditto	3	-
3.0	firm light grey yellow sandy SILT	5	-
4.5	firm light grey sandy SILT	5	-
6.0	Ditto	7	-
7.5	stiff light grey yellow sandy SILT	10	-
9.0	very stiff yellowish brown sandy SILT	18	-
10.5	hard light grey yellow sandy SILT	50	-
12.0	Ditto	50	-
13.5	hard light grey gravelly sandy SILT	50	-
15.0	hard light grey sandy SILT	50	-
16.5	hard dark grey sandy SILT	50	-
18.0	Ditto	50	-
19.5	Ditto	50	

End of BH8 at depth 19.785m

Appendix C9: BH9

Drill Method : Rotary Wash
Ground Level : 9.345 m
Water Level : Full

Depth	Description of Strata	SPT	RQD(%)
0.0	light grey medium SAND with traces of gravel	0	-
1.5	firm to stiff light grey sandy SILT with traces of gravel	8	-
3.0	Ditto	9	-
4.5	Ditto	12	-
6.0	very stiff light grey sandy SILT with traces of gravel	21	-
7.5	Ditto	25	-
9.0	Ditto	20	-
10.5	hard light grey sandy SILT with traces of gravel	50	-
12.0	light grey, very weak, highly fractured, moderately weathered, GRANITE	-	0.0
13.5	light grey, moderately weak, highly fractured, moderately weathered, GRANITE	-	24.0
15.0	Ditto	-	16.0
16.5	light grey, strong, moderately weathered, moderately fractured; GRANITE	-	56.0
18.0	light grey, moderately strong & weathered, fractured; GRANITE	-	30.0
19.5	light grey, strong, moderately weathered, moderately fractured; GRANITE	-	45.0
20.5	Ditto	-	0.0

