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Comparison between ultimate pile capacity of bored piles determine using analytical method, numerical method and pile load test along Sentul - Batu Caves Double Track Project

by

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CERTIFICATION OF APPROVAL

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Approved by,

____

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TRONOH, PERAK
January 2008

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.

NG JIUN HUEI

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ABSTRACT

The objectives of this project is to compare various method of bearing capacity determination (analytical method, numerical method and pile load test) as well as to back calculate soil parameters based on pile load test results.

Basically the main problem is how to derive the parameters from the early stages of construction in order to maximize benefits. Besides that through load test results what parameters control the results from the actual on-site results can be found. How much load is actually transferred to the pile will be found out and try to work out through it with this test by analytical methods on what empirical formula to be based.

The scope of study includes studying all pile test results along with the parameters which alters the result of each as well as to analyse the results by the analytical method through failing an actual pile test and then comparing the actual values with the one being generated by the test values. Other scopes would include find out the parameters that are the most important and try to reduce some of it through the numerical methods.

The methodology of the project would include to firstly, collecting and summarized all soil data pertaining to the site and characterize soil layering system along the track. Secondly, collect all pile test results and characterize response of pile load tests. Thirdly, reduce the number of parameters that are being considered so that the analysis will not be too complicated. Fourthly, calculate ultimate pile capacity based on analytical method, numerical method and pile load test results .Fifthly back calculate soil parameters based on pile load test results and lastly analyse and synthesize results as well as draw conclusions.

The findings that coincide with the project are the Load Settlement Curve which coincides with the Pile Dynamic Analysis and the Maintained Load Test results can be used to be compared with the results from the pile which has failed. Besides that, through the deflection of the curve, one is able to know the parameters that are involved

in determining the curve's shape and whether it complies with the theoretical curve. The last finding would be that every pile has different soil characteristics which may increase or decrease the pile's Bearing Capacity.

Keywords for this project would include Bearing Capacity, Bored Piles, Pile Load Tests, Soil Investigations, and Cone Penetration Tests.

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F_s = Factor of safety for skin friction

Q_s= Shaft friction resistance, kN/m^2

q_u = Unconfined compressive strength of rock or concrete whichever is lower, kN/m^2

π = pi or 3.142

D = diameter of pile, m

Q_b = pile bearing capacity, kN

Q_{all} = design allowable pile working load, kN/m^2

qs = allowable skin friction, kN/m^2

As = area of shaft under consideration, m^2

Ab = cross sectional area of pile, m^2

L = pile length under consideration, m

qb = Allowable base resistance or end bearing, kN/m^2

qs_{all} = allowable skin friction, kN/m^2

qb_{all} = Allowable base resistance, kN/m^2

r = radius of the pile, m

B = pile diameter, mm

P = Load, kN

A = Cross Sectional area of pile, m^2

E = Modulus of Elasticity of pile, mm^4

$E_{concrete}$ = Modulus of Elasticity of Concrete, mm^4

f_{cu} = Characteristic Strength of Concrete ,N/mm^2

A_{pile} = Cross Sectional Area of Pile, m^2

E_{steel} = Modulus of Elasticity of Steel, MPa

A_{steel} = Cross Sectional Area of Steel Bars, m^2

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background of Study

Kereta Api Tanah Melayu (KTM) is in the process of upgrading Sentul to Batu Cave line from single track into double tracks. Therefore in collaboration with Syarikat Pembenaan Yeoh Tiong Lay, data would be obtained to complete the FYP title of Comparison between ultimate pile capacity of bored piles determined using analytical method, numerical method and pile load test along the Sentul - Batu Cave Double Track Project. An important factor in this research is the ability to predict the Ultimate Bearing Capacity of Bored Piles that will be obtained for future references towards other companies.

1.2 Problem Statement

Kereta Api Tanah Melayu (KTM) is in the process of upgrading Sentul to Batu Cave line from single track into double track. The scope of the work includes survey and investigation (SID), construction of bridges over the track, soil improvement and embankment, and ballast construction. SID includes field test (CPTu and Macintosh Test), disturbed and undisturbed sampling followed with laboratory tests.

The bridges are founded on foundation bored piles with diameters ranging from 800 to 1200 mm. The piles are also subjected to a series of tests which include Maintained Load Test, Dynamic Loading Test, Statnamic Test and Pile Dynamic Analysis (PDA) Test. Certain criterias such as the maximum displacement under twice of the working load and maximum residual displacement have been used as the acceptance criteria for the pile.

1.2.1 Problem Identification

Basically the problem is that normally, it is hard to predict the Bearing Capacity of Bored Piles while designing them. This is because 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 (SI) can only give limited information and it is not encouraged to do too many SI's as it may be too costly and only companies which are capable financially can attempt to do so.

1.2.2 Significance of Project

The significance of this project is that in the future, companies that do piling would be able to refer to this project as a benchmark and be able to design their piles 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 or limestone areas and be able to design piles with lesser Factor of Safety.

Failure to design the proper bearing capacity will cause lots of pile settlement cases which will be a huge problem if not taken seriously. Bridges and structures may experience failures and in the worse case the structures may collapse. By taking around 10 samples, it is a fact that the soil in the areas is not homogeneous even through a short distance. Therefore it is important to know how to deal with it and learn form the response.

1.3 Objectives and scope of study

The objectives of this work are to compare various method of bearing capacity determination (analytical method, numerical method and pile load test), and to back calculate soil parameters based on pile load test results.

The scopes of studies involved would be on towards the various pile tests which include the maintained load test, dynamic loading test, statnamic test, Pile Integrity Test and PDA test. All results are to be provided first hand by Syarikat

Pembenaan Yeoh Tiong Lay. The analytical method would be based on the analyzing of the results obtained while the numerical method would be based on formulas being formulated in books and journals with alterations according to on-site conditions.

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. This is due to the fact that earthquake aftershocks from neighbouring countries are affecting our country by a larger scale every time it occurs. The project is also relevant to recent studies where the soil hardness is not considered as much as the rock quality underground this is because the soil situation underground is very hard to estimate and with the pile sitting on top of rocks will be more safe.

1.3.2 Feasibility of Project Within

The project is feasible as it utilizes a program called Plaxis and analyzes the data which can be obtained from the existing projects from the Sentul- Batu Caves Double Tracking Project. But before using the Plaxis software, one must use the Microsoft Excel spreadsheet and the Grapher software to input figures from Soil Investigations to know the SPT values and to obtain the graph that will be developed by the Maintained Load Test results. This project is low in cost for analysis and reaps in huge benefits for the future.

CHAPTER 2
LITERATURE REVIEW/THEORY

2.0 LITERATURE REVIEW/ THEORY

2.1 Literature Review

Problems relating to deep bored piling and their aftereffects on surrounding structures and soil situations are constantly increasing due to the rapid urban growth and the need to build high-rise structures. Different methods are used to calculate and estimate the ultimate bearing capacity of a certain bored pile. This literature review discusses the definition of bored piles and dynamic load testing, geotechnical design of bored piles, the Davisson's Criterion on the ultimate bearing capacity, the methods used as well as the achievements expected.

2.1.1 Drilled Piles/ Bored Piles

According to McVay(1992), drilled piles or 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. In particular, whether boring is to be undertaken in 'dry' ground conditions or through water-logged but stable strata for example wet boring.

Hussein et. all (1991) said that 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.

In some cases there may be a need to employ drilling fluids (such as bentonite suspension) in order to maintain a stable shaft. Rotary auger piles are available in diameters from 350 mm to 2400 mm and using these techniques, pile lengths of beyond 50 meters can be achieved.

2.1.2 Dynamic load testing

Fellenius (1980) stated that dynamic load testing is a fast and effective method of assessing foundation bearing capacity that requires instrumenting a deep foundation with accelerometers and strain transducers and analyzing data collected by these sensors. Examples for Dynamic load testing include the Pile Dynamic Analysis and the Maintained Load Test.

The procedure is based on the Case Method of pile testing and is standardized by ASTM D4945-00 Standard Test Method for High Strain Dynamic Testing of Piles. It may be performed on driven piles, drilled shafts and other cast in place foundations. In addition to bearing capacity, Dynamic Load Testing gives information on resistance distribution (shaft resistance and end bearing) and evaluates the shape and integrity of the foundation element.

The foundation bearing capacity results obtained with dynamic load tests correlate well with the results of static load tests performed on the same foundation element.

Eddie et. all (1990) made a fact that the static bearing capability of a pile is limited by either the structural strength of the pile shaft or the capacity of the supporting soils. Pile structural capacity is limited by allowable pile stresses which are based on material properties and building code requirements. The capacity of the pile-soil system may be evaluated by static analysis taking into account soil strength parameters derived from both in-situ and laboratory geotechnical test methods. Various analytical procedures have been described in the soil mechanics literature.

However, static analysis is considered preliminary and must be supported by additional field tests in most cases. Static load testing, which consists of applying loads of known magnitude to the pile top and measuring corresponding pile movement, or dynamic measurements and analyses of pile force and motion records during impact of a falling mass are generally used to evaluate deep foundation elements for axial static bearing capacity.

During the course of the project, the bearing capacity for the design of pile socket lengths is based on the calculations used by VE Consult who were the consultants being hired for the project. Besides the VE Consult's method, there are two other methods which are being applied for the analysis which are Bauer's Method as well as the Gue & Partners Method.

2.2 Theory

2.2.1 Geotechnical design of Bored Piles

2.2.1.1 VE Consult's Calculation

According to VE (2006), when limestone was encountered, the soil layer above and the contribution from the base are ignored. In this case it would mean the skin friction for soil and the end bearing provided by rock. Socketing length into rock will provide the geotechnical capacity of the pile.

Geotechnical Capacity of bored pile will be obtained by the equations,

$$Q_b = \frac{Q_s}{F_s}$$

$$Q_s = \frac{\pi D q_u L}{20}$$

Where,

F_s = Factor of safety for skin friction
= 1.5
Q_s= Shaft friction resistance
q_u = Unconfined compressive strength of rock or concrete whichever is lower

Table 2.1: Unconfined compressive strength of rock

RQD (Based on SI results)	q_u (N/mm^2)
0-9%	6
10-29%	10
30-49%	15
50-100%	20

A sample of calculations using VE's calculation will be inserted in the Appendix C section.

2.2.1.2 Bauer (M) Sdn. Bhd.'s Calculation

The anticipated geotechnical capacity of the piles will be estimated based on the following:

a) For compression piles

The safety factor to be adopted for unit skin friction will be 2.0 and 3.0 for end bearing.

The majority of the pile in this location will be terminated into limestone bedrock except at certain piers where the piles will be terminating in stiff soil.

Piles Embedded in Limestone Bedrock

The design pile length will be obtained from the following formula:-

Compression Pile

$$Q_{all} \approx \sum qs.As + qb.Ab$$
$$= \sum qs.(2\pi rL) + qb.(\pi r^2)$$

Q_{all} = design allowable pile working load
qs = allowable skin friction (kN/m^2)
As = area of shaft under consideration (m^2)
Ab = cross sectional area of pile (m^2)
L = pile length under consideration (m)
qb = Allowable base resistance or end bearing (kN/m^2)

All the piles will be terminated and socketted into competent limestone bedrock.

Unit Skin Friction & Base Resistance

Due to the highly variable rock qualities of the limestone bedrock obtained on site during probing works at each pile position, 4 general criterias have been defined to establish the rock socket length to be used for construction.

The unconfined compressive strength of the limestone bedrock in all cases shall not be less than 25 N/mm^2.

<u>Criteria 1</u>

Condition

- Where limestone bedrock exists continuously for 10 pile diameter or 12m (whichever greater) with a rock mass of RQD 0% to 5 % and is not located at the top edge or sides of a limestone cliff.
- Piles to be terminated at top edge or sides of limestone cliff (where the slope of the cliff is > 60 □)

Socketting Criteria

- Piles to be terminated at competent limestone rock with same quality rock mass extending continuously for 10 pile diameter or 12m (whichever greater)
- For pile located at steep limestone cliff, along each section, the deeper piles shall be constructed first before proceeding to shallower piles.
- In steep limestone cliff, no piles shall be terminated in overhang bedrock.
- The proposed allowable geotechnical parameters to be adopted are as follow:

				Compression (kN/m^2)
Allowable shaft resistant	=>	qs_{all}	=	275
Allowable base resistant	=>	qb_{all}	=	0

Table 2.2: Minimum rock socketting length provided for Criteria 1:

Pile Diameter (mm)	Working Load (kN)	Minimum rock socketting provided (m) / (Pile diameter)
	Compression	$Fs_{all} = 275kN/m^2$ $Qb_{all} = 0\%$ WL
1000	4000	5.0/5D
1000	5000	6.0/6D
1500	7000	6.0/4D

Criteria 2

Condition

- Where piles are to be terminated in limestone with RQD = 5% to 25% at its socketting length.

Socketting Criteria

- Piles to be terminated at competent limestone rock with same quality rock mass extending continuously for 9 pile diameter or 10m (whichever greater)
- The proposed allowable geotechnical parameters to be adopted are as follow:

				Compression (kN/m^2)
Allowable shaft resistant	=>	qs_{all}	=	300
Allowable base resistant	=>	qb_{all}	=	Limited to 10% of pile capacity

Table 2.3: Minimum rock socketting length provided for Criteria 2:

Pile Diameter (mm)	Working Load (kN)	Minimum rock socketting provided (m) / (Pile diameter)
	Compression	$Fs_{all} = 300kN/m^2$ $Qb_{all} = 10\%$ WL
1000	4000	4.0/4D
1000	5000	5.0/5D
1500	7000	4.5/3D

Criteria 3

Condition

- Where continuous limestone with RQD = 25% to 50% exists to a depth of 6 pile diameter or 8 m (whichever is greater)

Socketting Criteria

- The proposed allowable geotechnical parameters to be adopted are as follow:

				Compression (kN/m^2)
Allowable shaft resistant	=>	qs_{all}	=	500
Allowable base resistant	=>	qb_{all}	=	3000

Table 2.4: Minimum rock socketting length provided for Criteria 3:

Pile Diameter (mm)	Working Load (kN)	Minimum rock socketting provided (m) / (Pile diameter)
	Compression	$Fs_{all} = 500kN/m^2$ $Qb_{all} = 3000kN/m^2$
1000	4000	1.5/1.5D
1000	5000	2.0/2D
1500	7000	2.25/1.5D

Criteria 4

Condition

- Where continuous limestone bedrock with RQD > 50% exists to a depth of 6 pile diameter or 8 m (whichever is greater)

Socketting Criteria

- The proposed allowable geotechnical parameters to be adopted are as follow:

				Compression (kN/m^2)
Allowable shaft resistant	=>	qs_{all}	=	500
Allowable base resistant	=>	qb_{all}	=	5000

Table 2.5: Minimum rock socketting length provided for Criteria 4:

Pile Diameter (mm)	Working Load (kN)	Minimum rock socketting provided (m) / (Pile diameter)
	Compression	Fs_{all} = 500kN/m^2 Qb_{all} = 3000kN/ m^2
1000	4000	1.0/1D
1000	5000	1.0/1D
1500	7000	1.5/1D

As stated in criterias one to four, if the slope of the limestone cliff between two pile/probe points encountered is greater than 60°, the piles at the top of the cliff or at the side of the steep slope will be socketted using Criteria C1 as mentioned earlier. If it can be established that the piles at the top of the cliff is located a minimum of 3 pile diameter away from the commencement point of the steep slope, this criteria will not be applicable.

All the above criterias with the corresponding socketting length are summarized in Table 2.6 for ease of reference.

Table 2.6: Bored pile Socketting Schedule

Criteria	Rock (RQD)	Adopted Parameters		Proposed Rock Socket (m) / (pile diameter)		
		fs_{all} kN/m^2	fb_{all} kN/m^2	D = 1500mm	D = 1000mm	
				WL = 7000kN	WL = 5000kN	WL = 4000kN
1	0 to 5 % Limestone Cliff > 60 °	275	0	6.0/4D	6.0/6D	5.0/5D
2	5 to 25%	300	10% of WL	4.5/3D	5.0/5D	4.0/4D
3	25 to 50 %	500	3000	2.25/1.5D	2.0/2D	1.5/1.5D
4	50 to 100%	500	5000	1.5/1D	1.0/1D	1.0/1D

Note:

a) In the above mentioned case, if there is no competent rock below the pile toe the length of the socket will be revised on pile to pile basis.

b) In case of suspended rock layers without competent characters, the layers should be drilled through and socket in competent rock layers.

c) The unconfined compressive strength for all the cases above shall not be less than 25 N/mm^2.

Founding of Piles in Competent Limestone Bedrock

Bauer (2000) reported that in all cases for piles terminating into limestone bedrock, the philosophy of our proposal is to found/embed the piles into competent limestone bedrock extending through incompetent rock layers and cavities if necessary. Competent bedrock is defined as rocks with a continuous rock mass extending below the bored pile toe level to the depth as defined in the 4 criterias earlier.

To ascertain the final pile length or founding depth of the bored pile, probe holes will be conducted in each pile location in advance.

Piles Terminating in Stiff Soil

Pile Embedded In Soil

The design pile length will be obtained from the following formula:-

Compression Pile

$$Q_{all} \approx \sum qs.As + qb.Ab$$
$$= \sum qs.(2\pi rL) + qb.(\pi r^2)$$

Q_{all} = design allowable pile working load
qs_{all} = allowable skin friction (kN/m^2)
qb_{all} = Allowable base resistance (kN/m^2)
As = area of shaft under consideration (m^2)
Ab = cross sectional area of pile (m^2)
L = pile length under consideration (m)

Table 2.7: Allowable Skin Friction (qs_{all}) And Allowable Base Resistance (qb_{all})

SPT (N)	qs_{all} (kN/m^2)	qb_{all} (kN/m^2)
For 0 $\leq$N < 10	0	0
10 $\leq$N < 20	25	0
20 $\leq$N < 30	35	0
30 $\leq$N < 40	50	0
40 $\leq$N $\leq$50	60	0
> 50	75	0
> 100	125	0

> 150	175	0
> 200	250	0

A sample of calculations using Bauer's calculation will be inserted in the Appendix C section.

2.2.1.3 Gue & Partners Sdn. Bhd.'s Calculation

Tan et al. (2003) stated that the three major rock formations, namely sedimentary, igneous and metamorphic rocks, are commonly encountered in Malaysia. When designing structures over these formations using bored pile, the design approaches could vary significantly depending on the formations and the local experience established on a particular formation.

Generally, the design rock socket friction is the function of surface roughness of rock socket, unconfined compressive strength of intact rock, confining stiffness around the socket in relation to fractures of rock mass and socket diameter, and the geometry ratio of socket length-to-diameter.

Roughness is important factor in rock socket pile design as it has significant effect on the normal contact stress at the socket interface during shearing. The normal contact stress increases due to dilation resulting increase of socket friction. The level of dilation is mostly governed by the socket roughness.

The second factor on the intact rock strength governs the ability of the irregular asperity of the socket interface transferring the shear force, otherwise shearing through the irregular asperity will occur due to highly concentrated shear forces from the socket.

The third factor will govern the overall performance of strength and stiffness of the rock socket in jointed or fractured rock mass and the last factor is controlled by the profile of socket friction distribution. It is very complicated to quantify all these aspects in the rock socket pile design.

The design pile length will be obtained by the following formulae:

$$Q_{all} = \sum \frac{qb.AbL}{Fs}$$

$$= \sum \frac{qb.2\pi rL}{Fs}$$

Q_{all} = design allowable pile working load
qb = Allowable base resistance (kPa)
Ab = cross sectional area of pile (m^2)
Fs = Factor of Safety
= 2

Table 2.8 Summary of Rock Socket Friction Design Values

Rock Formation	Working Rock Socket Friction*	Source
Limestone	300 kPa for RQD< 25% 600 kPa for RQD = 25-70% 1000 kPA for RQD > 70% The above design values are subject to 0.05 X minimum value of (q_{uc}, f_{cu}) whichever is smaller	Neoh (1998)
Sandstone	0.10 X q_{uc}	Thorne (1977)
Shale	0.05 X q_{uc}	Thorne (1977)
Granite	1000-1500 kPa for q_{uc} > 30N/mm^2	-

A sample of calculations using Gue's calculation will be inserted in the Appendix C section.

2.2.2 Davisson's Criterion

Serrano et. all (2002) stated that the term 'Ultimate bearing capacity' is said to be the root towards obtaining the certain parameters needed to determine the function ability of the analysis.

Pariseau (2003) described that the Davisson's Criterion will be used to obtain the settlement of the pile according to the total load which is being maintained on the pile at the certain moment. The settlement obtained is used to graph out a line which may and may not intersect with the Load versus Settlement Curve from Maintained Load Test results. If there is an intersection point then the Ultimate Bearing Capacity, P_u can be obtained.

The Formulae for obtaining the settlement value by Davisson's Criterion is as below:

$$\text{Offset value} = x + \frac{PL}{AE}$$

Where,

$$\text{Settlement, } x = 4 + \frac{B}{120}, \text{ mm}$$

B = pile diameter, mm

P = Load, kN

L = Length of pile, m

A = Cross Sectional area of pile, m^2

E = Modulus of Elasticity of pile

$$= \frac{\left[\left(E_{concrete} * A_{pile}\right) + \left(E_{steel} * A_{steel} * BarNos.\right)\right]}{A_{pile} + \left(A_{steel} * BarNos\right)}$$

$E_{concrete}$ = Modulus of Elasticity of Concrete

$$= 4700\sqrt{f_{cu}}$$

f_{cu} = Characteristic Strength of Concrete ,N/mm^2

A_{pile} = Cross Sectional Area of Pile, m^2

E_{steel} = Modulus of Elasticity of Steel, MPa

A_{steel} = Cross Sectional Area of Steel Bars, m^2

A sample of calculations using the Davisson's Criterion is inserted in the Appendix C section.

2.2.3 Methods Used

During the duration of the project, a few things will be looked into and given more attention towards analyzing the terms and parameters involved in building up towards the reduction of parameters as well as to provide a more accurate assumption of the project.

The methods that were used to do the analysis would be to first collect as much data as possible from the site and then inputting the data into Microsoft Excel Spreadsheets to see the graphs that can be obtained from the results of Soil Investigation and Pile Load Tests such as the Maintained Load Test and Pile Dynamic Analysis Tests. By using the Davisson's Criterion, the Ultimate Bearing Capacity, P_u value can be obtained through the intersection point between the load cycle and the Davisson's line. And with the Ultimate Bearing Capacity a graph showing the difference between VE and Bauer's method can be obatined.

A section will be dedicated on the methods used to calculate the pile bearing capacity for the design of the piles. The methods used for the design of piles will be based on VE consults method as well as Bauer's method. The methods will be compared in order to determine which method is more feasible in terms of money, time and safety.

After that, an overall review of the results and graphs will be studied and the unwanted parameters or the parameters which are not that accurate will be cut out from the analysis later. This method is only applicable if an abundance of data is available so that the analysis later can be more accurate by only choosing parts of the data that are more applicable.

Once the parameters that are to be used for analysis are set, these parameters are to be inputted into the Plaxis Software to obtain an analysis for the project. The Plaxis software which can be used to do the back analysis for the project as well as the prediction for the soil and rock bearing capacity which will later be used to compare with the real time results to know whether the analysis can be trusted. It can also be done if the parent company in this case SPYTL would order for more pile load tests and load at least one of the piles to failure to know the Ultimate load which can be achieved by the piles. That value would then be considered as the benchmark to the calclations.

