Chapter 1
Introduction

1.1 Background

The Gold Coast is a relatively new and still developing city. As can be seen today, many buildings are still been constructed and there are many more proposed for the Surfers Paradise and Broadbeach areas. The importance of recognising the sub soils profiles are paramount due to the effect they have on the design of foundations. As of yet a soil map has not been produced for the Gold Coast. As a result all the sub soil layers must be determined from testing such as boreholes and Cone Penetration Testing. These give accurate results, but the use of a soil map would be much more efficient if the map was correctly made by all the information possible.

The buildings on the Gold Coast vary greatly in size, from single storied buildings to multi storied buildings and skyscrapers, which keep extending taller and taller recently, as evidenced by the Q1. Due to the great amount of variance in the size of the buildings a wide range of loading conditions are imposed on the foundations. Therefore, when designing the foundations that must be able to handle these loads, they must have the strength and compressibility characteristics of the sub soils in order to estimate the safe bearing pressure and the tolerable settlements.

To assess the soils parameters a soil map may help. Recent developments have established soil maps by use of the kriging method. That has been slowly and continually updated to produce soil maps that are more accurate and have more features. These soil map now use Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to make the most efficient use of all the data available. When the sub soil conditions are known, the mapping programs can then perform regression analysis by linear interpolation as well as extrapolation in order to establish trends amongst the soils profile.

This thesis compiles the available data from sites in Surfers Paradise, where the range in building size is large and the population dense, and from a section of land in Broadbeach. This location utilises the available data from the Convention Centre as well as from sites near to this location. Statistical analysis is performed on the various sub soil layers and the results will be analysed as to how they affect the foundation design.

1.2 Scope and Objectives

The aim of this thesis is to analyse the data obtained and perform statistical analysis on the data. There has been no prior soil map established for the Gold Coast and the data and information obtained would be very useful for the establishment of a soil map after it has been analysed. So therefore the aim is to obtain an understanding of the soil profiles for the Surfers Paradise and Broadbeach areas as well as understand how the soils properties in these areas might affect the design of foundations in these locations.

1.3 Layout of Thesis

This thesis is concerned with primarily obtaining relevant field data concerning the Surfers Paradise and Broadbeach areas. Once all the data such as boreholes and CPT results have been obtained they can be analysed. Included in this thesis is a breakdown of the soils profiles and distribution. From the Standard Penetration Tests performed, a closer examination of the soils density is observed as well as any trends in the data that may become apparent. From the results of the Cone Penetration Tests other soil properties can be observed as well as any more trends that may exist in the sub soils on the Gold Coast. This thesis focuses on the Surfers Paradise and Broadbeach areas because they are the most developing on the Gold Coast and have foundations of many different varieties and sizes.

The second chapter in this thesis is the literature review. This chapter focuses on the development of a soil map from the early days of kriging till the present where kriging is used in combination with a number of other developments so that an efficient program is utilised. The second part of this chapter focuses on the characterisation of the site and this chapter is finished by a third section examining the advantages of the GIS in place to map soils today.

The third chapter is the methodology and this chapter details the methods used for this thesis. Firstly the source of the data is explained and this is complimented by an examination of the quality of the data. After this has been done an explanation of the interpretation of the SPT and the CPT is given and how these results can be used. Lastly for the methodology chapter an examination is performed on how the SPT and CPT results can be used together is presented.

The fourth chapter is the results section. This is the most important chapter as it reviews the breakdown of the soils profile and distribution. After this has been done an analysis of the SPT results are performed for each area and any apparent trends will be recognised. An analysis is also performed on the CPT data and how this data can be used is also explained. Lastly in this chapter a brief review of how the soils properties affect the design of foundations is presented.

The fifth chapter is the conclusions and recommendations chapter. This section draws on the knowledge built from the previous chapters and compiles the conclusion and the recommendations for future research into this area.

Chapter 2
Literature review

2.1 Introduction

The mapping of soil is important for a number of reasons. One of these reasons is that the identification of soil profiles is of utmost concern for geotechnical engineers. A foundation can not be built upon a soil that is not stable otherwise the structure will be deemed unsafe. The identification of the location of these unsuitable soil and materials is therefore of paramount importance. From the very early days of soil mapping up to the development of the kriging method and now in the present with the use of Geographic Information Systems (GIS), the use of various techniques to map soil has been highly regarded. Without soil mapping inconsistencies in the soil profile may not be discovered and as a result the resulting structure or other use of the soil may not be suitable.

This chapter is based upon the works of other researchers that have encountered the use of software or other techniques to map soil. The chapter combines the works on soil mapping to give an overview of the past and the present with regard to map soil profiles. The use of GIS in the soil industry in the Gold Coast has not been used as of yet even though it would work perfectly to establish trends because as will be discussed later, the soil analysed is particularly consistent.

This chapter has two main parts to it. Firstly the development of technology in the engineering field of mapping soil is discussed using past methods up until now, where GIS is the basis upon which soils maps are established. The second part of this chapter deals with the advantages of using GIS.

2.2 Development of GIS in Civil Engineering

Recent developments in the technology industry have allowed for many changes to occur in the geotechnical field of engineering. An important development is the ability for scientists to be able to map soil profiles. Due to the fact that understanding a soils profile is of utmost importance before any developments can occur, soil mapping has proved to be very beneficial.

There are a number of systems that have been employed to map soil. Their purposes include mapping areas for development, soil drainage systems and environmental purposes. It is apparent that no matter what the reason is for developing a soil map, its use is very beneficial.

Parsons and Frost (2002) have revealed that soil mapping is necessary because accurate assessment of uncertainty is an important part of all engineering projects. Without the correct assessment the soil may prove to be inconsistent and obstruct the engineer in their purposes. Dobos et al. (2001) found that to support many aspects of our lives we need good quality information on natural resources and to do this an extensive range of data is needed. Parsons and Frost (2002) suggested in their paper that often the data collected on soil consists of samples that represent 1/100 000 or less of the total volume of soil. From these samples the soils parameters are estimated. However, Bell (1994) combined two systems to create a soil drainage map at a scale of 1:20 000. The importance of accurate soil mapping systems has also been recognised by the European Union. As researched by Dobos et al. (2001) the European Union has developed a soil mapping system database that covers 18 European nations and a further 8 nations have been added to the list. The database is significantly important because it has been successfully used for monitoring crop performance, (Vossen and Meyer Roux, 1995) and estimating environmental degradation risks (Giordano et al., 1991).

It should be noted that the assessment of uncertainty is particularly important for those projects that involve significant interaction with earth materials (Parsons and Frost, 2002). A factor of concern with Wielemaker et al. (2000) in this area is that the reliability of mapping units in terms of detail and variability of soils cannot be judged. Wielemaker et al. (2000) also realised that discontinuities in soil patterns resulting from abrupt changes in soil formation are not always evident. The wide variation in the geologic and geotechnical properties that are common to natural materials has led to significant and occasionally catastrophic deviations from predicted values on such projects (Parsons and Frost, 2002). Legget (1979) furthermore suggests that the resulting soil values are estimates and there exists some likelihood that actual soil conditions are significantly different from the estimation. It is therefore critical that soil maps are created with the aim of been as accurate as possible by taking into consideration all factors that may have an impact on the soil parameters.

Carre and Girrard (2002), have told how the use of a soil database can potentially allow for resolving environmental issues through soil mapping. Carre and Girrard (2002) believe that there are two main approaches to soil mapping for environmental purposes; nearest neighbour interpolation (Goulard et al., 1987) and kriging interpolation (Walter, 1990). Both these methods rely on interpolation between observation points (Carre and Girrard, 2002). The following picture, Figure 2.1, details how an area on the French Atlantic coast was divided into areas of observation and then mapped according to the kriging interpolation method.

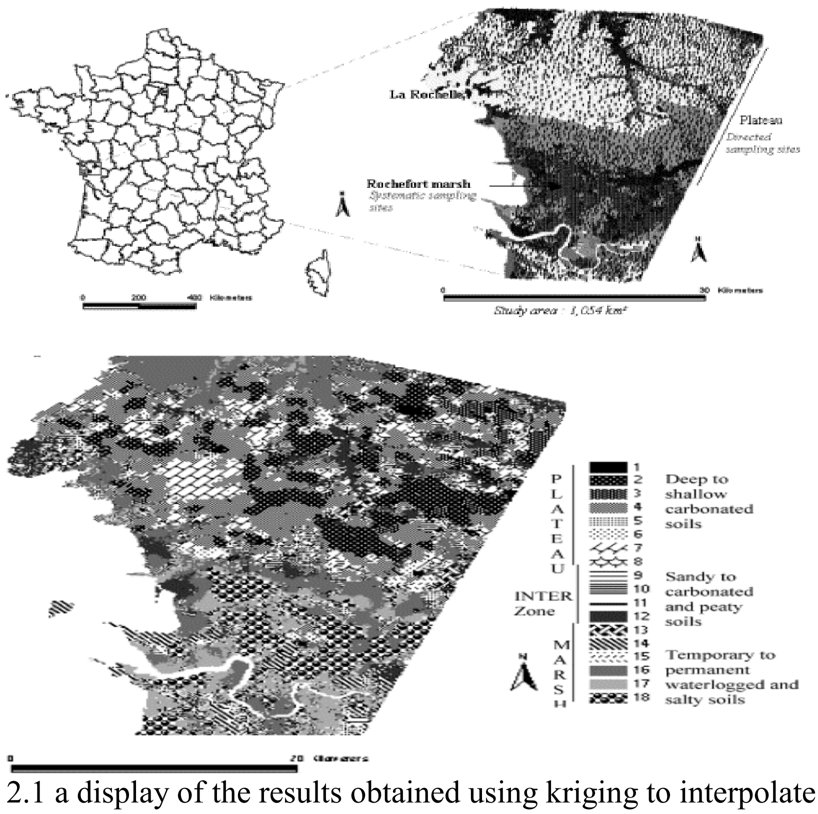


Figure 2.1 a display of the results obtained using kriging to interpolate areas

Wielemaker (2000) has said that traditionally soil maps were prepared to evaluate land for different uses, but recently the emphasis has been on crop suitability appraisals. Wielemaker (2000) then suggests that for effective mapping soil surveyors use the landscape and climatic context to predict what to expect within particular terrain units. Pennock et al. (1987) has suggested that in using Wielemaker's multi-hierachial system of soil mapping, the area been mapped should be divided into many smaller elements because each landscape element has its own specific soil and productivity. Wielemaker (2000) has said that his multi-hierachial model is mainly a deductive process with the aid of aerial photos, the general landscape is then subdivided into smaller units. At each step more information is added to provide greater detail into the map. A brief overview of Wielemaker's multi-hierachial process is presented in Figure 2.2 below.

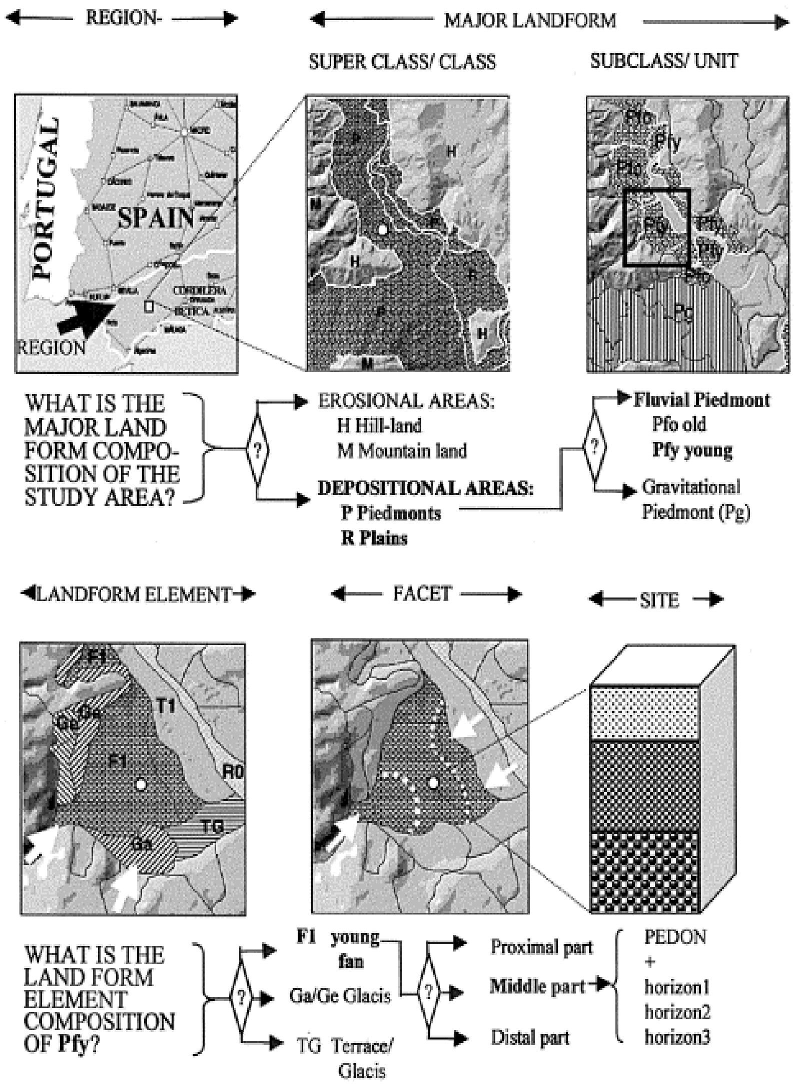


Figure 2.2(a) Wielemaker's multi-hierachial process

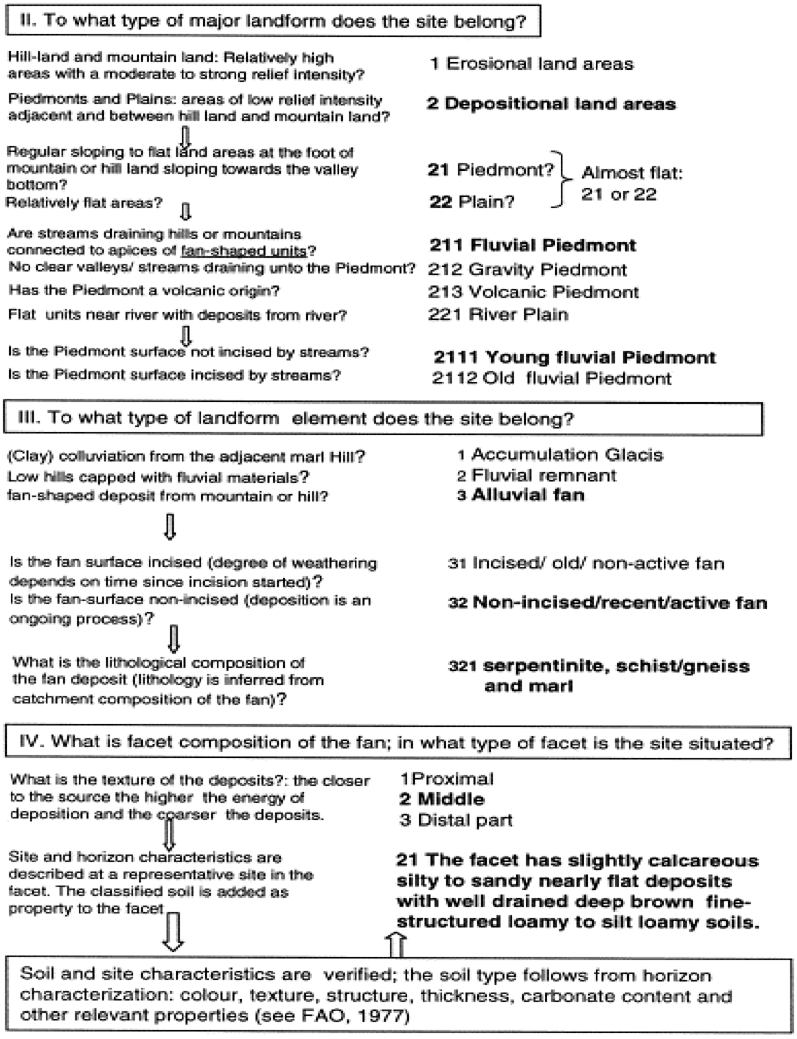


Figure 2.2(b) Wielemaker's multi-hierachial process

Freeland, Yoder and Ammons (1998) have also studied soil mapping systems for agricultural use. Freeland et al. (1998) believes that agricultural productivity is highly correlated to the physical characteristics of the soil and as a routine practice, a farmer or consultant approximates the overall physical characteristics of fields from soil surveys that provide general soil series information. After that Freeland (1998) suggests that a soil specialist survey the overall terrain and take manual samples using a soil probe to provide general soil classifications. An improved method to map site specific agriculture is based upon Global Positioning Systems (GPS). It combines with digital mapping and field machinery automatic control systems (Freeland et al., 1998). Doolittle and Asmassen (1992) have found that this near surface surveying has been proven as a very efficient and effective tool for the nonintrusive gathering of continuous agricultural field data on many soil types, soil moisture conditions and underground topographies. The purposes according to Freeland et al (1998) of accurate GPS mapping is to provide an efficient, economical and rapid means of 1) identifying areas of excessive soil compaction, 2) dimensioning soil horizon thickness and bedrock depth, and 3) assessing soil hydrological properties over vast agricultural production regions. The picture below gives an illustration of how the radar GPS method maps soil data.

Although it has already been mentioned by Parsons and Frost (2002) that there is no method to validate the accuracy of soil maps, Tsai and Frost (1999) combine the concept of investigation plan thoroughness with geostastical techniques to develop a spatially sensitive estimate of the site investigation plan quality, referred to as continuous thoroughness because it applies to geotechnical parameters that exist at every point throughout the sampling area. Parsons and Frost (2002) say that the approach was implemented using a geographic information system (GIS) platform (ARC-Info) so that the visual, analytical and data management benefits of GIS could be utilised for a more detailed analysis. ARC-Info is based on geostatics which stemmed from the concept of kriging (Parsons and Frost, 2002). Rouhani (1996) says that kriging has been widely used and using this method it is possible to calculate estimates of the value of a parameter and the error variance at any point based on a weighted linear average of nearby data points. It was first recommended by Journel and Huijbregts (1978) that kriging be used before any other method because the distribution of errors in estimates was nearly normally distributed. This was supported by Isaaks and Srivastava (1989) who suggested a similar approach after an exhaustive analysis performed on a generic data set.

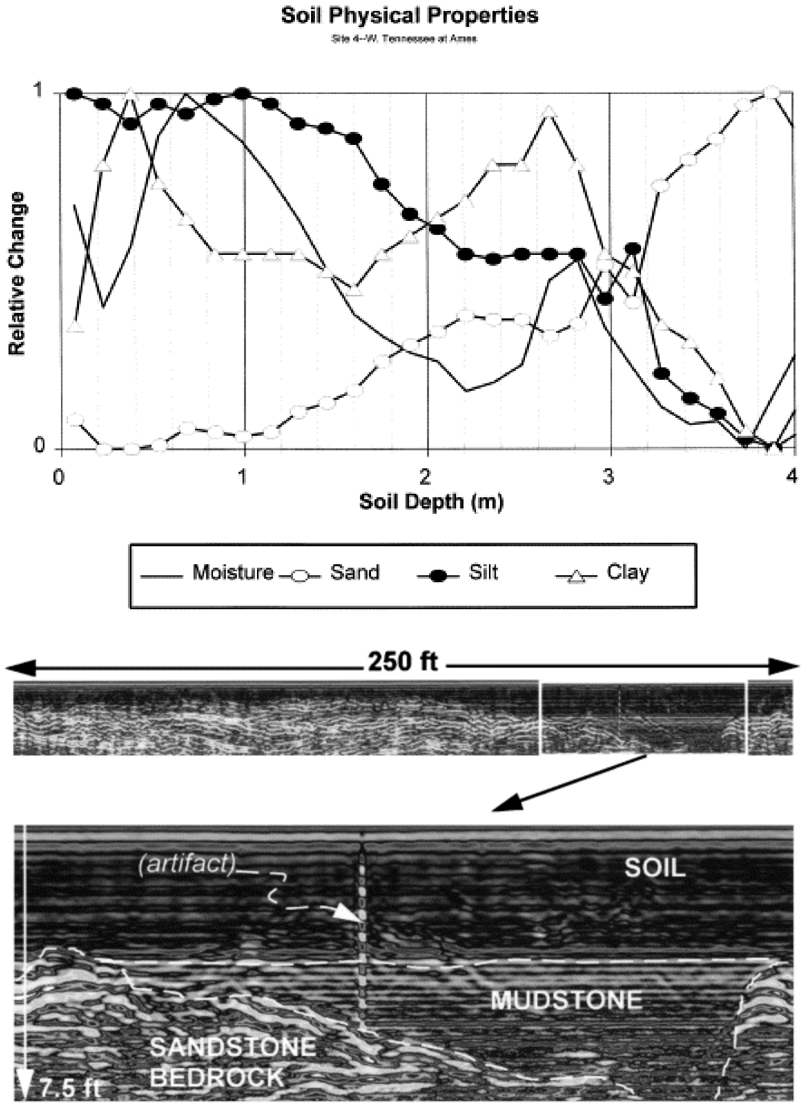


Figure 2.3 how radar GPS method maps soil data

Using the kriging method Fenton (1997) demonstrated how it could be used to estimate the probability that settlement beneath a footing would exceed an allowable amount. Slope stability could also be determined based on the methods applied by Honjo and Kuroda (1991). They achieved this by taking strength values at various depths. Rouhani (1996) used this method in an environmental study of groundwater leakage data. The kriging method is good for predicting values because it can be applied for a point or block area (Parsons and Frost, (2002). Prediction of engineering performance can be done by estimating two values, the actual value inherent to the soil (capacity) and the value required for acceptable performance (demand), (Englund and Stokes, 1991). When these values are known the reliability of the soil will also be known.

In applying the kriging method a program was required to also be able to process the data within a GIS. To perform the tasks required by Parsons and Frost (2002), ARC-Info was chosen because GIS systems are specifically designed to store, manipulate and display spatial data. Parsons et al. (1998) suggested the use of ARC-Info as well because it offers significant data analysis and visualisation capabilities. To incorporate the data analysis, ARC-Info has been programmed to import multiple types of information including piezocone data and a Standard Penetration Test (SPT). Information may then be extracted for analysis based on depth, elevation or soil type.

2.3 Advantages of GIS

The software packages of GIS-Assess and Arc Info were developed to enable the establishment of the continuous thoroughness images. ARC-Info was designed to be used as a tool capable of selecting the required data set to be analysed and then displaying the results of the analysis (Parsons and Frost, 2002). On the other hand GIS-Assess was developed based on geostatics to perform data analysis based on the kriging method of interpolation. With the development of GIS and database techniques, the presentation of soil data can become more easily accessible for all users.

ARC-Info, utilising GIS software, is a very quick and powerful tool for analysing soil properties because it has the capability to store, manipulate and display spatial data (Parsons and Frost, 2002). Dobos et al. (2001) suggest that the rapid development of GIS in the last two decades has made 'direct' data integration possible, when data from different origins are used simultaneously. In particular notes Parsons et al. (1999), GIS offer significant data analysis capabilities that make interpreting all data much easier. A primary advantage of GIS systems are their capabilities to consider such factors as wetlands, trees, slopes, utilities and proximity to sensitive structures or potential receptors (Parsons and Frost, 1999). Also notes Ziadat et al. (2002) GIS can be used to integrate data and produce information that might identify surface features that are unnoticeable in stereo aerial photographs, for example, a 'premap' produced form maps of slope, aspect and landform. This is important as attributes related to soil-landscape features are considered important for separating soils using remote sensing data (Florinsky, 1998). ARC-Info, incorporating the use of GIS's, is capable of superimposing structures and other obstacles on top of the soil surface in order to obtain a true report of the soils character and future behaviour. The importance of a GIS database can also be attributed to a reduction in overall cost and time, but more importantly, an increase in the detail of information gathered when represented on the map developed (Green, 1992). Without the capabilities of integrating GIS into a software system, mapping soil parameters to gain a better understanding of the overall profile would be much ore difficult. When GIS combines with a program to map the soil the result often is the production of an accurate map that represents as best it can the values needed by the person using the software.

GIS-Assess is a powerful tool for analysing the index properties of soils because it has a function that allows it to import multiple types of information from text files that may be generated from a spreadsheet or database program, including piezecone, SPT, and any other data that may be represented as values with spatial coordinates (Parsons and Frost, 2002). Using polygon shapes, the data is used to represent point coverage and generate an associated table containing the testing data (Parsons and Frost, 2002). From this table of data, information that is required may be extracted according to the users need based on depth, elevation or soil type within the boundary of the data recorded. The data extracted is then exported to a compatible file where the actual krigin interpolation is performed based on the modelling software within the program. Once this has been performed, images of thoroughness and accuracy are imported back to GIS-Assess where the results can be evaluated and used (Parsons and Frost, 2002). The user can then view the map of the area generated and obtain any information in this region which they may need. For instance, the user can click on a certain area with the hope of obtaining an SPT value at a particular depth. The GIS software developed for this purpose allows the user to do this as the built in krigin function evaluates all of the soils parameters at all depths and elevations. An advantage of this particular system however is not only is a value presented but so is a 'second opinion' value that is one standard deviation away form the interpolated value (Parsons and Frost, 2002).

A significant advantage of using a GIS package is that subsets of the data may be analysed based on location, elevation, soil unit or other criteria (Parsons and Frost, 2002). ARC-Info incorporating GIS ASSESS was designed to allow the user the option of selecting data from a specific depth, thus avoiding 'smearing' whereby data from a range of depths are averaged (Wild and Rouhani, 1996). Additionally, the critical $N_{1(60)}$ value at which liquefaction was expected to occur varied with depth. Separation of the data by depth made it possible to 'fine tune' the critical value for the depth of interest (Power et al., 1998).

ARC-Info incorporating GIS technology particularly GIS ASSESS is a powerful tool that maps soil profiles for a number of purposes. It can take into consideration many variables such as SPT and piezocone data and use that text file to perform data analysis. The resulting analysis indicates the soil profile and whether the soil is suitable for the desired use or not. The GIS technology allows any particular point on the map to be used at any desired depth to examine the soils characteristics. The program, based on an advanced kriging method is fairly accurate due to the errors been minimised by the formula. ARC-Info also ensures 'smearing' does not occur so the soils profile is accurate at each point or block and the value given is not an averaged one.

Overall, software utilising GIS has a definite advantage over other alternatives. GIS offers more clarity in the maps its produces whilst taking into consideration the effects of such obstacles as structures for the purpose of plotting soil maps. Another useful tool that is incorporated into GIS is the ability it has to integrate data input by the user. These requirements of the users are then evaluated, normally by the kriging method or by polygons and the results are displayed by utilising GIS and then displaying the results of the required area on the map developed. Therefore GIS is very useful in applying it with other software to exhibit soil profiles.

2.4 Closing Remarks

From the literature reviewed, it can be seen that soil mapping is very important and has many uses. It is also important in the geotechnical field as the establishment of a database that realises trends in the soil is important for the design of foundations. Without the recognition of hazardous materials some structures may not actually be appropriate for that particular site. GIS is an important tool in mapping soil and its use will be applied for many years to come within many industries because it is so flexible. It is especially beneficial in mapping soil as it can analyse and establish trends using extrapolation as well as interpolation between various borehole points. The respective borehole for the area can also be displayed so that the reader can view the real log taken in that area and compare it with the interpolation between data points as set out by the GIS with the mapping software.

Chapter 3
Methodology

3.1 Introduction

The source of data been used is always an important issue. In this particular case the borehole data has all come from the same company so its quality and testing methods will show very little deviation. The CPT data has also been obtained from the one company from the Broadbeach area so this as well will leave little room for any errors in the testing procedure. The interpretation of these two tests is very important as without standard classification systems the data would be useless. These classification systems are very similar and in this case the British classification system has been used. This will be discussed later. The use of the results from each of these tests is also very important and how these results effect the design of foundations is mentioned.