End of BH9 at depth 20.5m

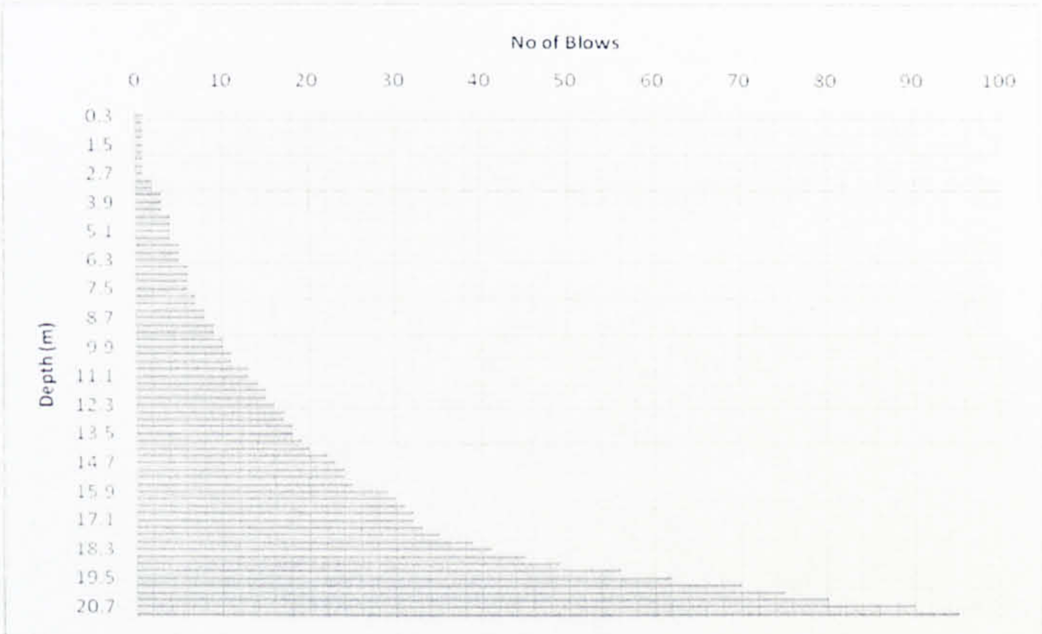
Appendix C10: BH10

Drill Method : Rotary Wash
Ground Level : 16.329 m
Water Level : 6.1 m

Depth	Description of Strata	SPT	RQD
0.0	light brown-medium SAND	0	-
1.5	loose to medium dense light brown-silty medium SAND	10	-
3.0	loose brown silty medium SAND with decayed wood	8	-
4.5	loose brown silty medium SAND	7	-
6.0	loose light brown grey silty medium SAND	9	-
7.5	Ditto	11	-
9.0	very stiff, light grey sandy SILT with traces of gravel	20	-
10.5	Ditto	21	-
12.0	hard light grey sandy SILT with traces of gravel	35	-
13.5	Ditto	38	-
15.0	hard light grey fine sandy SILT with quartz gravel	35	-
16.5	Ditto	35	-
18.0	very stiff, light grey sandy SILT with quartz gravel	28	-
19.5	Ditto	20	-
21.0	Ditto	21	-
22.5	hard light grey sandy SILT with quartz gravel	36	-
24.0	very stiff light grey sandy SILT with quartz gravel	21	-
25.5	hard light grey sandy SILT with traces of gravel	34	-
27.0	hard light grey fine sandy SILT with quartz gravel	48	-
28.5	Ditto	56	-

End of BH10 at depth 28. 5m

APPENDIX D:
Example for RC Pile Driving Record



Depth(m)	No of blows
0.3	1
0.6	1
0.9	1
1.2	1
1.5	1
1.8	1
2.1	1
2.4	1
2.7	1
3.0	2
3.3	2
3.6	3
3.9	3
4.2	3
4.5	4
4.8	4
5.1	4
5.4	4
5.7	5
6.0	5
6.3	5
6.6	6
6.9	6
7.2	6
7.5	6
7.8	7
8.1	7
8.4	8
8.7	8
9.0	9
9.3	9
9.6	10
9.9	10
10.2	11
10.5	11
10.8	13
11.1	13
11.4	14
11.7	15
12.0	15
12.3	16
12.6	17
12.9	17
13.2	18
13.5	18
13.8	19
14.1	20
14.4	22
14.7	23
15.0	24
15.3	24
15.6	25
15.9	29
16.2	30
16.5	31
16.8	32
17.1	32
17.4	33
17.7	35
18.0	39
18.3	41
18.6	45
18.9	49
19.2	56
19.5	62
19.8	70
20.1	75
20.4	80
20.7	90
21.0	95

APPENDIX E:

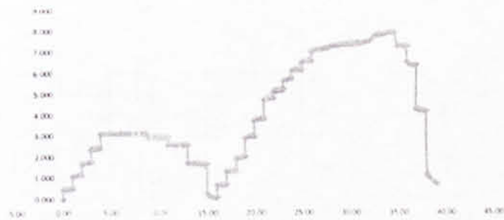
Data for Maintained Load Test:-

- Gridline 6/I-1 (BP)
- Gridline 9/C-4 (RC)
- Gridline 11/G-10 (RC)