2.2.4 Achievements Expected

Among the achievements which are expected in this project, the first one would be obtained after the collection of data would be a very huge supply of data which can be analyzed one by one and then by doing so the more useful and accurate data and parameters will be picked out to do further analyses.

The next achievement from the picked out parameters would be the ability to obtain the back analyses to predict the soil and rock bearing capacity so that a successful comparison can be made. If the difference from comparison is too high that would mean the parameters being considered maybe wrong and the analyses have to be redone.

The third achievement that is expected would be in the future, companies that do piling would be able to refer to this project as a benchmark and be able to design their piles 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 or limestone areas and be able to design piles with lesser Factor of Safety.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.0 METHODOLOGY/ PROJECT WORK

3.1 Methodology

The methodology of the project is divided into a five stages.

The first stage mainly consists of the job of collecting and summarizing all soil data pertaining to the site. After that is done the soil layering system along the track has to be characterized.

Once the first stage is done, the second stage will commence with collecting all pile test results and then later characterize the response of all pile load tests.

With that, the third stage is reached. During this stage, the analyzer has to reduce the number of parameters that are being considered so that the analysis will not be too complicated.

Once that part is done, the analyzer will start with the fourth stage where the ultimate pile capacity based on analytical method, numerical method and pile load test results has to be calculated.

Lastly, the fifth stage shall consist of back calculating the soil parameters based on pile load test results. Back calculation can be done by either the Plaxis Analysis or by increasing the pile load test cases and if possible to load them until pile failure. After that is done the results have to be analysed and synthesize. Conclusions will then be drawn from that point.

3.2 Tools/Equipment Required

The tools and equipment which are required in this Final Year Project are a Windows based PC together with the programs such as Microsoft Office and Plaxis which is used to analyse the data obtained from the site, equipment needed basically would be data from on site results as well as from the internet and other references. Microsoft Office programs include Microsoft Word used to type reports, Microsoft Excel to draw graphs and rearranging of data and Microsoft Visio to draw sketches as well as limestone profiles. The Grapher software which is a useful tool to plot the graphs is also utilised in this project to produce the graphs for the SPT N-values, RQD and Load Test graphs.

3.3 Background of Project

The basic methodology of this final year project is to obtain sufficient information to be able to redesign pile bearing capacities by using a new type of calculation method where only certain parameters which are considered as important to the analysis are only taken into consideration. The main aim of the project is to be able to compare various method of bearing capacity determination (analytical method, numerical method and pile load test) as well as to back calculate soil parameters based on pile load test results.

This Final Year Project is based on a ongoing project for the company of Syarikat Pembenaan Yeoh Tiong Lay. The Project name is the Sentul- Batu Caves Double Track Project. Basically this project is in collaboration with Keretapi Tanah Melayu together with Syarikat Pembenaan Yeoh Tiong Lay and the objective of this project is to build an electrified double track along Sentul to Batu Caves. The existing track that is already built will be removed and replaced with a new set of tracks.

In order to estimate the project budget, preliminary Soil Investigations were done to estimate the rough costs as well as the improvements that are to be made to accommodate the new track as well as to ensure the safety of the public is ensured. As an effect, it is decided that the soil alongside the tracks will be strengthen to at least 4 meters under Ground Level with the Surface Vibratory Compaction method and 5 extra bridges for vehicles will be built along the roads which have level crossings originally to ensure that the traffic situation is maintained as before.

The whole of this project will based on findings on the Soil Investigation results done for Bridge No. 3 or better known as the Batu Village Crossing for those involved in the project. It is decided that a total of 12 piers will be constructed inclusive of 2 abutments and that a total of 83 piles are to be bored using Bored Pile machines. The piles will be designed using VE Consults method and it would be designed through 3 different pile diameters which range from 800mm diameter piles to 1200mm diameter piles and also designed according to 4 different working loads which range from 3000 kN to 7500 kN.

3.3.1 Soil Condition

The soil condition of the site is mainly made out of either sand of clay and the original calculation which is based on the rock quality designation in the site is mostly made out of limestones. The soil condition on the site is bad as it is mostly made out of soil with a very low N-value normally ranging from 0 to 10. This N-value is too low and cannot be taken into consideration normally for the calculation of pile depth as well as the socket length required.

The clayey slit situation does not help in producing good rock for higher Rock Quality Designation values, as a matter a fact it simply means that an underground river flowing with groundwater exists as from the rock samples which are retrieved from Soil Investigations it is found that the rocks are mostly deformed and slightly fractured rock. The rock surfaces are normally smooth which indicates that the rock has been slowly eroded by a constant flow of water. Therefore this situation results in the infiltration of slit and clay into the cavity areas.

From the analysis of the soil situation for the Batu Village site, it is found that normally for the depth of 0 to 10 meters the soil consists of either silty or sandy material which is normally mixed with gravels. This is due to the fact that the site was an ex-mining area and the soil on the top surface is normally backfill material and construction debris. For the depth of 10 to 20 meters the soil type changes in either silt or clay or the mixture of both. This is because the soil here is near the limestone rock levels and the area here is normally an empty space which is created through the erosion by a constant flow of groundwater. As for the depth for 20 meters and lower, this level is usually dominated by limestone rocks ranging from the whitish grey colour to the yellowish brown colour.

3.3.2 Pile Loading Test

Pile testing traditionally has meant the application of a static load test and the measurement of the resulting pile top movement. The failure load is defined as the load which causes excessive pile movement. Various definitions exist for the excessive pile set.

For high capacity often a proof test to a certain load level is conducted when it is too expensive to load the piles to failure. This type of pile testing is expensive, time consuming, and in some case physically impossible to perform. Because of these restraints, only a few piles are tested on larger projects, and perhaps none on smaller jobs. In many instances, information obtained from only one loading test is used to judge the rest of the piles in a foundation.

Even under very well controlled conditions, the evaluation of piles for ultimate capacity based on static tests can easily contain errors of 10% or 20% relative to the true value.

CAPWAP (the Case Pile Wave Analysis Program) is a procedure which allows the computation of soil resistance forces and their distribution, along with other dynamic soil parameters from measured pile top force and velocity histories during a hammer blow.

3.4 Hazards Analysis

It is found out that throughout the whole process of the project, there would be two major safety concerns which are computer ergonomics and electrocution shock. Computer ergonomics is a factor as the project is mainly based on computer work through analysis done by a specific program. Electrocution shock however might occur if the electrical appliances used are left exposed to bad wiring or without proper grounding.

3.4.1 Computer Ergonomics

Marmaras, N., Poulakakis, G. and Papakostopoulos, V. (1999) said that ergonomics or human factors are the application of scientific information concerning objects, systems and environment for human use. Ergonomics is commonly thought of as how companies design tasks and work areas to maximize the efficiency and quality of their employees' work. However, ergonomics comes into everything which involves people. Work systems, sports and leisure, health and safety should all embody ergonomics principles if well designed.

A few conditions need to be satisfied beforehand to solve the ergonomics problem which is being faced in this project. Firstly, the head and body of the user should be straight with the shoulders relaxed. Secondly, the top level of text should be at the same level as the eyes of the user. Thirdly, the upper arms should be vertical, the elbows are closed to the body and the forearms should be horizontal. Fourthly, the fingers should be relaxed with the wrists at a neutral position. Fifthly, the work surface is to be adjusted to the elbow level. Sixthly, the backrest should be adjusted to the lumbar section of the spine. Seventhly, the chair height should allow adequate leg clearance and should maintain the keyboard or workstation at elbow level. And lastly, the feet should rest firmly on the ground or supported on a footrest.

3.4.2 Electrocution Shock

According to Folliot, Dominigue (1998) an electric shock can occur upon contact of a human's body with any source of voltage high enough to cause sufficient current flow through the muscles or hair. The minimum current a human can feel is thought to be about 1 milliampere (mA). The current may cause tissue damage or fibrillation if it is sufficiently high. Death caused by an electric shock is referred to as electrocution.

The shock effects can be divided into five kinds which are: psychological, burns, ventricular fibrillation, neurological effects and arc-flash hazards. Therefore, it is recommended that certain precautions such as the non usage of faulty appliances and the checking of the workability of the fuses should be done. A table based on the effects of electrocution is constructed below:

Table 3.1 After Effects of Electrocution

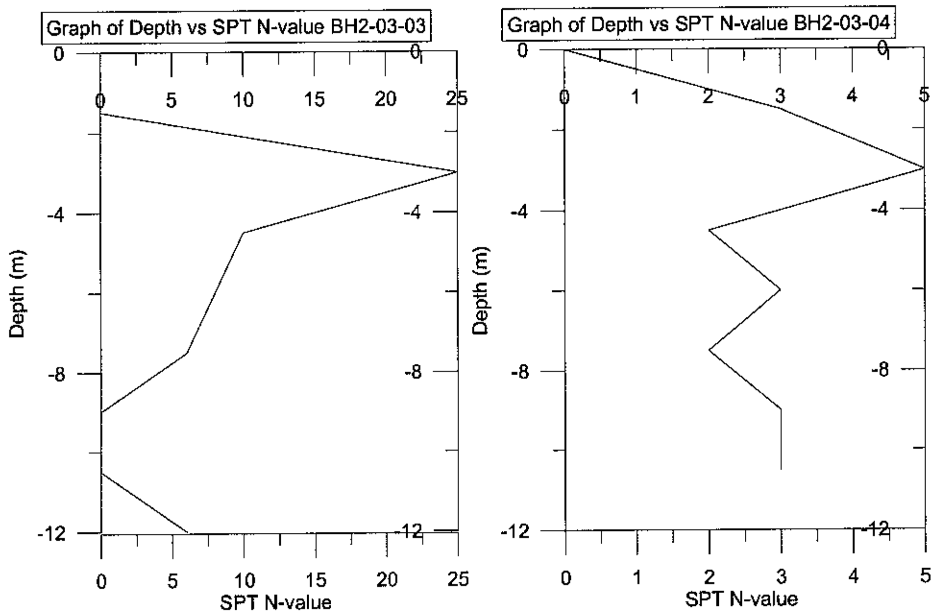
Electric current (amperes)	Voltage at 10,000 ohms	Voltage at 1,000 ohms	Maximum power (watts)	Physiological effect
0.001 A	10 V	1 V	0.01 W	Threshold of feeling an electric shock, pain
0.005 A	50 V	5 V	0.25 W	Maximum current which would be harmless
0.01-0.02 A	100-200 V	10-20 V	1-4 W	Sustained muscular contraction. "Cannot let go" current.
0.05 A	500 V	50 V	25 W	Ventricular interference, respiratory difficulty
0.1-0.3 A	1000-3000 V	100-300 V	100-900 W	Ventricular fibrillation. Can be fatal.
6 A	60,000 V	6,000 V	400,000 W	Sustained ventricular contraction followed by normal heart rhythm. These are the operation parameters for a defibrillator. Temporary respiratory paralysis and possibly burns.

CHAPTER 4

RESULTS & DISCUSSIONS

4.0 RESULTS & DISCUSSIONS

4.1 Results of Analysis on Pile SPT and RQD values

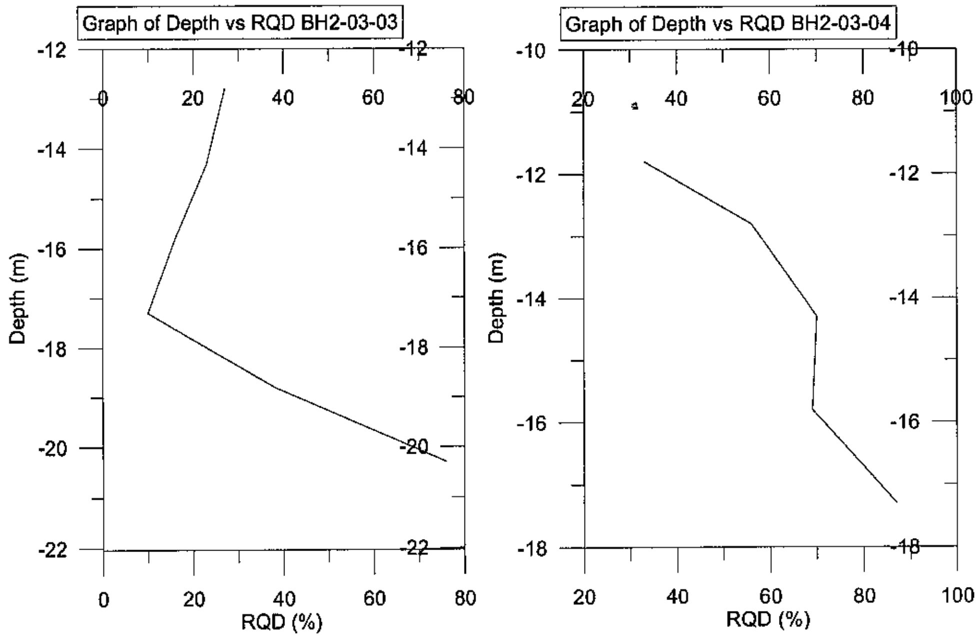


Graph 4.1 & 4.2: SPT Plot for BH2-03-03 and BH2-03-04

For all the results shown in this section, it is to be stated that only the more critical situations are being discussed as there are too many results. The extra results will be attached in the Appendix A section.

As seen from graphs 4.1 and 4.2, the results of the pile Standard Penetration Test results clearly state that the hit rock level for the piles are around 10 to 12 meters and that the SPT N-values are lower than 25. This means that the soil that is surrounding the site is not strong enough to allow the Bored Piles to be located within soil. Pile bearing capacity will then be determined using end bearing and not skin friction. This is due to the concern that the soil may not be strong enough to hold the pile while underground.

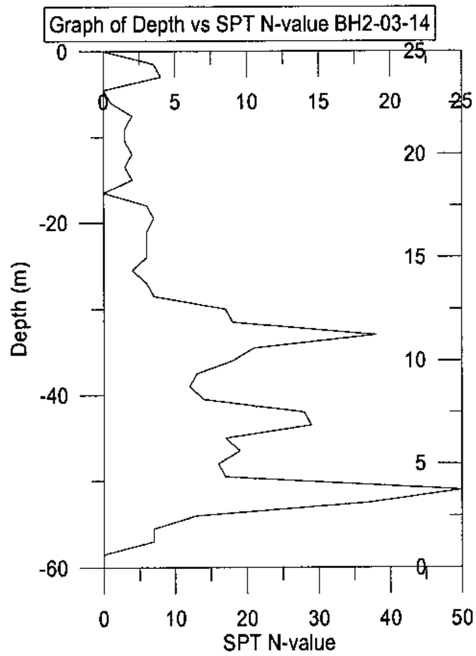
Another fact that was observed was that both the Soil Investigations hit rock at around the same value which is around 11 meters below ground level. This would probably mean that the rock level around that area is almost the same and that chances that the rock quality would be the same.

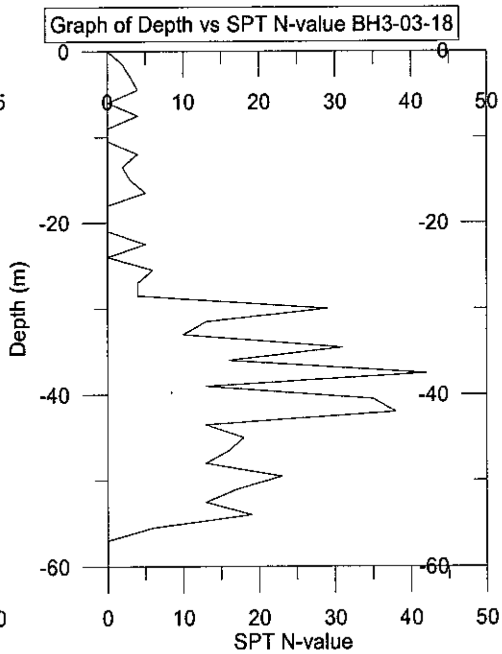


Graph 4.3 & 4.4: RQD plot for BH2-03-03 and BH2-03-04

From the results that are from graphs 4.3 and 4.4, it is observed that the rock layers below the weak soil layer are quite strong in the sense that the Rock Quality Designation for the rocks range from values from 10% to 90%. What is comforting about this fact that even though there are low RQD values, when the rock layer is at around 16-20 meters beneath ground level it is observed that the RQD values will increase to values ranging from 70% to 90%.

With these high RQD values, the consultant in this project which is VE consult has decided to sit the piles within the rock layer as the socket length. End bearing would be the only consideration in this case and all skin friction will be neglected.





Graph 4.5 & 4.6: SPT Plot for BH2-03-14 and BH2-03-18

For the whole process of the project, every Soil Investigation point has managed to hit rock at a certain value and that the Rock Quality Designation values have all been quite acceptable. But there are also cases that are rare where the Soil Investigation does not encounter rock even though it has gone down to the depth of 60 meters. This particular situation occurs on Boreholes number 14 and 18.

As a solution towards this problem, the consultants have decided to redesign the piles which were originally allocated for that area. It is decided that the original pile bearing capacity will be lowered from 4500 kN to 3750 kN and that instead of 4 piles in the pile cap, 6 piles will be constructed.

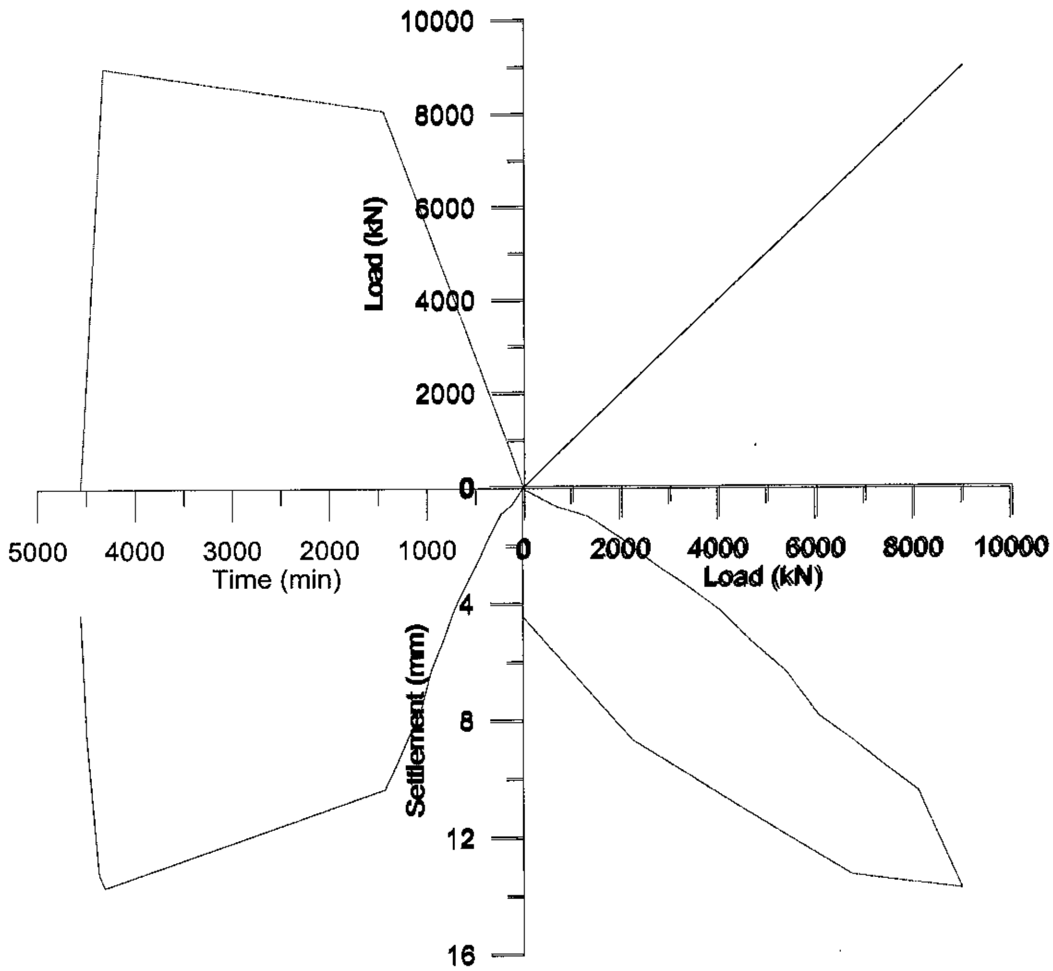
Table 4.1: Pile Load Test results for 900mm pile

Load Stage % WL	Applied Load kN	Maintained Time hours / minutes	Pile Head Settlement mm
0	0		0.000
15	675	2 hours	0.600
30	1350	2 hours	0.950
45	2025	2 hours	1.700
60	2700	2 hours	2.570
75	3375	2 hours	3.350
90	4050	2 hours	4.180
105	4725	2 hours	5.290
120	5400	2 hours	6.270
135	6075	2 hours	7.810
150	6750	2 hours	8.610
165	7425	2 hours	9.530
180	8100	2 hours	10.360
200	9000	48 hours	13.695
150	6750	1 hour	13.230
100	4500	1 hour	10.960
50	2250	1 hour	8.640
0	0	1hour	4.385

4.2 Results of Analysis on Maintained Load Test Results

Table 4.1gives the result for the 900mm Maintained Load Test. Through the results it is seen that the maximum settlement when sustaining 2 times working load is 13.695mm while the residual settlement after releasing the load is 4.385mm. The pile in this case in sustained under the Maintained Load Test of only 1 stage instead of the normal 2 stage scenario.

From the results, it is observed that the pile designed in this case did not fail as the guidelines state that the maximum settlement which can be achieved during two times working load should not exceed 32mm and the residual settlement should not exceed 6mm. Even though in the end the load test results were still acceptable but in the future more attention should be taken during the designation of the piles and higher factor of safeties should be implied.



Graph 4.7: Four Point Graph showing relationships between Load, Settlement and Time

Graph 4.4 is a four point graph which clearly states the relationship between Load versus Time, Load versus Load, Load versus Settlement and Settlement versus Time. This is a graph which has been plotted according to the results obtained from the Maintained Load Test for the 900mm pile. The results obtained will be used in the analysis of Davisson's Criterion.

4.3 Discussion on the Comparison of Pile Bearing Capacity's by different methods

The piles that are supposed to be designed in Batu Village are divided into three different sizes and four different criterias are which are the 800mm, 900mm and the 1200mm pile sizes. There will be two designs for the 900mm piles which are type 1 and type 2 piles respectively. With different sizes being allocated, it is believed that different working loads should be allocated to different piles and with respect to that, a table is constructed below for easy reading.