This chapter deals with where the data was obtained and its quality. More importantly the use of the CPT and SPT data is also discussed. These two field tests provide relevant, useful material that is important for establishing the soils profile as well as how this profile may have an effect on the design of foundations that are to rest on this particular soil

This chapter looks at the methods used to obtain the data for this thesis. The source of data is examined and the data's integrity is checked. The relevance of the data pieces are also examined. Lastly the establishment of the GIS program is discussed as well.

3.2 Characterisation of Site

Site characterization is an extremely difficult task as the data available is separated in many organizations. Small projects often overlook this process due to budgetary constraints. With Geographic Information Systems (GIS) and statistical analysis, it is possible to create a preliminary model of large geographic areas by uniting many datasets from various specific locations. GIS is a powerful tool for the collection, analysis, and interpretation of multiple datasets from a wide variety of sources and locations. The primary GIS software used in this project is Autodesk Map 2004 developed by Environmental Systems Research Institute (ESRI).

Urban planning of big cities such as Gold Coast cannot be performed without the notion that soil mechanics is a highly important determinant. Both its qualitative and quantitative aspects should be considered. The geotechnical characterization of an area through maps has been a difficult task to several researchers. This resulted in the need of transposing maps and letters from paper to digital media, which provides an easier access to data used in a Geographic Information System. With the evolution of computer science, the use of computers has provoked a great impact in geotechnical mapping due to the benefits of modern software. The integration of graphic data through a Geographic Information System (GIS), for instance, allows good results. This kind of software is available at progressive lower costs and easier interface.

To better characterize Surfers Paradise area of Gold Coast (the region studied), a geotechnical database was created. This database aims at locating geographically and estimating the geomechanical behaviour of the soils from this region through graphs, tables and pictures.

The structuring of a data base is of great importance for storing of information and makes it easier to compare several geotechnical properties observed in location. A database, in addition to allowing the development of correlations, can also provide a better understanding of certain soil behaviour when it is used in connection with a GIS**.** The results of the geotechnical experiments performed in field are referenced according to the amount of sampling, a necessary condition to their incorporation in a Geographic Information System.

Boring log data quality is always a challenge. Many of the older boring logs contain vague soil descriptions and minimal information on soil properties while the more current boring log data contain detailed information on soil description and soil properties. This database contains a wide variety of this combination of data sources. The analysis capabilities allow the irrelevant information to be ignored while examining only the data that is pertinent to the questions being posed. When more general soil type and stratigraphy information is being analysed all the information becomes relevant.

Collection and analysis of data from many different sources is an arduous task that requires the power of GIS. Data was available in many different forms and locations. The first objective was to research and obtain relevant data, which could be entered into the GIS database in a tabular form and combined or referenced with a spatial data features as assigned attributes. Once the data were compiled it was necessary to convert the database to a format, which allowed for spatial and geostatistical analysis. It was also necessary to arrange the data so that a wide range of users could easily query and view the data they required. Although ArcGISTM is an excellent tool for combining data of many different forms, considerable time and effort went into merging the data into coverage that could be spatially analysed. Transformation of several AutoCADTM drawings and layers was necessary to obtain spatial information from many different project sources. Several of the data sources were compiled in different coordinate systems and datum, which necessitated the use of coordinate projections.

3.3 Source of Data

3.3.1 Borehole Logs

The data obtained for the purpose of this thesis primarily originated from a company specialising in Geotechnical Engineering Services. It is a Gold Coast based company specialising in performing borehole tests. This company performs its testing on the Gold Coast and just south of the Queensland-New South Wales border. For the purpose of this thesis however only the boreholes that were logged in the Surfers Paradise and Broadbeach area (close to the Convention Centre) were used for analysis. Due to the number of data collected in these regions, Broadbeach and Surfers paradise have been divided into six basic areas where clusters of borehole data has been collected. The depth of the boreholes varies with each site but generally lie between four and fifteen metres depending on the clients need and the sub soil. For each area (there are five borehole areas) the SPT results have been averaged. From this a graph has been prepared with the average value of the results of the SPT taken at a depth of two metres and plotted at interventions every two metres. The mean SPT value of each region overall is presented as the subtitle of the graph. Each borehole chart is presented as a graph plotting the depth against the SPT N value.

A basic map plotting the location of each borehole in the six regions has been included in the appendices. The company that performed the testing are a small company only employing a handful of employees. For this reason there should be minimal discrepancy between the results obtained by one person performing the analysis of the soil profile and the results obtained by another person performing the same task.

3.3.2 Cone Penetration Test Data

The data obtained for the cone penetration tests were performed at various locations of the Gold Coast Convention site. A map indicating the location of the convention centre has been included in the appendices. Unlike the data obtained for the borehole logs, data from cone penetration tests has been limited to only the Convention Centre. The testing was performed in 2001 on the Convention Centre on multiple areas of this site to gain a thorough knowledge of the soil profile within this construction zone. In total there have been 103 sites at the Convention Centre where cone penetration tests have been performed. For each site a graph has been prepared illustrating the depth against the friction ratio for each site.

3.4 Quality of Data

3.4.1 Quality of Data for Borehole Logs

As each borehole log has been obtained from the same company there should be minimal discrepancy between the results obtained. Within the company performing these tests are a number of employees, however it has been brought to the writer's attention that each SPT is performed in the same manner. Therefore the quality of these results have not been interfered with and they represent a true sample of the soil's properties. It can be said however that it is impossible to replicate the in-situ properties of soil because after been taken out of the ground the soil has had a little disturbance. Apart from this minor detail that affects all geotechnical companies, minimal disturbance to the soil has been allowed.

A significant advantage of the CPT over the usual boring methods and standard penetration testing are that:

1. it (CPT) provides a virtually continuous record of ground conditions
2. it avoids the disturbance of the ground associated with boring and sampling, particularly that which occurs with the Standard Penetration Test.

To add to this the disturbance resulting from the advancement of the cone is consistent between the tests.

3.4.2 Quality of Data for Cone Penetration Tests

As with the borehole data, this data has been obtained from the one company operating at the Convention Centre. Therefore the testing standards are similar and little discrepancy can be allowed for this data.

3.5 Interpretation of SPT

The Standard Penetration Test is performed to evaluate the density of the sand deposits and is the most widely used of all field methods. The blow count (N) is recorded as the penetration resistance unless the blow count cannot be completed. This occurs when N>100 (Al-Khafaji and Andersland, 1992) or the sampler encounters rock and cannot be advanced any further. If the blow count exceeds 100 then the borehole log shall display borehole refusal.

Standard Penetration Test result are very useful for indicating the density of sands. However, the determination of the clay shear strength can be unreliable based on penetration resistance values obtained. In saying that, the N values do give useful preliminary indications of the consistency of clay and can be sufficient for the final design (Al-Khafaji and Andersland, 1992).

Al-Khafaji and Andersland (1992) have found that in fine grained deposists the standard penetration resistance at the level where N is measured is influenced by the effective vertical stress, density of the soil, stress history and other factors. Gibbs and Holtz (1957) have recognised the effect of effective overburden pressure in their correlation between N and the relative density. The standard penetration resistance has also been known to give an indication of the potential for liquefaction in sand deposits (Seed, 1983).

A density classification for sands was originally proposed by Terzaghi and Peck (1996). This chart is presented below and correlates the standard penetration resistance with the classification of the soil. Columns three and four were developed based on evidence discovered by Gibbs and Holtz (1957).

N Value	Classification	I_D (%)	$(N_1)_{60}$
0-4	Very Loose	0-15	0-3
4-10	Loose	15-35	3-8
10-30	Medium dense	35-65	8-25
30-50	Dense	65-85	25-42
>50	Very dense	85-100	42-58

Table 3.1 Density index of sands (reproduced from Craig, 1997).

The values that are on this table help to identify the relative densities of the soils encountered in Surfers Paradise as well as Broadbeach and Main Beach.

3.6 Interpretation of CPT

During a cone penetration test, many complex changes occur in the soils stresses, strains and pore pressures. This makes the analysis of the cone penetration test quite difficult at times. For this reason the use of the CPT remains essentially empirical.

The CPT has three basic applications. These are:

1. to determine the soil profile and identify the soils present
2. to interpolate ground conditions between control boreholes
3. to evaluate the engineering parameters of the soils and to assess the bearing capacity and settlement.

It should be noted that the role of the CPT in evaluating the engineering parameters of the soils is preliminary and needs to be supplemented by other tests. So for this reason the CPT is useful for providing guidance on the parameters of the soil. Exceptions can be made when the soil is fairly uniform and the results of the CPT have excellent correlations.

The use of CPT data is very useful for establishing the relevant parameters. These parameters include: the angle of shearing resistance and deformation characteristics in cohesion less soils, undrained shear strength and modulus in cohesive soils.

One of the important uses of the CPT is to delineate the soil profile. The CPT is more useful for establishing the soil profile than more conventional methods such as boring and sampling, however sometimes the accuracy can be affected by the technique used and the CPT does not allow for visual inspection of the soil. The cone indicates the cone resistance when the soil changes within 5 to 10 tip diameters above and below the cone, with the distance increasing with increasing soil density. This can often lead to imprecisiveness in locating soil interfaces and will therefore have an effect on the evaluation of engineering parameters. Due to this very thin layers of clay and sand may be missed by the cone. To increase the accuracy of soil sampling a pore pressure probe or a penetrometer tip fitter with a piezometer could be adopted.

A broad identification of the soil classification can be obtained from the cone resistance and the friction ratio obtained form the soil. Begemann (1965) developed a scheme for identification using the Dutch mechanical friction sleeve tip and this was later extended by Schmertmann (1969). Then Searle (1979) incorporated the results of further studies and produced Figure 3.2, shown below.

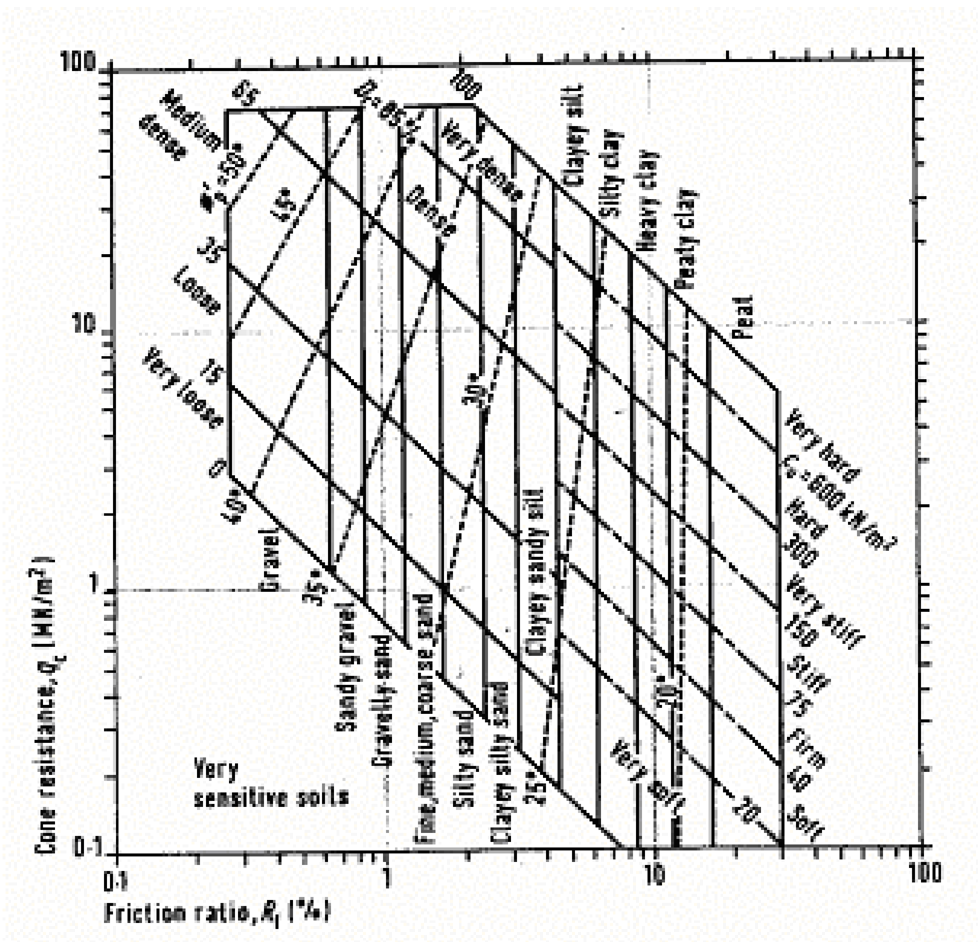


Figure 3.1 Identification of Soils (from Meigh, 1991)

However a simpler working version was established by Robertson and Campanella (1983) which is a plot of the cone resistance (q_c) against the friction ratio (R_f). This chart is replicated below.

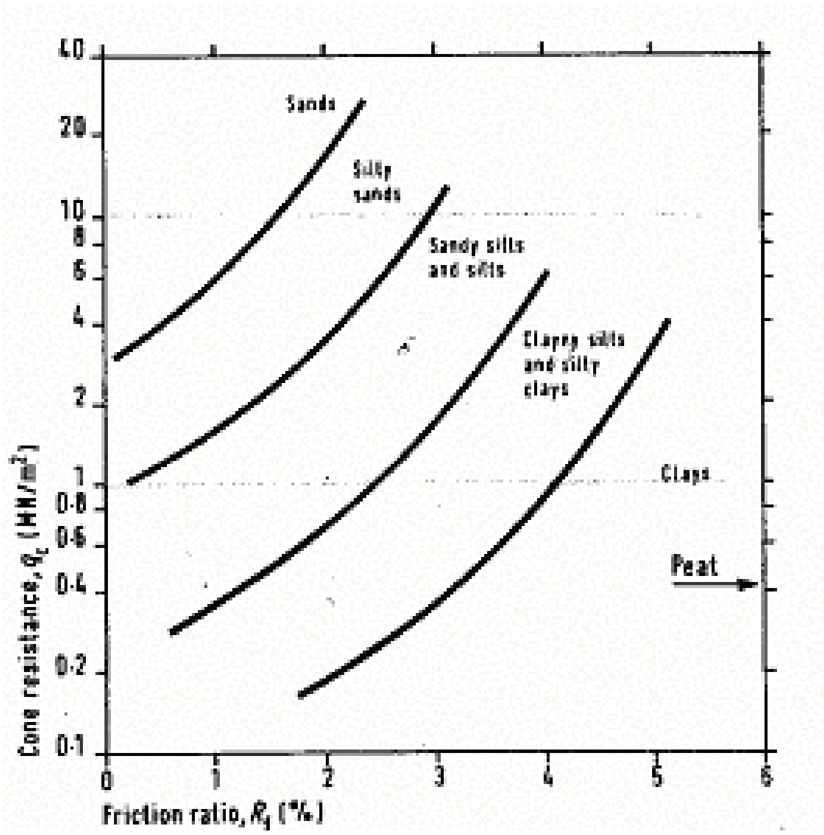


Figure 3.2 Robertson and Campella's simpler working version, 1983, (from Meigh, 1991)

As mentioned the identification of soils is done on an empirical basis by correlations between soil type and the ratio of skin friction to the cone resistance. The assessment however of other engineering parameters is also based on empirical correlations. These test results can be used to estimate the bearing capacity and settlements.

Even though the CPT is a reliable test it is advisable to correspond the data obtained from the CPT against one or more boreholes.

3.7 The CPT and SPT

Standard Penetration Test results have been very useful for calculating the bearing capacity and settlement on soils. Nixon (1982) in Meigh (1991) proposed a relationship that existed between the CPT and the SPT for fine sand. This relationship is

$$q_c = 0.4N$$

where q_c is measured in MN/m^2 and N is the standard penetration resistance in blows. However the relationship between these two values varied from about 0.25 for silty fine sands up to 1.2 for more coarse gravels (Meigh, 1991). It was also proposed by Burbidge (1982) that there was a relationship between q_c/N and the average grain size, D_{50}. The resulting average correlation is presented in the figure below which shows the zone with which the results fall on the data collected by Burbidge.

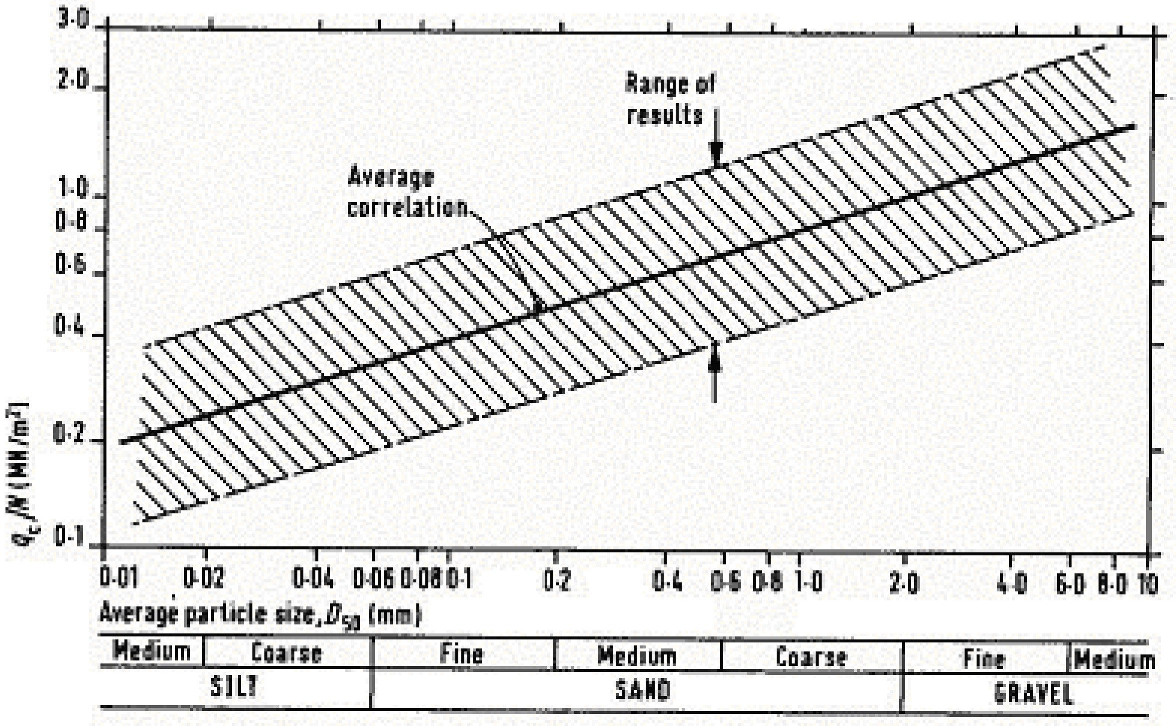


Figure 3.3 Relationships between CPT and SPT (from Meigh, 1991)

It should also be noted that the values obtained by Robertson and Capella (1982) also fall within the range identified on the chart. It should also be known that because of the amount of scatter within the results, direct use of CPT data would be preferred to conversion to N values.

Within this method of converting cone resistance values to N values arises the difficulty of assessing the accuracy of the conversion. This difficulty arises because the test procedure often varies for the Standard Penetration Test and as a result the conversion may be affected. Some factors affecting the procedure of the test is that the hammer may be released by different methods, and sometimes two different hammers can be used. Trials by Frydman (1970) indicate that there may be a variance of 1.4 times in the value recorded by for the number of blows. It should be appreciated that there is therefore a difference in the values obtained as a result of the different testing procedures. However the main complication arises when converting N values to q_c values. Often the resulting value of cone resistance is underestimated due to the different Standard Penetration Testing methods.

3.7 Establishment of Soil Map

In this thesis, a GIS map is generated using Autodesk Map 2004. Autodesk provides a demonstration CD with the basic functions of the software. Autodesk Map is an AutoCAD® based mapping product that contains all the functionality of AutoCAD, as well as its own powerful mapping tools designed for mapping and geographic information systems (GIS) professionals. The “Map” in this research is generated using the demonstration version of “AutoCAD Map”. The layout of the software is shown in Figure 3.4 (a) and (b).

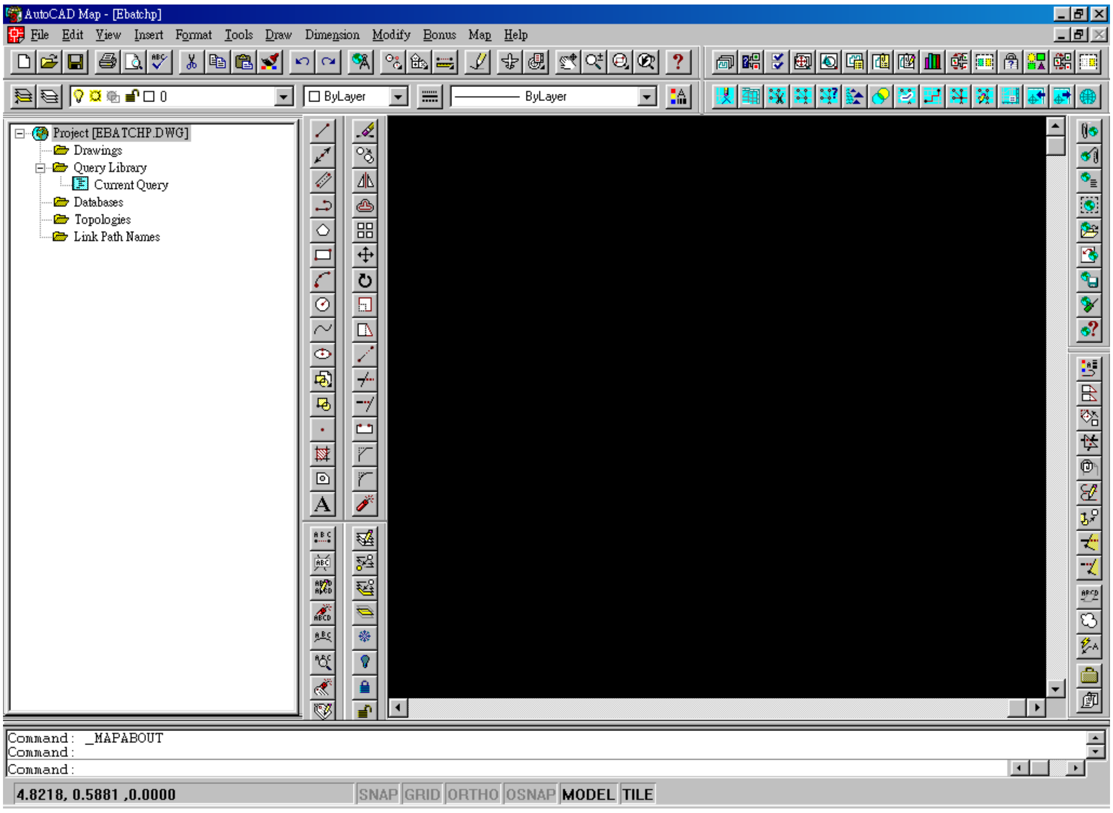


Figure 3.4(a) Layout of Autodesk Map 2004.

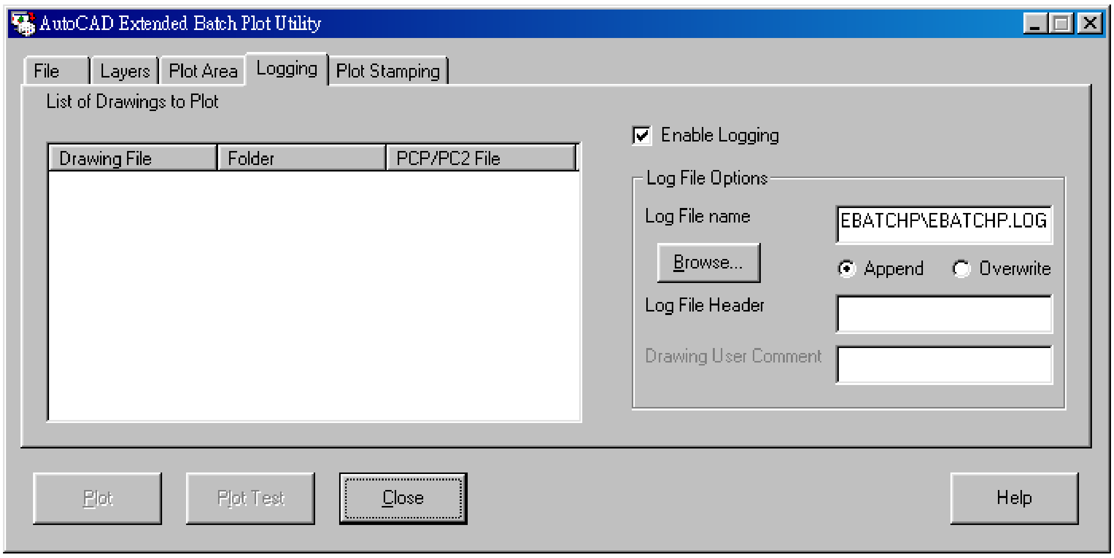


Figure 3.4(b) Layout of Autodesk Map 2004

3.8 Closing Remarks

The source of the data is important as it relates to the quality of the data. The quality is important as the information provided needs to be reliable and as accurate as possible. This can be achieved by a standard testing method and it is also better if the same company or person performs the test. Of course this is not always possible, but trying to achieve this standardises the results. The interpretation of the data is also important. There are many sources that say how CPT data can be interpreted and there are a number of methods used to correlate the data. The interpretation is therefore up to the reader, although the correlations are all very similar. Despite the differences in the methods of interpretation, generally very similar results should be obtained.

The soil map has been produced using Autodesk Map 2004. Further figures obtained from this software are displayed later in the appendices of this thesis.

Chapter 4
Analysis and Results

4.1 Introduction

The classification of soils for the design of foundations is of paramount important. Borehole logs conducted on the site produce results that can be analysed to give a description of the soil and its consistency. The relative densities are also found out by laboratory testing methods. A Standard penetration Test can also be performed on the soil and this gives a clear indication of the density of the soil below the surface. Another test that has been analysed is the Cone Penetration Test. This test is useful because it can help establish parameters such as settlement and also gives an indication of the soil type. The CPT is also useful for recognising thin layers of a soil that may have otherwise been missed by standard techniques such as the borehole. The results from the boreholes and the CPT data obtained then will be used to recognise the effects they have on the design of foundations.

This chapter concerns itself with the results obtained from the borehole logs and the Cone Penetration Test results obtained for the different areas. Firstly the results are broken down into their respective areas, with a description of the soil profile and a breakdown of the soils distribution provided. Area 5 is a bit ore complex as it has a lot of CPT data that has been analysed as well. After this has been achieved the effects the results have on the design of foundations is discussed with reference to the geotechnical parameters established from the results section.

The results for this chapter have been presented a little differently to a soil report. The major difference is that in a soil report the classification of soils in a borehole log or distribution of the soils is usually done according to the international standard. This international standard does not use colors to map the soil profile but rather different styles of hatching have been used. To make it easier for the readers to gain a proper understanding of the soils profile color plots have been presented instead of hatching so the results can be understood more easily. Some of the SPT's that have been performed have results indicating consistent resistance values. An example of this is shown in figure 4.9. This plot appears as though there have been three measurements of the penetration resistance been 50, this is not the case however. What actually happened is the operator of the sampler simply stopped performing the SPT when 50 blows, and in other cases 30 blows was reached. So the representation of the result been 50 blows is actually >50.

4.1.1 Definition of Soil Profiles

Soil names originate from the determination of the particle size distribution (or grading) and plasticity. From this the soil name can be deduced. These parameters are obtained by laboratory tests or in some cases visual inspection. Other but less important characteristics for determining the soils name are by observing the color, texture, soil shape and composition.

The classification of the soils found in this thesis have been done according to the British method. According to the British Standard (BS 5930 [3]) the basic soil types include boulders, cobbles, gravel, sand, silt and clay. They are then defined in terms of particle size. From Craig

(1991) a soil is sand or gravel if after the removal of any cobbles or boulders, over 65% of the material is of sand and gravel sizes. It is termed silt or clay if after the removal of cobbles or boulders, over 35% of the material is of silt and clay sizes. These can then be described in terms of coarse, medium and fine fractions as well as the grading description. Table 4.1 gives a description of the firmness or strength of the soil.