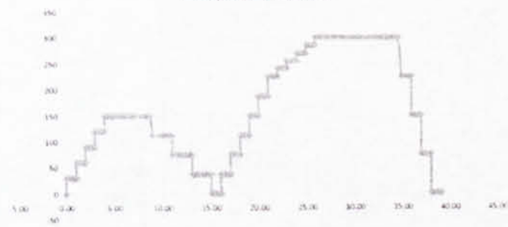
Load(Ton)	Settlement(mm)	Time(Hr)
0	0.000	0.00
30	0.430	0.00
30	0.450	0.33
30	0.470	0.67
30	0.500	1.00
60	1.050	1.00
60	1.120	1.33
60	1.150	1.67
60	1.150	2.00
90	1.650	2.00
90	1.700	2.33
90	1.730	2.67
90	1.770	3.00
120	2.360	3.00
120	2.390	3.33
120	2.420	3.67
120	2.420	4.00
150	3.090	4.00
150	3.110	4.33
150	3.110	4.67
150	3.120	5.00
150	3.110	5.33
150	3.120	5.67
150	3.120	6.00
150	3.120	6.33
150	3.120	6.67
150	3.130	7.00
150	3.130	7.33
150	3.130	7.67
150	3.130	8.00
150	3.130	8.33
150	3.130	8.67
112.5	2.960	9.00
112.5	2.960	9.33
112.5	2.960	9.67
112.5	2.960	10.00
112.5	2.960	10.33
112.5	2.960	10.67
112.5	2.960	11.00
75	2.580	11.00
75	2.580	11.33
75	2.570	11.67
75	2.570	12.00
75	2.570	12.33
75	2.570	12.67
75	2.570	13.00
37.5	1.700	13.00
37.5	1.680	13.33
37.5	1.680	13.67
37.5	1.680	14.00
37.5	1.680	14.33
37.5	1.650	14.67
37.5	1.650	15.00
0	0.210	15.00
0	0.100	15.33
0	0.080	15.67
0	0.040	16.00
37.5	0.630	16.00
37.5	0.650	16.33
37.5	0.660	16.67
37.5	0.670	17.00
75	1.290	17.00
75	1.320	17.33
75	1.330	17.67
75	1.330	18.00
112.5	1.880	18.00
112.5	1.820	18.33
112.5	1.960	18.67
112.5	2.210	19.00
150	2.860	19.00
150	2.950	19.33
150	2.980	19.67
150	2.980	20.00
187.5	3.710	20.00
187.5	3.740	20.33
187.5	3.820	20.67
187.5	3.820	21.00
225	4.700	21.00
225	4.785	21.33
225	4.795	21.67
225	4.800	22.00
240	5.090	22.00
240	5.150	22.33
240	5.175	22.67
240	5.210	23.00
255	5.610	23.00
255	5.670	23.33
255	5.720	23.67
255	5.780	24.00
270	6.110	24.00
270	6.150	24.33
270	6.160	24.67
270	6.160	25.00
285	6.500	25.00
285	6.550	25.33
285	6.570	25.67
285	6.570	26.00
300	6.990	26.00
300	7.080	26.33
300	7.110	26.67
300	7.120	27.00
300	7.160	27.33
300	7.170	27.67
300	7.310	28.00
300	7.310	28.33
300	7.330	28.67
300	7.340	29.00
300	7.340	29.33
300	7.370	29.67
300	7.380	30.00
300	7.390	30.33
300	7.410	30.67
300	7.410	31.00
300	7.410	31.33
300	7.490	31.67
300	7.500	32.00
300	7.640	32.33
300	7.740	32.67
300	7.800	33.00
300	7.810	33.33
300	7.840	33.67
300	7.880	34.00
300	7.910	34.33
300	7.920	34.67
225	7.280	35.00
225	7.270	35.33
225	7.270	35.67
225	7.270	36.00
150	6.510	36.00
150	6.380	36.33
150	6.360	36.67
150	6.360	37.00
75	4.270	37.00
75	4.200	37.33
75	4.170	37.67
75	4.150	38.00
0	1.150	38.00
0	0.960	38.33
0	0.810	38.67
0	0.670	39.00

Load(Ton) VS Settlement(mm)

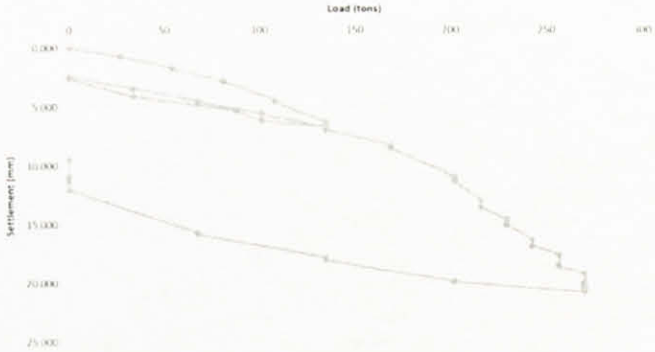
Settlement (mm) VS Time (Hr)



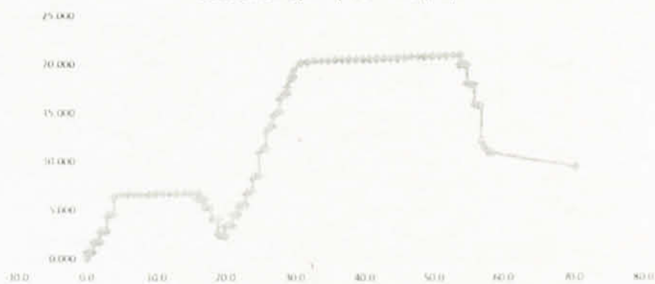
Load(Ton) VS Time(Hr)