Pile Diameter(mm)	Working Load required(kN)
800	3000
900 Type 1	3750
900 Type 2	4500
1200	7500

Table 4.2: Relationship between Pile diameter and Working Load

For 900mm bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 1
SI Based = BH2-03-02

Based on VE Consult's Calculations

Table 4.3: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	0	6	0.3	1272	1272	848
1.5	3.0	0	6	0.3	1272	2545	1696
1.5	4.5	0	6	0.3	1272	3817	2545
1.5	6.0	0	6	0.3	1272	5089	3393
1.5	7.5	0	6	0.3	1272	6362	4241
0.7	8.2	0	6	0.3	594	6955	4637
1.6	9.8	CAVITY					
1.5	11.3	29	10	0.5	2121	9076	**6051**

Minimum required cumulative socket length in limestone = **8.2m**

Additional socket length due to cavity = 1.5m

Based on Bauer's Calculation

Table 4.4: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	Q_s + Q_{ball} (kN)
1.5	N/A	0	275	0	1166.32	1166.32	0	1166.32
1.5	N/A	0	275	0	1166.32	2332.64	0	2332.64
1.5	N/A	0	275	0	1166.32	3498.96	0	3498.96
1.5	N/A	0	275	0	1166.32	4665.28	0	**4665.28**

Minimum required cumulative socket length in limestone = **6.0m**

Based on Gue's Calculation

Table 4.5: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	0	300	1273	1273	636
1.5	3.0	0	300	1273	2545	1273
1.5	4.5	0	300	1273	3818	1909
1.5	6.0	0	300	1273	5090	2545
1.5	7.5	0	300	1273	6363	3182
0.7	8.2	0	300	594	6956	3478
1.6	9.8	CAVITY				
1.5	11.3	29	600	2545	9501	**4751**

Minimum required cumulative socket length in limestone = **11.3m**

From the calculations in Table 4.2, 4.3 and 4.3, it is found that Gue's calculation is the most conservative among all three calculation methods. Bauer's calculations would reduce the socket length needed dramatically. But even so, from in-situ results it is found that VE consult actually provide more accurate calculations so even though using Bauer's method may save the company lots of money by reducing the socket length dramatically, it could also increase the chances where the working load designed for the piles are not enough and may cause the bridge that is being designed to collapse.

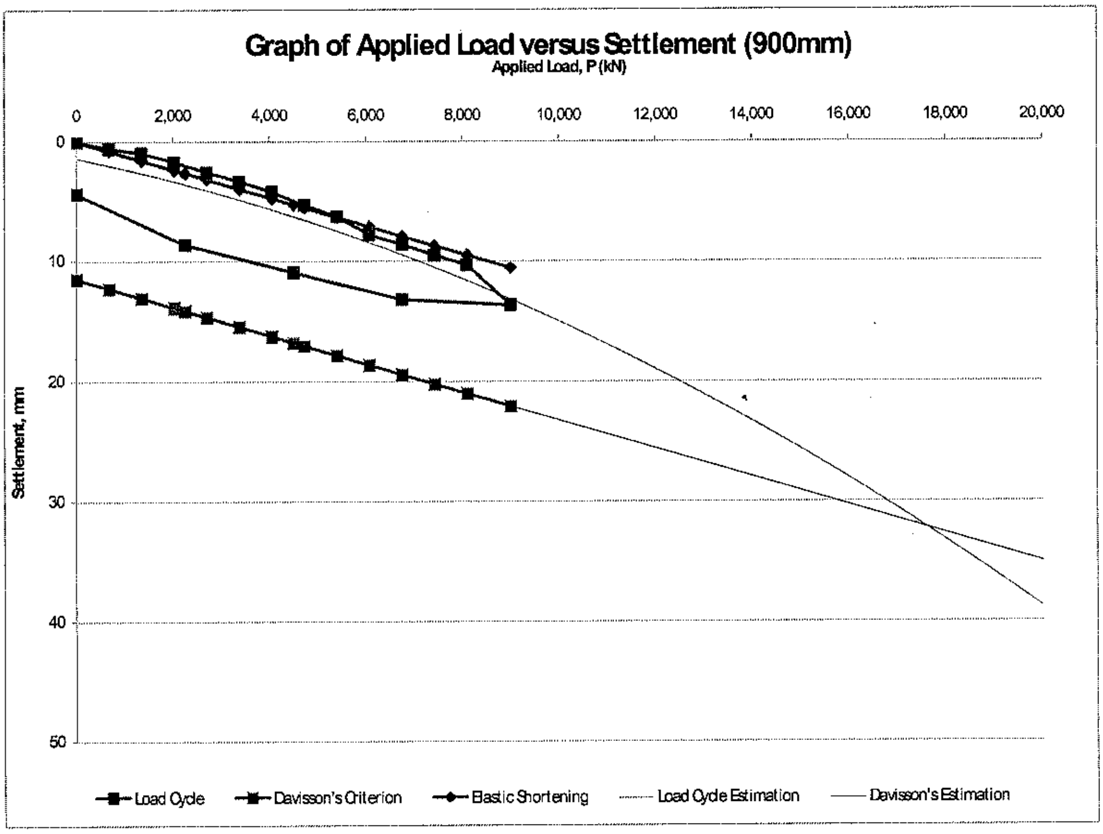
One of the reasons to why the results of the calculations provide so much contrast to each other may be the fact that Bauer's Calculation is more dependant to rock quality designation. As stated in the Literature Review, for Bauer's case as the rock quality designation reaches 50% or more, the rock end bearing value which is being assigned is a very high value and this differs from VE and Bauer as they do not consider rock end bearing in their calculation.

The fact of Bauer has no Factor of Safety cannot be used as a valid argument as in the standard of design of piles, every design formula must use a factor of safety of at least 2. Therefore it should be safe to say that Bauer is not as dangerous as what the calculations state.

Therefore even though Bauer's calculation may prove to be beneficial by cutting the overall project cost and the total time needed, it is advised to incorporate VE Consults method as it would be less conservative if compared to Gue's Method but safer compared to Bauer's method.

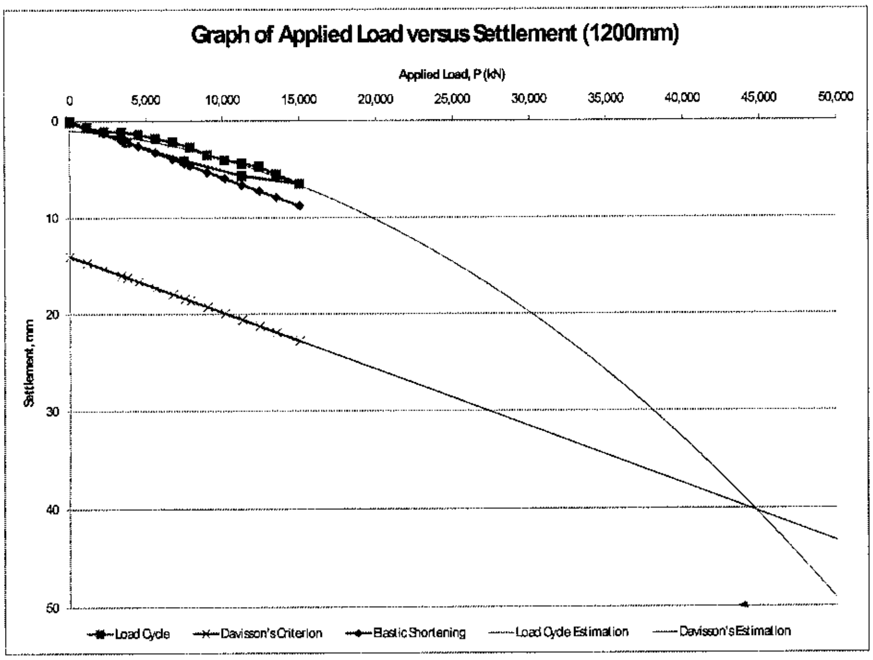
The full calculations of each method will be attached in the Appendix B section where a proper table of all values will be constructed.

4.4 Results of Analysis on Davisson's Criterion Graphs and the relationship between Ultimate Bearing Capacity and Theoretical Bearing Capacity



Graph 4.8: Graph of Applied Load versus Settlement (900mm Pile)

From Graph 4.5, it is found out that the intersection point between the Load Cycle and the Davisson's Criterion is 17523.81kN. This means that the Ultimate Bearing Capacity P_u is 17523.81kN for this test pile.

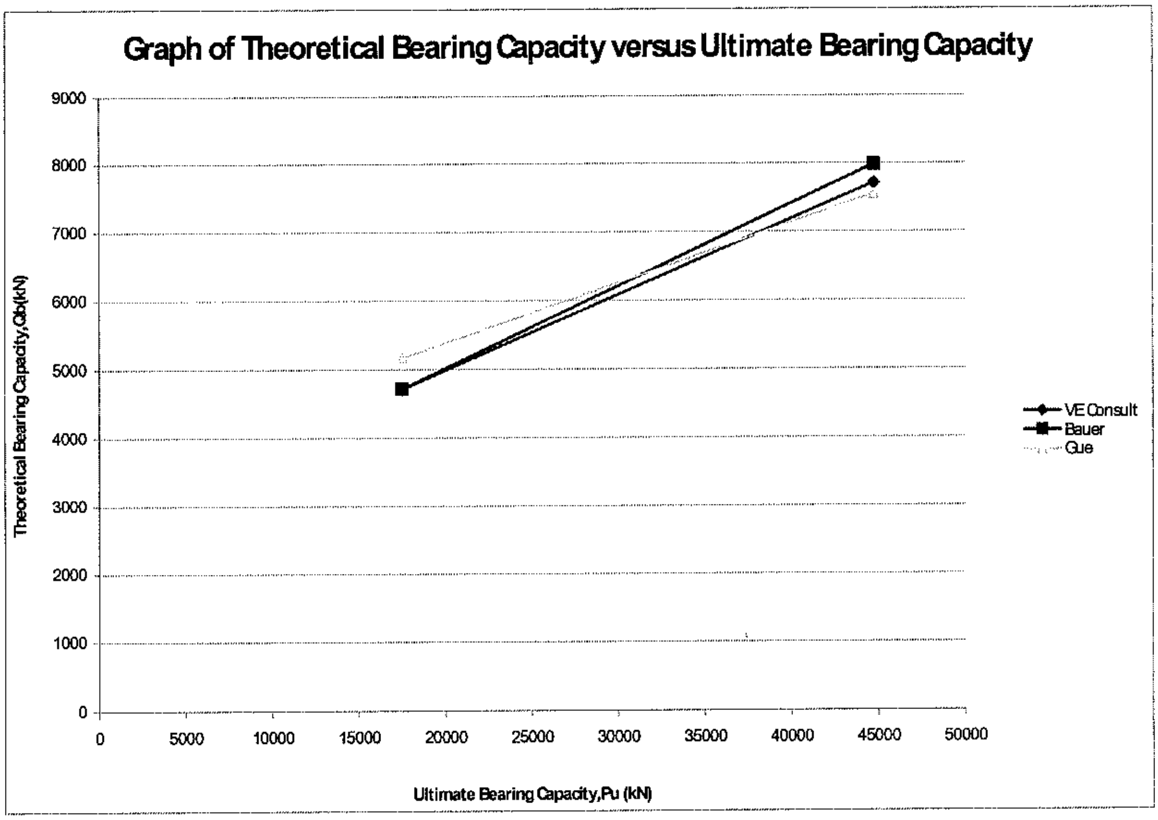


Graph 4.9: Graph of Applied Load versus Settlement (1200mm Pile)

From Graph 4.6 it is found out that the intersection point between the Load Cycle and the Davisson's Criterion is 44761.9kN. This means that the Ultimate Bearing Capacity P_u is 44761.9kN for this test pile.

The Ultimate Bearing Capacity which is designed for the 900mm pile is 9000kN whereas for the 1200mm pile it is 15000kN. Therefore, it is safe to assume that the piles had actually been over designed as the Ultimate Bearing Capacity which can be sustained by both piles are found to be at least 2 times higher than the required working load. A suggestion can be made here to reconsider the pile socket length to be reduced as extra socket length would mean wastage of time and resources.

With these two Ultimate Bearing Capacities, a graph showing the relationship between the theoretical bearing capacities of VE Consult, Bauer and Gue can be plotted out.



Graph 4.10: Graph of Theoretical Bearing Capacity versus Ultimate Bearing Capacity

From Graph 4.7, it is seen that both the piles designed after being tested do exceed the Ultimate Bearing Capacity which can be sustained by it. All three companies have achieved a linear line which means that whenever the Ultimate Bearing Capacity increases so does the Theoretical Bearing Capacity.

From the relationship shown, it is observed that Bauer is better in assuming the theoretical Bearing Capacity as they achieve a higher value as compared to the other companies. But this maybe due to the fact that Gue and VE do not consider much of the rock end bearing in their calculations.

In a nutshell, when doing a comparison between all three methods, it would be advisable to use Bauer's method as it is more feasible in this case due to the fact that it needs a lesser amount of socket length required. This will greatly decrease the project budget as well as the time consumption. While doing so, Bauer still provides a higher

Bearing Capacity than both the other companies. Therefore, it would be encouraged to apply Bauer's method of calculation.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 CONCLUSION

For the conclusion, the methodology which is used in this project can support the objectives in the project which are to compare various method of bearing capacity determination (analytical method, numerical method and pile load test) as well as to back calculate soil parameters based on pile load test results.

From the results in the methodology, it is found that the VE Consults calculation is more feasible in the long run and should be used as it considers that the bearing capacity may have wrong assumptions and an appropriate Factor of Safety is used to balance this irregularity and provide safety to the bridge that will be constructed. VE also provides the optimum calculation results as compared to the other companies.

But from results which are obtained from Graph 4.10, Bauer's method would prove to be more economical as it helps save time as well as socket length required while providing a higher Bearing Capacity while comparing to the other companies.

Therefore, in conclusion Bauer's method should be recommended to other construction companies in the future if they want to save cost and time. But if safety issues are the major concern then VE's method should be made as first priority.

Further conclusions regarding on the matter of the Plaxis Analysis are not available due to a computer glitch and thus erasing all data concerned but this project is advised to be continued for further research in order to obtain the necessary objectives.

5.2 RECOMMENDATIONS

For this project, a few items can be highlighted to ensure that the project is able to achieve the maximum potential at the least cost and manpower possible.

The first item to be revised is to try and use Bauer's calculation while calculating the bearing capacity for each pile. As seen from the results obtained for the Davisson's Criterion, the piles are over designed to at least 2 times the required working load, therefore prompting the question where the design method may have been over conservative. If a proper revision is made, then the company may save millions from the unnecessary wastage.

The second item that is to be highlighted would be to do more Soil Investigations as well as lab work for the soil. This would enable the designers to get a better idea of the soil situation on site and therefore save more costs while designing the piles. It is also helpful to those who are trying to do research on the project as more parameters would be better in determining the factors that are the most critical.

The third recommendation would be to ask students in the future to look into this topic as further research can be done towards this topic to find out which are the parameters which affect the designation of the piles the most.

The fourth recommendation would be to utilise more methods to obtain the Ultimate Bearing Capacity of the piles. Further research has to be done on the Ultimate Bearing Capacity. If that is done then, there would be a range of Ultimate Bearing Capacities and this would give the consultants or researchers a better idea of the Ultimate Bearing Capacity which can be obtained.

And lastly the recommendation for the lack of back analysis results for the project would be to do more pile load tests and in the best case to load the pile until failure. By doing so, the ultimate bearing capacity of the pile when failed as well as the maximum soil parameters can be obtained and this would be the first guideline towards back calculating the soil parameters.

REFERENCES

1) "Sample of Calculations for Bearing Capacity", (2000) by Bauer (M) Sdn. Bhd.

2) "Static or Dynamic Test – Which to Trust?", (1990), Geotechnical News, Vol.8, p. 28, Vancouver, BC. by Eddie, R.D. and Fellenius, B.H.

3) "The Analysis of Results from Routine Pile Load Tests", (1980) Ground Engineering by Fellenius, B.H.

4) "Bearing Capacity of deep foundations from Dynamic Measurements and Static Tests- Ten Correlation Cases", (1991) by M. Hussein, F. Rausche.

5) "Prediction of pile bearing capacity using artificial neural networks", (1994) by In-Mo Lee & Jeong-Hark Lee.

6) "Dynamic Pile Testing and Finite Element Calculations for the Bearing Capacity of a Quay Wall Foundation – Container Terminal Altenwerder, Port of Hamburg", (1999) by F. Kirsch, B. Plabmann, T. Huch and W. Rodatz.

7) "Design of socketed drilled shafts in limestone" (1992) by M.C. McVay, Associate Member, ASCE, F.C. Townsend, Member, ASCE, and R.C. Williams.

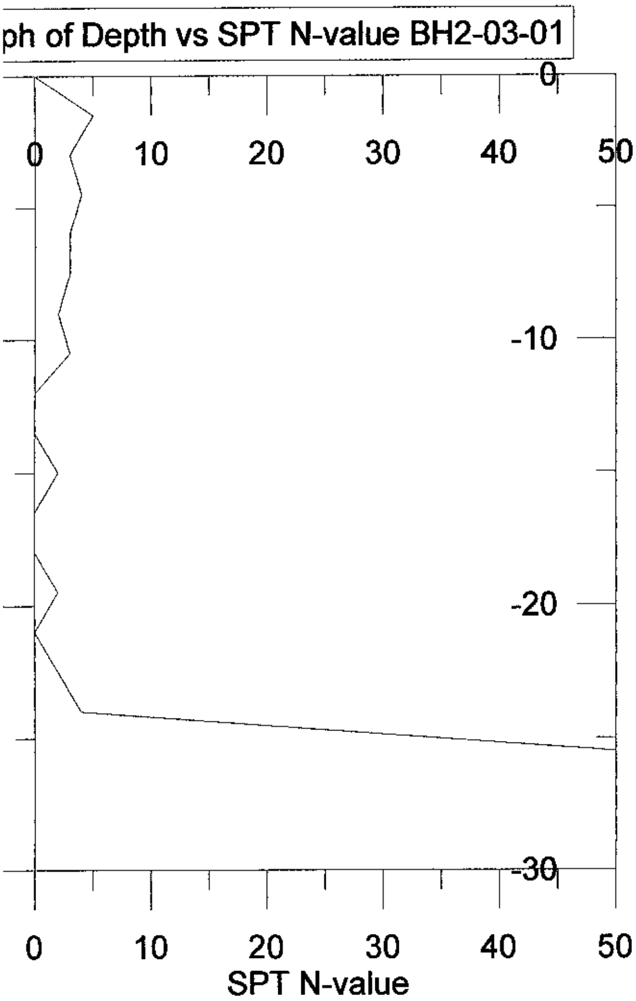
8) "Ultimate bearing capacity at the tip of a pile in rock-part 1: theory", (2002) by A. Serrano, C. Olalla.

9) "Sample of Calculations for Bearing Capacity", (2006) by VE Consult.

10) "Discussion on the paper: Ultimate bearing capacity at the tip of a pile in rock- Part 1: Theory", (2003) by William G. Pariseau.

11) "Design & Construction of Bored Pile Foundation", (2003) by Y.C. Tan and C.M. Chow

APPENDIX A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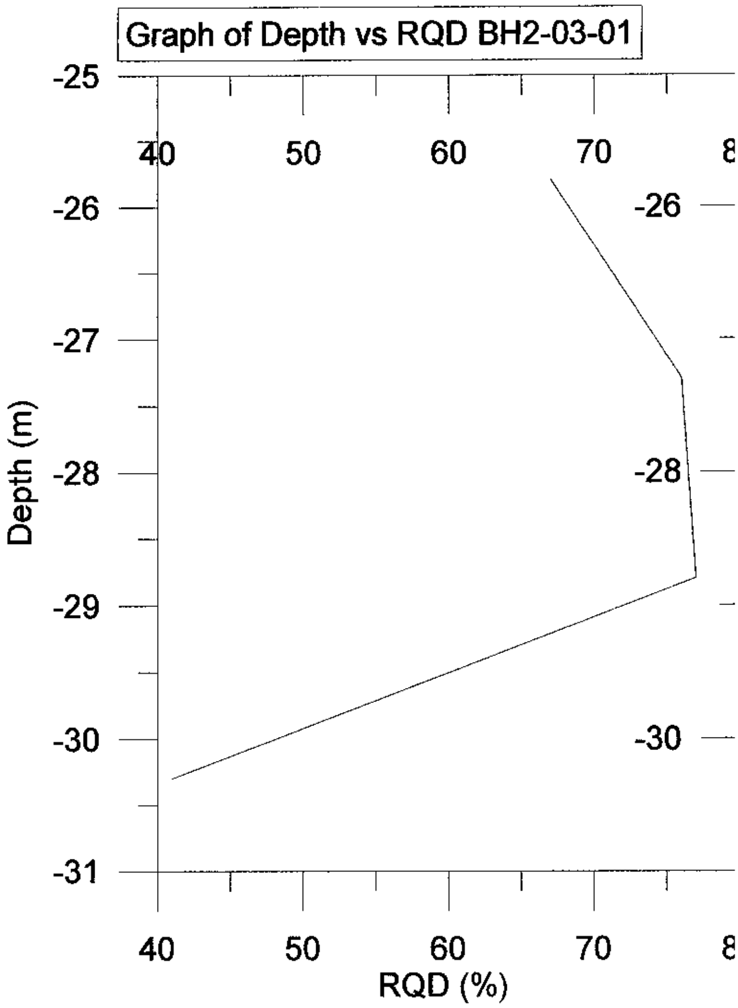
SPT N-value
0
10
20
30
40
50
0
-10
-20
-30