Soil type	Term	Field test
Sands, gravels SP, GP	Loose	Can be excavated with a spade; 50mm wooden peg can be easily driven
	Dense	Requires pick for excavation; 50mm wooden peg is hard to drive
	Slightly cemented	Visual examination; picks removes soil in lumps which can be abraded
Silts SC	Soft or loose	Easily moulded or crushed in the fingers
	Firm or dense	Can be moulded or crushed by strong pressure in the fingers
Clays SC,CL	Very soft	Exudes between the fingers when squeezed in the hand
	Soft	Moulded by light finger pressure
	Firm	Can be moulded by strong firm finger pressure
	Stiff	Cannot be moulded by the fingers; can be indented by the thumb
Organic, peats OH	Very stiff	Can be indented by the thumbnail
	Firm	Fibres already compressed together
	Spongy	Very compressible and open structure
	Plastic	Can be moulded in the hand and smears the fingers

Table 4.1 General Soil Classification

Table 4.2 below is the British soil classification system for engineering purposes. This gives a better overall description on how the British classify their soils.

Table 1.4 British Soil Classification System for Engineering Purposes

Soil groups			Subgroups and laboratory identification			
GRAVEL and SAND may be qualified sandy GRAVEL and gravelly SAND, etc., where appropriate			Group symbol	Subgroup symbol	Fines (% less than 0.06 mm)	Liquid limit
COARSE SOILS less than 35% of the material is finer than 0.06 mm	GRAVELS More than 50% of coarse material is of gravel size (coarser than 2 mm)	Slightly silty or clayey GRAVEL	G: GW, GP	GW GPu GPg	0 to 5	
		Silty GRAVEL Clayey GRAVEL	G–F: G–M, G–C	GWM GPM GWC GPC	5 to 15	
		Very silty GRAVEL Very clayey GRAVEL	GF: GM, GC	GML, etc GCL GCI GCH GCV GCE	15 to 35	
	SANDS More than 50% of coarse material is of sand size (finer than 2 mm)	Slightly silty or clayey SAND	S: SW, SP	SW SPu SPg	0 to 5	
		Silty SAND Clayey SAND	S–F: S–M, S–C	SWM SPM SWC SPC	5 to 15	
		Very silty SAND Very clayey SAND	SF: SM, SC	SML, etc SCL SCI SCH SCV SCE	15 to 35	
FINE SOILS more than 35% of the material is finer than 0.06 mm	Gravelly or sandy SILTS and CLAYS 35% to 65% fines	Gravelly SILT Gravelly CLAY	FG: MG, CG	MLG, etc CLG CIG CHG CVG CEG		<35 35 to 50 50 to 70 70 to 90 >90
		Sandy SILT Sandy CLAY	FS: MS, CS	MLS, etc CLS, etc		
	SILTS AND CLAYS 65% to 100% fines	SILT (M-SOIL) CLAY	F: M, C	ML, etc CL CI CH CV CE		<35 35 to 50 50 to 70 70 to 90 >90
ORGANIC SOILS		Descriptive letter 'O' suffixed to any group or subgroup symbol				
PEAT		Pt				

Table 4.2 The British soil classification system

4.2 Case Study 1

4.2.1 General Remarks

Area 1 is located in the north-western area of Surfers Paradise, bordering on Southport. The map displaying this location, using Autodesk Map 2004, can be found in Appendix A. The boreholes have been located with very close proximity to each other in this area. Identified in area 1 are five borehole locations. The borehole logs of this area are presented in Appendix B.

4.2.2 Soil Profile for Area 1

The boreholes performed in area 1 give fairly consistent results concerning the soil profile. The soils profile is displayed below in Figure 4.1 which is a picture depicting the soil profile for this area. The picture is a display of the borehole profiles as if they were located next to each other. However, this is not the case, rather, they are located within close proximity of each other.

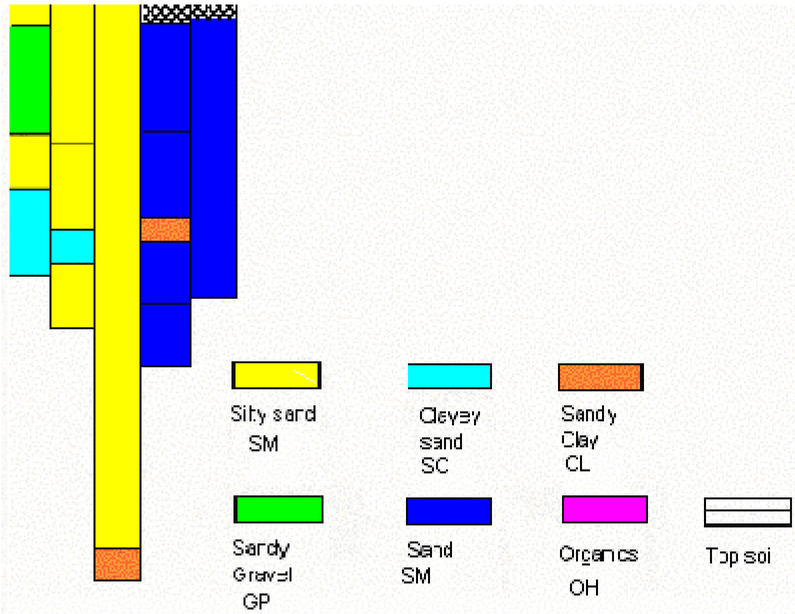


Figure 4.1- Soil profiles for area 1

As can be seen from the plot, the results are fairly consistent with sand and silty sand been the dominating profiles. A breakdown of the distribution of the soil profile is presented in Figure 4.2 below.

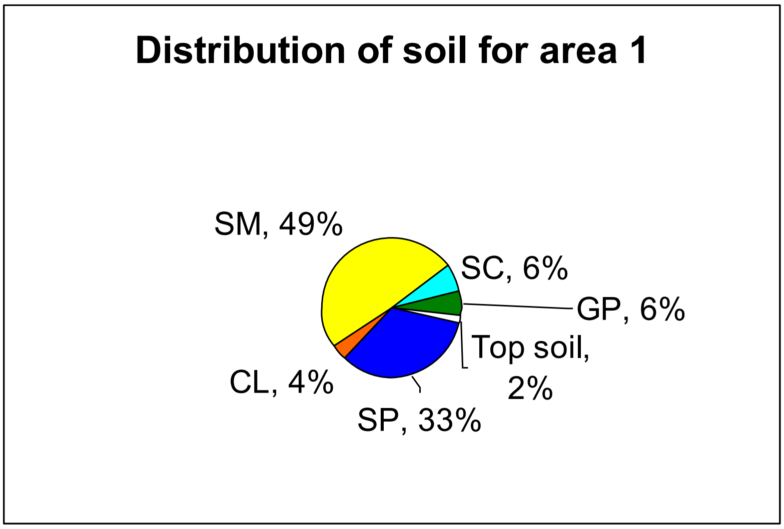


Figure 4.2- Distribution of soil for area 1.

The pie chart presents the results percentage wise for the distribution of the soil profiles for area 1. As can be see from the results the dominating profiles are sand and silty silty making up a large majority of the profile. However, it is apparent that traces of sandy gravel, clay, clayey sand and top soil are also present in this area.

Using Autodesk Map 2004, two maps have being established that displays the study area with the soil profile and soil distribution. Appendix C displays the results obtained from the mapping program when the soil distribution and soil profile are viewed along with the map of the study area.

4.2.3 Standard Penetration Test Results for Area 1

The Standard Penetration Test results for area 1 has come from site 7935 which is located on The Boulevard, Surfers Waters. The plot of the number of blows does not display the normal trend of the common relationship that exists between the depth and the soil density. This relationship is characterised by increasing depth relating to an increase in the soils density. The plot is shown in figure 4.3. The trend is not apparent in this case because of the different soil densities discovered beneath the surface. By referring to the soil characterisation profile corresponding to the depth of the borehole beside the SPT plot it can be seen that at the greatest depth the borehole reached, silty sandy clay was encountered. By referring to Appendix B and borehole log number 7935, it can be seen that the density of the soils actually decrease with depth in this case. The top of the subsurface layer is characterised by medium dense soil and then the profile changes to very loose to very firm. This therefore is the reason explaining why the Standard Penetration resistance does not increase with depth in this location. The mean number of blows for this site is 6 and using figure 3.1 the table concludes that this soil profile is indeed loose. The borehole log has found that the majority of the soil is in fact medium dense but due to the degree of looseness in the soil the chart indicates otherwise.

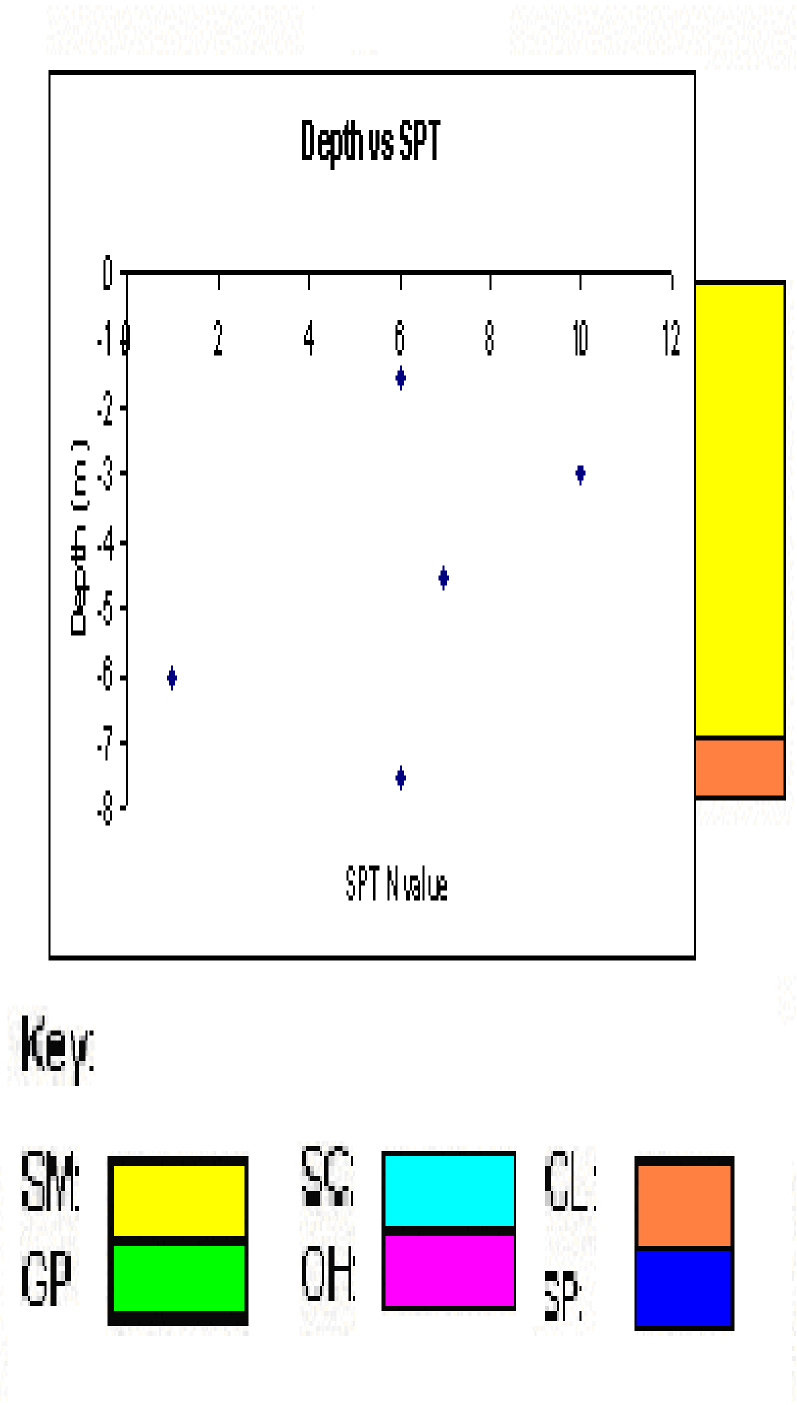


Figure 4.3 Depth vs SPT N value for site 7935

4.3 Case Study 2

4.3.1 General Remarks

The data obtained pertaining to area 2 can be found on or around the area of the Isle of Capri. In this area five suitable borehole logs were taken and the location of these, using Autodesk, can be seen in Appendix D. The actual borehole logs of this area are presented in Appendix E.

4.3.2 Soil Profile for Area 2

The distribution of the soils profiles for this area are relatively inconsistent. Even though the soil types are similar their actual distribution at the various depths they were found to be at are quite inconsistent. A reason for this could be that because some of the data is found on the Isle of Capri while some of the data is located opposite the island. Disruption caused by the formation of this island as well as other contributors such as dredging and other activity in the Nerang River could have had a detrimental affect to the layers of the subsurface soils. As a result some of the soil may have actually been displaced producing the unusual mix of the soil profile found for this area. The soil profile plot for area 2 is presented below in Figure 4.4.

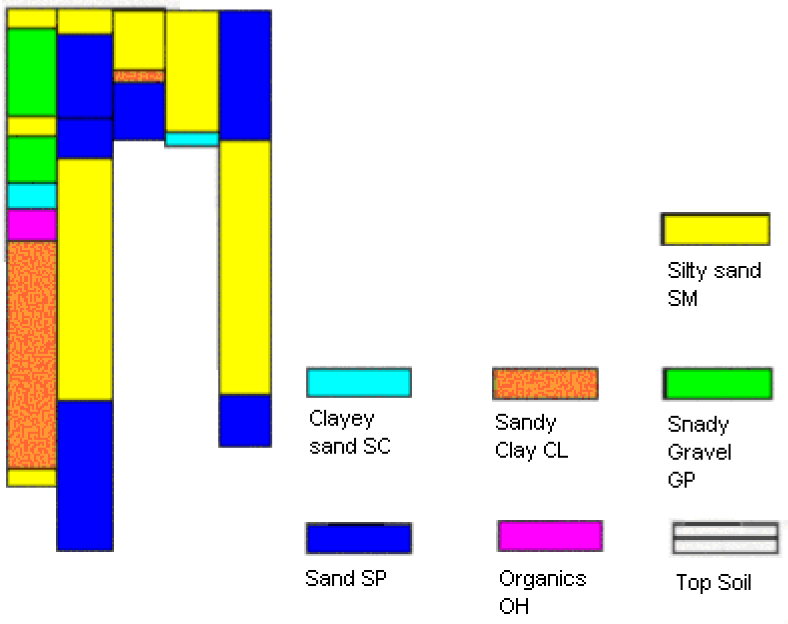


Figure 4.4 – Soil Profiles for Area 2

As can be seen from the results of the soil profile sand and silty sand are the dominant profiles. Also found in this area that is not as common in other areas is a borehole log that found a substantial portion of a sandy clay deposit. Traces of sandy gravel and the peat material have been found. Presented below in Figure 4.5 is the breakdown of the distribution of soils for area 2.

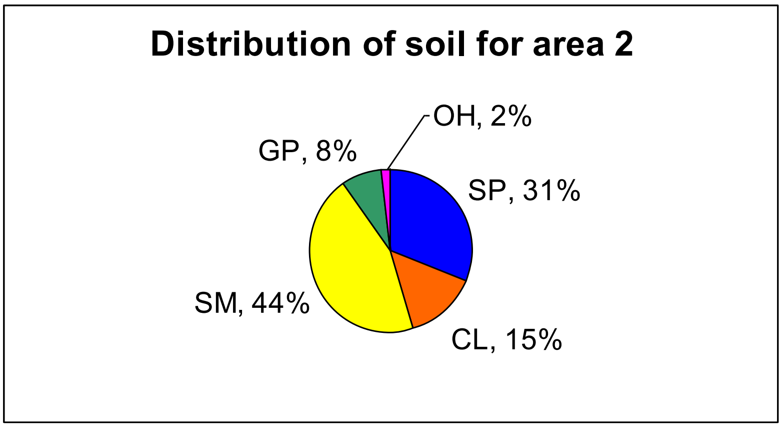


Figure 4.5 – Soil Distribution for Area 2

The resulting pie chart from the distribution of the soils for area 2 produces a fairly scattered display of the soils found. Silty sand comprises 44% of the total soil profile while sand makes up a little less at 31%. The remaining soils are clay, sandy gravel and a fine trace of the organic material has also been recorded.

Using Autodesk 2004, the soil map displaying the soil profiles and soil distribution can be found in Appendix F. Here the study area is presented along with the results of the tests performed.

4.3.3 Standard Penetration Test Results for Area 2

The Standard Penetration Test results for area 2 have come from three different locations. These sites are 7066 (located at Panorama Towers), 7539 (located at The Promenade, Surfers Waters), and 7695 (located at Sunrise Boulevard, Surfers Paradise). The plot of the Standard Penetration resistance for site 7066 is Figure 4.6, site 7539 is Figure 4.7 and site 7695 is Figure 4.8. Figure 4.7 of site 7066 only has two data points available but products very different results. The SPT is performed at depths of 6 meters and 6.5 meters but produces resistance values of 7 and 28 respectively. By referring to the borehole log in Appendix C it can be seen that the densities of the soil do vary between these depths as the soil profile changes. This change in soil profile can be seen in figure 4.8 where the soil changes from a medium dense silty sand to a more dense sand. This contributes to the dramatic change in the penetration resistance recorded.

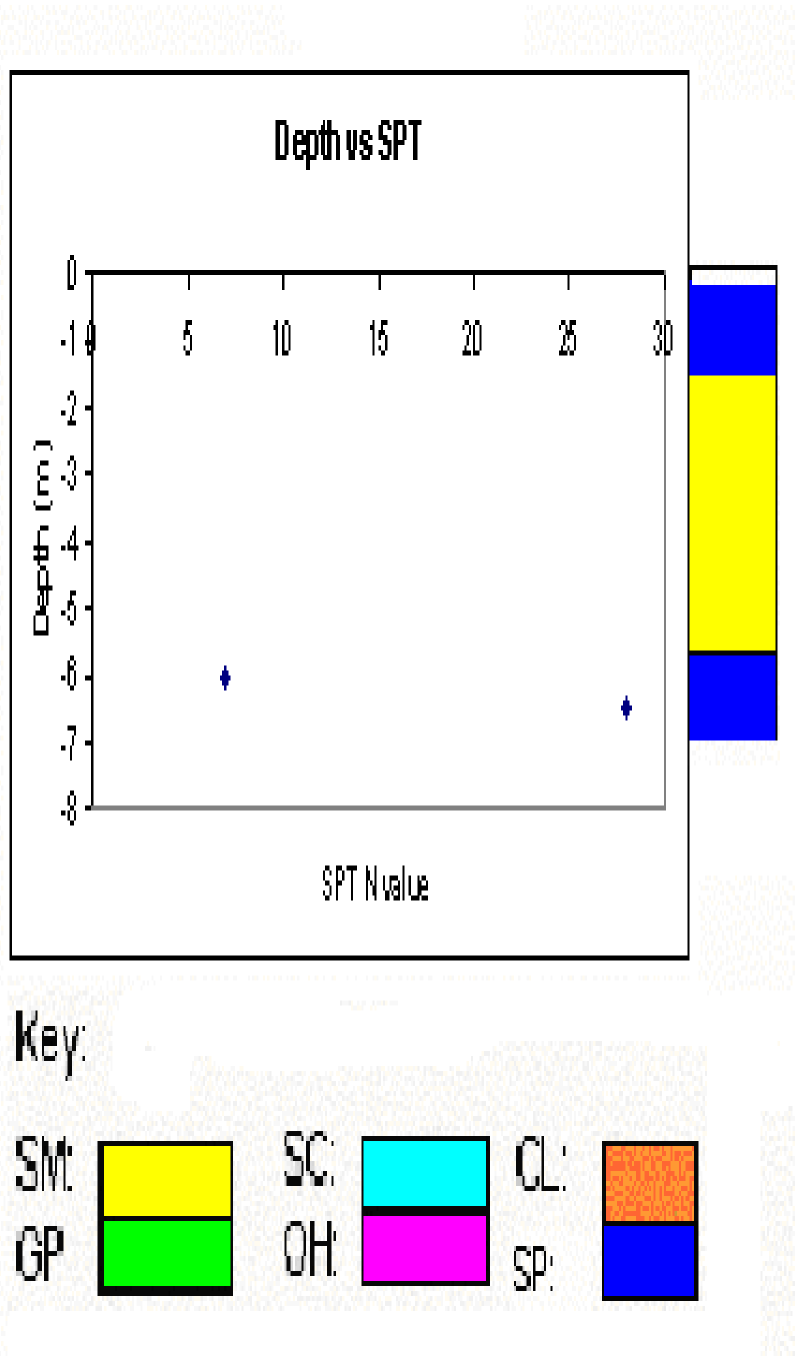


Figure 4.6 Depth vs SPT N Value for Site 7066

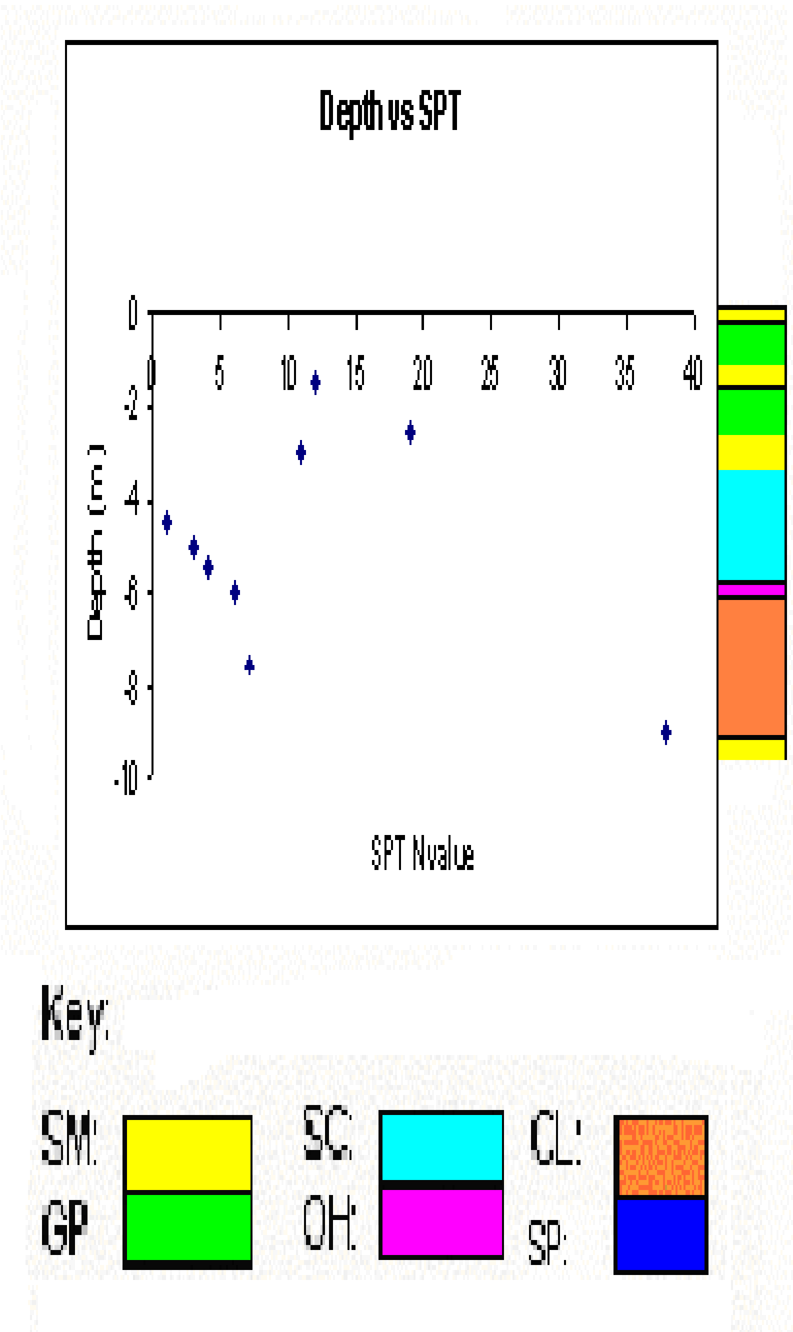


Figure 4.7 Depth vs SPT N Value for Site 7539

The soil profile for site 7539 is unique in that it is the only site encountered in this thesis that does not have any sand present. By saying this there is a lot of silty sand but not just sand. Figure 4.7 presents the curve of the relationship that exists between depth and the density of the soil. This curve downwards is interrupted by a dense upper layer of sandy gravel. This leads the standard penetration resistance to be quite large at a very shallow depth beneath the surface. The borehole profile is generally characterised by loose deposits of soil and then at a depth of about 6 meters a stiff sandy clay is found lying above a very dense silty sand. Although the sandy clay is quite stiff the resistance recorded is not large because the material is in fact clay which measures smaller values for the Standard Penetration resistance. The mean of this site is in fact quite low at 11 blows. This indicates that the soil is in fact quite loose (refer to Table 3.1 for reference) even though the borehole profile tends to suggest quite a large combination of dense and medium dense sands with few loose layers.

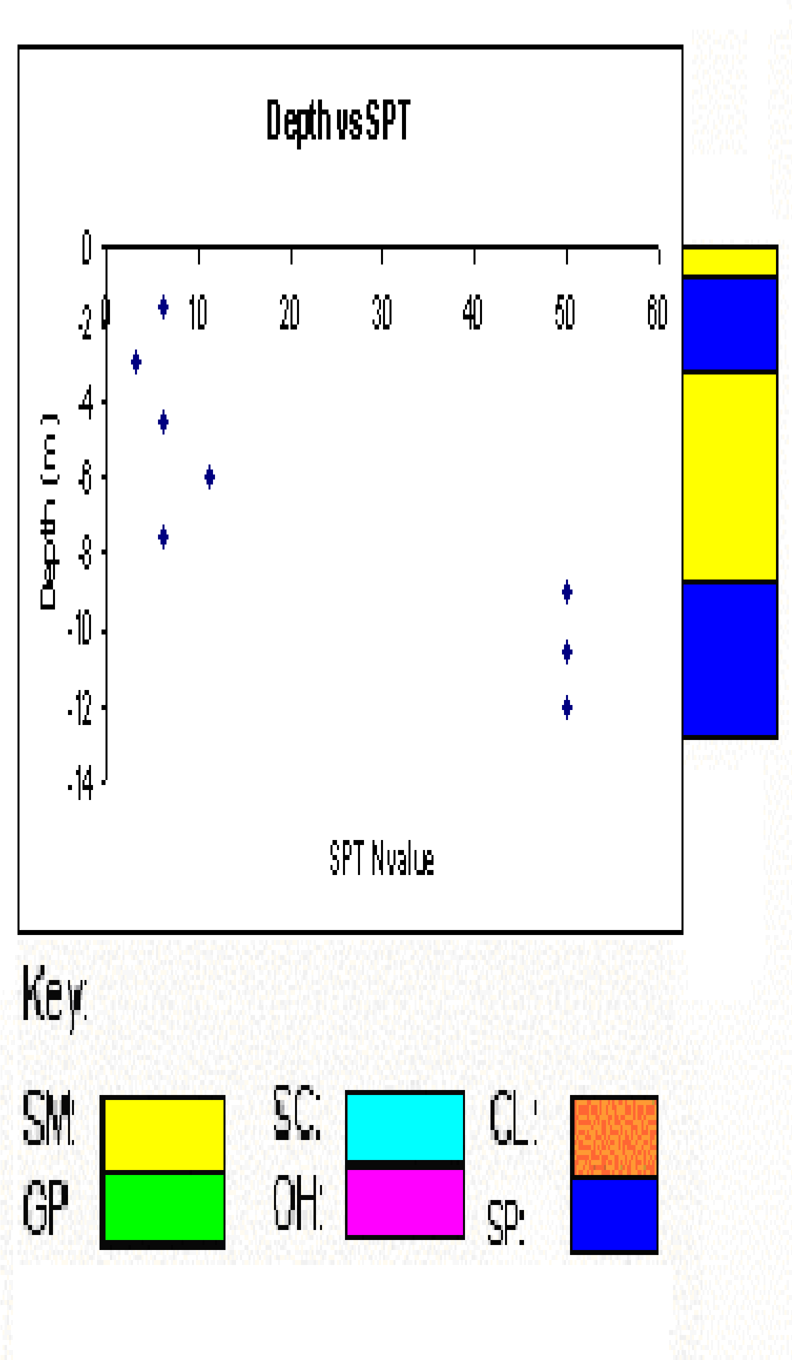


Figure 4.8 Depth vs SPT N Value for Site 7695

The soil profile of Figure 4.8 indicates deposits of sand and silty sand. This is a typical representation of the density increasing as the depth increases. However, to gain a true representation of the SPT the soil needs to be the same material. A curve is therefore not produced as the sand interchanges from silty sand to sand a number of times. The results of the SPT are scattered up to a depth of about 8 meters and then a very dense sand deposit is encountered. Figure 4.8 represents this as resistance values of 30 are encountered. The case however is that the operator of the sampler recorded the results as >30 thereby preventing the establishment of any curve for this section of the soil. However, it can be said that the resistance for this sand deposit would be quite large as the soil profile is very dense.

