INVESTIGATION ON HEAVING OF SOIL IN THE VICINITY OF CAYPOMBO, STA. MARIA, BULACAN

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Abstract. The conversion of agricultural lands into residential areas in Caypombo, Sta. Maria, Bulacan has led the researchers to determine the physical characteristics of the converted grounds. Furthermore, it has led the researchers to consider the heaving of soils and its effects on the properties of the residents of Caypombo. The researchers have conducted an investigation that was carried out in accordance with the procedures recommended by the American Society for Testing and Materials (ASTM). The results of the study showed that the soil in the vicinity is well-graded. Moreover, the soil present in the area is silty clay and that the primary cause of on heaving of soils in the area is the existence of highly expansive organic soil. The heaving is also made worse by the poor drainage property of the soil, as manifested by the small effective size.

Keywords*: Heaving, silty clay, Sieve Analysis*

1. INTRODUCTION

Soil is a natural body consisting of layers of mineral constituents of variable thicknesses, which varies from the parent materials in their morphological, physical, chemical, and mineralogical characteristics. Soil is formed from the physical and chemical weathering of rocks. Physical weathering involves decrease of size without any change in the original composition of the parent rock. Common descriptive terms such as gravels, sands, silts, and clays are used to identify special types of soil.

Water is the agent responsible for changing the states and behaviour of soil. Water content is one of the most variable characteristics of soil. The spaces that exist between soil particles, called pores, provide for the passage and/or retention of gases and water within the soil profile.

Heaving is the process by which the saturated soil causes the deformation and upward thrust of the ground surface. Heaving occurs on heavy soil with high water content. Generally, most agricultural soil in the world develop only moderate volumetric changes during wetting and drying.

Expansive soil is known as problematic soil in civil engineering construction because of their swelling pressure and volume change characteristics. Soil is composed of a variety of materials, most of which do not expand in the presence of moisture. However, a number of clay minerals are expansive. When soil contains large amount of expansive minerals it has the potential of significant expansion. Expansive soil is possibly the most common cause of foundation movement and settlement. Certain type of soil, such as clay, absorbs water like a sponge. When the weather is hot and dry, this type loses water due to evaporation. When this soil absorbs and then loses water, its volume expands and contracts. All these soil movements are transferred to the foundation of the structure. When the soil contracts, the foundation above it loses contact with the soil and therefore loses its support. When the soil expands, the foundation moves upward.

The volumetric change of a soil is the decrease or increase in the volume of the soil mass when the water content is reduced or increased from a given percentage. Soil volumetric changes may possibly cause both positive and negative effects on human activities. Adverse effects are the damage of buildings, roads and pipelines in uncropped soil, and the leaching of fertilizers and chemicals below the root zone through desiccation cracks. Soil is a vital component in the construction and stability of a structure that is often overlooked by owners and buyers. Since the structure is built on soil, structural damage can occur if the soil expands, contracts or slides.

With the crowdedness of Metro Manila, people are beginning to look for alternative locations where they can build their houses outside the busy and jam-packed areas of the city. The conversion of agricultural lands into residential areas has allowed the researchers to investigate the characteristics of the converted grounds. Furthermore, it has made the researchers consider the swelling of soil and the damages incurred due to the heaving of soil.

Caypombo is one of the twenty-four barangays comprising the municipality of Santa Maria, Bulacan. The general geology of Caypombo, Sta. Maria Bulacan is generally underlain by the tuff and tuff breccia called Diliman Tuff, the upper member of Guadalupe Formation as thin-to-medium-bedded fine-grained vitric tuff and welded volcanic breccia with subordinate amount of tuffaceous, thin-to-medium- grained sandstone Tuff (from the Italian "tufo") is a type of rock consisting of consolidated volcanic ash ejected from vents during a volcanic eruption. Tuff is sometimes called tufa, particularly when used as construction material, although tufa also refers to a quite different rock. Figure 1 shows an example of a site being developed as a residential subdivision.

Figure 1. Example of sites being developed in Caypombo, Sta. Maria, Bulacan.

As development extends into these areas, identification and quantification of soil properties that define shrink-swell potential are essential to evaluate properly the stability of a soil as foundation material. The problem of instability of structures constructed on expansive soil is mainly due to the lifting up of the structures on heaving of soil mass on saturation during the rainy season and settling back from heaved condition on drying during summer season. Such cycle of heaving and settling occurs as the season changes. Soil investigation is necessary to provide information for design and for construction. Considering the adverse effects of the problem, much attention has been directed towards studying the nature of such soil in relation to their swelling and swelling pressure aspects. Cracked foundations, floors and basement walls are typical types of damage done by swelling soil.

Figure 2 shows the damages in some of the structures due to heaving of soil. All these factors and data acquired were used for carrying out the following objectives:

1. Determination of the physical characteristics of the soil in the vicinity of Caypombo, Sta. Maria, Bulacan.
2. Investigation of the causes of heaving of soil in the vicinity of Caypombo, Sta. Maria, Bulacan.
3. Coming up with possible recommendations regarding the effects of heaving of soil.

Since expansive soil is predominant in Caypombo, the results of this study will be beneficial to the local residents as well as to the developers. The residents will benefit because they will gain proper understanding of the effects and causes of the heaving of soil in their vicinity. On the other hand, the developers will benefit because they can come up with more economical means of dealing with the swelling of soil. Finally, other researchers will also benefit because they can use the results of this study as baseline data for conducting further research. To attain the objectives of this study, tests were done to characterize the properties of soil. Results of the Standard Penetration Test (SPT) were reckoned and served as the primary source of data for analysis.