Graph of Depth vs RQD BH2-03-01
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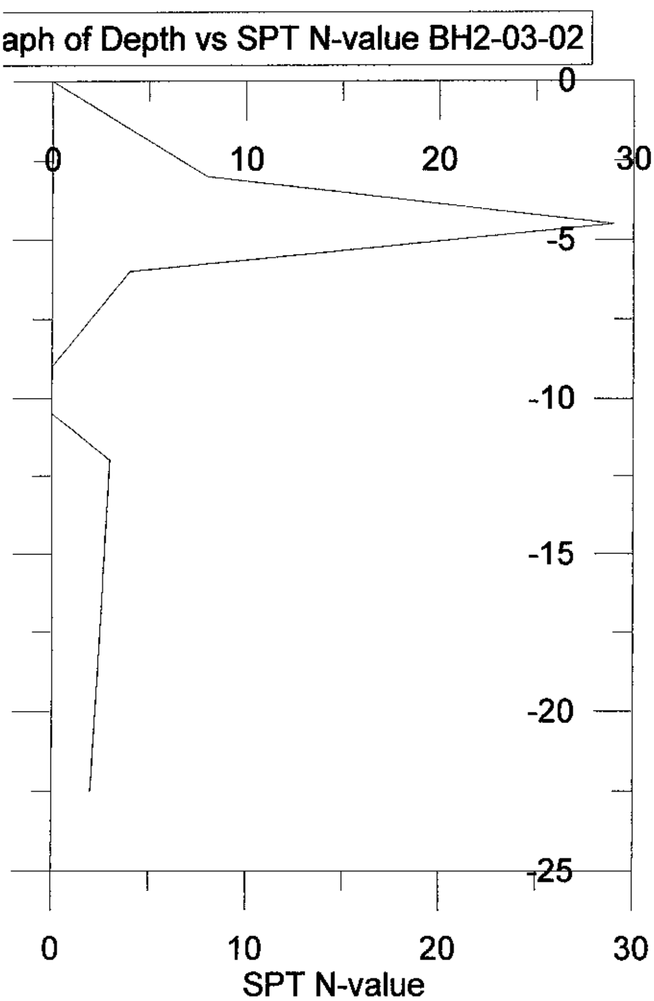
RQD (%)
40
50
60
70
-25
-26
-27
-28
-29
-30
-31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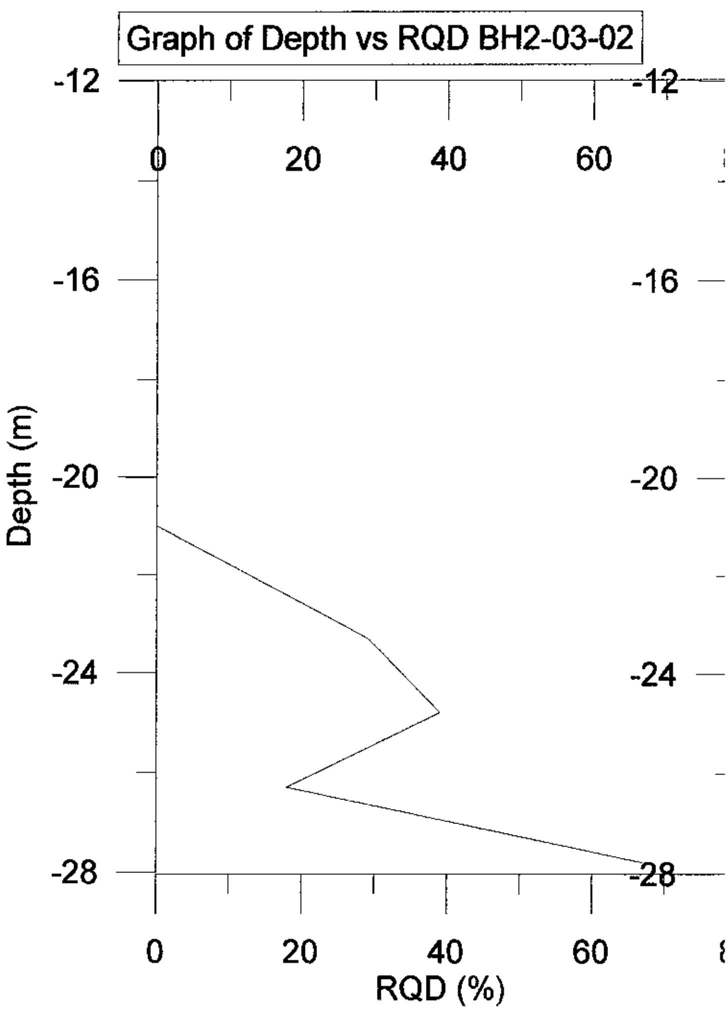
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Depth (m)
RQD (%)
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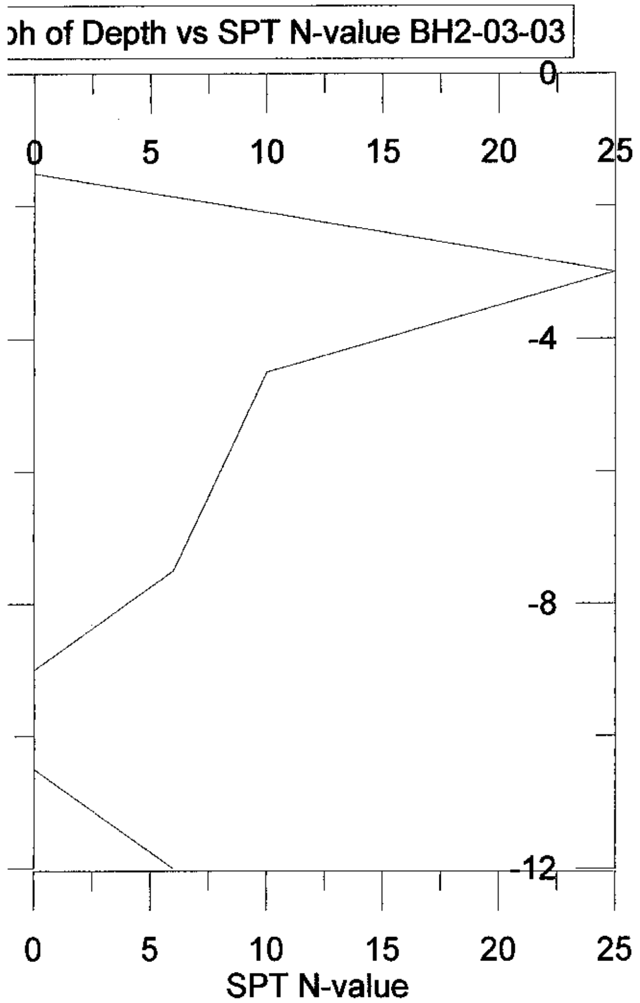
20
40
60
-12
-16
-20
-24
-28



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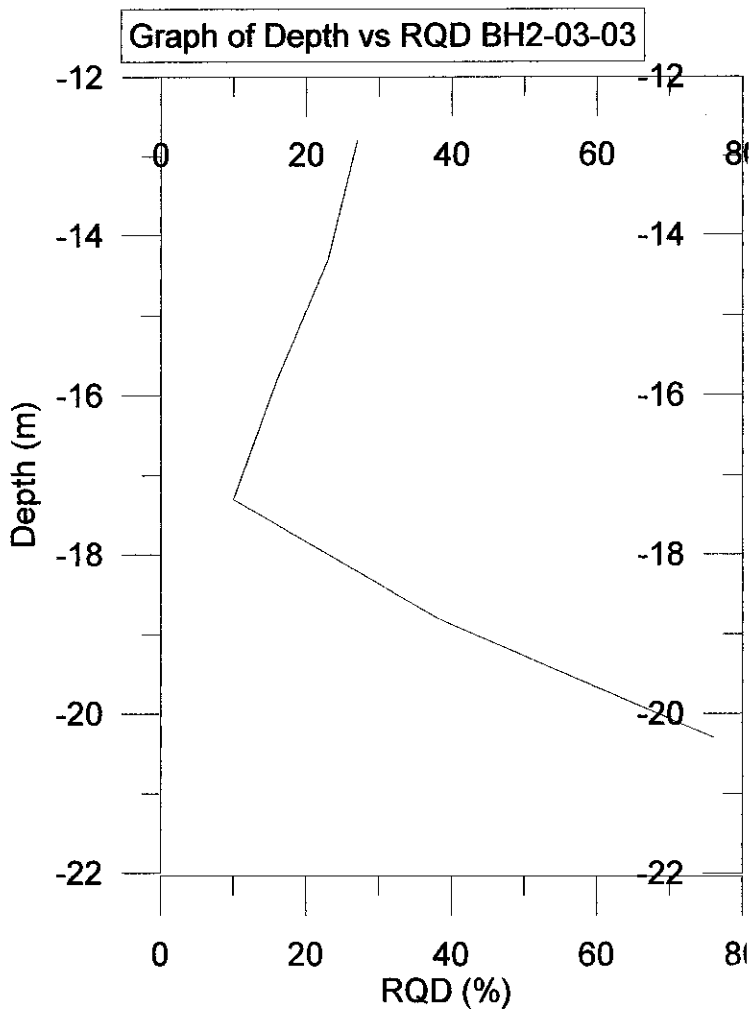
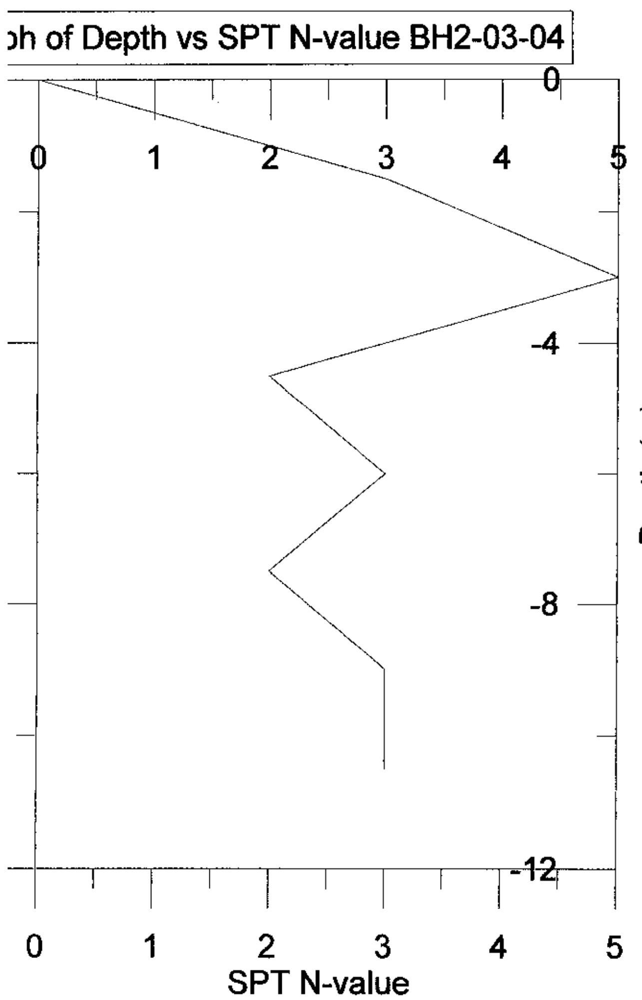
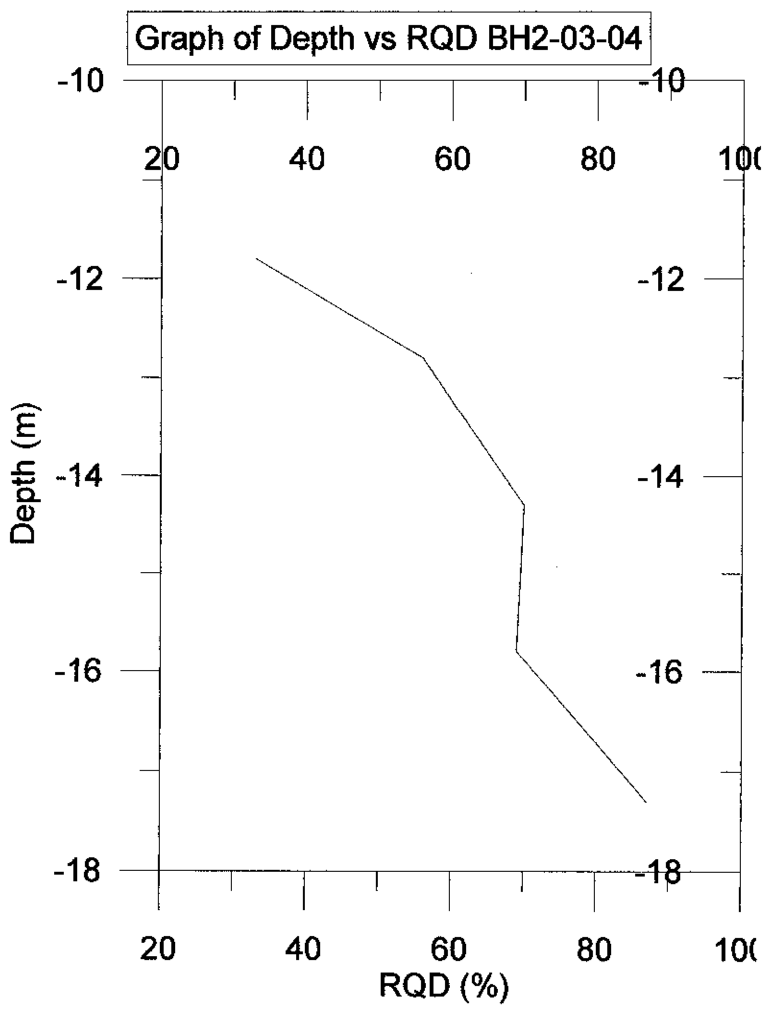
-4
-8
-12
0 5 10 15 20 25
SPT N-value



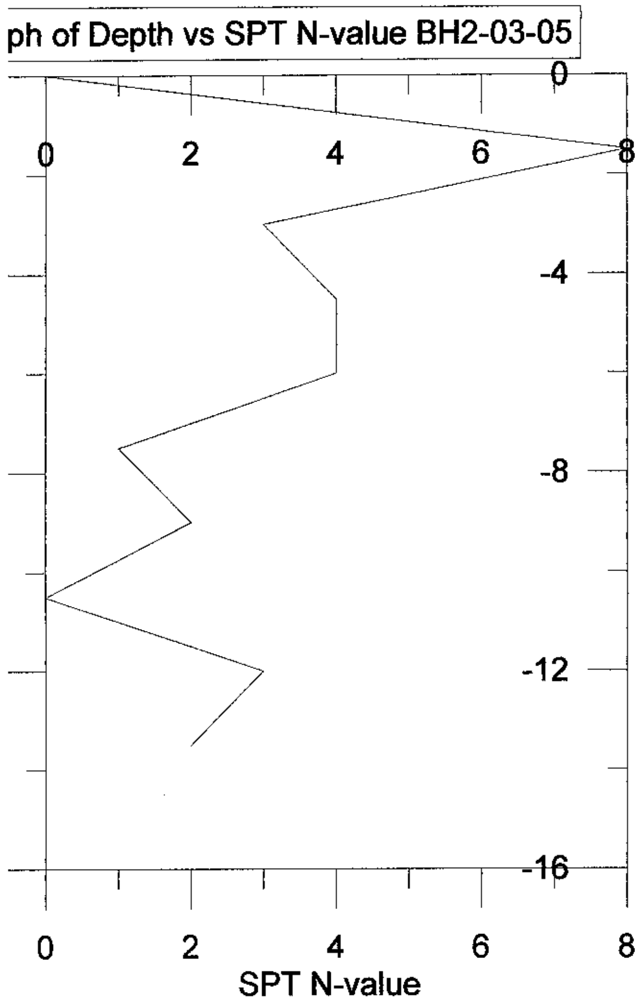
Graph of Depth vs RQD BH2-03-03
-12
-14
-16
-18
-20
-22
Depth (m)
0 20 40 60 8
RQD (%)

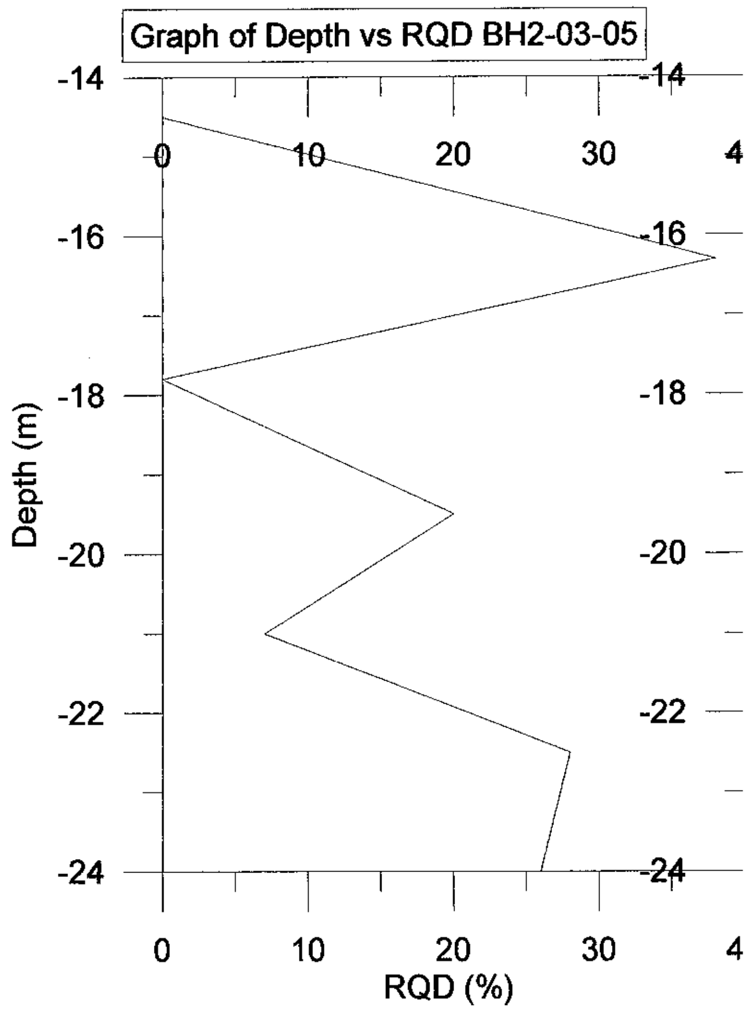


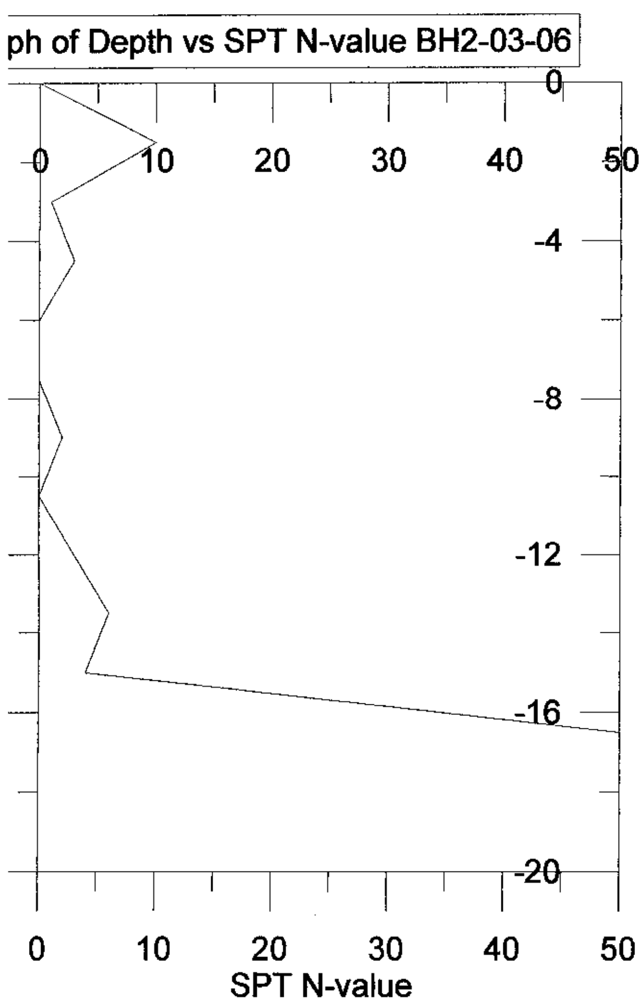
ph of Depth vs SPT N-value BH2-03-04
0
-4
-8
-12
0 1 2 3 4 5
SPT N-value

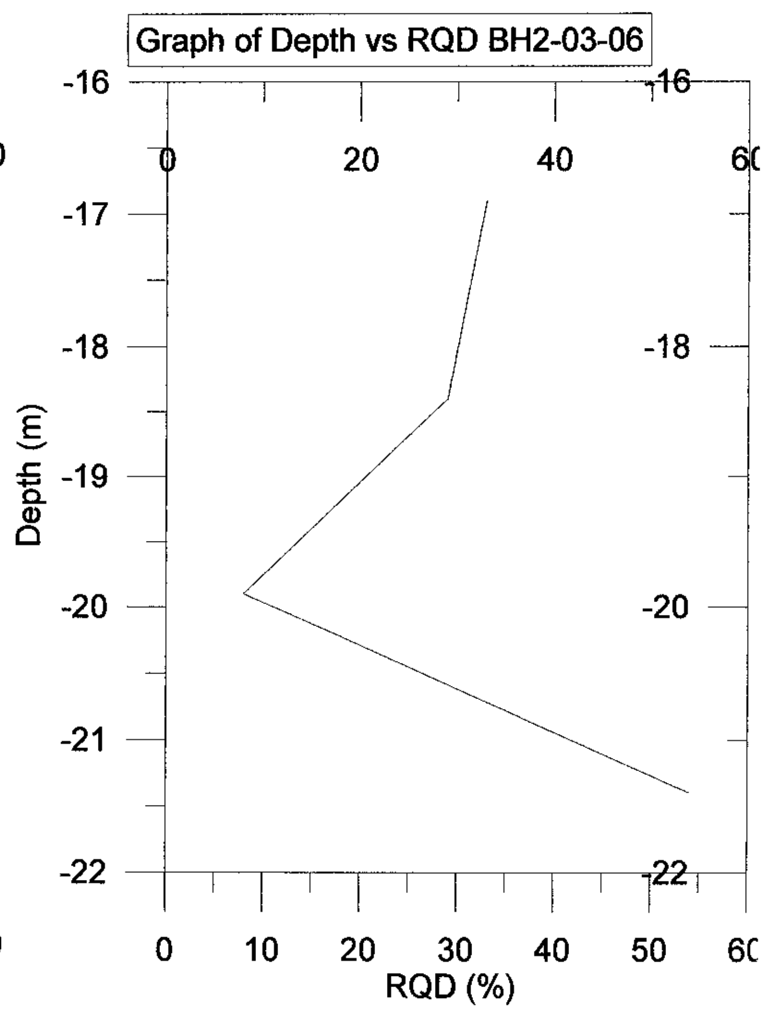


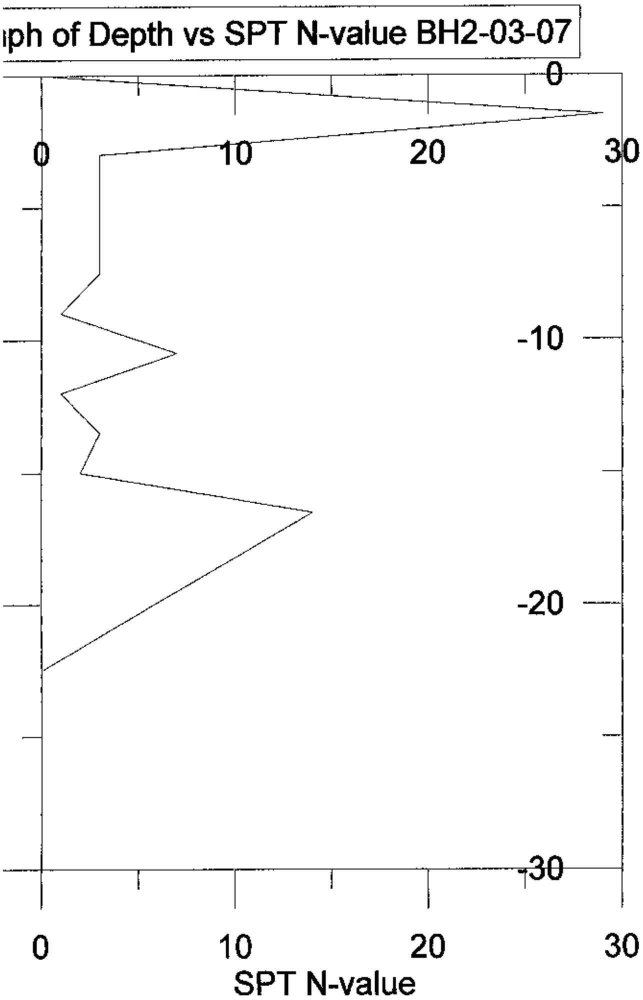
Graph of Depth vs RQD BH2-03-04
-10
-12
-14
-16
-18
Depth (m)
20 40 60 80 10
RQD (%)


ph of Depth vs SPT N-value BH2-03-05
0
-4
-8
-12
-16
0
2
4
6
8
SPT N-value

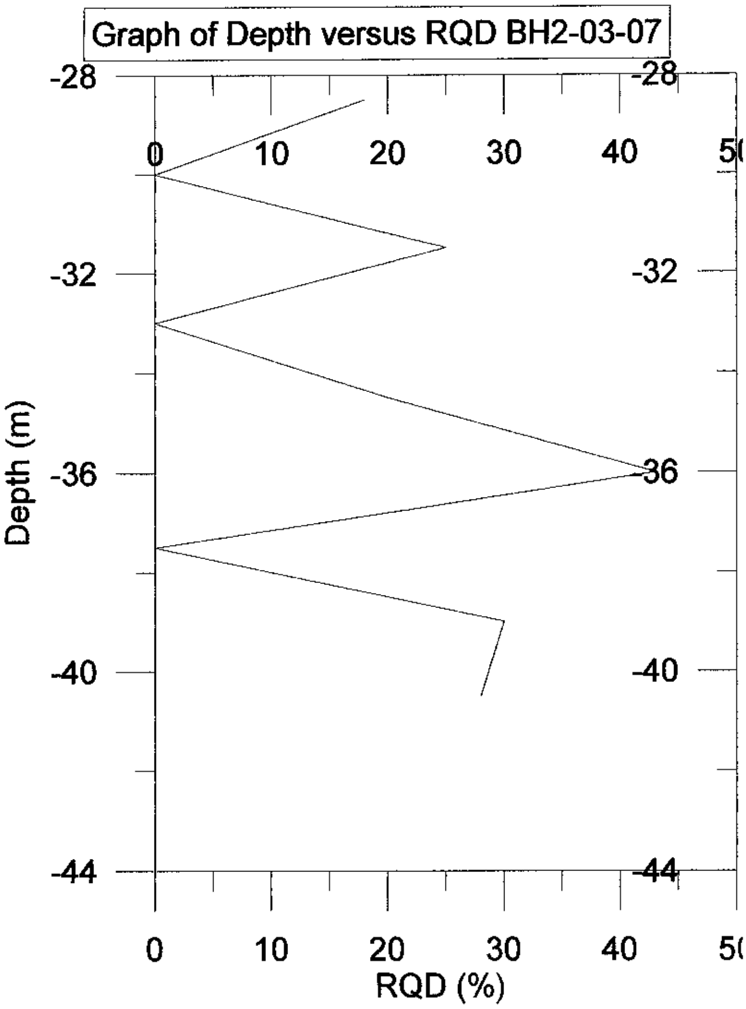

Graph of Depth vs RQD BH2-03-05
-14
-16
-18
-20
-22
-24
Depth (m)
0
10
20
30
RQD (%)


ph of Depth vs SPT N-value BH2-03-06
0
-4
-8
-12
-16
-20
0
10
20
30
40
50
SPT N-value