4.4 Case Study 3

4.4.1 General Remarks

Area 3 encompasses borehole data obtained from Chevron Island and Budd's Beach. The data found in this area was limited to only three sets however this proving sufficient to view the soil profile. Once again the location of area 3 can be seen on the map in Appendix G while the actual boreholes referring to this area can be viewed in Appendix H.

4.4.2 Soil Profile for Area 3

The soil profile for area 3 is based on limited data from this area. However, from the results it is conclusive that the soil profiles are consistent in this area and match the data obtained from other areas reasonably accurately. The profile for area 3 is produced below as figure 4.9.

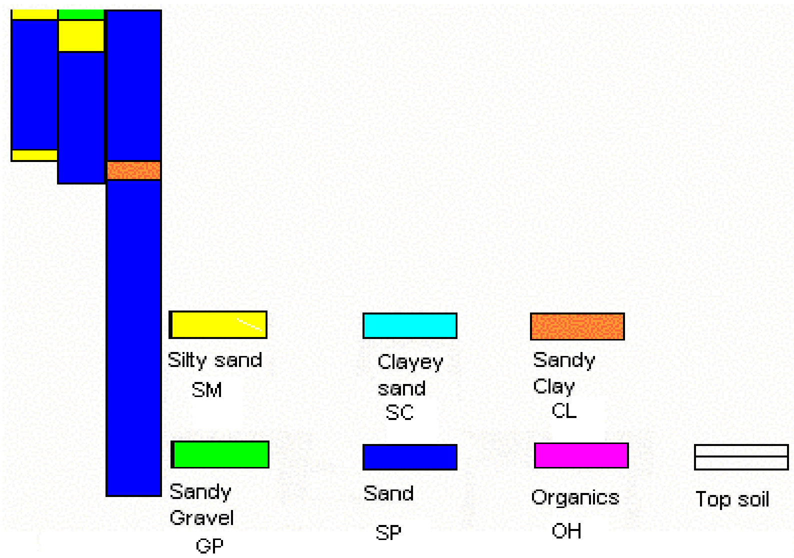


Figure 4.9 – Soils Profiles for Area 3.

As can be seen from the results, the most dominant profile is the sand. This can be attributed to the fact that each piece of data collected for this profile was obtained from a site 'on the water'. This means that the borehole log was taken no further than 30 meters away from the shoreline of the Nerang River and that is why an extremely large portion of the soils profile is sand. The distribution of the soil for area 3 is presented below in Figure 4.10.

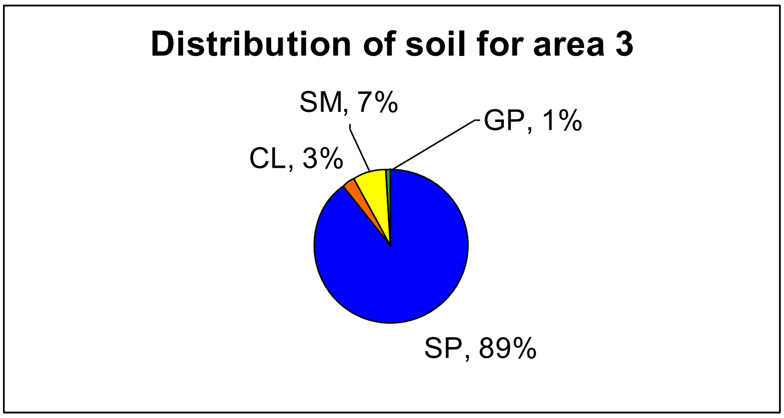


Figure 4.10 – Soil Distribution for Area 3.

It is evident from the pie chart produced that sand is the dominant profile. Traces of silty sand, sandy gravel and clay have also been located. However, these elements pale in comparison to the massive 89% of sand found in this area.

Using Autodesk Map 2004, a soil map has been plotted that displays the study area as well as the soil profiles and distributions. This map can be seen in Appendix F and Appendix I.

4.4.3 Standard Penetration Test Results for Area 3

The Standard Penetration resistance values for this are have been obtained from site 4819 which is located on two lots along Tarcoola Crescent, Chevron Island. The plot of the Penetration resistance is presented in Figure 4.11 below.

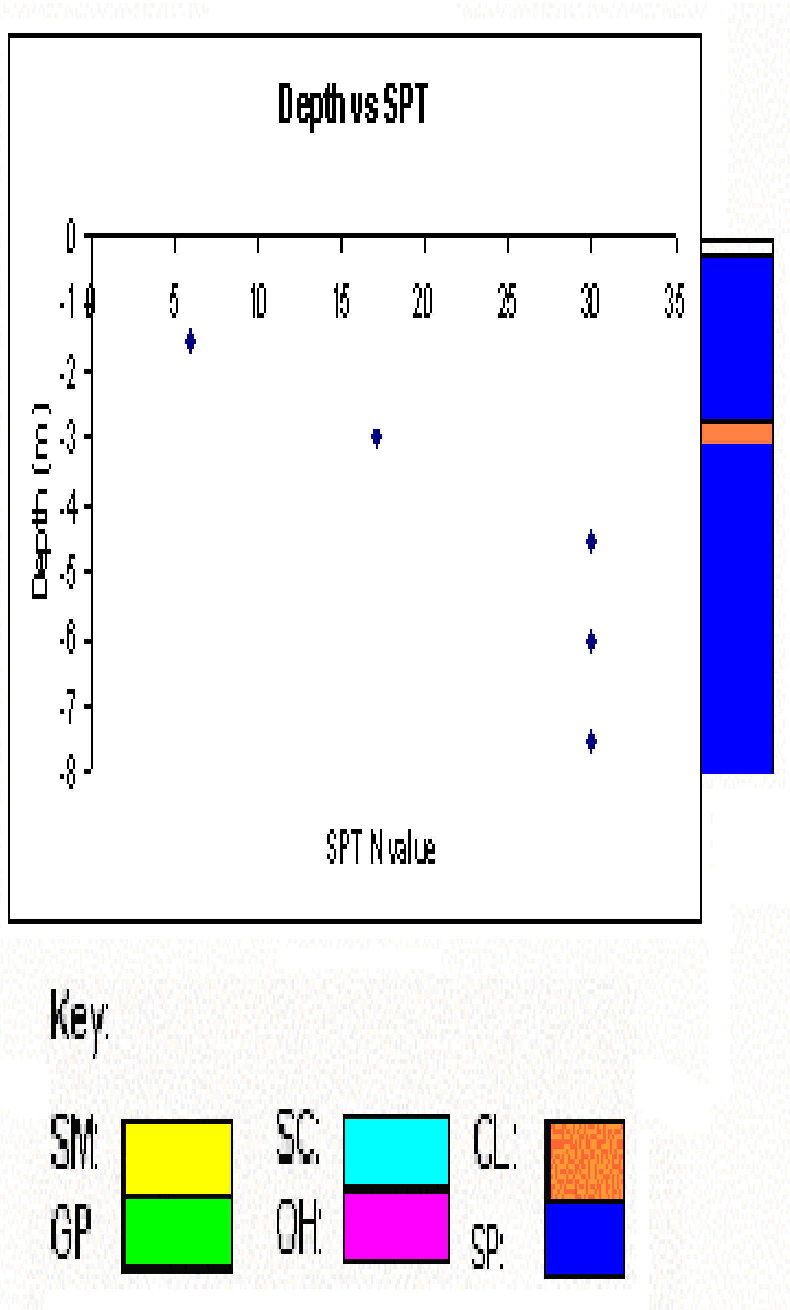


Figure 4.11 Depth vs SPT N Values for Site 4819

The soil profile for this site indicates that the soil is composed of sand with a thin layer of clay approximately 2.7 meters below the surface. The relative density of the soil at this location is dense-very dense. This can be viewed in Appendix D, site 4819. Again the operator has stopped driving the sampler when 30 blows have being registered. This prohibits a curve been established displaying the relationship between depth and resistance. From the soil profile map beside the graph in Figure 4.11 it can be seen that the larger of the two recorded results was taken in a firm clay layer. Had this clay layer not been encountered the resistance measured would actually be larger if the sand layer was there instead. It would have become denser as the depth increased and therefore the sampler would have recorded more blows.

4.5 Case Study 4

4.5.1 General Remarks

The data obtained for area 4 has been located in southern Main Beach, just north of Surfers Paradise. The map plotting the location of these data points can be found in Appendix J. The actual borehole plots of this location can also be found in Appendix K. The amount of data found in this area was very disappointing with only two boreholes been obtained for lower Main Beach.

4.5.2 Soil Profile for Area 4

The profiles of the soils found for area 4 are extremely consistent, however, this been determined on only two data sets for this area. From the boreholes obtained from area 4 a soil profile chart is presented below as Figure 4.12.

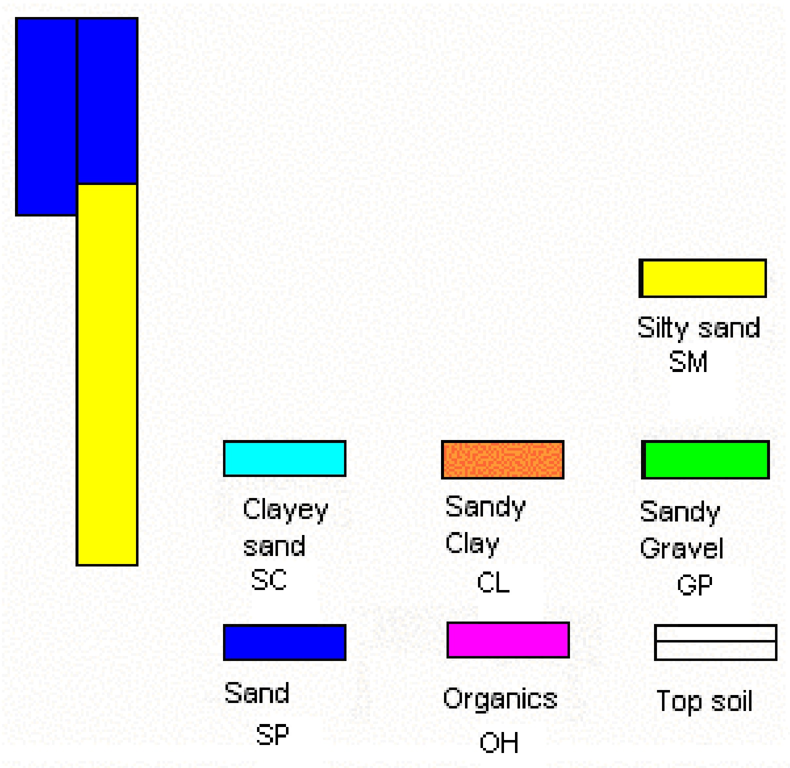


Figure 4.12 – Soils Profiles for Area 4

It can be seen that the boreholes obtained for this area only encountered sand and silty sand. The correlation between the two profiles is consistent as the sand profiles match one another fairly evenly until the second profile encounters silty sand. A breakdown of the distribution of the soil profiles is presented below in Figure 4.13.

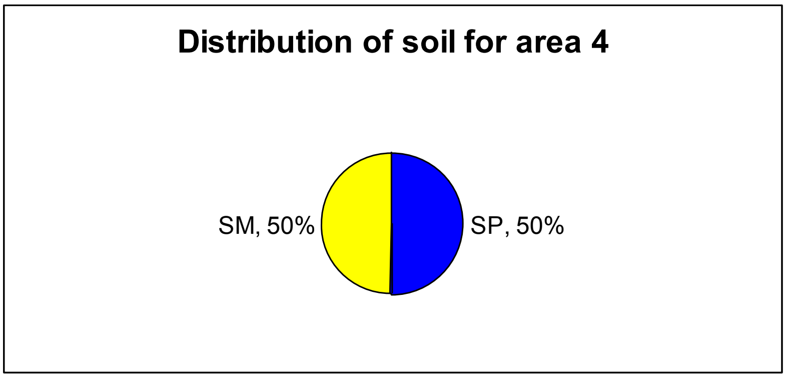


Figure 4.13 – Soil Distribution for Area 4

As depicted by the pie chart in Figure 4.13, sand and silty sand are equally distributed in area 4. The reasons underlying the finding of only two profiles is due to the relative depth the boreholes reached.

Autodesk Map 2004 has successfully plotted the study area along with the soil distribution and soil profile of area 4. This can be seen in Appendix L.

4.5.3 Standard Penetration Test Results for Area 4

The results of the Standard Penetration Tests for area 4 come from site 7897 located on Tedder Avenue, Main Beach. Figure 4.14 below represents the resistance encountered by the sampler at the various depths up to 6 meters. The soil profile of this particular location shows that silty sand and sand were encountered of generally loose nature, particularly the uppermost part of the silty sand which was recorded as very loose. An initial dense deposit of sand was encountered and that's the underlying reason why a larger N value was recorded at such a shallow depth (approximately 2.7 meters). However apart from this, the plot indicated consistent results correlating to an increase in the silty sands density as the depth increased.

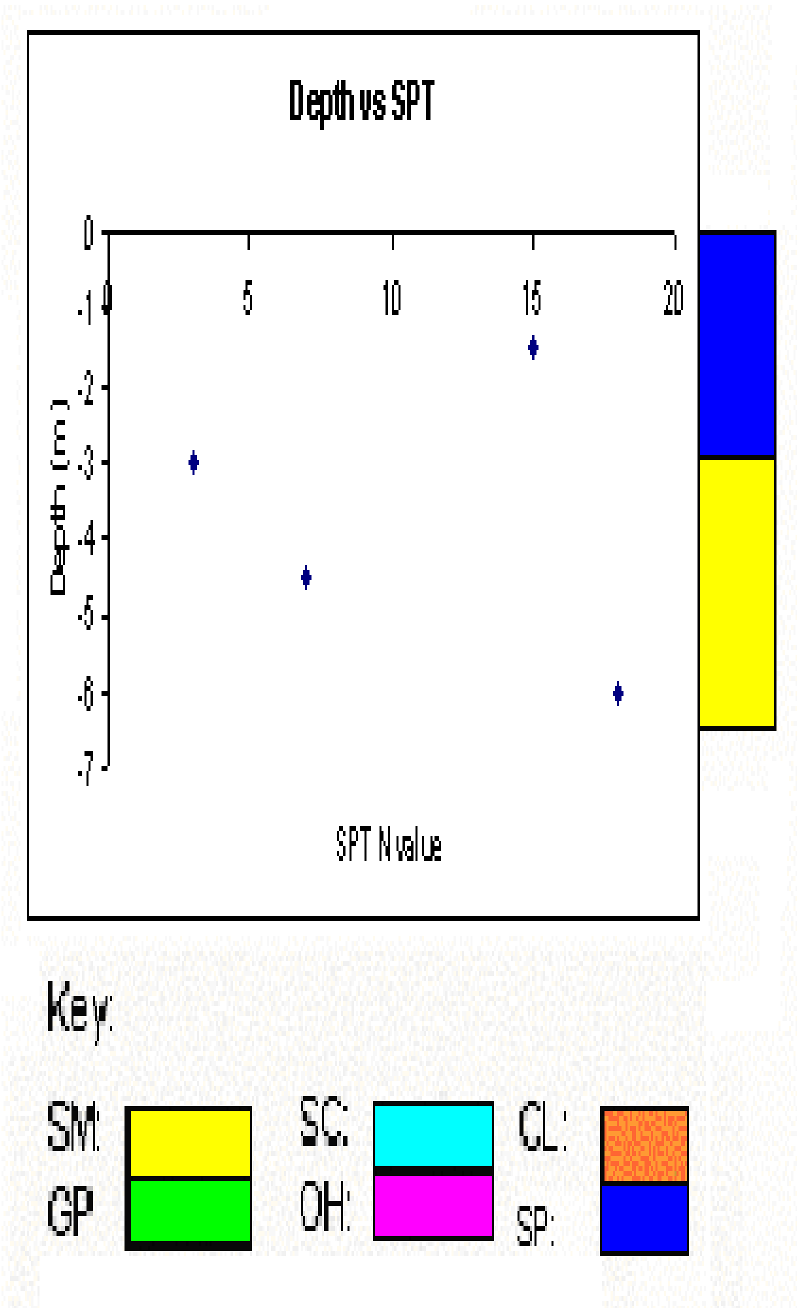


Figure 4.14 Depth vs SPT N Value for Site 7897

4.6 Case Study 5

4.6.1 General Remarks

The data collected for area 5 includes both borehole logs and Cone Penetration Test results. This focus area has been established around the CPT data obtained for the Convention Centre. In this area four different locations were found to have borehole logs and the map of this area is found in Appendix M. The actual borehole logs are located in Appendix N. A large amount of CPT data was obtained for this area but only a few samples are produced that give an overall picture of the general nature of the results produced by the CPT data.

4.6.2 Soil Profile for Area 5

Area 5 produced consistent results from each of the boreholes obtained from this location. Only sands and a fine layer of organic material or the peat layer was encountered. The profile is presented in Figure 4.15.

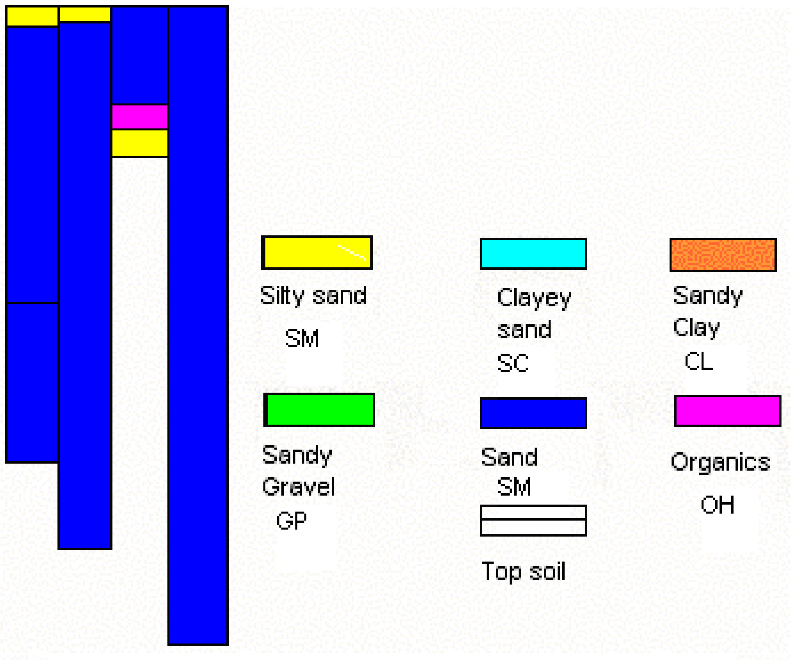


Figure 4.15 – Soils Profiles for Area 5

As can be seen from the above profile of the soils the boreholes encountered, the peat layer has been found at a relatively shallow depth. This is of concern to geotechnical engineers as the peat layer can cause a great deal of damage to a structure if the foundations lie in this layer. Peat is a very compressible layer of organic material that may cause the foundations of a building to settle more than expected thus causing disruption in the design of the building. Seen as the peat was located at such a shallow depth in a residential area, the design of the foundation that is to rest on this peat layer must not lie within this peat layer. The foundation must either rest above the peat layer or be placed below the peat layer so that the foundation is not compromised by the peat material. Figure 4.16 presents the breakdown of the distribution of the soil profiles for area 5 and is displayed below.

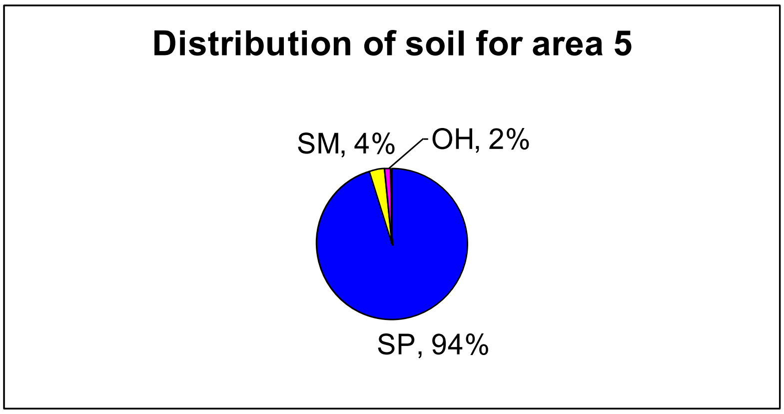


Figure 4.16 – Soil Distribution for Area 5

Figure 4.16 shows that Area 5 is high in sand (94%) and has traces of silty sand (4%) and peat (2%). This data has been collected over a few boreholes so the profile for Area 5, which is Broadbeach, is consistent. This could be due to the fact that the data has been collected from locations that are very close to one another and little ground activity has occurred in this area to disrupt the sub soil layers.

Using Autodesk Map 2004 a final presentation of the study area and the soil profile and distribution has been presented in Appendix O.

4.6.3 Standard Penetration Test Results for Area 5

The results of three Standard Penetration Test results have been found for area 5. These are sites 4723 (Anne Avenue, Broadbeach), 8102 (Brittania Avenue, Broadbeach), and 8079 (Broadbeach Boulevard, Broadbeach). The plots of the Standard Penetration resistance is presented below (site 4723 is Figure 4.17, site 8102 is Figure 4.18, site 8079 is Figure 4.19).

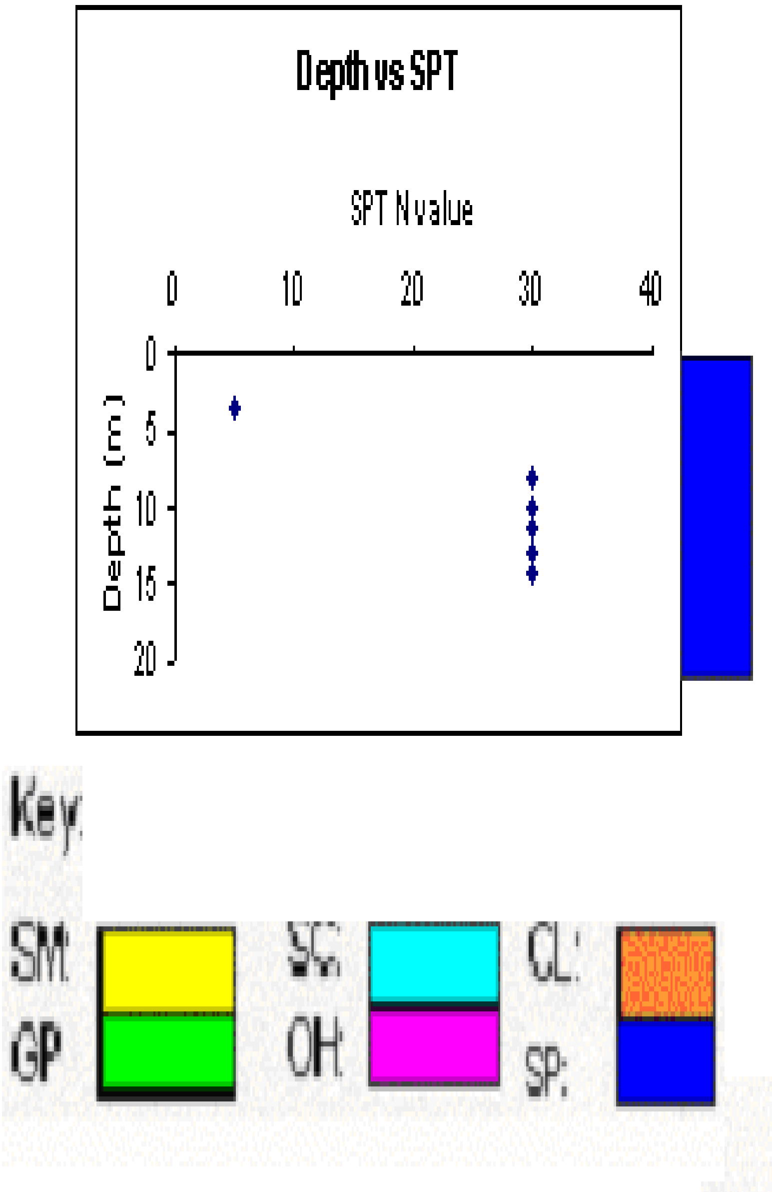


Figure 4.17 Depth vs SPT N Value for Site 4723

The results for Figure 4.17 are disappointing. All that can be established from this plot is that the soil profile was a very dense sand and as a result of this high values of Penetration resistance were encountered. The operator of the sampler considered the results consistently high and were easily predicted to continue along this trend and as a result, the test was not performed any longer after 30 blows had been exceeded.

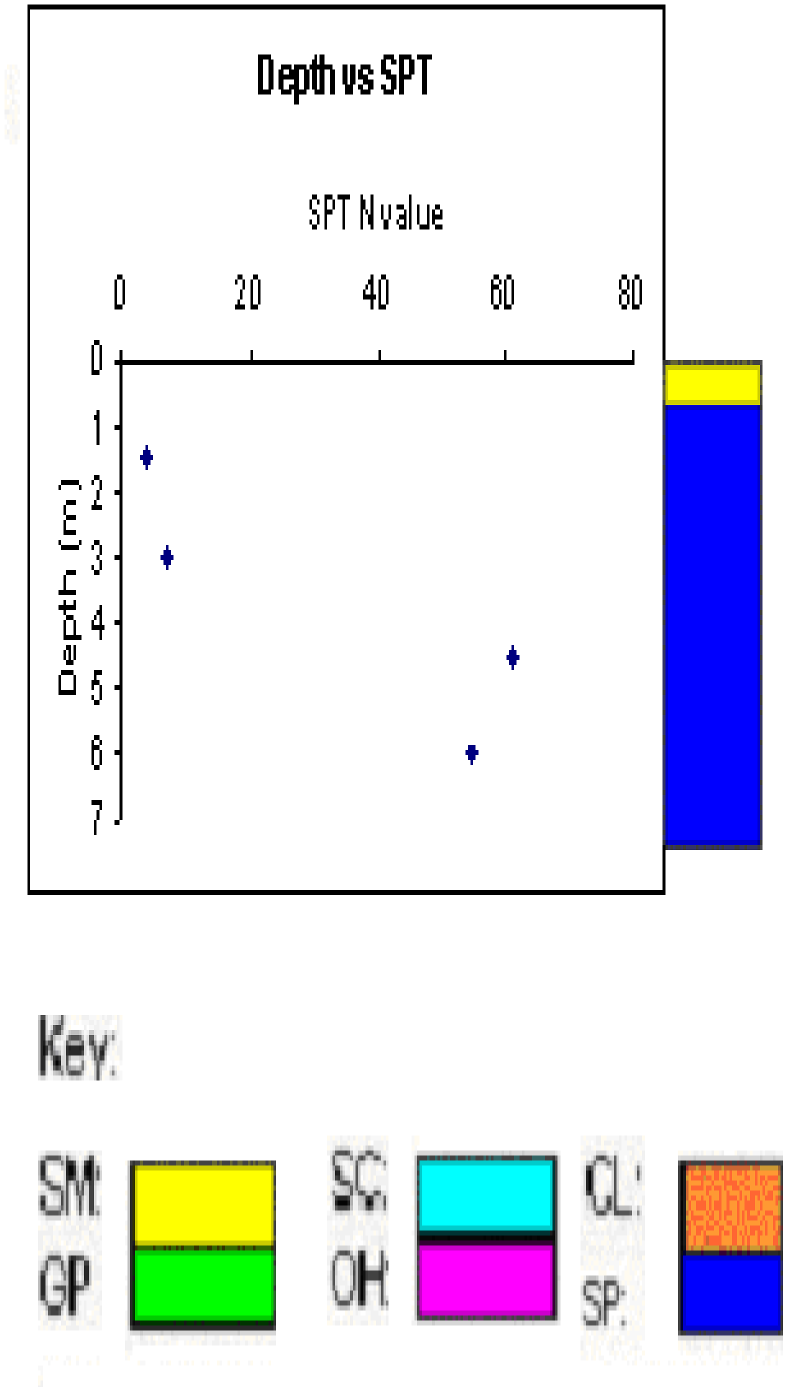


Figure 4.18 Depth vs SPT N Value for Site 8102

The results for Figure 4.18 are a little better. From the soil profile it is clear to see that the soil is consistently sand. The densities vary from loose at the uppermost portion of the sand, down to a very dense profile at the depth the borehole reached. As the depth increased so did the penetration resistance, apart from the result obtained from the greatest depth. The average resistance was measured to be about 32 blows which generally described the soil as quite dense when referring to table 3.1.