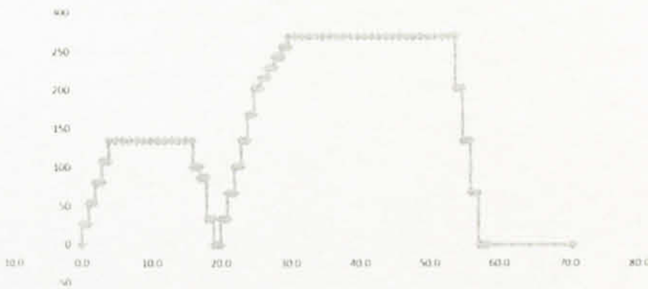
Load(ton)	Settlement(mm)	Time(Hr)	
0	0.000	0.0	0.000
27	0.665	0.0	-0.665
27	0.687	0.5	-0.687
27	0.707	1.0	-0.707
54	1.660	1.0	-1.660
54	1.742	1.5	-1.742
54	1.765	2.0	-1.765
81	2.742	2.0	-2.742
81	2.817	2.5	-2.817
81	2.837	3.0	-2.837
108	4.397	3.0	-4.397
108	4.547	3.5	-4.547
108	4.585	4.0	-4.585
135	6.325	4.0	-6.325
135	6.580	5.0	-6.580
135	6.632	6.0	-6.632
135	6.595	7.0	-6.595
135	6.630	8.0	-6.630
135	6.575	9.0	-6.575
135	6.692	10.0	-6.692
135	6.735	11.0	-6.735
135	6.735	12.0	-6.735
135	6.735	13.0	-6.735
135	6.735	14.0	-6.735
135	6.735	15.0	-6.735
135	6.735	16.0	-6.735
101.25	6.187	16.0	-6.187
101.25	6.167	16.5	-6.167
101.25	6.167	17.0	-6.167
87.5	5.335	17.0	-5.335
87.5	5.297	17.5	-5.297
87.5	5.297	18.0	-5.297
33.75	4.112	18.0	-4.112
33.75	4.112	18.5	-4.112
33.75	4.112	19.0	-4.112
0	2.570	19.0	-2.570
0	2.432	19.5	-2.432
0	2.363	20.0	-2.363
33.75	3.393	20.0	-3.393
33.75	3.432	20.5	-3.432
33.75	3.432	21.0	-3.432
67.5	4.492	21.0	-4.492
67.5	4.530	21.5	-4.530
67.5	4.547	22.0	-4.547
101.25	5.520	22.0	-5.520
101.25	5.592	22.5	-5.592
101.25	5.612	23.0	-5.612
135	6.747	23.0	-6.747
135	6.955	23.5	-6.955
135	6.992	24.0	-6.992
168.75	8.247	24.0	-8.247
168.75	8.520	24.5	-8.520
168.75	8.530	25.0	-8.530
202.5	11.000	25.0	-11.000
202.5	11.302	25.5	-11.302
202.5	11.365	26.0	-11.365
216	13.060	26.0	-13.060
216	13.512	26.6	-13.512
216	13.612	27.0	-13.612
229.5	14.647	27.0	-14.647
229.5	15.000	27.5	-15.000
229.5	15.122	28.0	-15.122
243	16.375	28.0	-16.375
243	16.880	28.5	-16.880
243	16.937	29.0	-16.937
256.5	17.697	29.0	-17.697
256.5	18.522	29.5	-18.522
256.5	18.682	30.0	-18.682
270	19.282	30.0	-19.282
270	20.068	31.0	-20.068
270	20.225	32.0	-20.225
270	20.320	33.0	-20.320
270	20.357	34.0	-20.357
270	20.380	35.0	-20.380
270	20.405	36.0	-20.405
270	20.445	37.0	-20.445
270	20.450	38.0	-20.450
270	20.450	39.0	-20.450
270	20.460	40.0	-20.460
270	20.502	41.0	-20.502
270	20.512	42.0	-20.512
270	20.527	43.0	-20.527
270	20.545	44.0	-20.545
270	20.567	45.0	-20.567
270	20.607	46.0	-20.607
270	20.730	47.0	-20.730
270	20.717	48.0	-20.717
270	20.725	49.0	-20.725
270	20.745	50.0	-20.745
270	20.757	51.0	-20.757
270	20.792	52.0	-20.792
270	20.835	53.0	-20.835
270	20.855	54.0	-20.855
202.5	19.922	54.0	-19.922
202.5	19.900	54.5	-19.900
202.5	19.890	55.0	-19.890
135	18.022	55.0	-18.022
135	17.812	55.5	-17.812
135	17.817	56.0	-17.817
67.5	15.815	56.0	-15.815
67.5	15.720	56.5	-15.720
67.5	15.682	57.0	-15.682
0	11.972	57.0	-11.972
0	11.325	57.5	-11.325
0	10.898	58.0	-10.898
0	10.895	58.5	-10.895
0	9.408	70.5	-9.408



Settlement (mm) VS Time (Hr)