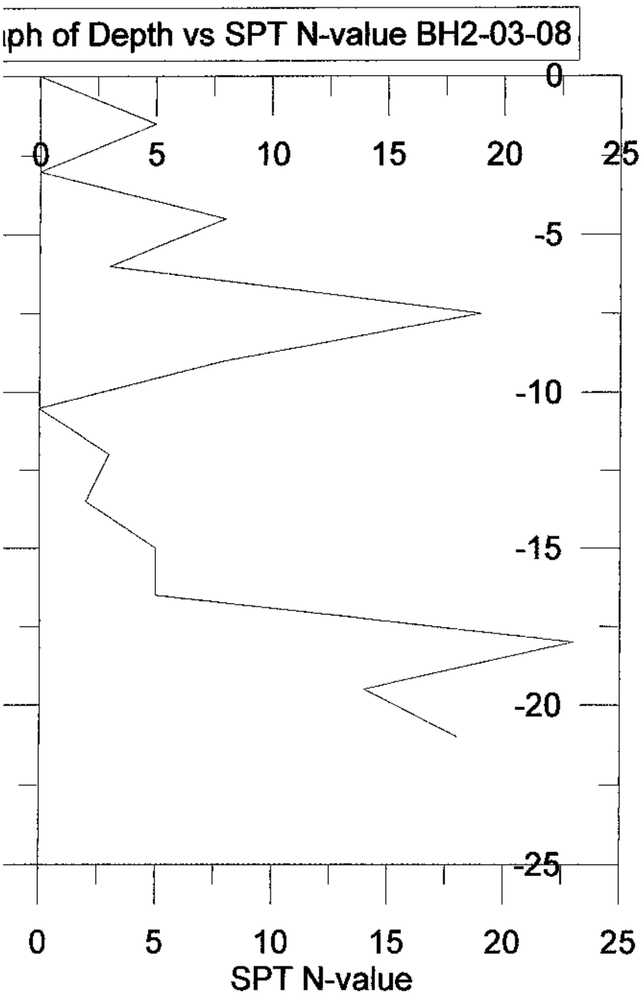

Graph of Depth vs RQD BH2-03-06
-16
-17
-18
-19
-20
-21
-22
Depth (m)
0
10
20
30
40
50
RQD (%)



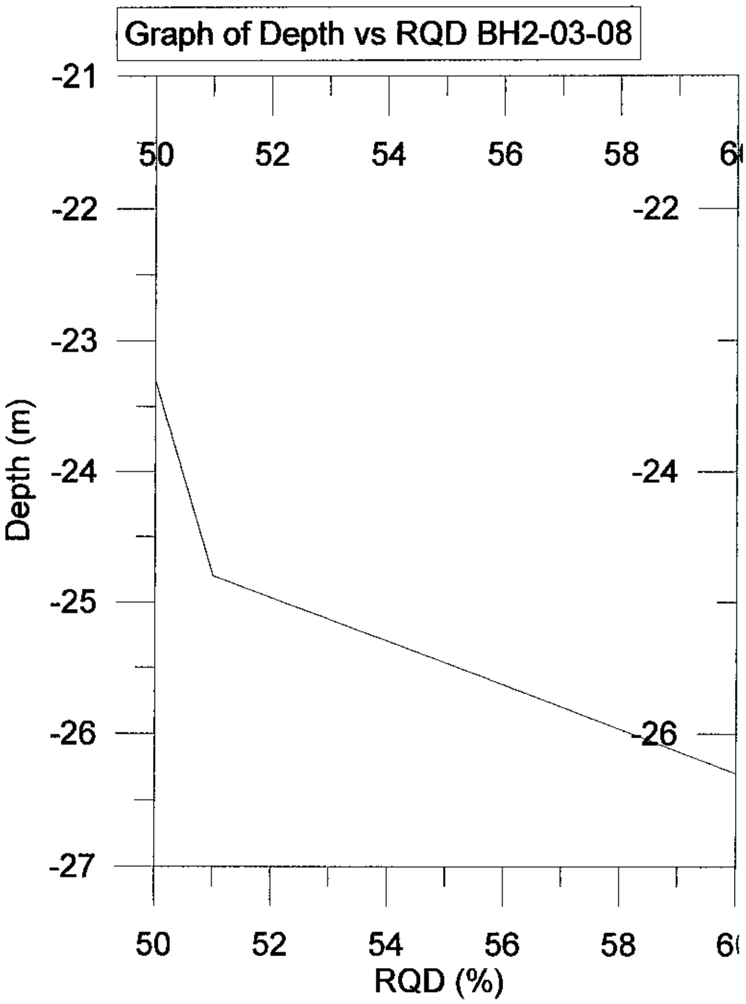
ph of Depth vs SPT N-value BH2-03-07
SPT N-value
0
10
20
30
0
-10
-20
-30



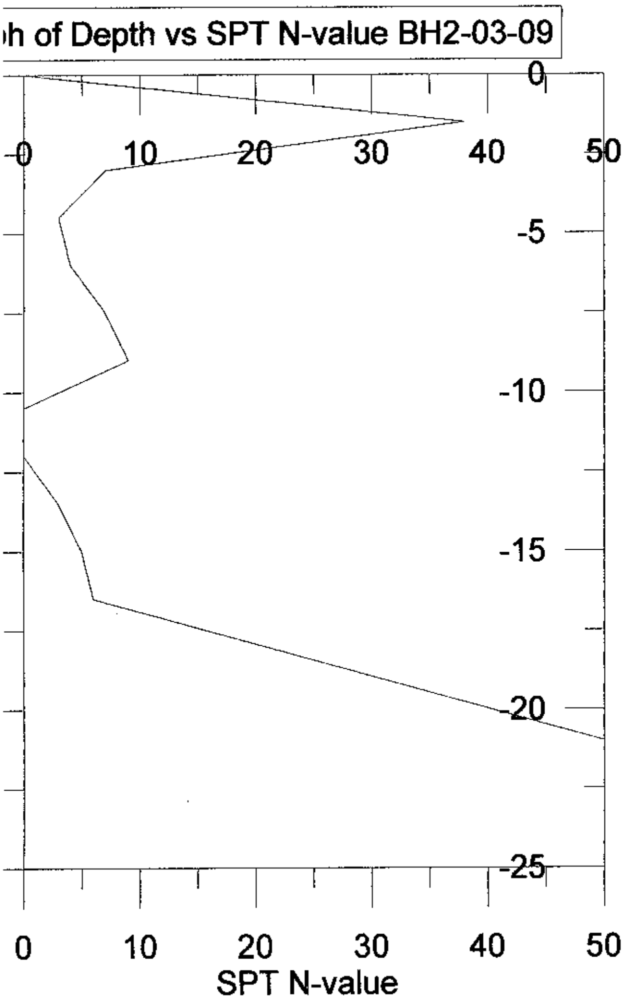
Graph of Depth versus RQD BH2-03-07
Depth (m)
RQD (%)
0
10
20
30
40
-28
-32
-36
-40
-44

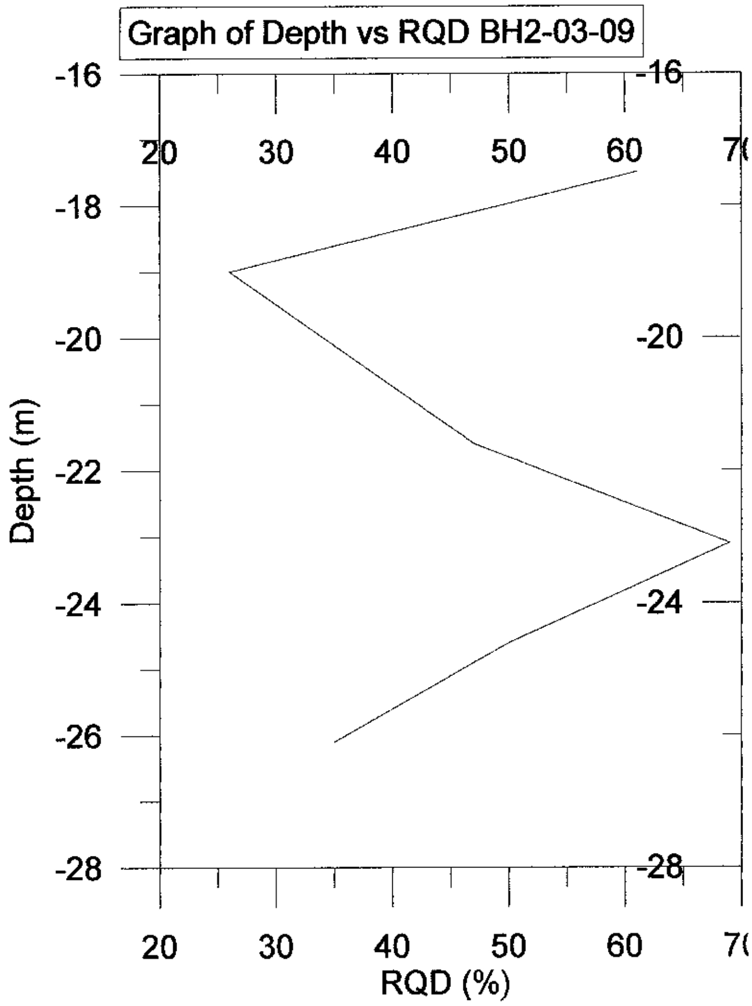


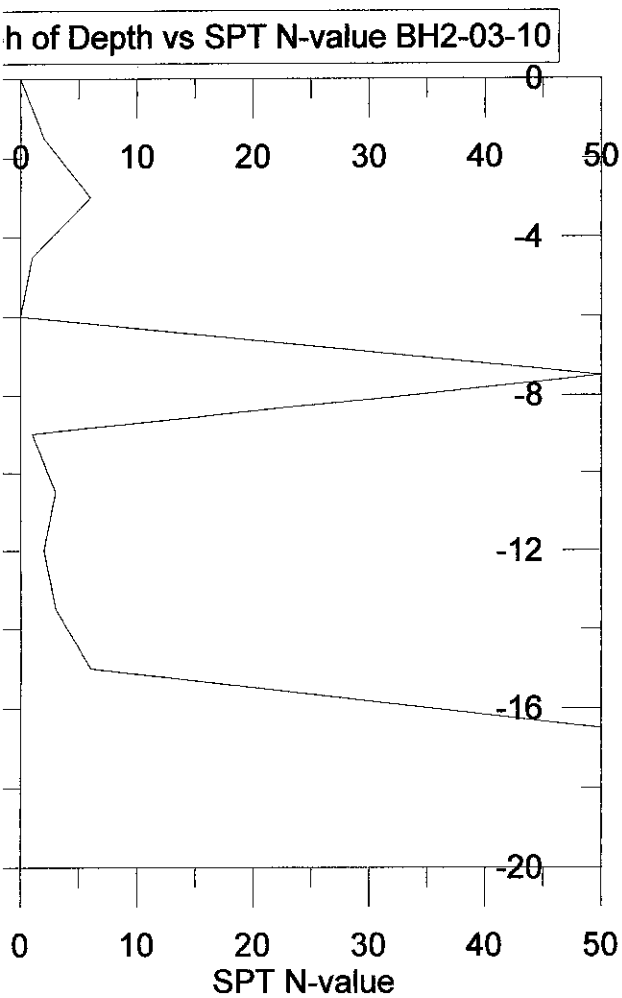
ph of Depth vs SPT N-value BH2-03-08
SPT N-value
0
5
10
15
20
25
0
-5
-10
-15
-20
-25

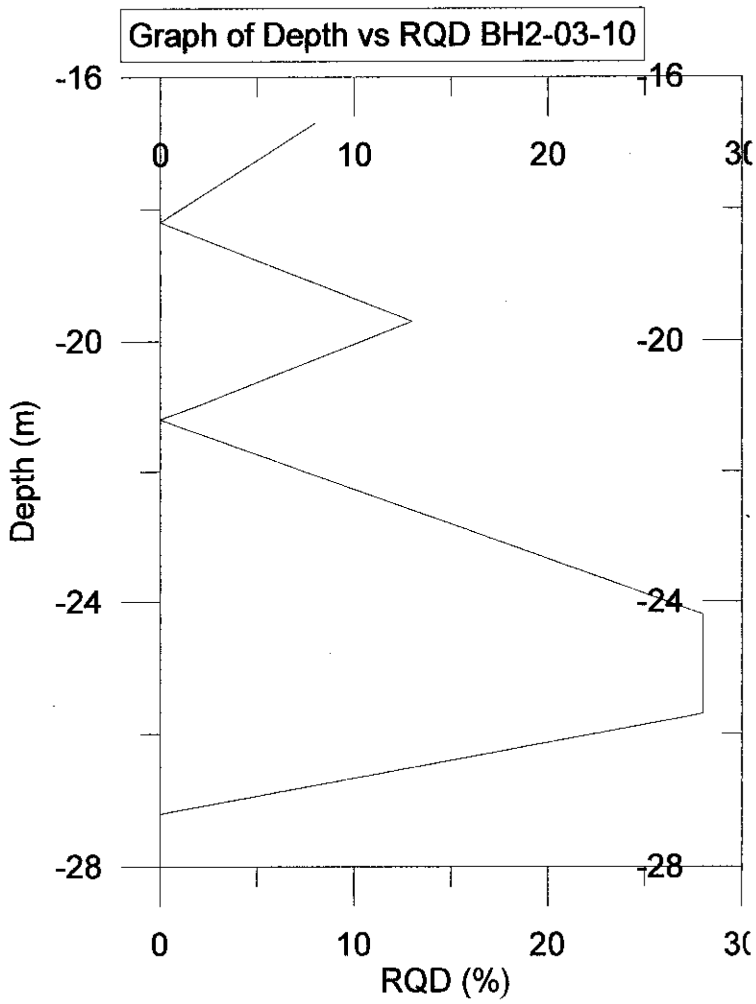


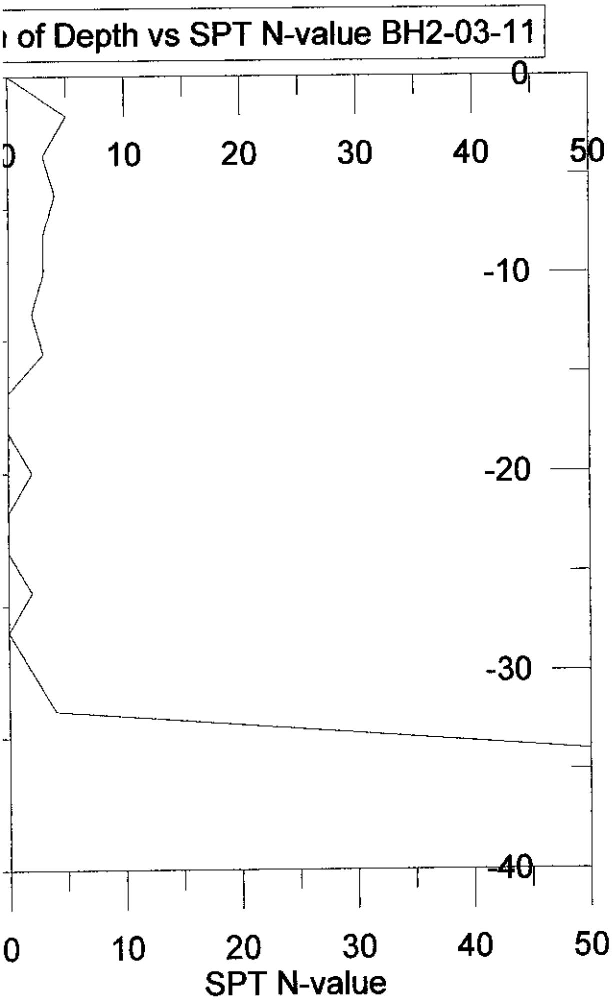
Graph of Depth vs RQD BH2-03-08
Depth (m)
RQD (%)
50
52
54
56
58
-21
-22
-23
-24
-25
-26
-27

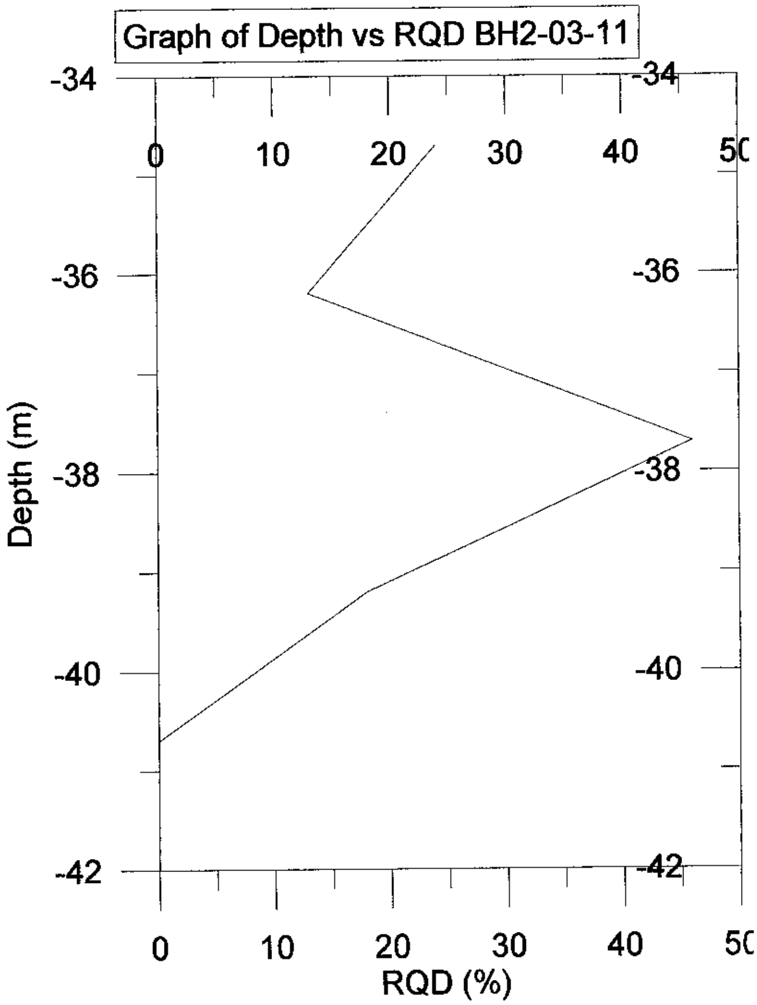

h of Depth vs SPT N-value BH2-03-09
0
10
20
30
40
50
-5
-10
-15
-20
-25
SPT N-value

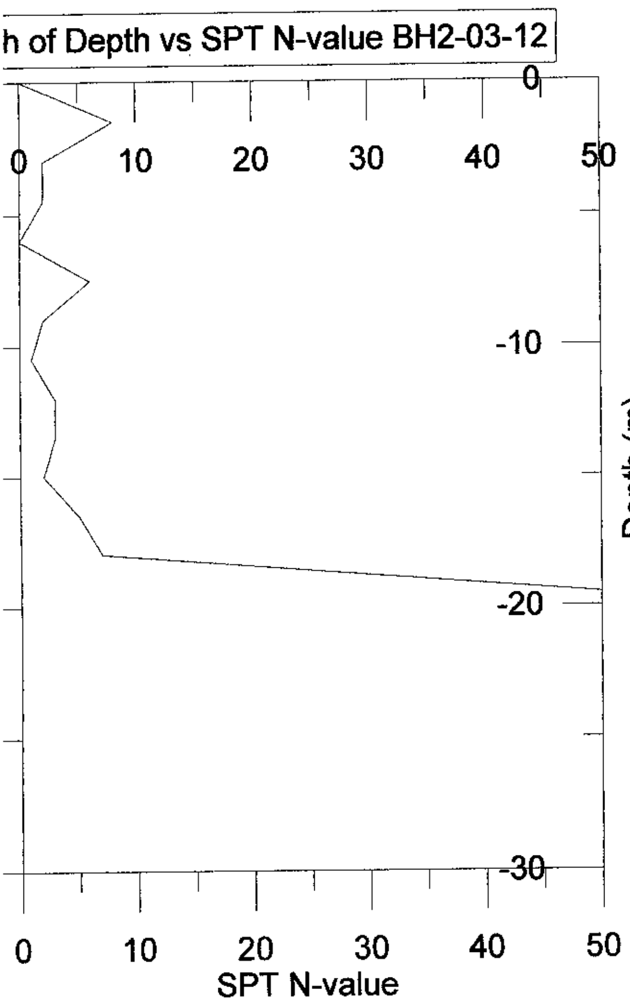

Graph of Depth vs RQD BH2-03-09
-16
-18
-20
-22
-24
-26
-28
20
30
40
50
60
Depth (m)
RQD (%)