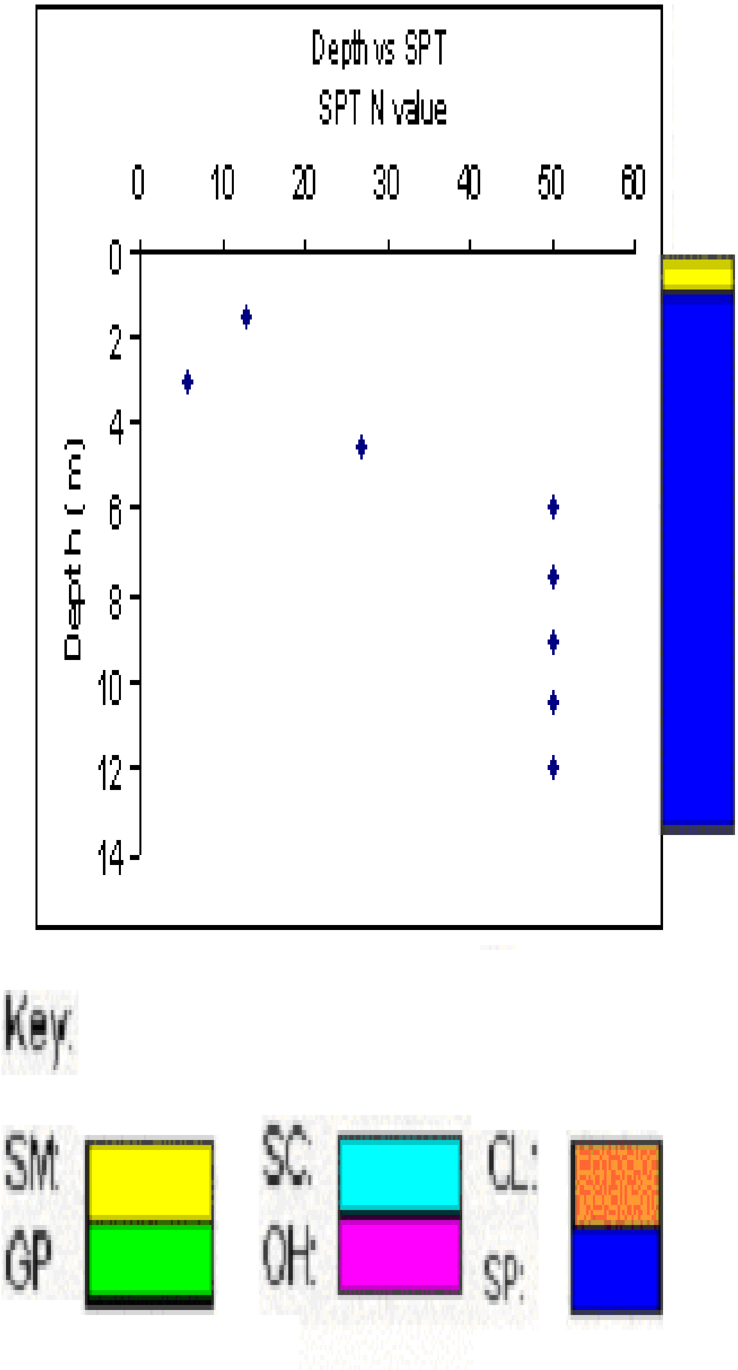


Figure 4.19 Depth vs SPT N Value for Site 8079

When referring to Figure 4.19 it is obvious that there is a common trend in the soil profiles for area 5. Site 8079 is no exception, characterised by a thin layer of silty sand then sand underneath. Once again the trend is similar, characterised by increasing densities in the soil as the depth increases. The mean number of blows for this site is 37 and this indicates an even denser sub surface soil than the previous site. This is however an inaccurate representation of the true mean as when the sampler recorded counts above 30 blows the test was aborted. This therefore gives an indication that, consistent with site 4723, the soil around area 5 is much denser than other soil deposits encountered in this thesis. This is due to the proximity of this area. This area is a bit further away from the other locations and the soils profile is therefore a little bit different to those observe in the first four areas.

4.6.4 Cone Penetration Test Results for Area 5

4.6.4.1 General Remarks

The data pertaining to the Cone Penetration Tests have all been performed at the Convention Centre, Broadbeach. There have been over 100 CPT's undertaken on this site, all with similar results. The tests have recorded sufficient information to plot the depth against the friction ratio as well as the skin friction and cone resistance.

4.6.4.2 Friction Ratio

The friction ratio is a measure of the ratio of local side friction to cone resistance. The friction ratio can be used to identify and classify soils.The two figures below are typical plots of depth against the friction ratio for the Convention Centre. They are presented in Figures 4.20 and 4.21.

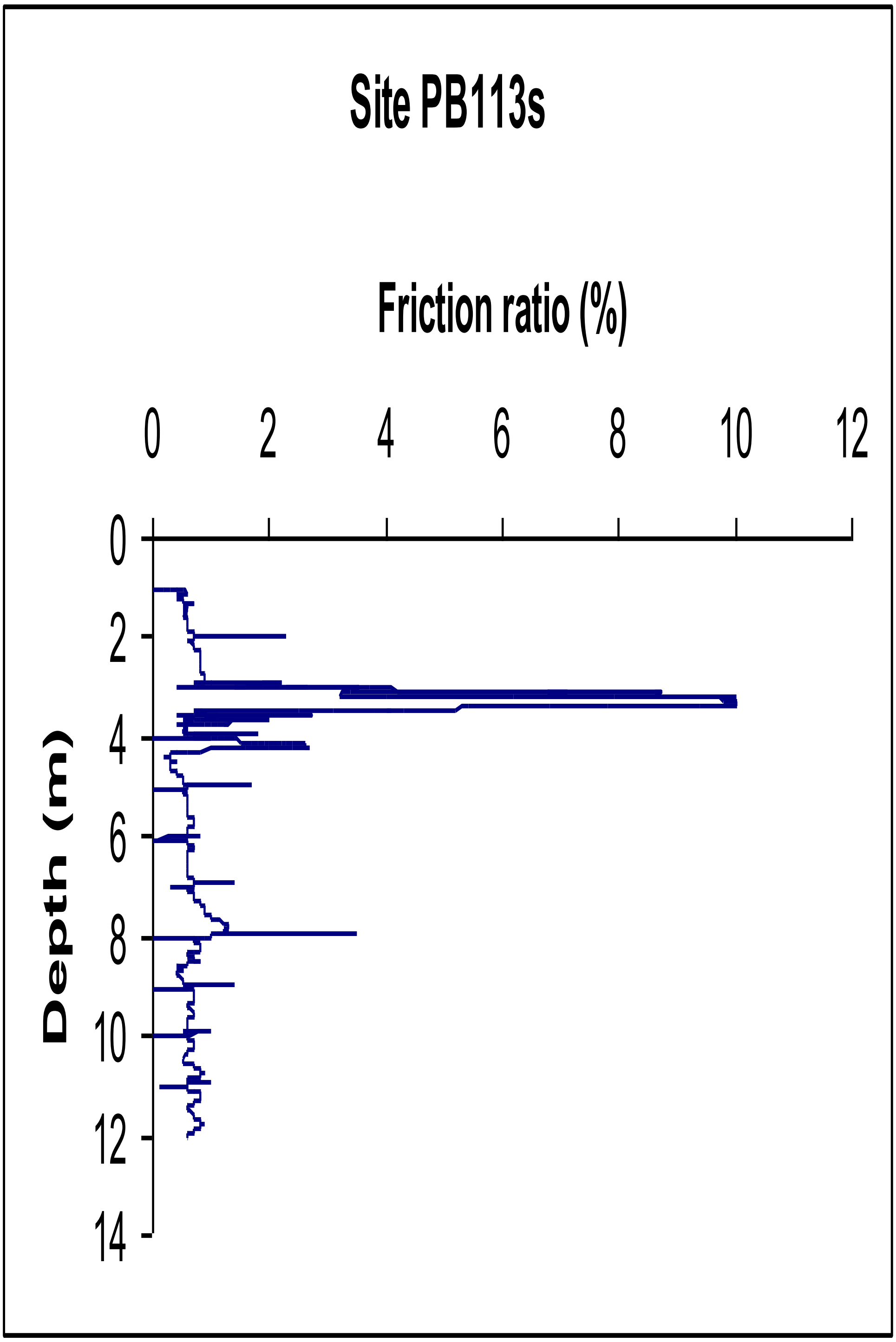


Figure 4.20 Depth vs Friction Ratio for Site PB113s

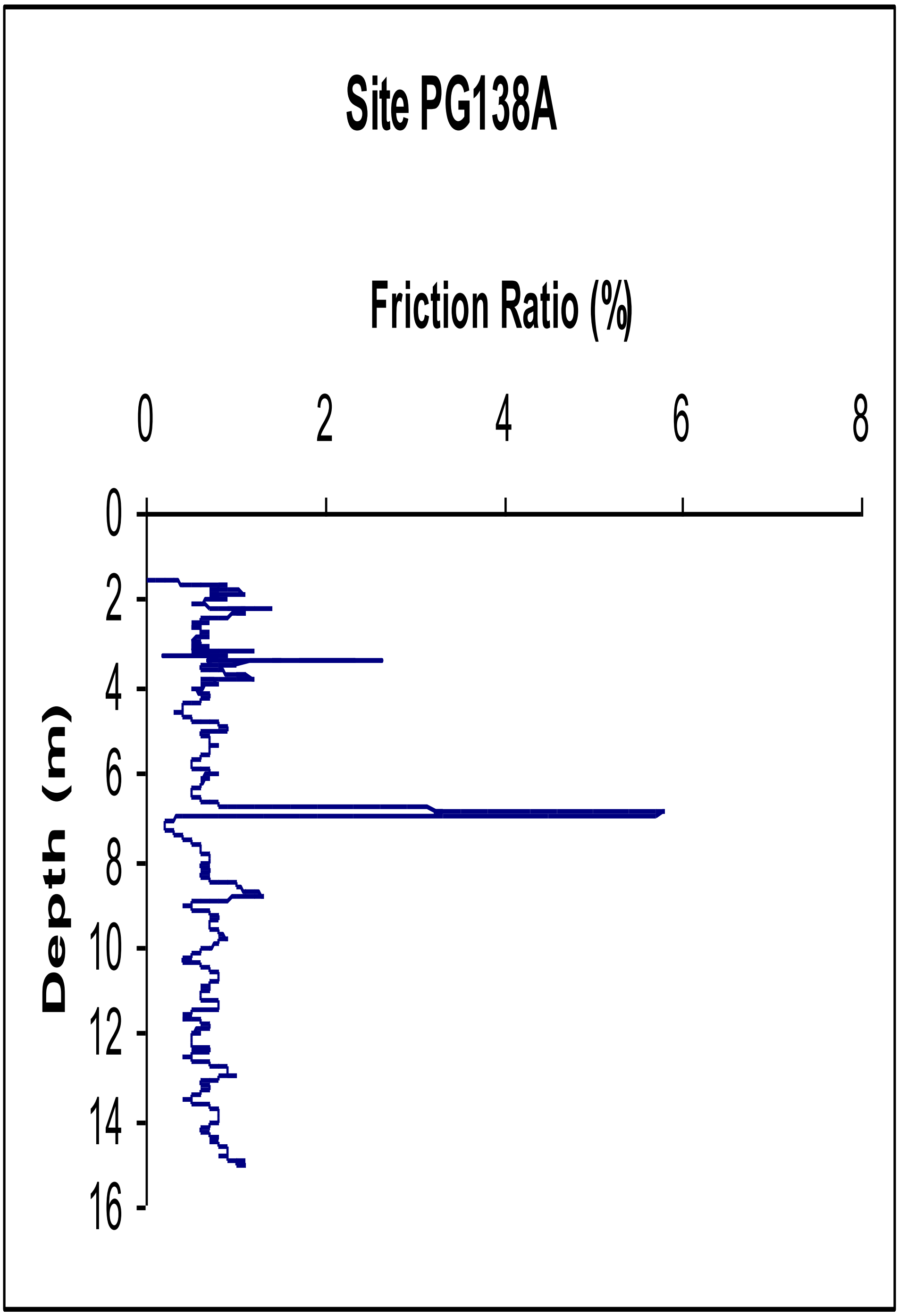


Figure 4.21 Depth vs Friction Ratio for Site PG138A

The above two Figures (4.20 and 4.21) are typical plots of the friction ratio for the Convention Centre site. The curve is consistent except for one minor portion where the curve 'jumps' out to a much larger ratio. As mentioned in chapter three the CPT is useful for identifying smaller layers of different materials that may be missed by typical tests such as boreholes. The 'jump' in the curve indicates that there has been a change in the density of the soil. Meigh (1991) found that friction ratios lying between 1-2% indicate a soil profile of sand, about 5% clay and higher is more organic material. Figures 4.20 and 4.21 give a perfect profile of a sandy soil. The jump indicates that a clayey type material or an organic material may be present. Referring to Figure 4.22, which is borehole log 7063, taken in the vicinity of the location where the CPT was performed, it is clear why the friction ratio jumped as it did.

A peat layer was located which caused the cone to measure higher values causing the plot of the friction ratio to record the curve it did.

BOREHOLE PROFILE

CLIENT:		**BOREHOLE No:**	BH 1
PROJECT:	Broadbeach	**JOB No:**	BT 7063
EQUIPMENT TYPE: HAND AUGER		**HOLE DIAMETER:**	85mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL			6.1		**SAND:** Fine grained, Moist, Pale brown **(SP)**	**MEDIUM DENSE**
ALLUVIUM			7.7		**ORGANICS:** Decomposed vegetable matter (strong odour), Very moist, Dark brown/black **(OH)**	**VERY LOOSE**
			15.5		Silty **SAND:** Fine grained, Wet, Dark grey **(SM)**	**LOOSE**
					BH 1 TERMINATED AT 15.5m **LIMIT OF INVESTIGATION**	

Figure 4.22 Borehole 7063

Referring to Figure 4.23 it is clear that no peat layer has been found in this location of the Convention Centre. The curve almost entirely lies between 0.5% and 1% representing a sandy soil profile. The friction ratio is normally about 1-2% for sands but in this case the sand would be less dense than most sand profiles.

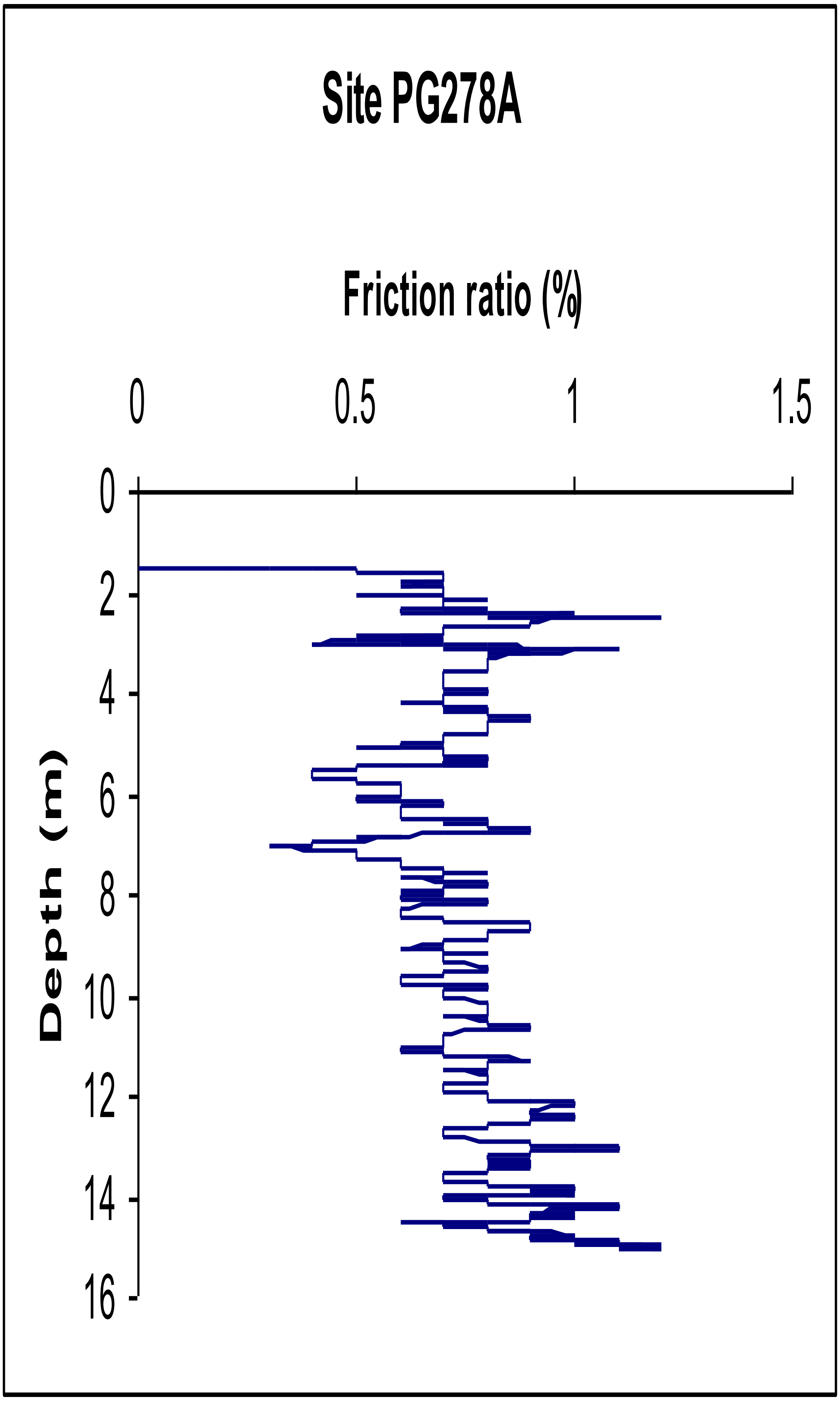


Figure 4.23 Depth vs Friction Ratio for Site PG278A

Figures 4.24 and 4.25 are plots of the skin friction and the cone resistance against the depth respectively. When plotting these results a correlation in the curves of the skin friction, cone resistance and the friction ratio can normally be found. This is due to the formulas been used to find each. In this instance there is a strong relationship in the curves as they seem to compliment each other. It may not be as noticeable on the plot of the friction ratio in Figure 4.21 and this is because the curve has been a little distorted by the discovery of the peat layer which caused the penetrometer to 'jump'.

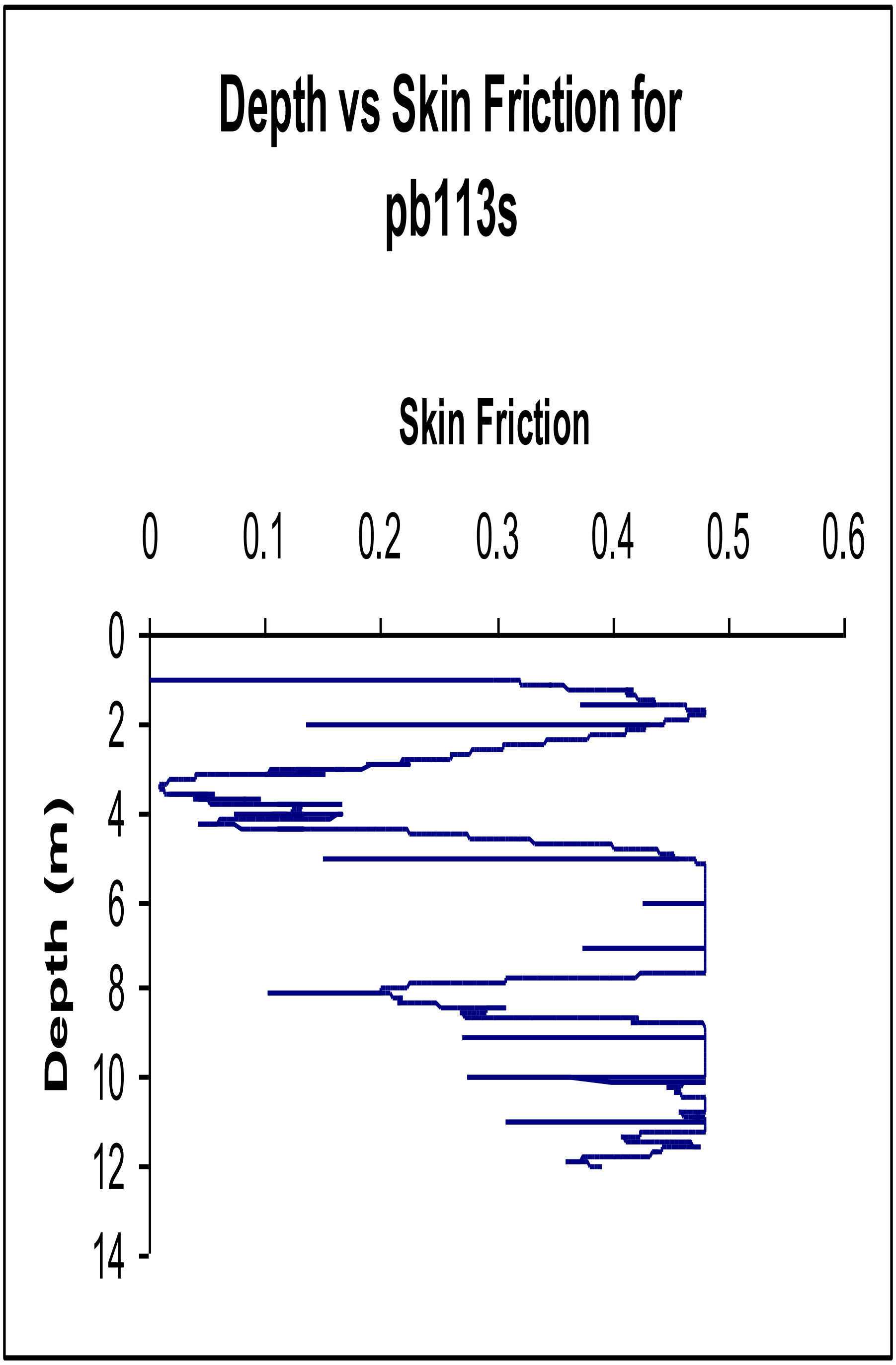


Figure 4.24 Depth vs Skin Friction for Site PB113s

The use of the CPT is to provide geotechnical parameters. The skin friction is found so it can be converted to a friction ratio. By plotting the friction ratio a general classification of the soils profile can be established. In the above plots (Figures 4.20, 4.21 and 4.23) of the friction ratios the soil can be confidently named sand as well as the location of other trace deposits.

The plot of the cone resistance is also useful in establishing geotechnical parameters. Firstly the cone resistance values are needed to establish the friction ratio which classifies the soil.

Then based on a number of formulae and charts the settlement can be calculated by using the cone resistance. A plot of the cone resistance against depth is presented in Figure 4.25 and is site PB113S.

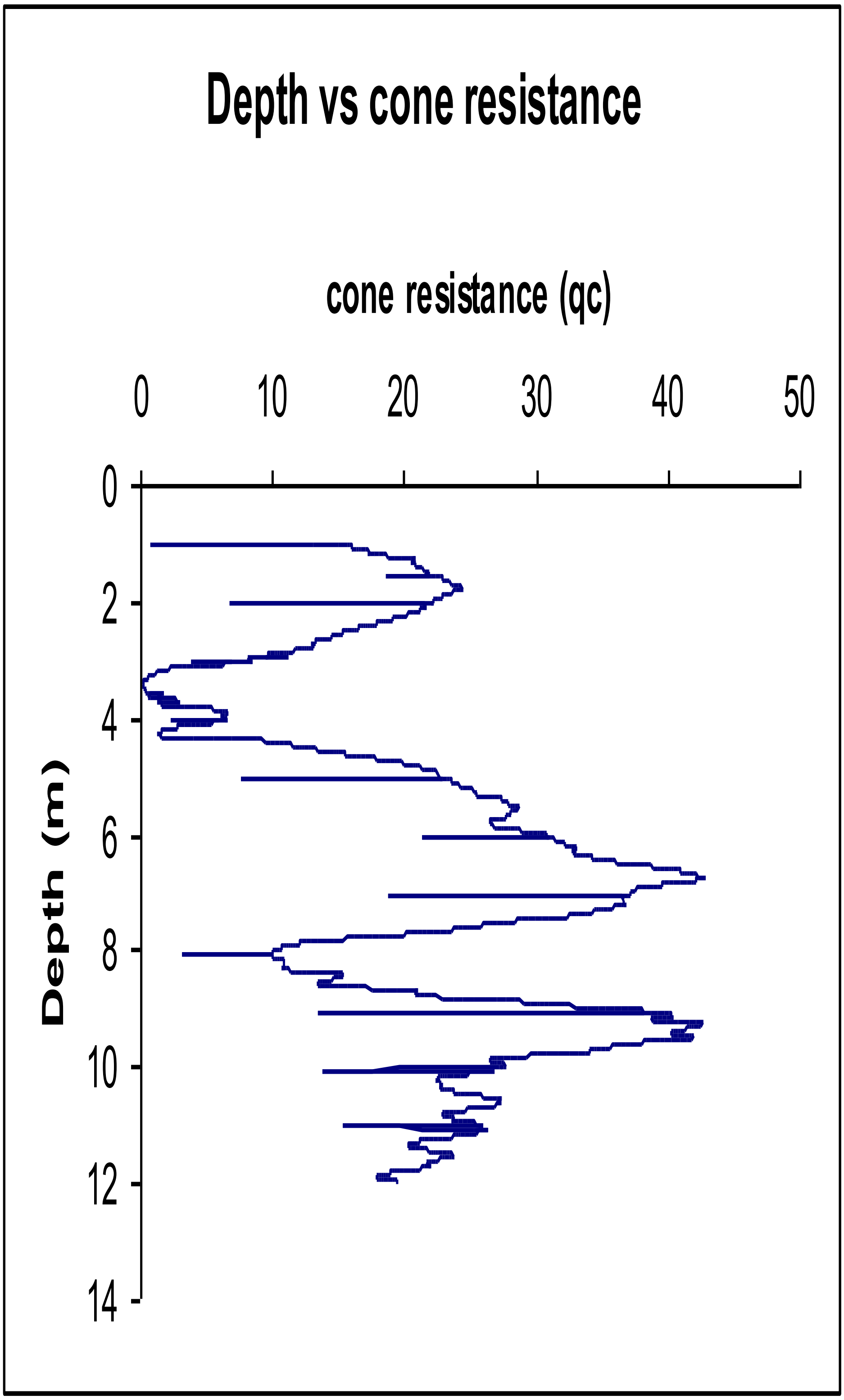


Figure 4.25 Depth vs Cone Resistance for Site PB113s

Another useful purpose of the cone resistance value is when it is plotted (log scale) against the friction ratio. A plot of this can be seen in Figure 4.26 below. The horizontal curve that crosses the x-axis in this case provides the information to classify the soil. By referring to figure 3.3 in the previous chapter and taking into consideration the scales of the charts are a little different, the soil could be seen to be sand. Although this has already been discussed the classification of the soil is now obvious from the analysis performed on the friction ratio plots. However, this is just another method for classifying the soils. The most useful purpose of utilising the cone resistance values comes from its usefulness in been able to assist in predicting the settlement of foundations. Obviously, other parameters need to be considered but the CPT aids in determining the immediate settlement of a foundation.