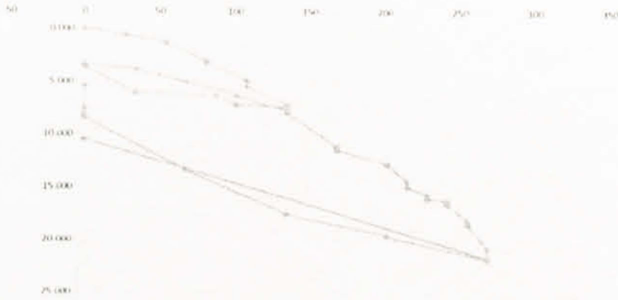


Load(Ton) VS Time(Hr)

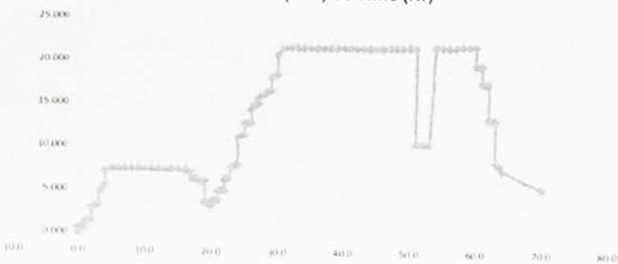


Load(ton)	Settlement(mm)	Time(Hr)
0	0.000	0.0
27	0.552	0.0
27	0.620	0.5
27	0.623	1.0
54	1.285	1.0
54	1.378	1.5
54	1.400	2.0
81	3.015	2.0
81	3.140	2.5
81	3.145	3.0
108	4.813	3.0
108	4.915	3.5
108	5.508	4.0
135	7.153	4.0
135	7.410	5.0
135	7.425	6.0
135	7.425	7.0
135	7.428	8.0
135	7.398	9.0
135	7.393	10.0
135	7.395	11.0
135	7.395	12.0
135	7.395	13.0
135	7.395	14.0
135	7.395	15.0
135	7.395	16.0
101.25	7.190	16.0
101.25	7.169	16.5
101.25	7.169	17.0
87.5	6.330	17.0
87.5	6.298	17.5
87.5	6.298	18.0
33.75	6.100	18.0
33.75	6.073	18.5
33.75	6.043	19.0
0	3.603	19.0
0	3.443	19.5
0	3.365	20.0
33.75	3.818	20.0
33.75	3.825	20.5
33.75	3.830	21.0
67.5	4.980	21.0
67.5	5.003	21.5
67.5	5.010	22.0
101.25	6.240	22.0
101.25	6.330	22.5
135	7.752	23.0
135	7.930	23.5
135	7.973	24.0
168.75	11.115	24.0
168.75	11.353	24.5
168.75	11.400	25.0
202.5	12.725	25.0
202.5	12.783	25.5
202.5	12.803	26.0
216	14.375	26.0
216	14.835	26.5
216	14.898	27.0
229.5	15.643	27.0
229.5	15.973	27.5
229.5	16.055	28.0
243	16.185	28.0
243	16.470	28.5
243	16.530	29.0
256.5	18.038	29.0
256.5	18.290	29.5
256.5	18.325	30.0
270	20.680	30.0
270	21.463	31.0
270	21.473	32.0
270	21.468	33.0
270	21.453	34.0
270	21.468	35.0
270	21.468	36.0
270	21.468	37.0
270	21.468	38.0
270	21.468	39.0
270	21.468	40.0
270	21.468	41.0
270	21.468	42.0
270	21.463	43.0
270	21.463	44.0
270	21.463	45.0
270	21.475	46.0
270	21.498	47.0
270	21.523	48.0
270	21.523	49.0
270	21.523	50.0
270	21.523	51.0
0	10.468	51.0
0	10.468	52.0
0	10.468	53.0
270	21.588	54.0
270	21.588	55.0
270	21.588	56.0
270	21.588	57.0
270	21.708	58.0
270	21.710	59.0
270	21.710	60.0
202.5	19.548	60.0
202.5	19.450	60.5
202.5	19.440	61.0
135	17.575	61.0
135	17.508	61.5
135	17.498	62.0
67.5	13.390	62.0
67.5	13.365	62.5
67.5	13.303	63.0
0	8.445	63.0
0	8.165	63.5
0	7.600	64.0
0	5.445	70.0

Load(Ton) VS Settlement(mm)



Settlement (mm) VS Time (Hr)



Load (ton) VS Time (Hr)