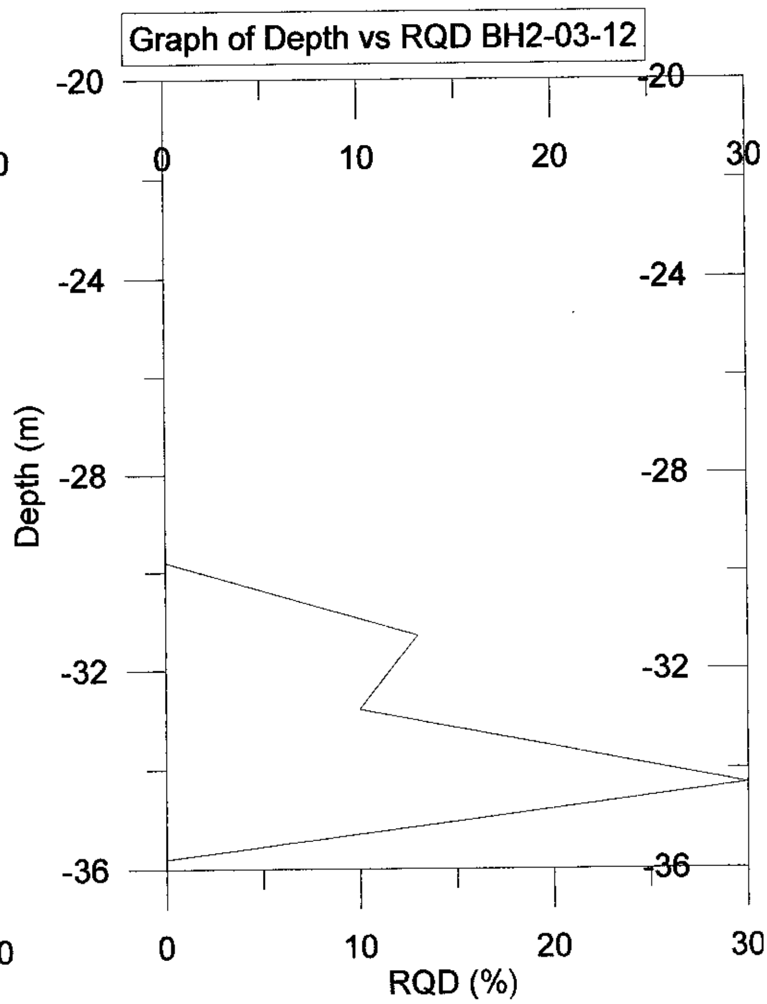

h of Depth vs SPT N-value BH2-03-10
0
10
20
30
40
50
-4
-8
-12
-16
-20
SPT N-value

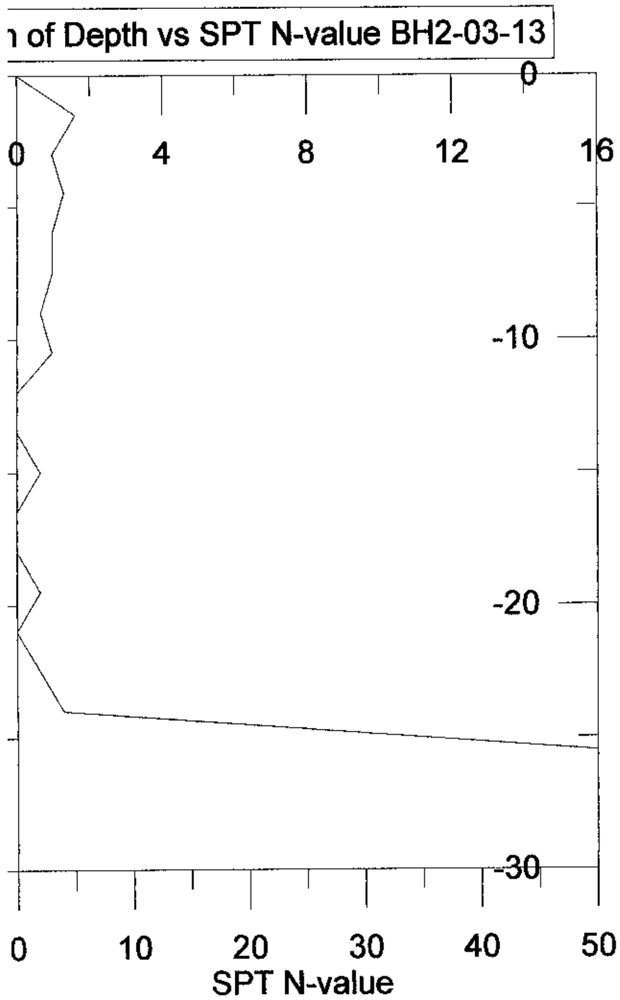

Graph of Depth vs RQD BH2-03-10
-16
-20
-24
-28
0
10
20
Depth (m)
RQD (%)


of Depth vs SPT N-value BH2-03-11
SPT N-value
0
10
20
30
40
50
-10
-20
-30
-40

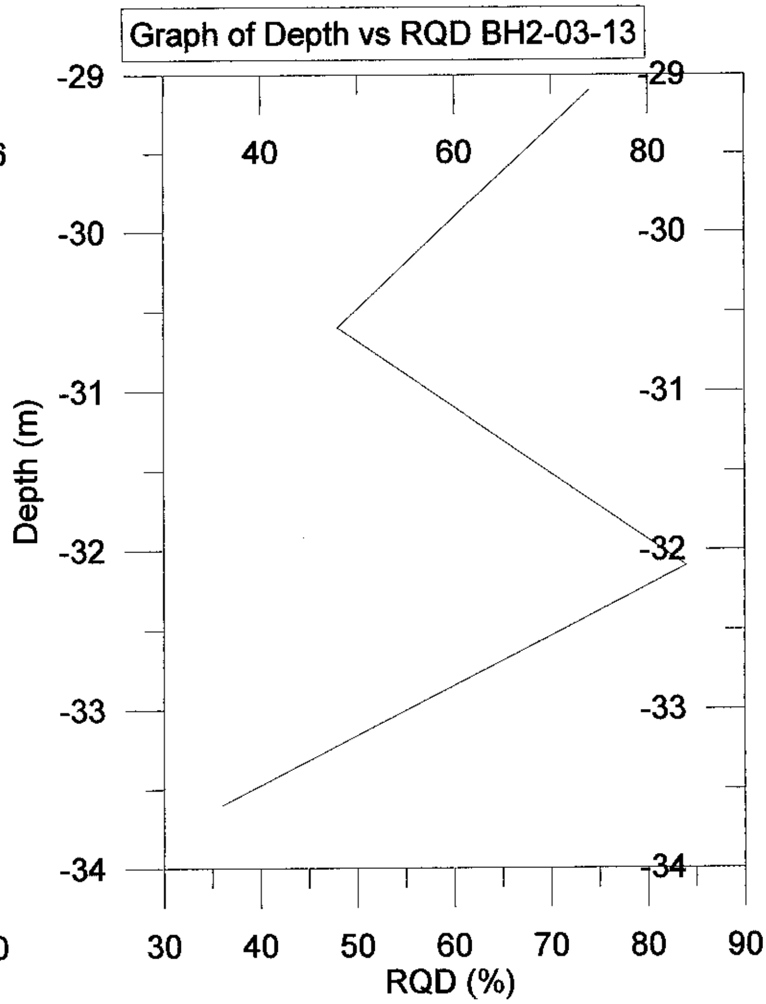

Graph of Depth vs RQD BH2-03-11
Depth (m)
RQD (%)
-34
-36
-38
-40
-42
0
10
20
30
40


h of Depth vs SPT N-value BH2-03-12
SPT N-value
0
10
20
30
40
50
-10
-20
-30

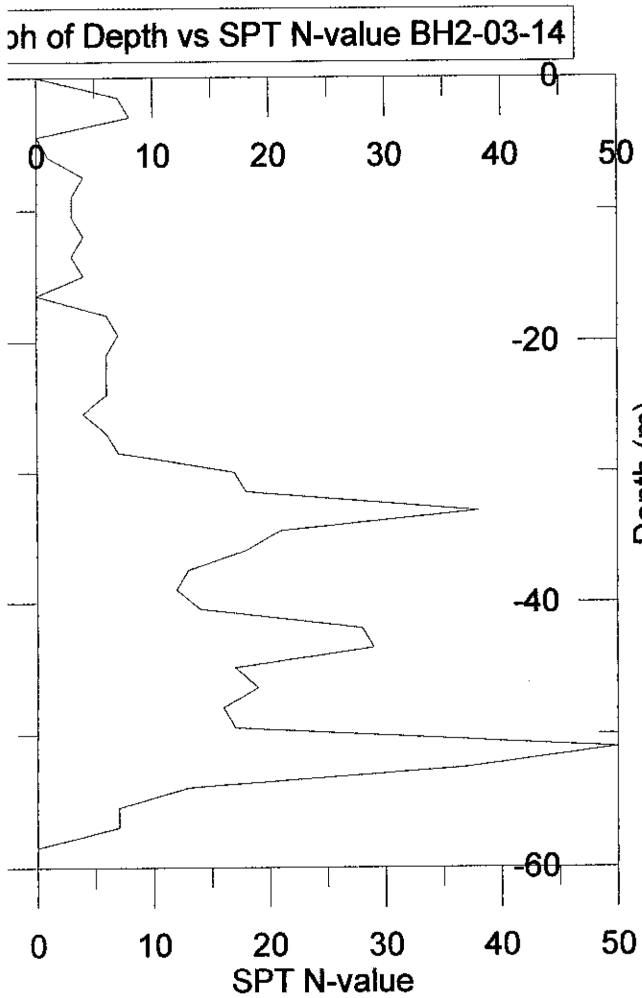

Graph of Depth vs RQD BH2-03-12
Depth (m)
RQD (%)
-20
-24
-28
-32
-36
0
10
20
30



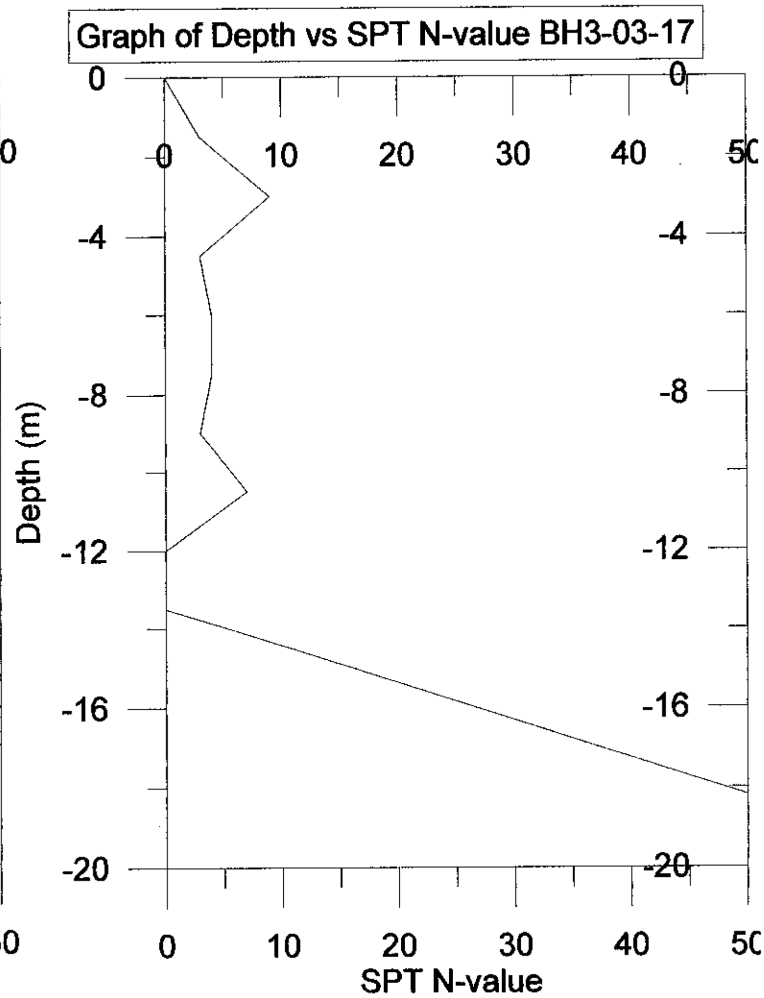
Graph of Depth vs SPT N-value BH2-03-13
SPT N-value



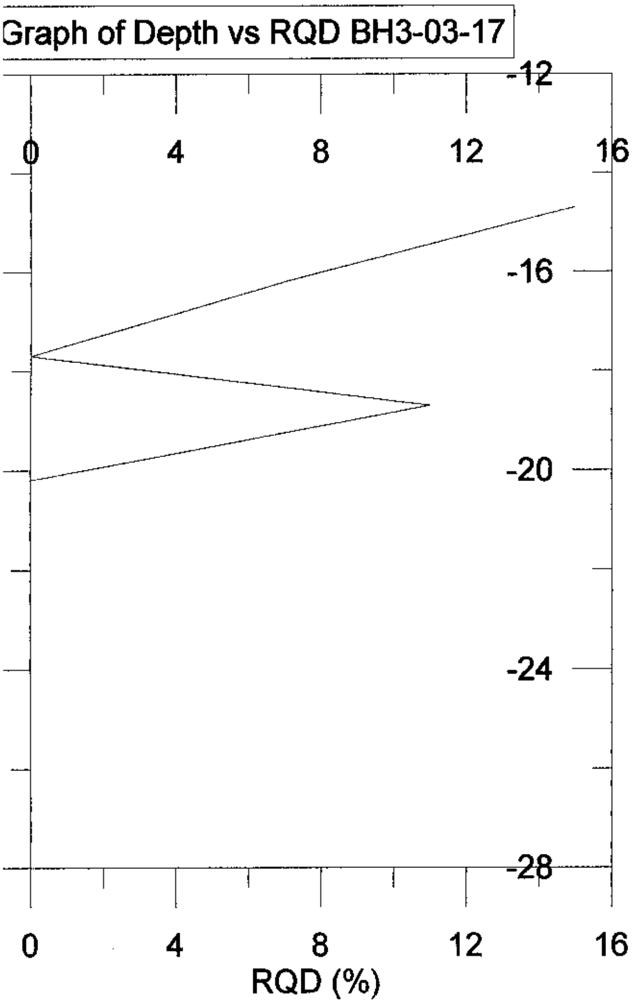
Graph of Depth vs RQD BH2-03-13
Depth (m)
RQD (%)



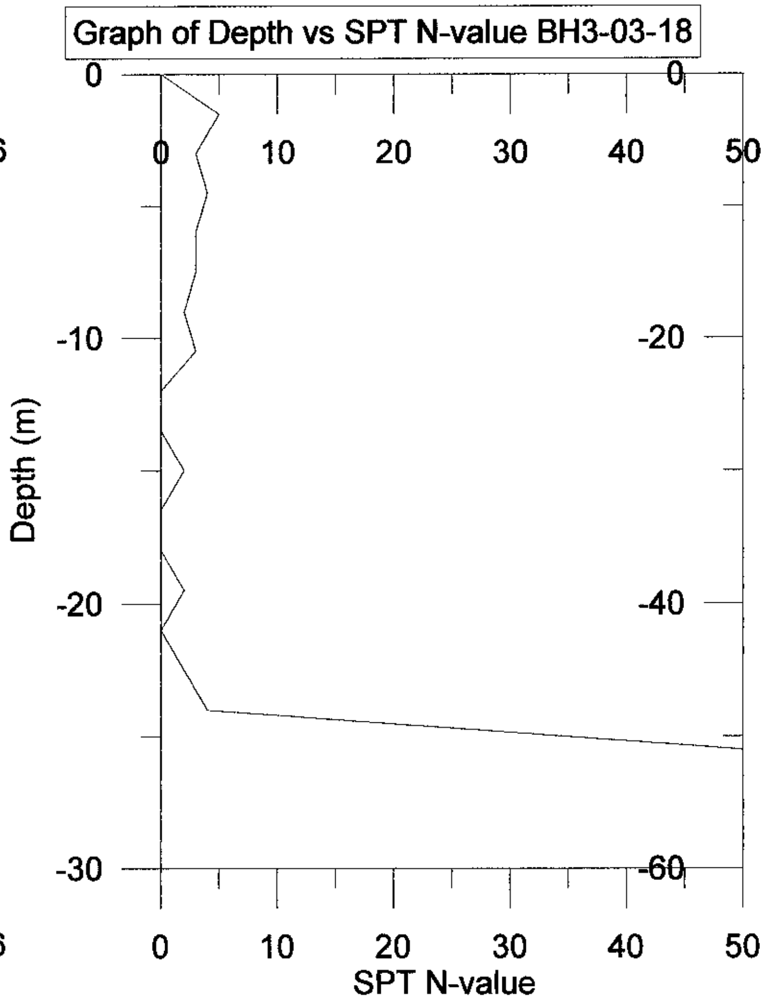
Graph of Depth vs SPT N-value BH2-03-14
SPT N-value



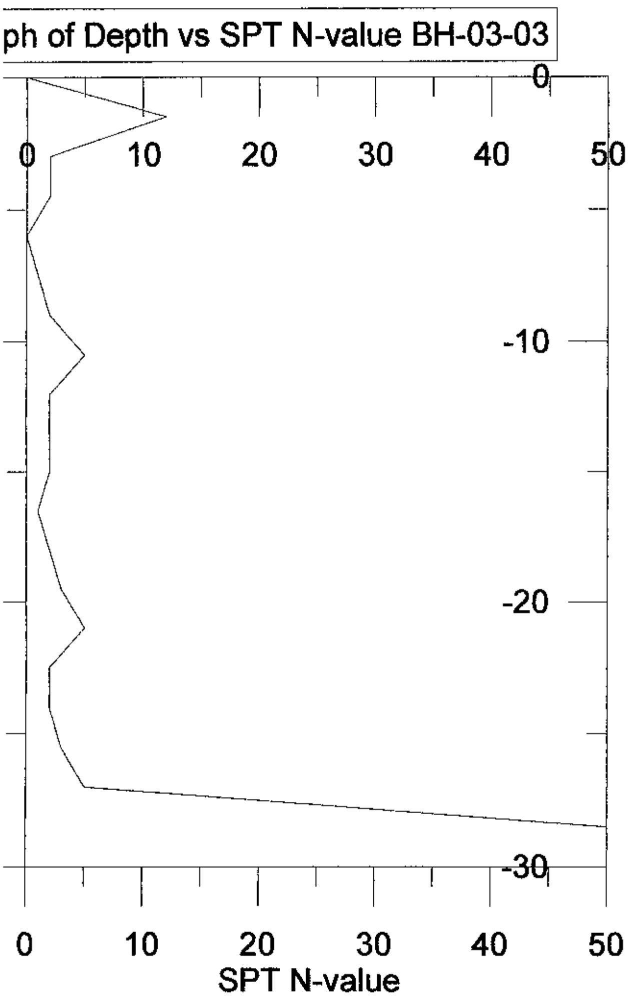
Graph of Depth vs SPT N-value BH3-03-17
Depth (m)
SPT N-value



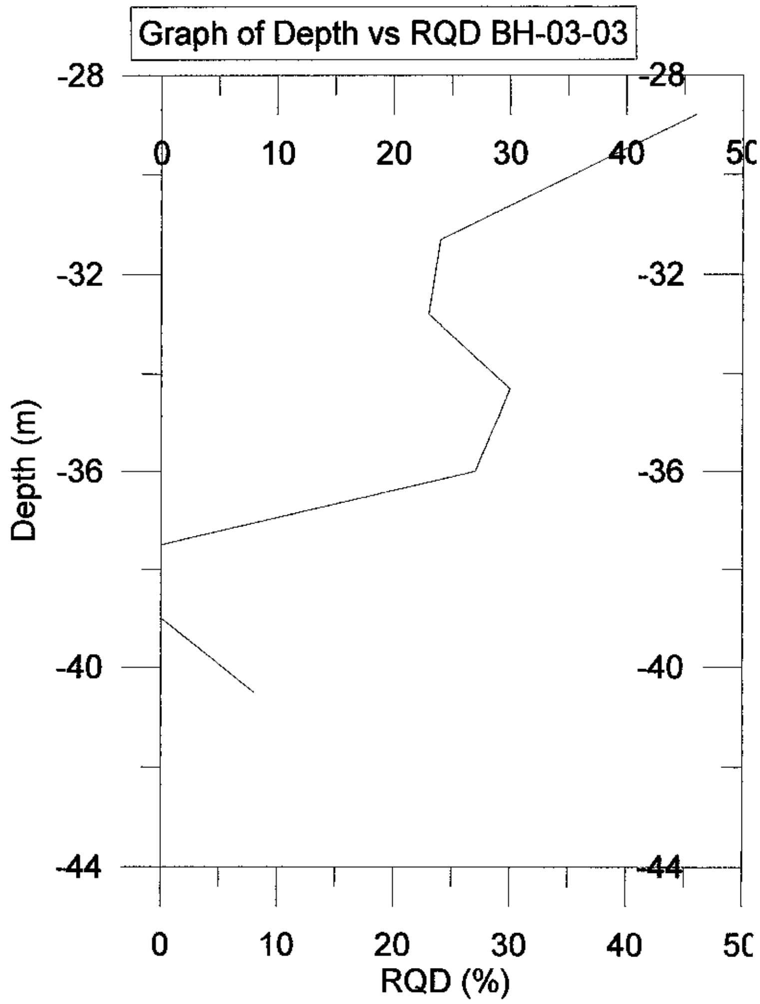
Graph of Depth vs RQD BH3-03-17
RQD (%)



Graph of Depth vs SPT N-value BH3-03-18
Depth (m)
SPT N-value



ph of Depth vs SPT N-value BH-03-03
SPT N-value



Graph of Depth vs RQD BH-03-03
Depth (m)
RQD (%)

APPENDIX B

Geotechnical Capacity of Bored Pile
For 800mm bored pile, Adopt Working Load of 3000kN
Location = Batu Village
Pier = Abutmen A
SI Based = BH2-03-01

Based on VE Consult's Calculations

Table 1: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	67	20	1	3770	3770	2513
1.0	2.5	76	20	1	2513	6283	**4189**
0.5	3.0	76	20	1	1257	7540	5027

Minimum required cumulative socket length in limestone = 2.5m

Based on Bauer's Calculation

Table 2: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
0.5	N/A	67	500	5000	628.32	628.32	2513.27	**3141.59**

Minimum required cumulative socket length in limestone = 0.5m

Based on Gue's Calculation

Table 3: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	67	600	2262	2262	1131
1.5	3.0	76	1000	3769	6031	**3016**

Minimum required cumulative socket length in limestone = 3.0m

For 900mm bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 1
SI Based = BH2-03-02

Based on VE Consult's Calculations

Table 4: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	0	6	0.3	1272	1272	848
1.5	3.0	0	6	0.3	1272	2545	1696
1.5	4.5	0	6	0.3	1272	3817	2545
1.5	6.0	0	6	0.3	1272	5089	3393
1.5	7.5	0	6	0.3	1272	6362	4241
0.7	8.2	0	6	0.3	594	6955	4637
1.6	9.8	CAVITY					
1.5	11.3	29	10	0.5	2121	9076	**6051**