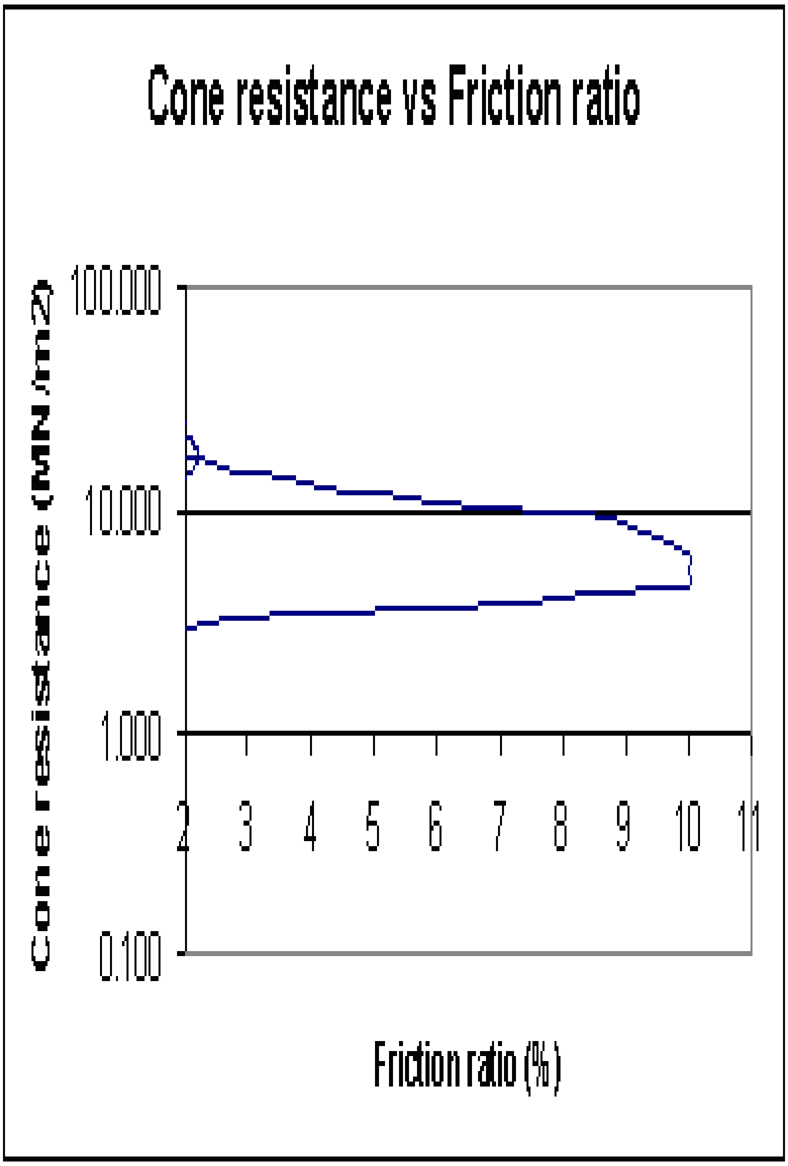


Figure 4.26 Cone Resistance vs Friction Ratio for Site PG138A

4.7 Considerations for the Design of Foundations

A foundation is that part of a structure which transmits loads directly to the underlying soil. If a soil stratum near the surface is capable of adequately supporting the structural loads it is possible to use either footings or a raft (Craig, 1997), these been referred to as shallow foundations.

The allowable bearing capacity of sands for shallow foundations is limited by settlement considerations except for the case of narrow footings. For the limit state design the serviceability limit state is normally the governing criterion and the allowable settlement is reached at a pressure for which the factor of safety against shear is greater than 3. However in the case of narrow footings, shear failure may be the limiting consideration. The pressure that will produce the allowable settlement in a dense sand will be greater than that needed to produce the allowable settlement in a loose sand (Craig, 1997). The soil profile of the areas covered is generally sand and for this reason the settlement should be estimated using the dead load plus the maximum live load. This is because the settlement in sand is rapid and occurs almost entirely during construction and initial loading. Craig (1997) suggests that a reasonable design criterion for footings on sands is an allowable settlement of 25mm and that the settlement of footings is governed by the soil characteristics relatively near the surface and any one of the footings may be influenced by a loose pocket of soil. However, the settlement of a raft is different and is governed by the soil characteristics over a much greater depth.

A building cannot be loaded close to its bearing capacity as the settlements would be too large and the building would be damaged as a result. To limit the settlements to an allowable limit engineers must find a way to reduce the allowable bearing pressure. This is achieved by employing a factor of safety to the bearing capacity. Generally, engineers who design foundations will need to calculate the following parameters (Atkinson, 1993):

1. the bearing capacity (to ensure the foundation has an adequate factor of safety against collapse),
2. the allowable bearing pressure and either the drained settlements or the immediate settlement.
3. for consolidation after loading, the final consolidation settlement and the variation of settlement after time.

For foundations on sand, as will be the case after analysing the data for the areas, the soil will be drained and the settlements will occur as the loads are applied. An appropriate design procedure would be to relate the allowable bearing pressure directly to the relative density measured by an in situ test. This is where the Standard Penetration Test is useful. A relationship established by Terzaghi and Peck (1967) and simple rule of thumb is :

$$q_a = 10N \text{ kPa}$$

This bearing pressure will give settlements of the order of 25mm (Atkinson, 1997). This formula is therefore very useful in the design of foundations.

Another material encountered in the analysis of the soil was the peat material. This material is highly compressible and must be avoided by any sort of foundation. If the foundation is piled then the piles must be driven through the peat layer and must not rest in this layer. If it is a shallow foundation been built then the foundation must not sit in the peat layer. Any material that does rest in this layer will settle much ore than any other material and at a much faster rate. Therefore it must be avoided at all costs, which is why an appropriate method for testing is performed so that the location of the peat layer is known.

4.8 Closing Remarks

The analysis of the soil below the surface for the five areas has proved that in the areas observed sand is the most abundant soil. Other trace materials have been found but none have the volume of the subsurface layers as sand. The sand has an important part to play in the design of foundations. As mentioned any foundation built on top of sand will have to consider the drained characteristics. As the load is applied to the foundation the settlements will start to occur. This is important for the engineers designing these structures as all the relative parameters must be known and an appropriate factor of safety must be applied to the bearing capacity. Only then can the foundation be successfully constructed.

Chapter 5
Conclusions and Recommendations

5.1 Conclusions

5.1.1 Soil Profiles and Distributions

From the results obtained it is clear that a large majority of the sub soil layers are sand and silty sands. Trace elements of clay, sandy gravel, peat and clayey sand have also been found, although not to the extent of the sand layers. The distribution of each soil is relatively even for each area. This means that the distribution of sand for area 1 is approximately the same for area 2. So generally the results for each area are pretty similar, however in area 2 the consistency of the soils profile is questionable. One of the sites in the area does not even have sand whilst the alignment of the other soil profiles appears distorted. The reasons behind this are mentioned in section 4.3.2 but basically it is because the sites are located on either side of Chevron Island and this would have had an affect on the profiles and distribution of the soil in this area.

5.1.2 Standard Penetration Test Results

The results from the standard penetration tests have indicated that some very dense deposits of sand and other materials have been found whilst also the discovery of some very loose deposits have also been located. A general trend that has been observed is that the soil density increases as the depth below the subsurface increases and therefore an increase in the blow count should also occur. However, this is not always the case as often the material below the surface changes and even though the material may be more dense, the blow count may actually decrease. This has been found to occur in a number of locations.

On a broader perspective the standard penetration resistance has often bee found to be quite high. On a number of occasions the operator stopped testing because the blow count of either 30 or 50 had been exceeded indicating a very dense deposit of soil. This also has been found to occur in a number of locations especially in Broadbeach where the soil profile is a very dense sand.

5.1.3 Cone Penetration Test Results

The results from the Cone Penetration test have concluded, based on a number of methods, that the soils profile can be classified as sand. This is based on the plot of the friction ratio against depth as well as the friction ratio plotted against the cone resistance. Another interesting conclusion drawn from the CPT was the ‘jump’ in the cone measurements recorded on figure 4.21. These types of plots are very useful for recognising thin sub soil layers that may have otherwise been missed. More consistent plots such as figure 4.25 are better for soil characterisation. The other parameters found from the CPT are more useful for substitution into equations and charts to help aid with the design of foundations. The cone resistance can be used to help estimate the settlement for instance.

5.1.4 The Effect on the Design of Foundations

The effect the soil has on the design of foundations is very significant. The soils profile must be fully understood before any construction should occur on the building. Located at a site in area 2 was the discovery of the peat material. The effects of this layer have already been discussed but the importance of locating this hazardous material cannot be stressed enough.

The cone resistance is important for the design of foundations as this can give an indication of the settlement and ultimate bearing capacity of the foundation. From the results of the soil profiles, any foundation built in the areas mentioned must consider the drained immediate settlement as sand tends to drain more easily than any other soil material. The soil distribution also plays an important part in the design of foundations. It is required to know whether the soils are dense or loose and the distribution is important. For instance on one side of the foundation could lie a very dense sand whilst on the other side a very loose clay could be beneath the surface. Therefore it is apparent that a thorough ground investigation and analysis is performed prior to the design of the foundation.

The establishment of a soil map can prove to be very useful for many types of applications. It is imperative that the soil profile beneath the surface is known when any construction is due to take place on that particular site. The establishment of a soil map will help identify what substances and the amount of each substance that lie beneath the surface. Autodesk Map 2004 is therefore a user friendly application that can aid in the soil mapping process and will therefore be of use for those wishing to obtain an over view of the sub surface conditions.

5.2 Recommendations

From this thesis it is recommended that more data be obtained. The data that has been obtained is consistent enough to provide consistent results however it would have been more useful to obtain more sites. It is also recommended that a thorough ground investigation and analysis is performed on the sub surface profiles before the effects the soils has on the design of foundations is considered. The construction of a soil map would also be very useful for future use as it would help establish soil profiles and distributions. Then, using interpolation and extrapolation where required, the soil profile and consistency can be viewed in the desired areas. With these issues in mind, it would make the design of foundations much easier for preliminary investigations.

With regards to the soil map, it is recommended that as mentioned earlier, more data can be obtained and analysed and then included in the soil map. This would enable much greater utilisation of the data and create a much better picture of the soils distribution and profiles. With this in mind, the design of any foundation on that particular area could then become more reliable on the soil map as much more information would have been included which would present a better overall picture of the sub surface conditions.

References:

Al-Khafaji, A.W., & Andersland, O.B., (1992). *Geotechnical Enginereing and Soil Testing,* Saunders College Publishing, Sydney.

Begemann. J., (1965), in Craig, R.F., (1997). *Soil Mechanics*, sixth edition. E & FN Spoon, London.

Bell, J.C. (1994). Soil drainage class probability mapping using a soil landscape model. *Soil Science Society of America, 58,* 465-472.

Burbidge (1982) in Craig, R.F. (1997). *Soil Mechanics*, sixth edition. E & FN Spoon, London.

Carre, F., & Girrard, M.C., (2002). Quantitative mapping of soil types based on regression kriging of taxonomic distances with landform and land cover attributes. *Elsevier Science, 110,* 241-263.

Craig, R.F. (1997). *Soil Mechanics*, sixth edition. E & FN Spoon, London.

Dobos, E., Montanarella, L., Negre, T., Micheli, E., (2001). A regional scale soil mapping approach using integrated AVHRR and DEM data. JAG, 3, 30-42.

Doolittle, J.A., & Asmerssen, L.E., (1992). Ten years of applications of ground penetrating radar by the United States Department of Agriculture. *Geological Survey of Finland, Special paper 16, fourth international conference on Ground Penetrating Radar, Rovaniemi, Finland, June 8-13, 139-147.*

Englund, E., & Sparks, A., (1991). Geo-EAS 1.2.1 Users guide Rep. No. EPA-600/8-91/008, EPA-ERISC, Las Vegas.

Fenton, G.A., (1997). Data Analysis/Geostatistics, Probabilistic methods in geotechnical engineering. G.A. Fenton ed. ASCE Geotechnical Safety andf Reliability Committee.

Florinsky, I.V., (1998). Combined analysis of digital terrain models and remotely sensed data in landscape investigations. Progress in Physical Geography, 22, 33-60.

Freeland, R.S., yoder, R.E., & Ammons, J.T., (1998). Mapping shallow underground features that influence site specific agricultural production. *Journal of Applied Geophysics, 40,* 19-27.

Frydman (1970) in Meigh, A.C., (1991). *Cone Penetration Testing: methods and interpretation.* Butterworths, Sydney.

Gibbs, H.J., & Holtz, W.G. (1957). Research on determining the density of sands by spoon penetration testing, in *Proceedings 4th International Conference SMFE, London*, Vol. 1, Butterworths, London, 35-39.

Giordano, A., Bonfils, P., Briggs, D.J., Menezes de Sequeir, A.E., Roquero de Laburu, C., & Yassoglou, N., (1991). The methodological approach to soil erosion and important land resources evaluation of the Europeans Communities. *Soil Technology, 4,* 65-77.

Goulard, M., (1987). An approach to landscape analysis with emphasis on soils. *Georderma, 21,* 1-23.

Green, K., (1992). Spatial imagery and GIS, integrated data for natural resource management. Journal of Forestry, 90, 32-36.

Ho, C.L., Di Stasi, J.M., (2001). Development of priority based statewide scour Monitoring systems in New England. New England Transportation Consortium Project No. 99-3.

Honjo, Y., & Kuroda, K., (1991). A new look at fluctuating data for reliability design soils and foundations. *Japan Social, Soil, Mechanical Foundations Engineering, 31 (1),* 110-120.

Isaaks, E.H., & Srivasta, R.M., (1989). *An Introduction to Applied Geostatistics*, Oxford University Press, New York.

Journel, A.G., & Huijbregts, C.J., (1978). *Mining Geostatistics*. *Academic Publishing*, San Diego.

Legget, R.F., (1979). Geology and Geotechnical Engineering. *Journal of Geotechnical Engineering, 105,* 342-392.

Leibold, A.M., Blaskowski, M.J., Farnes, R.J., (1997). Environemntal data management and GIS. ESRI User Conference Proceedings paper 511.

Meigh, A.C., (1991). *Cone Penetration Testing: methods and interpretation.* Butterworths, Sydney.

Nixon, F., (1982) in Meigh, A.C., (1991). *Cone Penetration Testing: methods and interpretation.* Butterworths, Sydney.

Parsons, R.L., & Frost, J.D., (2002). Evaluating site investigation quality using GIS and Geostatics. *Journal of Geotechnical and Geoenvironmental Engineering, 128,* 451-459.

Parsons, R.L., Frost, J.D., Charneau, J.L., & Tsai, Y.C. (1998). GIS ASSESS: A spatial analysis tool for site investigation planning and evaluation. Geotechnical site characterisation, P.K. Robertson & P.W. Mayne eds., Balkema, Rotterdam, The Netherlands, *251-256.*

Pennock, D.J., Zebarth, B.J., & de Jong, E., (1987). Landform classification and soil distribution in hummocky terrain ,Saskatchewas. *Geoderma, 40,* 297-315.

Robertson & Campanella (1983), in Meigh, A.C. (1991). *Cone Penetration Testing: methods and interpretation.* Butterworths, Sydney.

Rouhani, S., (1996). Geostatistical estimation;Kriging geostatistics for environmental and geotechnical applications, *ASTM STP 1283, 20-31.*

Schmertmann, J.H., (1975). Measurement of in-situ shear strength, in *Proceedings of Conference on In-Situ Measurement of Soil Properties,* ASCE, New York, Vol.II, 57-138.

Searle, K., (1979) in Craig, R.F., (1997). *Soil Mechanics*, sixth edition. E & FN Spoon, London.

Seed, R.I, (1983). *Soil Mechanics and Foundations,* as cited in Craig (1997), *Soil Mechanics,6th edition.* E & FN Spoon, London.

Terzaghi, K., & Peck, R.B., (1996). *Soil Mechanics in Engineering Practice*, 3rd edition. John Wiley and Sons, New York.

Tipping, D.C., (1999). Contaminat transport assessment using GIS. Bachelors degree thesis for Department of Civil, Mining and Environmental Engineering, University of Wollongong, Australia.

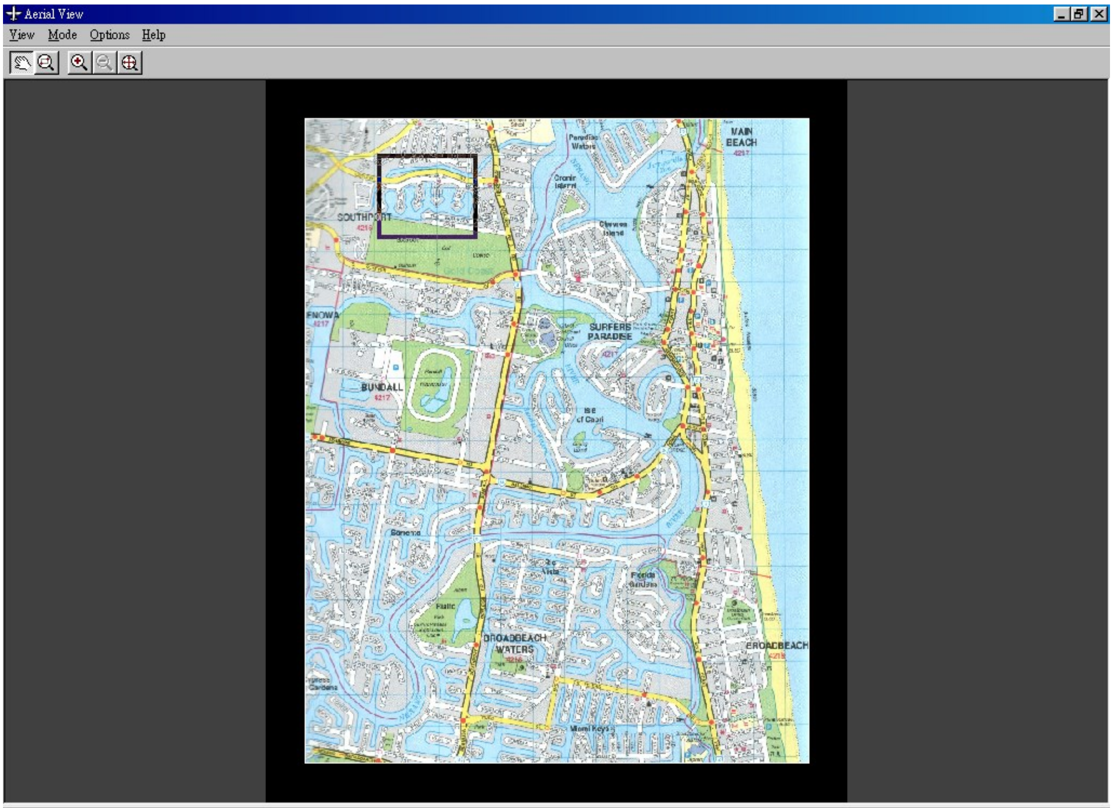
Vossen, P., & Meyer Roux, J., (1995). Crop monitoring and yield forecasting activities of the MARS project in D. King, R.J.A. Jones & A.J. Thomasson, European land information systems for agro-environmental Monitoring, *CEC-JRC DGxii,* Luxembourg, 11-29.

Walter, C., (1990). Estimation des proprietes du sol et quantification de leur variabilite a mogeme echelle. *Cartographie pedologique et geostatistique dans le sued de l'Ilte et Vilaire,13,* 27-43.

Wielemaker, W.G., de Bruin, S., Epema, G.F., & Veldkamp, A., (2000). Significance and application of the multihierachial land systems in soil mapping. *Elsevier Science,43,* 15-34.

Ziadat, F.M., Taylor, J.C., Brewer, T.R. (2002). Merging Lansat TM imagery with topographic data to aid soil mapping in the Badia region of Jordan. Journal of Arid Environments, 10, 1-15.

Appendix A


Aerial View
View Mode Options Help
SOUTHPORT
MAIN BEACH
SURFERS PARADISE
BUNDALL
BROADBEACH WATERS
BROADBEACH

Appendix B

BOREHOLE PROFILE

CLIENT:					**BOREHOLE No:**	BH 1
PROJECT:	LOT 85 CNR THE BOULEVARD & THE AVENUE SURFERS WATERS				**JOB No:**	BT 7746
EQUIPMENT TYPE:	JACRO 200		**HOLE DIAMETER:**	100mm		

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL			1.3		Silty **SAND:** Fine grained sand, Moist, Dark brown **(SM)**	**MEDIUM DENSE**
			2.1		Silty **SAND:** Fine grained sand, Very moist becoming moist, Dark grey **(SM)**	**DENSE**
ALLUVIUM			2.4		Clayey **SAND:** Fine grained sand, With silt, Very moist, Black **(SC)**	**DENSE**
			3.0		Silty **SAND:** Fine grained sand, Moist, Dark grey **(SM)**	**DENSE**
					BH 1 TERMINATED AT 3.0m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	6/3/00	Checked By	Date

BOREHOLE PROFILE

CLIENT:		**BOREHOLE No:**	BH 1
PROJECT:	LOT 108 THE BOULEVARD SURFERS WATERS	**JOB No:**	BT 7935
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 110mm		

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL / TOPSOIL			0.2		Silty **SAND:** Fine grained sand, Dry to moist, Dark brown **(SM)**	**MEDIUM DENSE**
FILL	1.5m SPT 3,3,3 N = 6 1.95m 3.0m SPT 2,4,6 N = 10 3.45m	τ	3.2 3.3		Silty **SAND:** Fine grained sand, Moist, Dark grey (Black) **(SM)**	**MEDIUM DENSE**
ALLUVIUM	4.5m SPT 5,4,3 N = 7 4.95m		5.3		Silty **SAND:** Fine grained sand, With a trace of clay, Wet, Dark grey **(SM)**	**MEDIUM DENSE**
	6.0m SPT 1/300 N = 1 6.3m		6.9		Silty **SAND:** Fine grained sand, With some clay and bands of clayey sand and clay throughout, Wet, Dark grey **(SM)**	**VERY LOOSE**
RESIDUAL	7.5m SPT 2,3,3 N = 6 7.95m		7.5		Silty Sandy **CLAY:** Low to medium plasticity, Fine grained sand, Moist to wet ($w>w_p$), Pale orange with some pale grey mottling **(CL/CL-CH)**	**VERY SOFT To FIRM**
					BH 1 TERMINATED AT 7.5m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	30/5/00	Checked By	Date

BOREHOLE PROFILE

CLIENT:	**BOREHOLE No:** BH 1
PROJECT: LOT 124 THE POINT, SURFERS WATERS ESTATE	**JOB No:** BT 4557
EQUIPMENT TYPE: JACRO 200 **HOLE DIAMETER:** 100mm	

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
TOPSOIL		1	0.2		**TOPSOIL**	
FILL		2 3 4 5	1.1		**SAND:** Fine to medium grained, With silt, Moist, Dark brown **(SP)**	**DENSE**
		6 7 8 ➢	1.8		**SAND:** Fine to medium grained, With clay, Moist, Grey **(SP)**	**DENSE** **MEDIUM DENSE**
ALLUVIUM		| 0	2.0		**CLAY:** High plasticity, With silt, Fine to medium grained sand, Moist, Dark grey **(CH)**	**FIRM**
		1 2 τ	2.5		**SAND:** Fine to medium grained, With silt and clay, Moist to wet, Grey/brown **(SP)**	**MEDIUM DENSE**
		3 4 5	3.0		**SAND:** Fine to medium grained, Uniformly graded, Wet, Pale grey/brown **(SP)**	**DENSE**
		6 7 8 9 0 1 2 3			**BH 1 TERMINATED AT 3.0m**	

Logged By	JED	Date	4/9/96	Checked By	Date

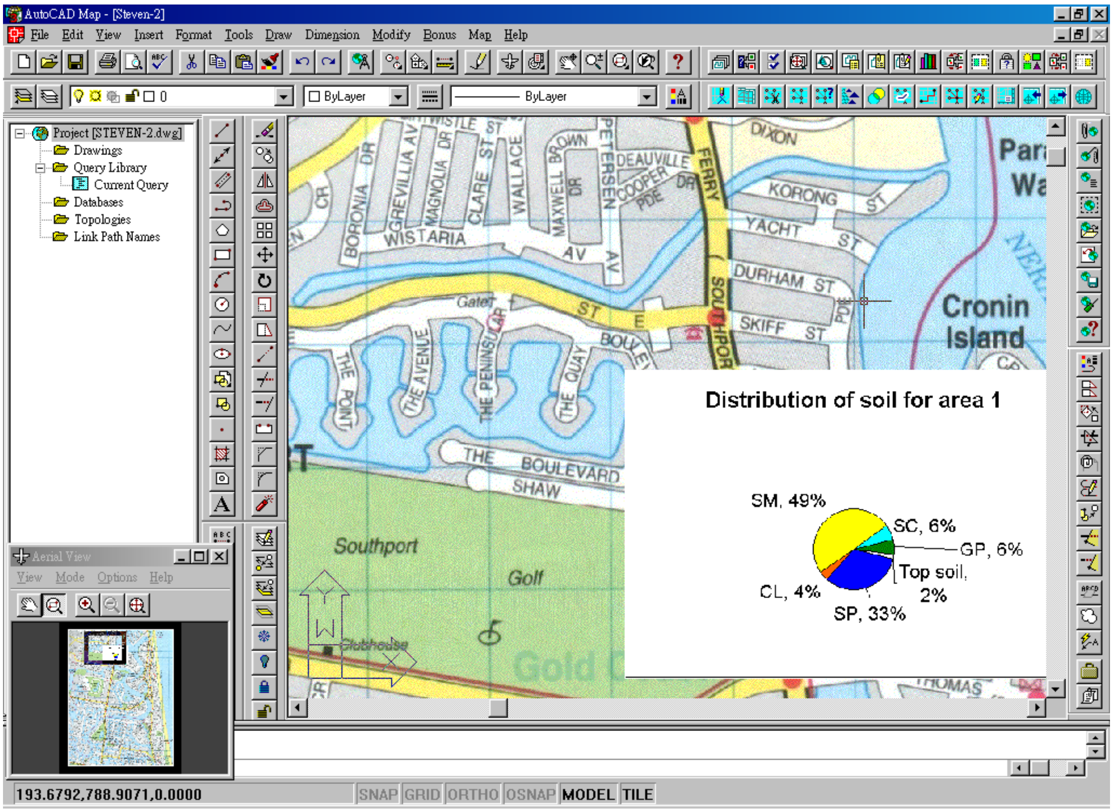
BOREHOLE PROFILE

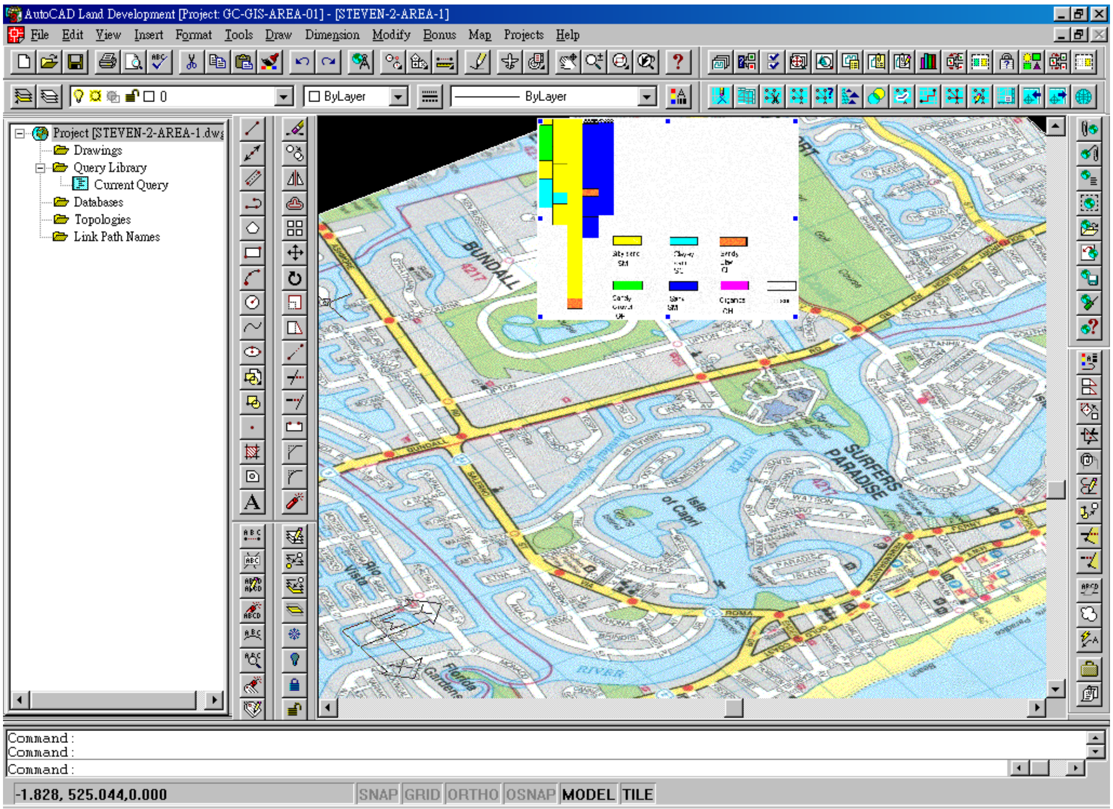
CLIENT:	**BOREHOLE No:**	BH 2
PROJECT: LOT 71 THE BOULEVARD SURFERS WATERS ESTATE	**JOB No:**	BT 5593
EQUIPMENT TYPE: JACRO 200	**HOLE DIAMETER:**	65mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
TOPSOIL		1	0.2		**TOPSOIL**	
FILL		2 3 4 5 6 7 8 9 0	2.0		**SAND:** Fine to medium grained, Trace of silt, Moist, Dark brown **(SP)**	**DENSE** **VERY DENSE** **DENSE**
		1 2 τ	2.6		**SAND:** Fine to medium grained, Uniformly graded, Moist, Very pale brown **(SP)**	**DENSE**
ALLUVIUM		4 5 6 7	3.5		**SAND:** Fine to medium grained, Uniformly graded, Wet, Pale grey **(SP)**	**DENSE**
		8 9 0 1 2 3			**BH 2 TERMINATED AT 3.5m** **LIMIT OF INVESTIGATION**	