Minimum required cumulative socket length in limestone = 8.2m

Additional socket length due to cavity = 1.5m

Based on Bauer's Calculation

Table 5: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.5	N/A	0	275	0	1166.32	1166.32	0	1166.32
1.5	N/A	0	275	0	1166.32	2332.64	0	2332.64
1.5	N/A	0	275	0	1166.32	3498.96	0	3498.96
1.5	N/A	0	275	0	1166.32	4665.28	0	**4665.28**

Minimum required cumulative socket length in limestone = 6.0m

Based on Gue's Calculation

Table 6: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	0	300	1273	1273	636
1.5	3.0	0	300	1273	2545	1273
1.5	4.5	0	300	1273	3818	1909

1.5	6.0	0	300	1273	5090	2545
1.5	7.5	0	300	1273	6363	3182
0.7	8.2	0	300	594	6956	3478
1.6	9.8	CAVITY				
1.5	11.3	29	600	2545	9501	**4751**

Minimum required cumulative socket length in limestone = 11.3m

For 900mm bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 2
SI Based = BH2-03-03

Based on VE Consult's Calculations

Table 7: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	27	10	0.5	2121	2121	1414
1.5	3.0	23	10	0.5	2121	4241	2827
1.5	4.5	16	10	0.5	2121	6362	4241
0.5	5.0	10	10	0.5	707	7069	**4712**

Minimum required cumulative socket length in limestone = 5.0m

Based on Bauer's Calculation

Table 8: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	Q_s + Q_{ball} (kN)
1.5	N/A	27	500	3000	2120.58	2120.58	1908.52	4029.10
1.5	N/A	23	300	10% of WL	1272.35	3392.93	450	3842.93
1.0	N/A	16	300	10% of WL	848.23	4241.19	450	**4691.19**

Minimum required cumulative socket length in limestone = 4.5m

Based on Gue's Calculation

Table 9: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	27	600	2545	2545	1273
1.5	3.0	23	300	1273	3818	1909
1.5	4.5	16	300	1273	5090	2545
1.5	6.0	10	300	1273	6363	3182
1.5	7.5	38	600	2545	8908	4454
0.5	8.0	76	1000	1414	10321	**5161**

Minimum required cumulative socket length in limestone = 8.0m

For 900mm bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 3
SI Based = BH2-03-04

Based on VE Consult's Calculations

Table 10: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
0.8	0.8	33	15	0.75	1696	1696	1131
0.2	1.0	CAVITY					
1.5	2.5	56	20	1	4241	5938	3958
0.7	3.2	70	20	1	1979	7917	**5278**

Minimum required cumulative socket length in limestone = 3.0m

Based on Bauer's Calculation

Table 11: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	Q_s + Q_{ball} (kN)
0.8	N/A	33	500	3000	1130.97	1130.97	1908.52	3039.49
0.2	N/A	CAVITY						
0.7	N/A	56	500	5000	989.60	2120.57	3180.86	**5301.43**

Minimum required cumulative socket length in limestone = 1.5 m

Based on Gue's Calculation

Table 12: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
0.8	0.8	33	600	1357	1357	679
0.2	1.0	CAVITY				
1.5	2.5	56	600	2545	3902	1951
1.5	4.0	70	600	2545	6446	3223
1.5	5.5	69	600	2545	8991	4496
0.5	6.0	80	1000	1414	10404	**5202**

Minimum required cumulative socket length in limestone = 6.0m

For 1200mm bored pile, Adopt Working Load of 7500kN
Location = Batu Village
Pier = Pier 4
SI Based = BH2-03-05

Based on VE Consult's Calculations

Table 13: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.0	1.0	0	6	0.3	1131	1131	754
0.8	1.8	CAVITY					
1.5	3.3	38	15	0.75	4241	5372	3581
0.3	3.6	0	6	0.3	339	5711	3808
1.4	5.0	CAVITY					
1.5	6.5	20	10	0.5	2827	8539	5693
1.5	8.0	7	6	0.3	1696	10235	6824
0.7	8.7	28	10	0.5	1319	11555	**7703**

Minimum required cumulative socket length in limestone = 6.5m

Based on Bauer's Calculation

Table 14: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.0	N/A	0	275	0	1036.73	1036.73	0	1036.73
0.8	N/A	CAVITY						
1.5	N/A	38	500	3000	2827.43	3864.16	3392.92	7257.08
0.3	N/A	0	275	0	311.02	4175.18	0	4175.18
1.4	N/A	CAVITY						
1.5	N/A	20	300	10% of WL	1696.46	5871.64	750	6621.64
1.2	N/A	7	300	10% of WL	1357.17	7228.81	750	**7978.81**

Minimum required cumulative socket length in limestone = 5.5 m

Based on Gue's Calculation

Table 15: Bearing Capacity calculations based on Gue

Core	Cumulative	RQD	Q_b	Q_{all}	SUM	Q_s/F_s

Length, L (m)	Length (m)	(%)	(kN/m^2)	(kN)	Q_{all} kN	(kN)
1.0	1.0	0	300	1131	1131	566
0.8	1.8	CAVITY				
1.5	3.3	38	600	3393	4524	2262
0.3	3.6	0	300	339	4863	2432
1.4	5.0	CAVITY				
1.5	6.5	20	300	1697	6560	3280
1.5	8.0	7	300	1697	8257	4128
1.5	9.5	28	600	3393	11650	5825
1.5	11.0	28	600	3393	15083	**7542**

Minimum required cumulative socket length in limestone = 11.0m

For 1200mm bored pile, Adopt Working Load of 7500kN
Location = Batu Village
Pier = Pier 5
SI Based = BH2-03-06

Based on VE Consult's Calculations

Table 16: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	33	15	0.75	4241	4241	2827
1.5	3.0	29	10	0.5	2827	7069	4712
1.5	4.5	8	6	0.3	1696	8765	5843
1.0	5.5	54	20	1	3770	12535	**8357**

Minimum required cumulative socket length in limestone = 5.5 m

Based on Bauer's Calculation

Table 17: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.5	N/A	33	500	3000	2827.43	2827.43	3392.92	6220.35
1.0	N/A	29	500	3000	1884.96	4712.39	3392.92	**8105.31**

Minimum required cumulative socket length in limestone = 2.5 m

Based on Gue's Calculation

Table 18: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	33	600	3393	3393	1696
1.5	3.0	29	600	3393	6785	3393
1.5	4.5	8	300	1697	8482	4241
1.5	6.0	54	600	3393	11874	5937
1.5	7.5	38	600	3393	15267	**7634**

Minimum required cumulative socket length in limestone = 7.5m

For 1200mm bored pile, Adopt Working Load of 7500kN
Location = Batu Village
Pier = Pier 6
SI Based = BH2-03-07

Based on VE Consult's Calculations

Table 19: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	18	10	0.5	2827	2827	1884
1.5	3.0	0	6	0.3	1696	4523	3015
1.5	4.5	25	10	0.5	2827	7350	4900
1.5	6.0	0	6	0.3	1696	9046	6030
1.5	7.5	20	10	0.5	2827	11873	**7915**

Minimum required cumulative socket length in limestone = 7.5 m

Based on Bauer's Calculation

Table 20: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.5	N/A	18	300	10% of WL	1696.46	1696.46	750	2446.46
1.5	N/A	0	275	0	1555.09	3251.55	0	3251.55
0.5	N/A	25	500	3000	942.48	4194.03	3392.92	**7586.95**

Minimum required cumulative socket length in limestone = 3.5 m

Based on Gue's Calculation

Table 21: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	18	300	1697	1697	849
1.5	3.0	0	300	1697	3393	1697
1.5	4.5	25	600	3393	6786	3393
1.5	6.0	0	300	1697	8483	4242
1.5	7.5	20	300	1697	10180	5090
1.5	9.0	43	600	3393	13573	6787
1.5	10.5	0	300	1697	15270	**7635**

Minimum required cumulative socket length in limestone = 10.5m

For 1200mm bored pile, Adopt Working Load of 7500kN
Location = Batu Village
Pier = Pier 7
SI Based = BH2-03-08

Based on VE Consult's Calculations

Table 22: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	50	20	1	5654	5654	3769
1.5	3.0	50	20	1	5654	11308	**7538**

Minimum required cumulative socket length in limestone = 3.0 m

Based on Bauer's Calculation

Table 23: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	Q_s + Q_{ball} (kN)
1.5	N/A	50	500	3000	2827.43	2827.43	3392.92	6220.35
1.0	N/A	50	500	3000	1884.96	4712.39	3392.92	**8105.31**

Minimum required cumulative socket length in limestone = 2.5 m

Based on Gue's Calculation

Table 24: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	50	600	3393	3393	1697
1.5	3.0	50	600	3393	6785	3393
1.5	4.5	51	600	3393	10179	5090
1.5	6.0	60	600	3393	13572	6786
1.0	7.0	63	600	2262	15833	**7917**

Minimum required cumulative socket length in limestone = 7.0m

For 900mm Type 1 bored pile, Adopt Working Load of 3750 kN
Location = Batu Village
Pier = Pier 8 LHS
SI Based = BH2-03-09

Based on VE Consult's Calculations

Table 25: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	61	20	1	4241	4241	2827
1.0	3.0	26	10	0.5	1414	5655	3770

Minimum required cumulative socket length in limestone = 2.5 m

Based on Bauer's Calculation

Table 26: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
0.5	N/A	61	500	5000	706.86	706.86	3180.86	**3887.72**

Minimum required cumulative socket length in limestone = 0.5 m

Based on Gue's Calculation

Table 27: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	61	600	2545	2545	1273
1.5	3.0	26	600	2545	5090	2545
1.5	4.5	CAVITY				
1.5	6.0	47	600	2545	7635	**3818**

Minimum required cumulative socket length in limestone = 6.0m

For 900mm Type 1 bored pile, Adopt Working Load of 3750 kN
Location = Batu Village
Pier = Pier 8 RHS
SI Based = BH2-03-10

Based on VE Consult's Calculations

Table 28: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	8	6	0.3	1272	1272	848
1.5	3.0	0	6	0.3	1272	2544	1696
1.5	4.5	13	10	0.5	2120	4664	3109
1.5	6.0	0	6	0.3	1272	5936	**3957**

Minimum required cumulative socket length in limestone = 6.0 m

Based on Bauer's Calculation

Table 29: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	Q_s + Q_{ball} (kN)
1.5	N/A	8	300	10% of WL	1272.35	1272.35	450	1722.35
1.5	N/A	0	275	0	1166.32	2438.67	0	2438.67
1.5	N/A	13	300	10% of WL	1272.35	3711.02	450	**4161.02**

Minimum required cumulative socket length in limestone = 4.5 m

Based on Gue's Calculation

Table 30: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	8	300	1273	1273	636
1.5	3.0	0	300	1273	2545	1273
1.5	4.5	13	300	1273	3818	1909
1.5	6.0	0	300	1273	5090	2545
1.5	7.5	14	300	1273	6363	3182
1.0	8.5	28	600	1696	8059	**4030**

Minimum required cumulative socket length in limestone = 8.5m

For 900mm Type 2 bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 9*
SI Based = BH2-03-11

Based on VE Consult's Calculations

Table 31: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	24	10	0.5	2120	2120	1414
1.5	3.0	13	10	0.5	2120	4241	2828
1.5	4.5	46	15	0.75	3180	7421	**4947**

Minimum required cumulative socket length in limestone = 4.5 m

Based on Bauer's Calculation

Table 32: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.5	N/A	24	300	10% of WL	1272.35	1272.35	450	1722.35
1.5	N/A	13	300	10% of WL	1272.35	2544.7	450	2994.7
0.5	N/A	46	500	3000	706.86	3251.56	1908.52	**5160.08**

Minimum required cumulative socket length in limestone = 3.5 m

Based on Gue's Calculation

Table 33: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	24	300	1273	1273	636
1.5	3.0	13	300	1273	2545	1273
1.5	4.5	46	600	2545	5090	2545
1.5	6.0	18	300	1273	6363	3182
1.5	7.5	0	300	1273	7636	3818
1.0	8.5	25	600	1696	9332	**4666**

Minimum required cumulative socket length in limestone = 8.5m

*Even though there is only one Pier 9 due to the changes in design that were updated on the 4^{th} of October 2007, there were originally two SI's done for the Pier 9 position. Therefore design of pile bearing capacity will depend on on-site conditions and assumptions to be made in whichever SI case which is more critical.

For 900mm Type 2 bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 9*
SI Based = BH2-03-12

Based on VE Consult's Calculations

Table 34: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	0	6	0.3	1272	1272	848
1.5	3.0	0	6	0.3	1272	2544	1696
2.0	5.0	CAVITY					
1.5	6.5	0	6	0.3	1272	3816	2544
1.5	8.0	0	6	0.3	1272	5088	3392
1.5	9.5	0	6	0.3	1272	6360	4240
0.5	10.0	13	10	0.5	706	7066	**4711**

Minimum required cumulative socket length in limestone = 10.0 m

Based on Bauer's Calculation

Table 35: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.5	N/A	0	275	0	1166.32	1166.32	0	1166.32
1.5	N/A	0	275	0	1166.32	2332.64	0	2332.64
2.0	N/A	CAVITY						
1.5	N/A	0	275	0	1166.32	3498.96	0	3498.96
1.5	N/A	0	275	0	1166.32	4665.28	0	**4665.28**

Minimum required cumulative socket length in limestone = 6.0 m

Based on Gue's Calculation

Table 36: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	0	300	1273	1273	636
1.5	3.0	0	300	1273	2545	1273
2.0	5.0	CAVITY				
1.5	6.5	0	300	1273	3818	1909
1.5	8.0	0	300	1273	5090	2545

1.5	9.5	0	300	1273	6363	3182
1.5	11.0	13	300	1273	7635	3818
1.5	12.5	10	300	1273	8908	4454
0.5	13.0	30	600	848	9756	**4878**

Minimum required cumulative socket length in limestone = 13.0m

*Even though there is only one Pier 9 due to the changes in design that were updated on the 4th of October 2007, there were originally two SI's done for the Pier 9 position. Therefore design of pile bearing capacity will depend on on-site conditions and assumptions to be made in whichever SI case which is more critical.

For 900mm Type 2 bored pile, Adopt Working Load of 4500kN
Location = Batu Village
Pier = Pier 10**
SI Based = BH2-03-13

Based on VE Consult's Calculations

Table 37: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	74	20	1.0	4241	4241	2827
1.5	3.0	48	15	0.75	3180	7421	**4947**

Minimum required cumulative socket length in limestone = 3.0 m

Based on Bauer's Calculation

Table 38: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	$Q_s + Q_{ball}$ (kN)
1.0	N/A	74	500	5000	1413.72	1413.72	3180.86	**4594.58**

Minimum required cumulative socket length in limestone = 1.0 m

Based on Gue's Calculation

Table 39: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	74	1000	4241	4241	2121
1.5	3.0	48	600	2545	6786	3393
1.0	4.0	84	1000	2827	9613	**4807**

Minimum required cumulative socket length in limestone = 4.0m

**Due to the changes in the construction plans on the 4th of October 2007, the design for bearing capacity for Pier 10 will depend on the SI results on BH2-03-13 only and not on BH2-03-14 and BH2-03-18 where both SI's did not encounter rock. Proper on-site assumptions are to be made.

For 900mm Type 1 bored pile, Adopt Working Load of 3750 kN
Location = Batu Village
Pier = Abutmen B
SI Based = BH-03-03

Based on VE Consult's Calculations

Table 40: Bearing Capacity calculations based on VE consult

Core Length, L (m)	Cumulative Length (m)	RQD (%)	q_u (N/mm^2)	$q_u/20$ (N/mm^2)	Q_s (kN)	SUM Q_s kN	Q_s/F_s (kN)
1.5	1.5	46	15	0.75	3180	3180	2120
1.5	3.0	24	10	0.5	2120	5300	3533
0.5	3.5	23	10	0.5	706	6006	**4004**

Minimum required cumulative socket length in limestone = 3.5 m

Based on Bauer's Calculation

Table 41: Bearing Capacity calculations based on Bauer

Length (m)	SPT (N)	RQD (%)	F_{sall} (kN/m^2)	F_{ball} (kN/m^2)	Q_s (kN)	Q_{sall} (cumulative) (kN)	Q_{ball} (kN)	Q_s + Q_{ball} (kN)
1.5	N/A	46	500	3000	2120.58	2120.58	1908.52	**4029.1**

Minimum required cumulative socket length in limestone = 1.5 m

Based on Gue's Calculation

Table 42: Bearing Capacity calculations based on Gue

Core Length, L (m)	Cumulative Length (m)	RQD (%)	Q_b (kN/m^2)	Q_{all} (kN)	SUM Q_{all} kN	Q_s/F_s (kN)
1.5	1.5	46	600	2545	2545	1273
1.5	3.0	24	300	1273	3818	1909
1.5	4.5	23	300	1273	5090	2545
1.0	5.5	30	600	1696	6786	3393
0.7	6.2	CAVITY				
1.0	7.2	27	600	1696	8482	**4241**

Minimum required cumulative socket length in limestone = 7.2m

APPENDIX C

Sample of calculations for in-situ Bored Piles located in Batu Village

For 800mm bored pile, Adopt Working Load of 3000kN

Location = Batu Village

Pier = Abutmen A

SI Based = BH2-03-01

Based on VE Consult's Method

$$Q_b = \frac{Q_s}{F_s}$$

$$Q_s = \frac{\pi D q_u L}{20}$$

Where,
F_s = Factor of safety for skin friction
= 1.5
Q_s= Shaft friction resistance
q_u = Unconfined compressive strength of rock or concrete whichever is lower

Table 43: Unconfined compressive strength of rock

RQD (Based on SI results)	q_u (N/mm^2)
0-9%	6
10-29%	10
30-49%	15
50-100%	20

From 0 to 1.5 meters of socket length,

$$Q_s = \frac{\pi D q_u L}{20}$$

$$= \frac{3.142 * 800 \text{ mm} * 20 \text{ N/mm}^2 * 1.5 \text{ m}}{20} * \frac{1000\text{mm}}{1 \text{ m}} * \frac{1 \text{ kN}}{1000\text{N}}$$

= 3770 kN

$$Q_b = \frac{Q_s}{F_s}$$

$$= \frac{3770}{1.5}$$

= 2513 kN

From 1.5 to 2.5 meters of socket length,

$$Q_s = \frac{\pi D q_u L}{20}$$

$$= \frac{3.142 * 800 \text{ mm} * 20 \text{ N/mm}^2 * 1.0 \text{ m}}{20} * \frac{1000\text{mm}}{1 \text{ m}} * \frac{1 \text{ kN}}{1000\text{N}}$$

= 2513 kN

$$Q_b = \frac{Q_s}{F_s}$$

$= \frac{2513 \text{ kN}}{1.5}$

$= 1675$ kN

$Q_{ball} = 2513 + 1675$

$= 4188$ kN > 3000 kN

Therefore, socket length of 2.5 meters is sufficient.

Based on Bauer's Method

$$Q_{all} \approx \sum qs.As + qb.Ab$$
$$= \sum qs.(2\pi rL) + qb.(\pi r^2)$$

Q_{all} = design allowable pile working load
qs = allowable skin friction (kN/m^2)
As = area of shaft under consideration (m^2)
Ab = cross sectional area of pile (m^2)
L = pile length under consideration (m)
qb = Allowable base resistance or end bearing (kN/m^2)

$$Q_{all} \approx \sum qs.As + qb.Ab$$
$$= \sum qs.(2\pi rL) + qb.(\pi r^2)$$

= 500 kN/m^2 * (2* 3.142 * 0.4m * 0.5m) + 3000 kN/m^2 * (3.142 *(0.4* 0.4) m^2)

= 628.32 kN + 2513.27 kN

= 3141.59 kN > 3000 kN

Therefore, socket length of 0.5 meters is sufficient.

Based on Gue's Method

$$Q_{all} = \sum \frac{qb.AsL}{Fs}$$
$$= \sum \frac{qb.2\pi rL}{Fs}$$

Q_{all} = design allowable pile working load
qb = Allowable base resistance (kPa)
Ab = cross sectional area of pile (m^2)
Fs = Factor of Safety
= 2

For 0 to 1.5 meters of socket length,

$$Q_{all} = \sum \frac{qb.AsL}{Fs}$$

$$= \sum \frac{qb.2\pi rL}{Fs}$$

$$= \frac{600 \text{ kN/m}^2 * (2*3.142*0.4\text{m}) * 1.5\text{m}}{2}$$

$$= 1131.12 \text{ kN}$$

For 1.5 to 3.0 meters of socket length,

$$Q_{all} = \sum \frac{qb.AsL}{Fs}$$

$$= \sum \frac{qb.2\pi rL}{Fs}$$

$$= \frac{1000 \text{ kN/m}^2 * (2*3.142*0.4\text{m}) * 1.5\text{m}}{2}$$

$$= 1885.2 \text{ kN}$$

$Q_{all} = 1131.12 + 1885.2$
$= 3016.32 \text{ kN} > 3000 \text{ kN}$

Therefore, socket length of 3.0 meters is sufficient.