Logged By	JSD	Date	10/11/97	Checked By	Date

Appendix C


AutoCAD Map - [Steven-2]
File Edit View Insert Format Tools Draw Dimension Modify Bonus Map Help
ByLayer
Project [STEVEN-2.dwg]
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
Aerial View
View Mode Options Help
Distribution of soil for area 1
SM, 49%
SC, 6%
GP, 6%
Top soil, 2%
CL, 4%
SP, 33%
Cronin Island
Southport
Golf
193.6792,788.9071,0.0000
SNAP GRID ORTHO OSNAP MODEL TILE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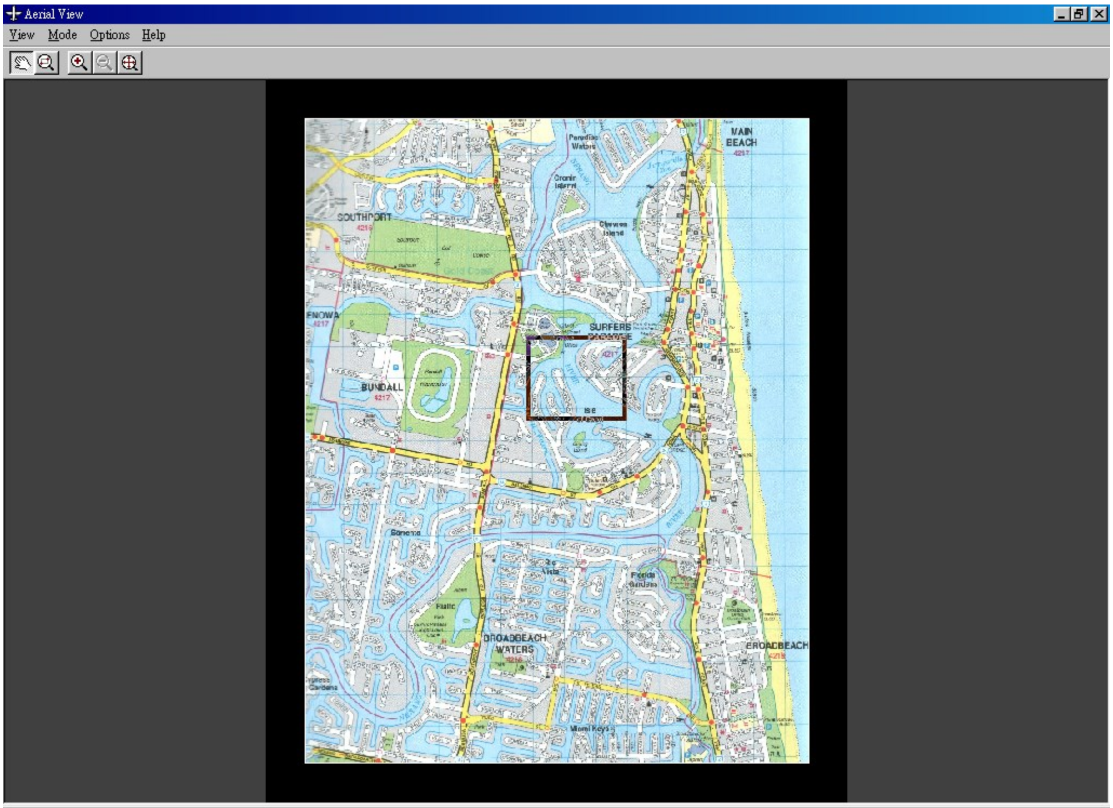
File Edit View Insert Format Tools Draw Dimension Modify Bonus Map Projects Help
ByLayer
ByLayer
Project [STEVEN-2-AREA-1.dwg
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
BUNDALL
SURFERS PARADISE
Isle of Capri
RIVER
Rio Vista
Florida Gardens
Command :
Command :
Command :
-1.828, 525.044,0.000
SNAP GRID ORTHO OSNAP MODEL TILE

Appendix D



Aerial View
View
Mode
Options
Help
MAIN BEACH
SOUTHPORT
BUNDALL
SURFERS
BROADBEACH WATERS
BROADBEACH

Appendix E

BOREHOLE PROFILE

CLIENT:					**BOREHOLE No:** BH 1	
PROJECT: 1/29 VESPA CRESCENT SURFERS PARADISE					**JOB No:** BT 7882	
EQUIPMENT TYPE: HAND AUGER				**HOLE DIAMETER:** 85mm		
Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL / TOPSOIL			1.0		Silty **SAND:** Fine grained sand, With a trace of clay throughout, Moist, Dark grey/black **(SM)**	**MEDIUM DENSE**
FILL			1.2		Sandy **CLAY:** Low to medium plasticity, Fine grained sand, With a trace of organic material (fine roots and bark), Moist ($w>w_p$), Dark grey mottled orange **(CL/CL-CH)**	**STIFF**
ALLUVIUM			1.7		**SAND:** Fine grained sand, Moist to wet, Pale brown **(SP)**	**DENSE**
		τ	1.8 1.9		**SAND:** Fine grained sand, Wet, Brown **(SP)**	**VERY DENSE**
					BH 1 TERMINATED AT 1.9m **DUE TO CAVE IN**	
Logged By DAW		Date 3/5/00		Checked By	Date	

BOREHOLE PROFILE

CLIENT:						BOREHOLE No: BH 1
PROJECT: No.9 INGA AVENUE SURFERS PARADISE						**JOB No:** BT 7945
EQUIPMENT TYPE: HAND AUGER				**HOLE DIAMETER:** 65mm		
Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL / TOPSOIL			0.2		Silty **SAND:** Fine grained sand, Moist, Dark grey **(SM)**	**LOOSE**
FILL			0.4		Silty **SAND:** Fine grained sand, Moist, Pale brown **(SM)**	**VERY LOOSE**
FILL / TOPSOIL			0.6		Silty **SAND:** Fine grained sand, Moist, Dark grey **(SM)**	**VERY LOOSE**
FILL			0.8		Silty **SAND:** Fine grained sand, Moist, Brown **(SM)**	**LOOSE**
			1.8		Silty **SAND:** Fine grained sand, Moist to wet, Pale brown **(SM)**	**LOOSE To MEDIUM DENSE**
ALLUVIUM			2.0		Clayey **SAND:** Fine grained sand, Wet, Dark grey **(SC)**	**VERY LOOSE**
					BH 1 TERMINATED AT 2.0m DUE TO HOLE CAVE IN	

Logged By	GDM	Date	26/5/00	Checked By	Date

BOREHOLE PROFILE

CLIENT:	**BOREHOLE No:** BH 1
PROJECT: No.68 SUNRISE BOULEVARD SURFERS PARADISE	**JOB No:** BT 7695
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 110mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL			0.6		Silty **SAND:** Fine grained sand, With building rubble, Dry to moist, Grey **(SM)**	**VERY LOOSE**
	1.5m SPT 2,3,3 N = 6	τ	2.4		**SAND:** Fine grained, Moist, Pale grey **(SP)**	**LOOSE**
ALLUVIUM	1.95m 3.0m SPT 1,1,2 N = 3		3.2		**SAND:** Fine grained, Wet, Pale grey **(SP)**	**VERY LOOSE**
	3.45m 4.5m SPT 1,3,3 N = 6 4.95m 6.0m SPT 6,5,6 N = 11 6.45m 7.5m SPT 3,2,4 N = 6 7.95m		8.7		Silty **SAND:** Fine grained sand, With shell fragments and lenses of clayey sand throughout, Wet, Dark grey **(SM)**	**LOOSE To MEDIUM DENSE**
	9.0m SPT 20,34 N = > 50 9.3m 10.5m SPT 32 N = > 50 10.65m 12.0m		12.0		**SAND:** Fine to medium grained, With some shell fragments, Wet, Pale grey **(SP)**	**VERY DENSE**
	SPT 21,30/130 N = > 50 12.28m				**BH 1 TERMINATED AT 12.0m** **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	22/3/00	Checked By	Date

BOREHOLE PROFILE

CLIENT:	**BOREHOLE No:** BH 1
PROJECT: LOT 136 THE PROMENADE SURFERS WATERS ESTATE	**JOB No:** BT 7539
EQUIPMENT TYPE: GCH 200 **HOLE DIAMETER:** 110mm	

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL			0.3		Silty **SAND:** Fine to coarse grained sand, With some fine gravel, Dry to moist, Dark grey **(SM)**	**HARD CRUST**
FILL			1.1		Sandy **GRAVEL:** Fine to coarse grained sand, Fine to coarse gravel, With some clay, Dry to moist, Pale yellow/brown **(GP)**	**MEDIUM DENSE**
FILL			1.6		Sandy **GRAVEL:** Fine to coarse grained sand, Fine to coarse gravel, With some clay, Dry to moist, Brown **(GP)**	**DENSE**
FILL			1.9		Silty **SAND:** Fine grained sand, With some clay, Moist, Dark grey **(SM)**	**MEDIUM DENSE**
FILL			2.6		Sandy **GRAVEL:** Fine to coarse grained sand, Fine to coarse gravel, With some clay, Dry to moist, Dark grey **(GP)**	**DENSE**
ALLUVIUM		τ	2.8 3.0		Clayey **SAND:** Fine grained sand, Wet, Dark grey **(SC)**	**LOOSE**
					BH 1 TERMINATED AT 3.0m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	17/12/99	Checked By	Date

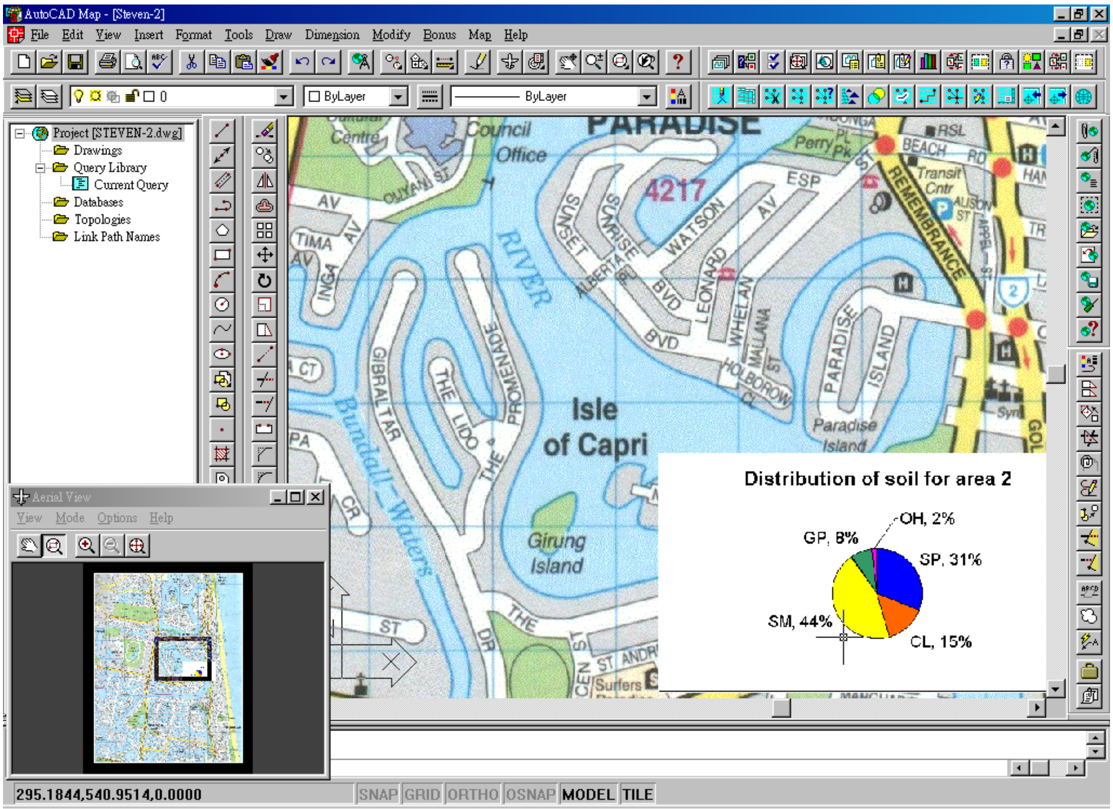
BOREHOLE PROFILE

CLIENT:	**BOREHOLE No:** BH 7
PROJECT: PANORAMA TOWERS – 30 WATSON ESP SURFERS PARADISE	**JOB No:** BT 7066
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 110mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
			0.2		Road Seal & Road Base Gravel	**VERY DENSE**
FILL		▽	1.8		**SAND:** Fine grained sand, Moist, Pale brown **(SP)**	**LOOSE** **MEDIUM DENSE**
ALLUVIUM			1.9		Silty **SAND:** Fine grained sand, Wet, Dark grey **(SM)**	**VERY LOOSE**
			3.3		Silty **SAND:** Fine grained sand, With some clay and clayey sand bands throughout, Wet, Dark grey **(SM)**	**VERY LOOSE**
	6.0m SPT 4,4,3 N = 7 6.45m		6.5		Silty **SAND:** Fine grained sand, Wet, Grey **(SM)**	**LOOSE** **MEDIUM DENSE**
	6.5m SPT 10,12,16 N = 28 6.95m		8.0		**SAND:** Fine grained sand, Wet, Pale brown **(SP)**	**DENSE**
					BH 7 TERMINATED AT 8.0m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	22/6/99	Checked By	Date

Appendix F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Distribution of soil for area 2
OH, 2%
GP, 8%
SP, 31%
SM, 44%
CL, 15%
Isle
of Capri
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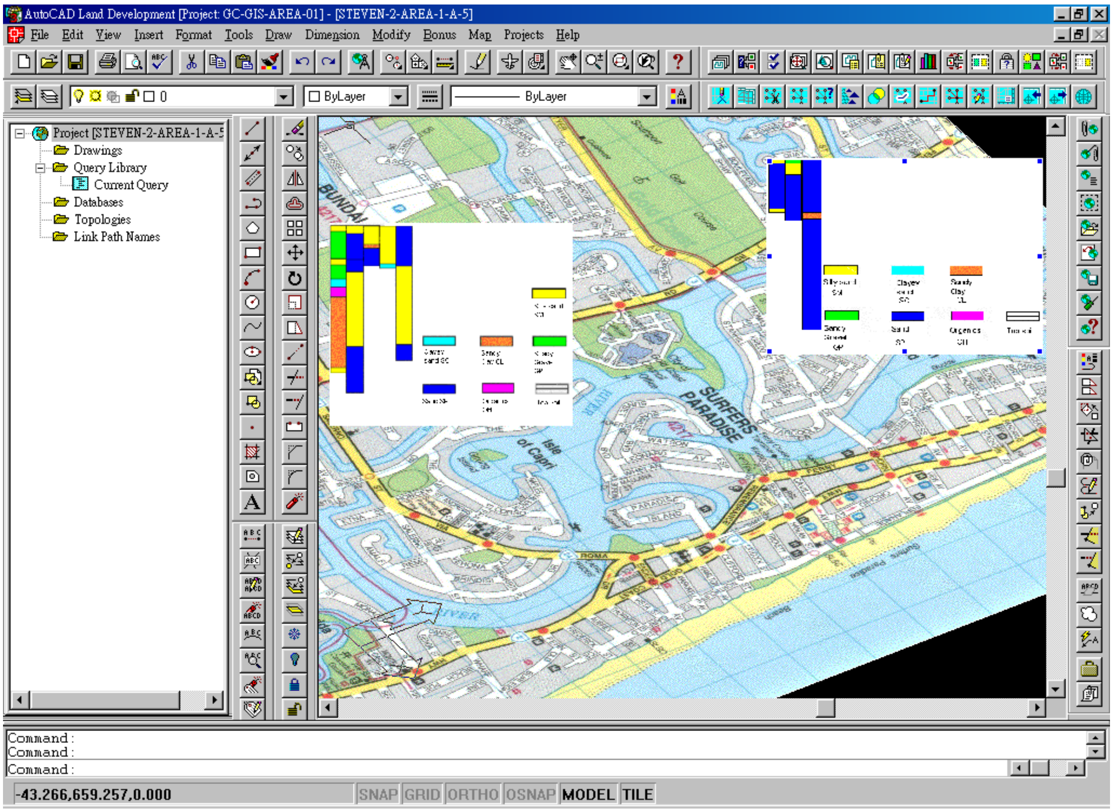
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ByLayer
ByLayer
Project [STEVEN-2-AREA-1-A-5
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
SURFERS PARADISE
Isle of Capri
BUNDALL
Command :
Command :
Command :
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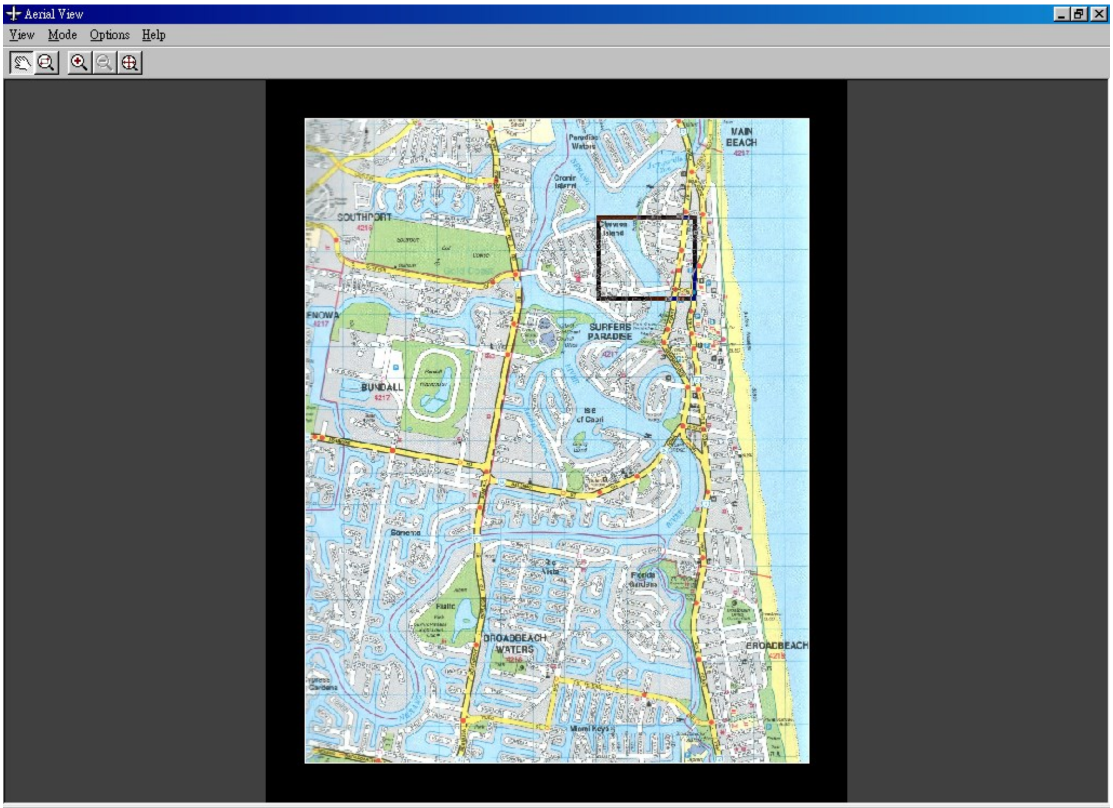
SNAP GRID ORTHO OSNAP MODEL TILE

Appendix G


Aerial View
View Mode Options Help
SOUTHPORT
MAIN BEACH
SURFERS PARADISE
BUNDALL
BROADBEACH WATERS
BROADBEACH

Appendix H

BOREHOLE PROFILE

CLIENT:	**BOREHOLE No:** BH 1
PROJECT: LOTS 547 & 548 TARCOOLA CRESCENT, CHEVRON ISLAND	**JOB No:** BT 4819

EQUIPMENT TYPE: GCH 200 **HOLE DIAMETER:** 110mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
TOPSOIL			0.2		**TOPSOIL**	
FILL	1.5m SPT 3,3,3 N = 6 1.95m	τ	2.4		**SAND:** Fine to medium grained, Uniformly graded, Moist, Pale brown **(SP)**	**DENSE**
ALLUVIUM (MARINE DEPOSITS)			2.5 2.7		**SAND:** Fine to coarse grained,With shell grit (lenses), Wet, Dark grey **(SP)**	**DENSE**
	3.0m		3.0		**CLAY:** High plasticity, With fine to medium grained sand, Moist ($w>w_p$), Dark grey/brown (Trace of organic material) **(CH)**	**FIRM/ STIFF**
	SPT 4,8,9 N = 17 3.45m 4.5m SPT 14,18,24 N = >30 4.95m 6.0m SPT11,20/100 N = >30 6.3m 7.5m SPT15,30/100 N = > 30 7.95m		8.5		**SAND:** Fine to medium grained, Trace of silt, Wet, With medium fragments of shell grit, Pale grey **(SP)**	**DENSE** **VERY DENSE** **VERY DENSE**
					BH 1 TERMINATED AT 8.5m	

Logged By	JED	Date	19/12/96	Checked By	Date

BOREHOLE PROFILE

CLIENT:					**BOREHOLE No:**	BH 1
PROJECT:	No.47 STANHILL DRIVE CHEVRON ISLAND				**JOB No:**	BT 7708
EQUIPMENT TYPE:	JACRO 200		**HOLE DIAMETER:**	100mm		

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL / TOPSOIL			0.1		Silty **SAND:** Fine grained sand, Dry to moist, Dark grey **(SM)**	**LOOSE**
FILL			2.0		**SAND:** Fine grained, Dry to moist becoming moist, Pale brown **(SP)**	**VERY LOOSE To LOOSE**
		τ	2.5		**SAND:** Fine to coarse grained, With shell and shell fragments, Moist, Pale brown **(SP)**	**VERY LOOSE**
ALLUVIUM			2.7		Silty **SAND:** Fine grained sand, Wet, Dark grey **(SM)**	**VERY LOOSE**
					BH 1 TERMINATED AT 2.7m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	28/2/00	Checked By	Date

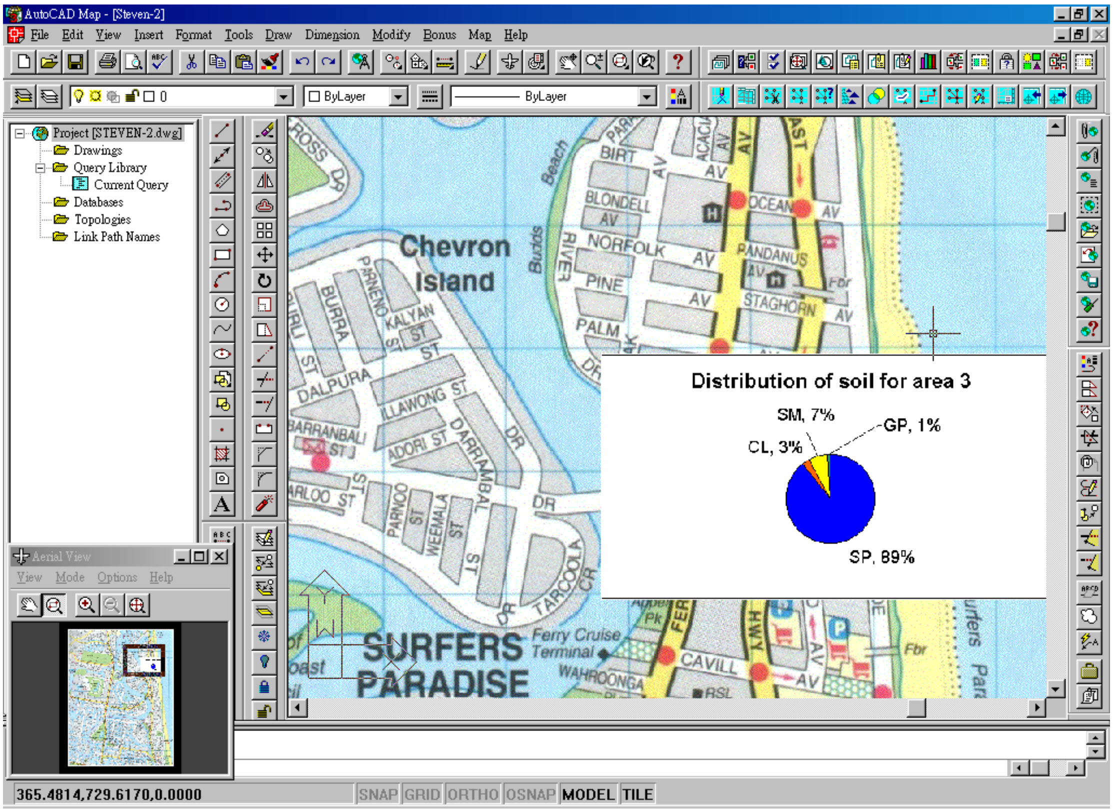
BOREHOLE PROFILE

CLIENT:	**BOREHOLE No:** BH 1
PROJECT: LOT 11 OAK AVENUE BUDDS BEACH	**JOB No:** BT 7309
EQUIPMENT TYPE: JACRO 200 & HAND AUGER **HOLE DIAMETER:** 100mm & 65mm	

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL			0.1		Sandy **GRAVEL:** Fine to coarse grained sand, Fine gravel, Dry to moist, Pale orange **(GP)**	**HARD CRUST**
FILL/ TOPSOIL			0.8		Silty **SAND:** Fine grained sand, Dry to moist, Dark grey **(SM)**	**LOOSE**
FILL		τ	2.6		**SAND:** Fine grained, Moist, Pale brown **(SP)**	**LOOSE To MEDIUM DENSE**
ALLUVIUM			2.9		**SAND:** Fine to medium grained, With some clayey sand and clay lenses, Decomposed wood and wood chips, Wet, Dark grey **(SP)**	**LOOSE To VERY LOOSE**
			3.0		**SAND:** Fine grained, Wet, Dark grey **(SP)**	**LOOSE TO MED DENSE**
					BH 1 TERMINATED AT 3.0m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	17/9/99	Checked By	Date

Appendix I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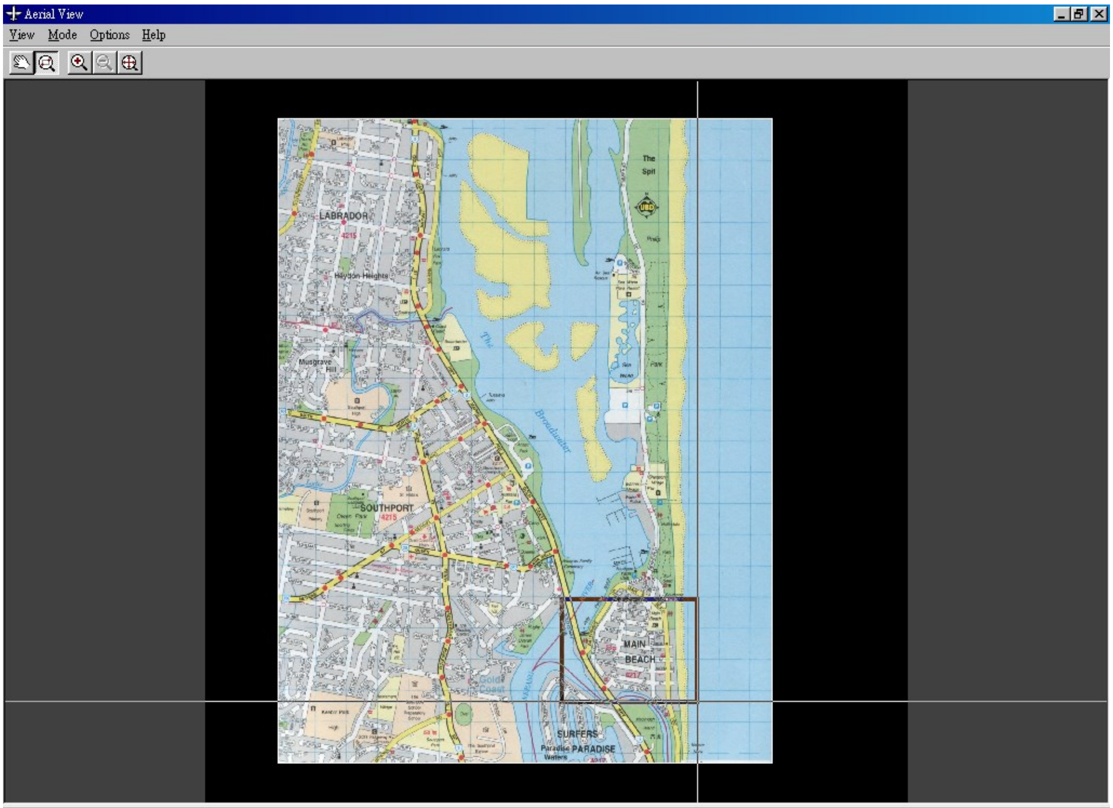
ByLayer
Project [STEVEN-2.dwg]
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
Aerial View
View Mode Options Help
Chevron Island
SURFERS PARADISE
Ferry Cruise Terminal
Distribution of soil for area 3
SM, 7%
GP, 1%
CL, 3%
SP, 89%
365.4814,729.6170,0.0000
SNAP GRID ORTHO OSNAP MODEL TILE

Appendix J



Aerial View
View
Mode
Options
Help
LABRADOR
SOUTHPORT
MAIN
BEACH
SURFERS
PARADISE
The
Spit

Appendix K

BOREHOLE PROFILE

CLIENT:	KAVANAUGH McANANY CONSULTING ENGINEERS	**BOREHOLE No:**	BH 3 Page 1
PROJECT:	Nos.42 & 44 TEDDER AVENUE MAIN BEACH	**JOB No:**	BT 7897
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	110mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL	1.5m SPT 4,7,8 N = 15 1.95m		2.7		**SAND:** Fine grained sand, Dry to moist becoming moist, Pale brown **(SP)**	**LOOSE To MEDIUM DENSE**
ALLUVIUM		τ	2.8		Silty **SAND:** Fine grained sand, With lenses of clayey sand and marine clay throughout, Moist to wet, Dark grey **(SM)**	**VERY LOOSE**
	3.0m SPT 2,1,2 N = 3 3.45m 4.5m SPT 2,3,4 N = 7		4.7		Silty **SAND:** Fine grained sand, With a trace of clay, Wet, Dark grey **(SM)**	**LOOSE**
	4.95m		***5.0***		Silty **SAND:** Fine grained sand, Wet, Grey **(SM)** ***Continued on BH 3 Page 2***	**MEDUIM DENSE**

Logged By	GDM	Date	18/5/00	Checked By	Date

BOREHOLE PROFILE

CLIENT:	KAVANAUGH McANANY CONSULTING ENGINEERS	**BOREHOLE No:**	BH 3 Page 2
PROJECT:	Nos.42 & 44 TEDDER AVENUE MAIN BEACH	**JOB No:**	BT 7897
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	110mm

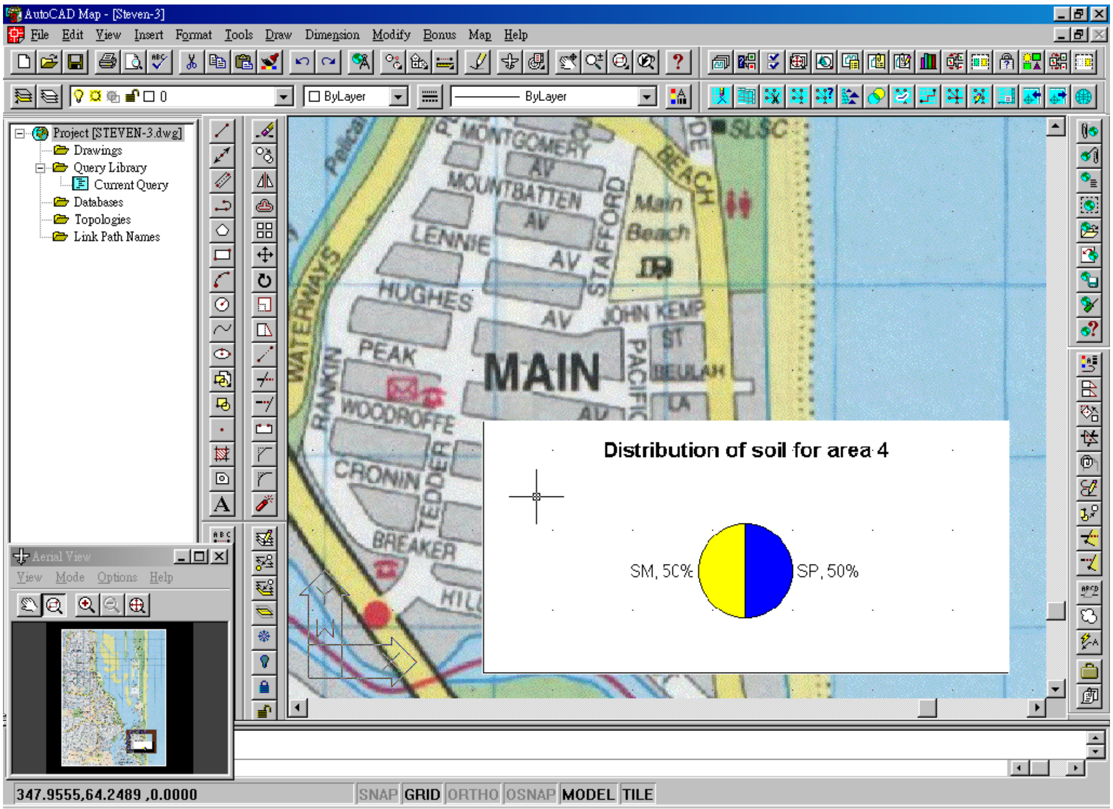
Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
ALLUVIUM	6.0m		***5.0*** 6.0		***Continued from BH 3 Page 1*** Silty **SAND:** Fine grained sand, Wet, Grey **(SM)**	**MEDIUM DENSE**
	SPT 6,8,10 N = 18 6.45m				**BH 3 TERMINATED AT 6.0m** **LIMIT OF INVESTIGATION**	**LOOSE**

Logged By	GDM	Date	18/5/00	Checked By	Date

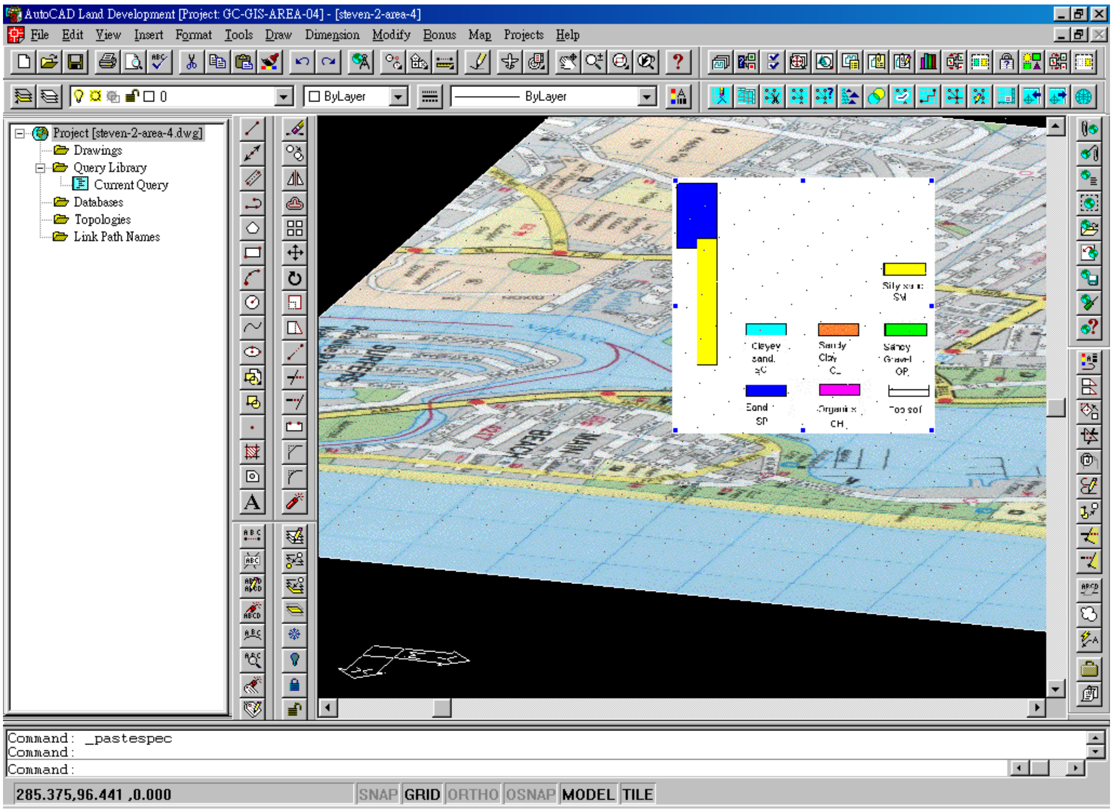
BOREHOLE PROFILE

CLIENT:					**BOREHOLE No:** BH 1	
PROJECT: No.27 RANKIN PARADE MAIN BEACH					**JOB No:** BT 7883	
EQUIPMENT TYPE: HAND AUGER				**HOLE DIAMETER:** 65mm		
Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL / TOPSOIL			0.4		Silty **SAND:** Fine grained sand, Dry to moist, Dark grey **(SP)**	**LOOSE**
FILL		▯	2.7 2.8		**SAND:** Fine grained sand, Moist, Pale brown **(SP)**	**MEDIUM DENSE**
			3.0		**SAND:** Fine grained sand, Wet, Pale brown **(SP)**	**MEDIUM DENSE**
					BH 1 TERMINATED AT 3.0m **LIMIT OF INVESTIGATION**	
Logged By GDM		Date 9/5/00			Checked By	Date

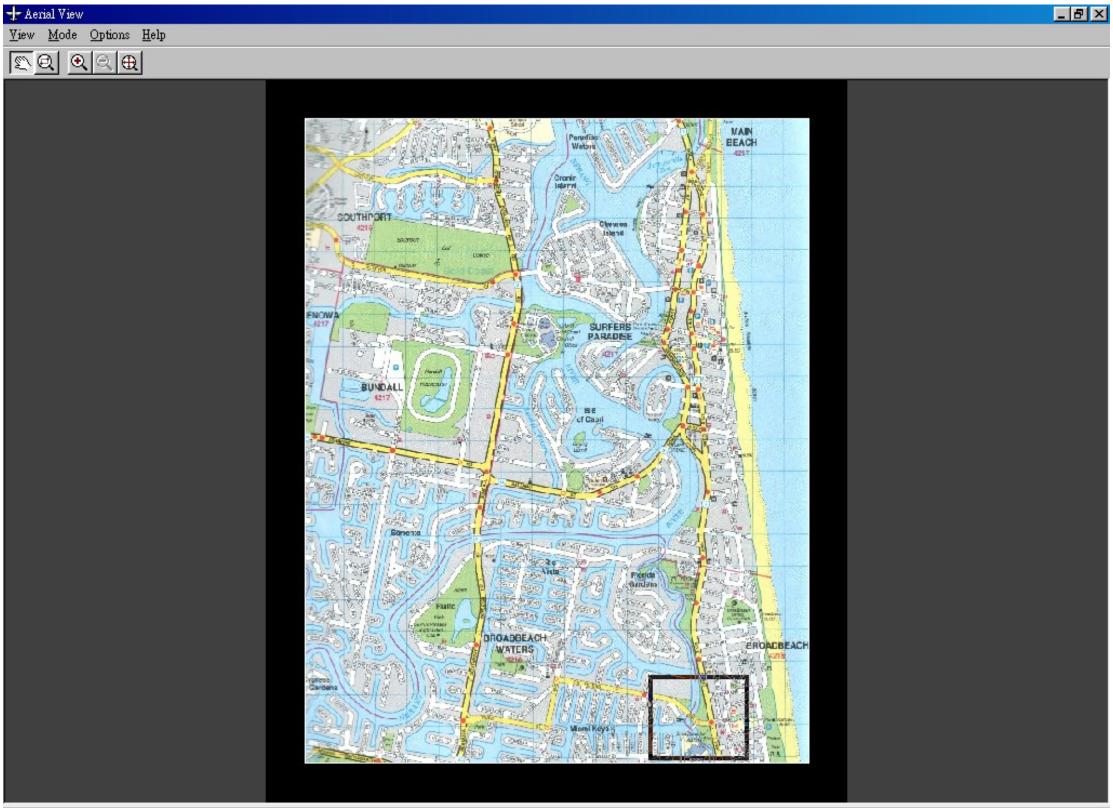
Appendix L



AutoCAD Map - [Steven-3]
File Edit View Insert Format Tools Draw Dimension Modify Bonus Map Help
Project [STEVEN-3.dwg]
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
Aerial View
Distribution of soil for area 4
SM, 50%
SP, 50%
347.9555,64.2489 ,0.0000
SNAP GRID ORTHO OSNAP MODEL TILE



Appendix M


Aerial View
View
Mode
Options
Help
MAIN BEACH
SOUTHPORT
SURFERS PARADISE
BUNDALL
BROADBEACH WATERS
BROADBEACH

Appendix N

BOREHOLE PROFILE

CLIENT:		**BOREHOLE No:** BH 1
PROJECT: LOT 318 (No.19) BRITTANIA AVENUE BROADBEACH		**JOB No:** BT 8102
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 110mm	

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL / TOPSOIL			0.3		Silty **SAND:** Fine grained sand, Dry to moist, Dark grey **(SM)**	**VERY LOOSE**
FILL	1.5m SPT 1,2,2 N = 4		1.9		**SAND:** Fine grained sand, Moist, Pale orange/brown **(SP)**	**LOOSE**
AEOLIAN	1.95m 3.0m SPT 2,3,4 N = 7 3.45m		3.9		**SAND:** Fine grained sand, With lenses of mineral sand throughout, Moist, Pale brown **(SP)**	**LOOSE To MEDIUM DENSE**
	4.5m SPT 17,25,36 N = 61 4.95m 6.0m	τ	4.0 6.0		**SAND:** Fine to medium grained sand, Wet, Pale brown **(SP)**	**VERY DENSE**
	SPT 16,31 N = > 50 6.3m				**BH 1 TERMINATED AT 6.0m** **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	14/8/00	Checked By	Date

BOREHOLE PROFILE

CLIENT:		**BOREHOLE No:**	BH 3
PROJECT:	13-15 ANNE AVENUE, BROADBEACH	**JOB No:**	BT 4723
EQUIPMENT TYPE:	GCH 200	**HOLE DIAMETER:**	110mm

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL		1	0.5		**SAND:** Fine to medium grained, Poorly graded, Dry, Pale grey **(SP)**	**DENSE**
AEOLIAN	3.5 SPT 2,3,2 N = 5 3.95	2 3 4 5 6 7 ∇	4.5		**SAND:** Fine to medium grained, Uniformly graded, Dry to moist, Pale brown **(SP)**	**MEDIUM DENSE**
ALLUVIUM	8.0	8 9 0 1 2 3	8.0		**SAND:** Fine to medium grained, Uniformly graded, With some coarse grained sand, Shell grit and fine rounded to sub angular gravel, Wet, Pale brown (bands of more prominant gravel) **(SP)**	**VERY DENSE**
	SPT 30/130 N = >30 8.13 10.0 SPT 30/75 N = >30 10.75 11.50 SPT 30/80 N = >30 11.58 13.0 SPT 30/70 N = >30 13.07 14.50 SPT 30/70 N = >30 14.57	4 5 6 7 8 9 0 1 2 3	15.50		**SAND:** Fine to medium grained, Poorly graded, Trace of shell grit and gravel parts, Wet, Pale brown (bands of more prominant gravel & shell) **(SP)**	**VERY DENSE**
					BH 3 TERMINATED AT 15.5 M	

Logged By	JSD	Date	14/11/96	Checked By	Date

BOREHOLE PROFILE

CLIENT:		**BOREHOLE No:**	BH 1
PROJECT:	No.49 BROADBEACH BOULEVARD BROADBEACH	**JOB No:**	BT 8079
EQUIPMENT TYPE: GCH 200	**HOLE DIAMETER:** 110mm		

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL			0.3		Silty **SAND:** Fine grained sand, Dry to moist, Dark grey **(SM)**	**LOOSE**
			0.6		**SAND:** Fine grained sand, Dry to moist, Pale grey/ brown **(SP)**	**LOOSE**
AEOLIAN	1.5m SPT 4,6,7 N = 13 1.95m 3.0m SPT 3,3,3 N = 6 3.45m 4.5m SPT 6,10,17 N = 27 4.95m	τ	4.6		**SAND:** Fine grained sand, Moist, Pale brown **(SP)**	**MEDIUM DENSE**
ALLUVIUM	6.0m SPT 18,32 N = > 50 6.3m 7.5m SPT 22,30/110 N = > 50 7.76m 9.0m SPT 20,30/120 N = > 50 9.27m 10.5m SPT 30/130 N = > 50 10.63m 12.0m SPT 30/140 N = > 50 12.14m		12.0		**SAND:** Fine to medium grained sand, With some fine rounded gravel and shell fragments, Wet, Pale brown **(SP)**	**DENSE To VERY DENSE**
					BH 1 TERMINATED AT 12.0m **LIMIT OF INVESTIGATION**	

Logged By	GDM	Date	2/8/00	Checked By	Date

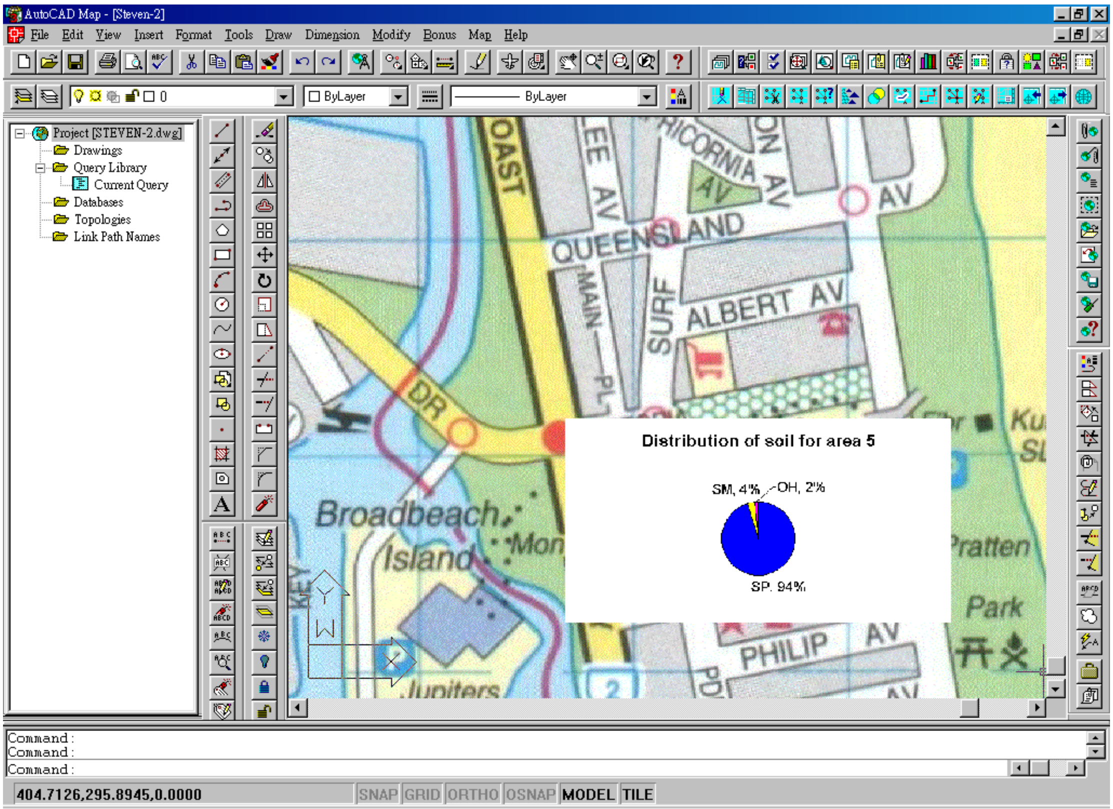
BOREHOLE PROFILE

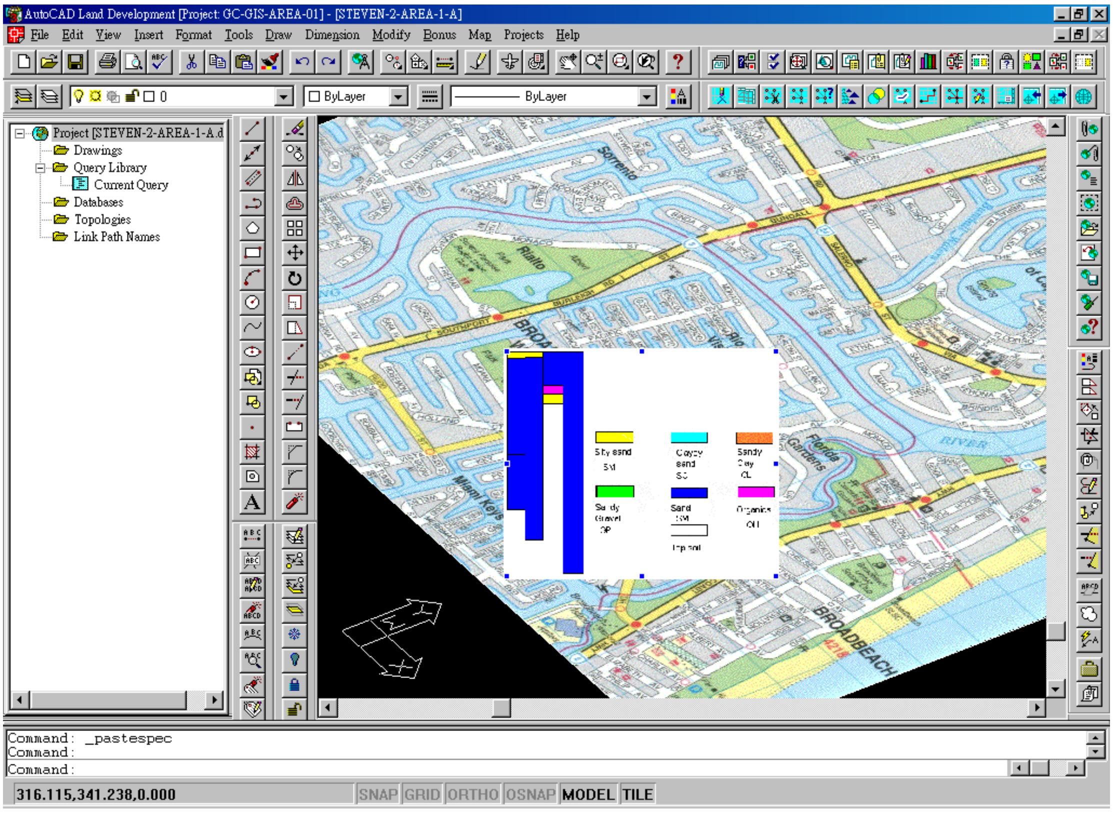
CLIENT:	**BOREHOLE No:** BH 2
PROJECT: PACIFIC FAIR SHOPPING CENTRE	**JOB No:** BT 7063
EQUIPMENT TYPE: HAND AUGER **HOLE DIAMETER:** 85mm	

Geological Profile	Samples	WATER	Depth in m	Graphic Log	Soil or Rock Type, Structure	Consistency/ Rel. Density
FILL/ TOPSOIL			0.4		Silty **SAND:** Fine grained, Moist to wet, Dark grey **(SM)**	**VERY LOOSE**
FILL			1.0		**SAND:** Fine grained, Moist to moist/wet, Pale brown **(SP)**	**LOOSE TO MEDIUM DENSE**
ALLUVIUM		▽	1.3		**ORGANICS:** Decomposed vegetable matter (strong odour), Very moist, Dark brown/black **(OH)**	**VERY LOOSE**
			1.5		**SAND:** Fine grained, Wet, Dark grey **(SP)**	**MEDIUM DENSE**
					BH 2 TERMINATED AT 1.5m **LIMIT OF INVESTIGATION**	

Logged By GDM Date 16/6/99	Checked By Date

Appendix O


AutoCAD Map - [Steven-2]
File Edit View Insert Format Tools Draw Dimension Modify Bonus Map Help
Project [STEVEN-2.dwg]
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
ByLayer
ByLayer
Distribution of soil for area 5
SM, 4%
OH, 2%
SP, 94%
QUEENSLAND
ALBERT AV
PHILIP AV
Broadbeach
Island
Park
Command :
Command :
Command :
404.7126,295.8945,0.0000
SNAP GRID ORTHO OSNAP MODEL TILE


AutoCAD Land Development [Project: GC-GIS-AREA-01] - [STEVEN-2-AREA-1-A]
File Edit View Insert Format Tools Draw Dimension Modify Bonus Map Projects Help
ByLayer
ByLayer
Project [STEVEN-2-AREA-1-A.d
Drawings
Query Library
Current Query
Databases
Topologies
Link Path Names
Command: _pastespec
Command:
Command:
316.115,341.238,0.000
SNAP GRID ORTHO OSNAP MODEL TILE