Sample of Calculations for Davisson's Criterion

Offset value = $x + \frac{PL}{AE}$

Where,

Settlement, x $= 4 + \frac{B}{120}$, mm

B = pile diameter, mm

P = Load, kN

L = Length of pile, m

A = Cross Sectional area of pile, m^2

E = Modulus of Elasticity of pile

$$= \frac{\left[\left(E_{concrete} * A_{pile}\right) + \left(E_{steel} * A_{steel} * BarNos.\right)\right]}{A_{pile} + \left(A_{steel} * BarNos\right)}$$

$E_{concrete}$ = Modulus of Elasticity of Concrete

$$= 4700\sqrt{f_{cu}}$$

f_{cu} = Characteristic Strength of Concrete ,N/mm^2

A_{pile} = Cross Sectional Area of Pile, m^2

E_{steel} = Modulus of Elasticity of Steel, MPa

A_{steel} = Cross Sectional Area of Steel Bars, m^2

Based on results from Maintained Load Test 1 at Pile No. Bridge 3-P2-PL3,

Pile Length, L = 21.5m

Pile Diameter, B = 900mm

Load, P = 9000kN

Settlement, x $= 4 + \frac{B}{120}$

$$= 4 + \frac{900}{120}$$
$$= 4 + 7.5$$
$$= 11.5mm$$

Cross Sectional Area of pile, A

$$= \frac{\pi d^2}{4}$$
$$= \frac{\pi(0.9^2)}{4}$$
$$= 0.636172512m^2$$

Modulus of Elasticity of pile, E

$$= \frac{[(E_{concrete} * A_{pile}) + (E_{steel} * A_{steel} * BarNos.)]}{A_{pile} + (A_{steel} * BarNos)}$$
$$= \frac{\left[\left(4700\sqrt{35N/mm} * \frac{\pi(900mm)^2}{4}\right) + \left(200000MPa * \frac{\pi(32mm)^2}{4} * 9bars\right)\right]}{\frac{\pi(900mm)^2}{4} + \left(\frac{\pi(.32mm)^2}{4} * 9bars\right)}$$
$$= \frac{(1.768914249 * 10^{10} + 1448140418)N}{665125.4302mm^2}$$
$$= 28772.44207N/mm^2$$
$$= 28772442.07kN/m^2$$

$$\text{Offset value} = x + \frac{PL}{AE}$$

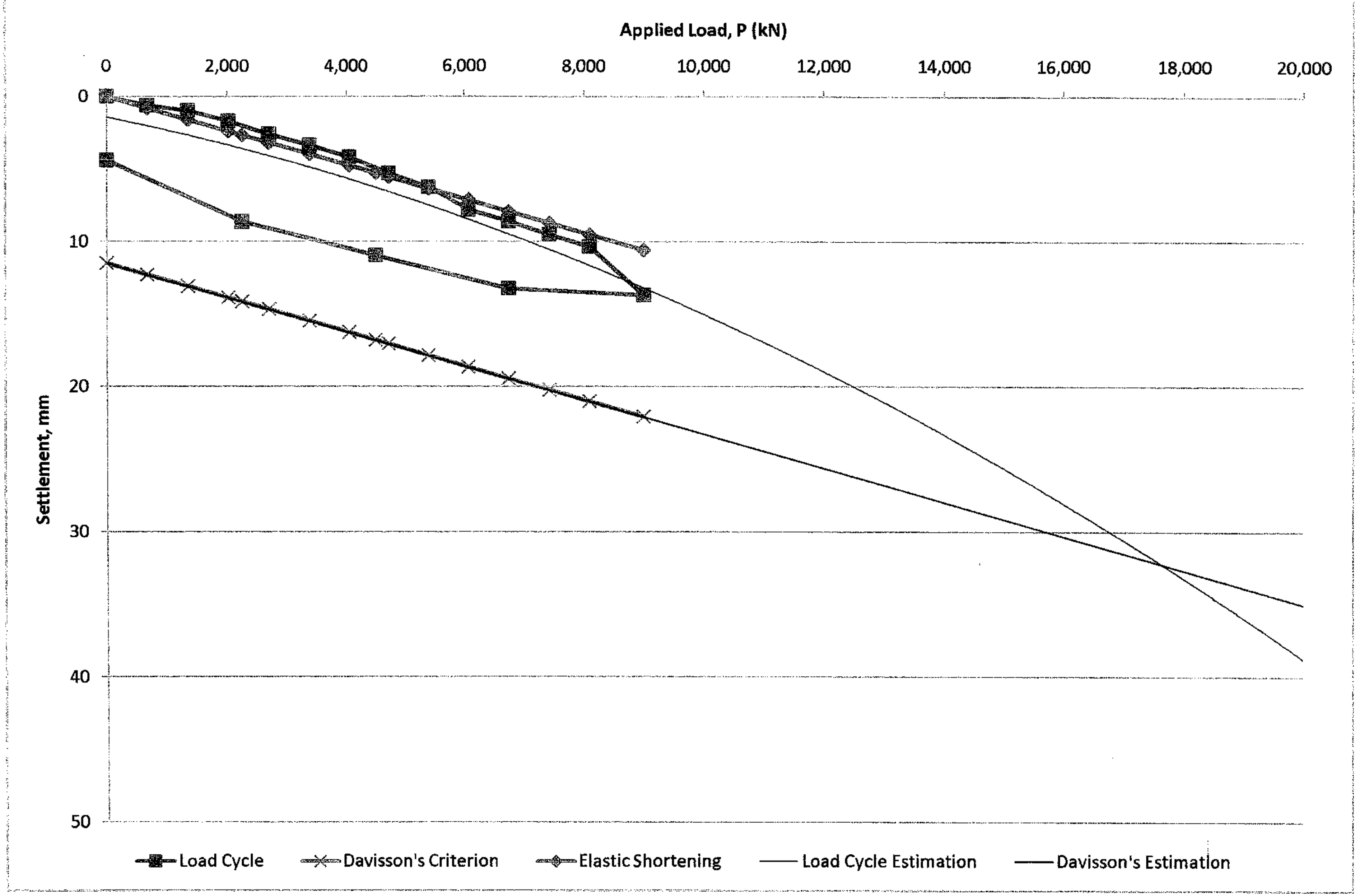
$$= 11.5mm + \frac{9000kN(21.5m)}{0.636172512m^2(28772442.07kN/m^2)}$$
$$= 11.5mm + 0.010571323m$$
$$= 11.5mm + 10.571mm$$
$$= 22.071mm$$

APPENDIX D

PILE NO : Bridge 3 -P2 -PL 3
PILE SIZE : 900mm Diameter Bored Pile
BORE LENGTH : 21.5m from existing ground level

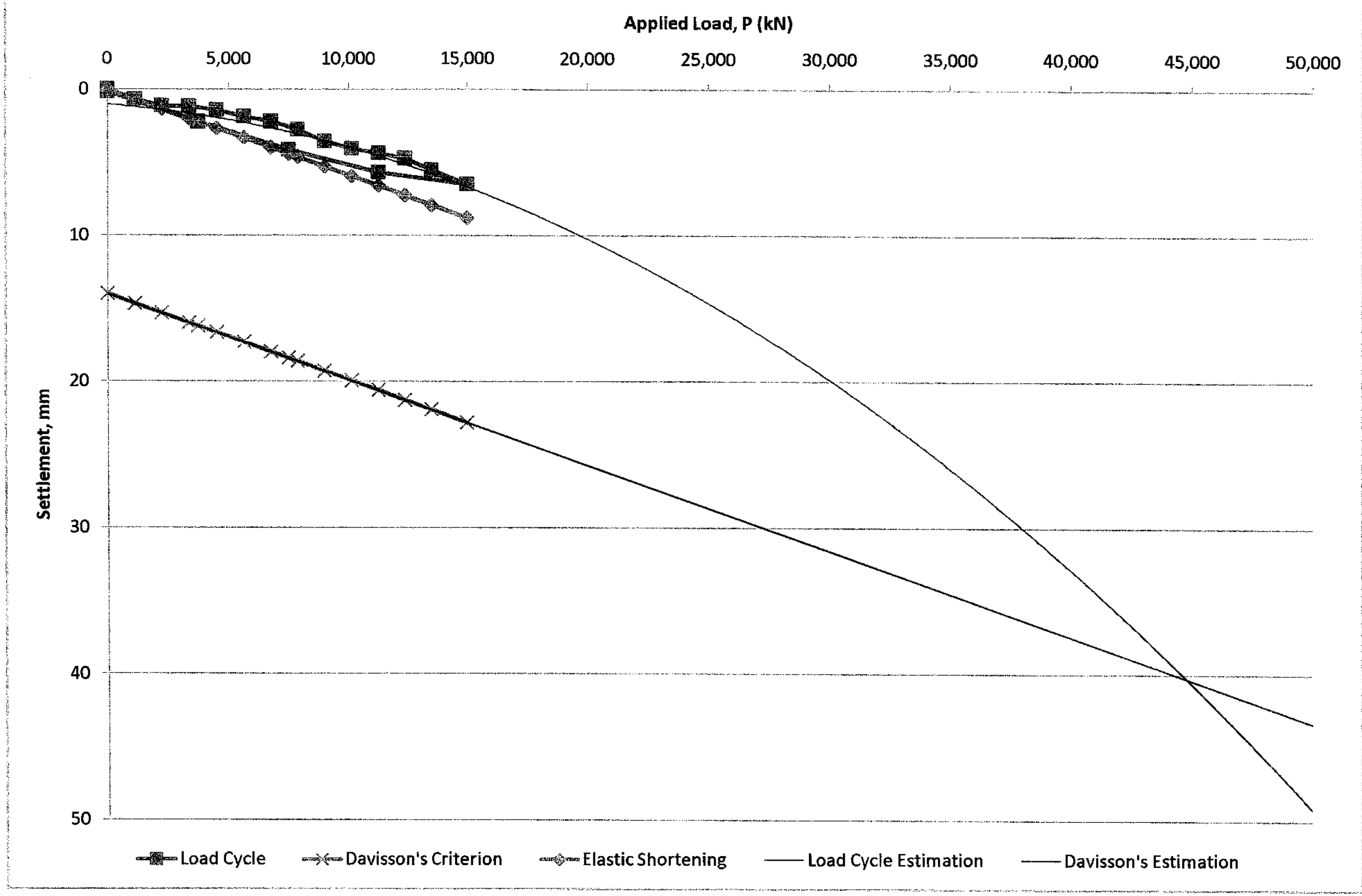
WORKING LOAD : 4500 kN
TEST LOAD : 9000 kN (2.0 times)

Load Stage % WL	Applied Laod kN	Maintained Time hours / minutes	Pile Head Settlement mm	Elastic Shortening PL/AE	Offset x	Remarks
0	0		0.000	0.000	11.500	Load test commenced at 16:00 on 24/05/2007
15	675	120	0.600	0.793	12.293	
30	1350	120	0.950	1.586	13.086	
45	2025	120	1.700	2.379	13.879	
60	2700	120	2.570	3.171	14.671	
75	3375	120	3.350	3.964	15.464	
90	4050	120	4.180	4.757	16.257	
105	4725	120	5.290	5.550	17.050	
120	5400	120	6.270	6.343	17.843	
135	6075	120	7.810	7.136	18.636	
150	6750	120	8.610	7.928	19.428	
165	7425	120	9.530	8.721	20.221	
180	8100	120	10.360	9.514	21.014	
200	9000	2880	13.695	10.571	22.071	
150	6750	60	13.230	7.928	19.428	
100	4500	60	10.960	5.286	16.786	
50	2250	60	8.640	2.643	14.143	
0	0	60	4.385	0.000	11.500	End of Load test at 08:45 on 28-05-2007

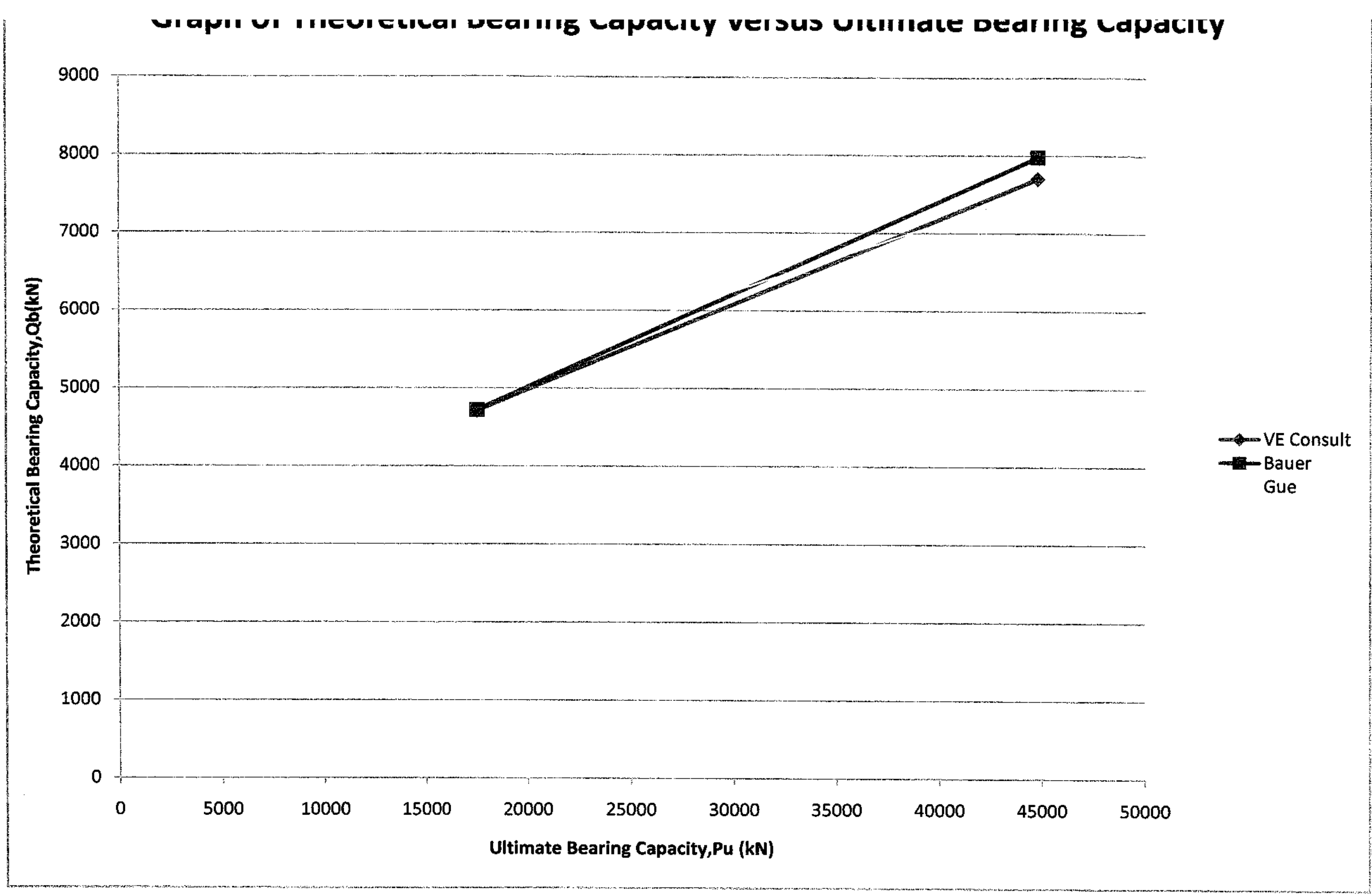

Applied Load, P (kN)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
Settlement, mm
0
10
20
30
40
50
Load Cycle
Davisson's Criterion
Elastic Shortening
Load Cycle Estimation
Davisson's Estimation

PILE NO	:	Bridge 3 -P4 -PL 3	WORKING LOAD	:	7500 kN
PILE SIZE	:	1200mm Diameter Bored Pile	TEST LOAD	:	15000 kN (2.0 times)
BORE LENGTH	:	19.6m from existing ground level			

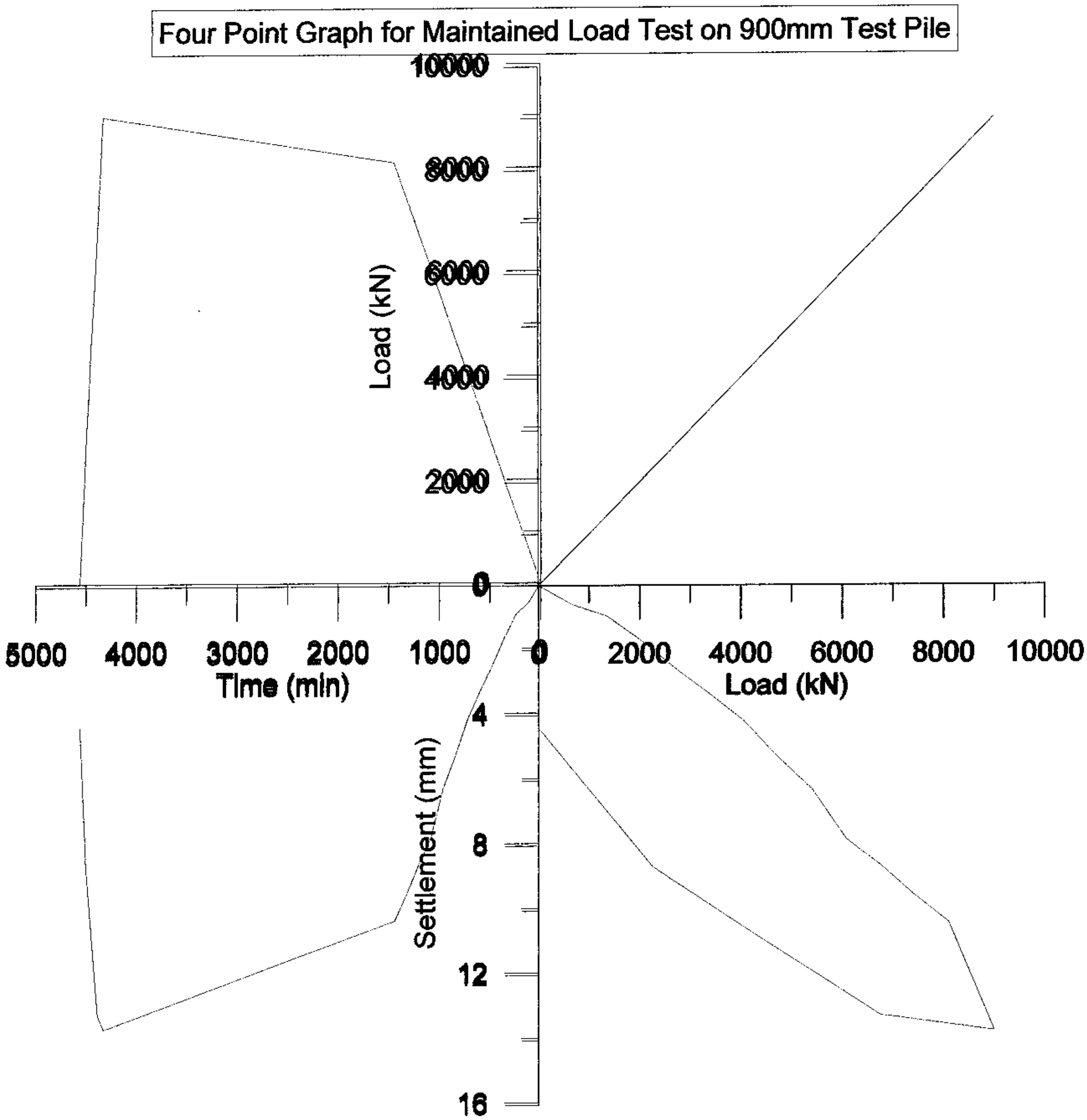
Load Stage % WL	Applied Laod kN	Maintained Time hours / minutes	Pile Head Settlement mm	Elastic Shortening PL/AE	Offset x	Remarks
0	0		0.000	0.000	14.000	Load test commenced at 12:45 on 15/06/2007
15	1125	2 hours	0.670	0.659	14.659	
30	2250	2 hours	1.110	1.318	15.318	
45	3375	2 hours	1.140	1.977	15.977	
60	4500	2 hours	1.390	2.636	16.636	
75	5625	2 hours	1.850	3.295	17.295	
90	6750	2 hours	2.180	3.955	17.955	
105	7875	2 hours	2.750	4.614	18.614	
120	9000	2 hours	3.530	5.273	19.273	
135	10125	2 hours	4.040	5.932	19.932	
150	11250	2 hours	4.380	6.591	20.591	
165	12375	2 hours	4.740	7.250	21.250	
180	13500	2 hours	5.510	7.909	21.909	
200	15000	48 hours	6.490	8.788	22.788	
150	11250	1 hour	5.670	6.591	20.591	
100	7500	1 hour	4.110	4.394	18.394	
50	3750	1 hour	2.210	2.197	16.197	
0	0	1hour	0.160	0.000	14.000	End of Load test at 18:58 on 18/06/2007

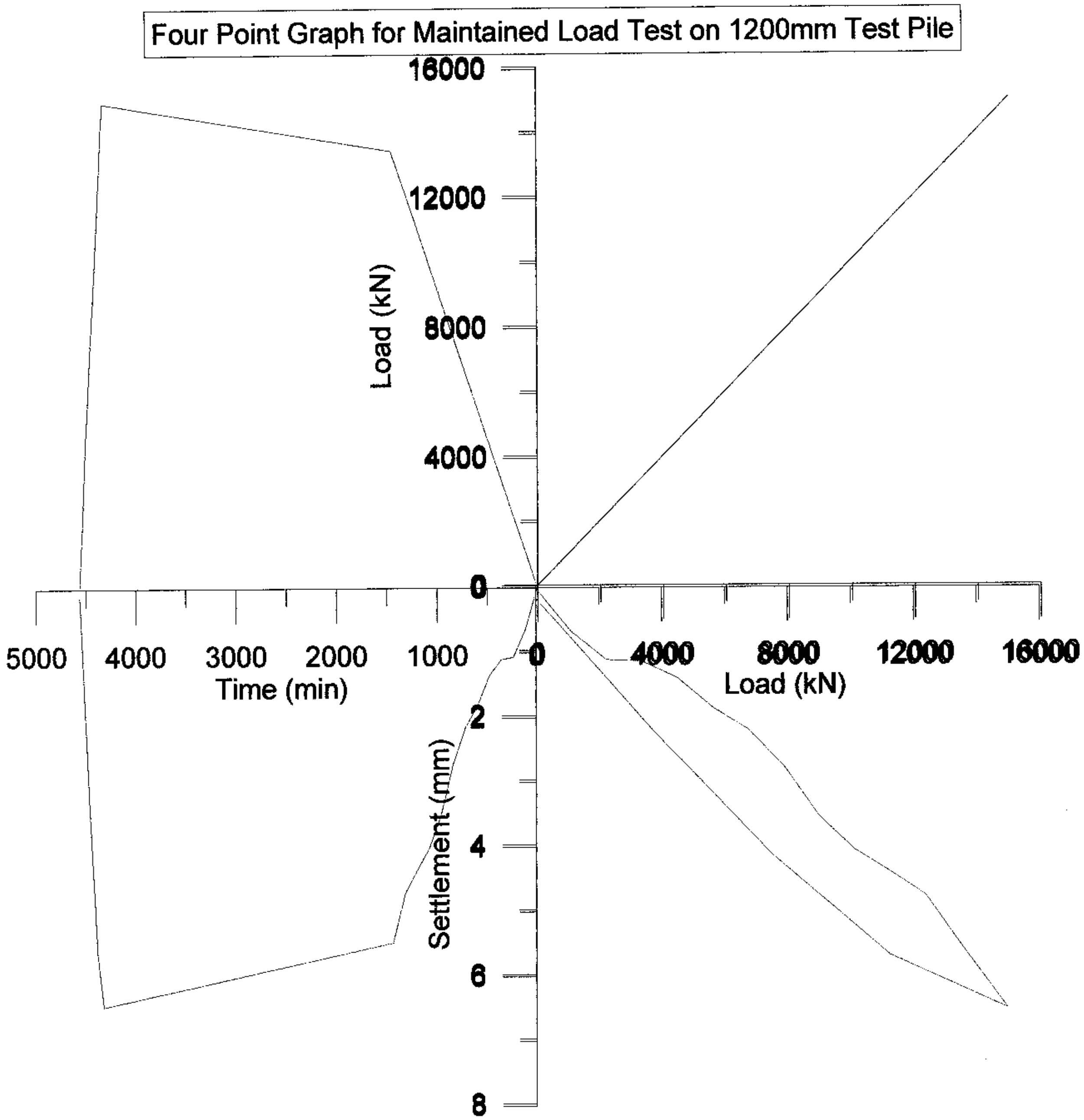


Applied Load, P (kN)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
Settlement, mm
0
10
20
30
40
50
Load Cycle
Davisson's Criterion
Elastic Shortening
Load Cycle Estimation
Davisson's Estimation



Graph of Theoretical Bearing Capacity versus Ultimate Bearing Capacity
Theoretical Bearing Capacity,Qb(kN)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Ultimate Bearing Capacity,Pu (kN)
VE Consult
Bauer
Gue


Four Point Graph for Maintained Load Test on 900mm Test Pile
Load (kN)
10000
8000
6000
4000
2000
0
Time (min)
5000
4000
3000
2000
1000
0
Load (kN)
2000
4000
6000
8000
10000
Settlement (mm)
4
8
12
16



Four Point Graph for Maintained Load Test on 1200mm Test Pile
16000
12000
8000
4000
0
Load (kN)
5000
4000
3000
2000
1000
0
Time (min)
4000
8000
12000
16000
Load (kN)
2
4
6
8
Settlement (mm)