Figure 2. Damages in the constructed structures due to the heaving of soil.

2. METHODOLOGY

The researchers have made some observations in the soil in the locality of Caypombo, Sta. Maria, Bulacan and have conducted interviews with the residents about the heaving of soil and its effects on their real properties. After some observations and interviews, an investigation was conducted by the researchers. The investigation was carried out in accordance with the procedures recommended by the American Society for Testing and Materials (ASTM). The ASTM is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

2.1. **Field Tests**. Standard Penetration Tests (SPT) were performed in rotary wash borehole following the procedures specified in ASTM D 56. In these tests, a 63.5 kg hammer that falls 450 mm was used to drive a standard split-spoon sampler into the ground. The number of hammer blows necessary to drive the last 300 mm of penetration was recorded as blow counts (N). Where refusal is reached before the full 300 mm penetration, the penetration achieved with the total number of blows applied was recorded.

The N-value was used to estimate the angle of friction of cohesionless soil and the unit weight of soil based on published correlations that relate the N-value and the engineering behavior of foundation materials.

2.2. **Laboratory Tests**. The soil samples used for the laboratory tests in deter mining the physical properties of soil were extracted from a dug hole of approximately 1 meter in depth. Figure 3 shows the researchers extracting the soil samples.

2.2.1. **Sieve analysis**. Sieve Analysis was used to determine the grain size distribution of coarse-grained soil. A weighed sample of dry soil was separated through a series of sieves of progressively smaller openings for the determination of particle size distribution. The apparatus used consisted of balance that was sensitive to 0.01g, set of standard sieves, and oven. The soil samples were dried to constant weight at a temperature of 110 + 5 ^{0}C. The samples were passed through a series of standard sieves. The sieving operation was conducted by means of lateral and vertical motions of the sieve accompanied by jarring action to keep the sample moving continuously on the surface of the sieve. Finally, the quantity retained on each sieve was weighed and recorded.

Figure 3. Extraction of soil samples.

2.2.2. **Casagrande Cup Method**. The liquid limit of the sample of soil that was determined from Casagrande Apparatus that consisted of a semispherical brass cup that repeatedly dropped onto a hard rubber base by a cam-operated mechanism. The liquid limit was defined as the water content that caused the soil to change from a liquid to a plastic state. The apparatus used included a balance that was sensitive to 0.01g, Casagrande Apparatus, spatula, grooving tool, evaporating dish, oven, and containers. The soil sample obtained was mixed thoroughly in accordance with standard procedures in the preparation of disturbed soil sample for testing with distilled water to create a uniform paste. Then a portion of the paste was placed in the Casagrande Cup, leveled on the surface with a spatula and divided the soil pat into two segments by means of the standard grooving tool. The Casagrande Cup was mounted to the carriage such that it can be raised and allowed to drop sharply on the base by rotating the crank at an approximate rate. The number of blows to close the groove in the soil was recorded. A sample from the portion which was taken and placed in a drying can for moisture content determination. This procedure was repeated four times using different moisture contents of the soil in the range of 10 to 40 blows. To draw the flow curve, the moisture content was plotted against the logarithm of the number of blows.

2.2.3. **Plastic Limit Test**. The plastic limit of the soil sample was determined by rolling a small clay sample into threads and finding the water content at which threads approximately 3 mm in diameter will just start to crumble. At least two measurements were made and the average or mean water content was considered as the plastic limit. Plastic limit was defined as the water content that causes the soil to change from a plastic to a semisolid state.

2.3. **Classification**. Classification schemes provide methods of identifying soil in particular group that would likely exhibit similar characteristics. Soil classification was used to specify a certain soil type best suitable for a given application. There were several classification schemes available. Each was devised for a special use. The American Association of State Highway and Transportation Officials (AASHTO) has developed one scheme that classifies soil according to its usefulness in roads and highways. The Unified Soil Classification System (USCS) was originally developed for use in airfield construction but was later modified for general use.

The AASHTO system classifies the group A-7-5 as clayey soil. Subgroup A-7-5 includes those materials with moderate Plasticity Indexes in relation to Liquid Limit and which may be highly elastic as well as subject to considerable volume change. Based on Unified Soil Classification System (USCS), the soil that falls under the OH subgroup is organic clay with medium to high plasticity and is characterized by the presence of organic matter. The Atterberg limits of this soil generally plots below the A-line. The soil in this group has high plasticity and the soil is fat clay or elastic silt. The soil is organic and is manifested by the presence of peats.

3. RESULTS AND DISCUSSION

3.1. **Determination of Particle Size of Soil**. The distribution of particle sizes or average grain diameter of soil was obtained by screening a known weight of the soil through a stack of sieves of progressively finer mesh size. Each sieve was identified by a number that corresponds to the number of square holes per linear inch of mesh. The particle diameter in the screening process was the maximum particle dimension to pass through the square of hole of a particular mesh. A known weight of dry soil was placed on the largest sieve, located at the top of the stack, and the nest of sieve was then placed on a vibrator and shaken. The nest of sieves was dismantled one sieve at a time. The soil on each sieve was weighed and the percentage of soil retained on each sieve was calculated using the following formula:

(3.1) % Retained on ith sieve = (Wi/W) *100

Table 1 summarizes the percentage retained in each sieve. The results were plotted as a graph of percentage of particles finer than a given sieve as the ordinate versus the logarithm of the particle sizes. Percent finer is computed using the following formula.

(3.2) % Finer than the ith Sieve = 100 - Σ (% Retained on ith Sieve)

Table 1. Percent Retained on Each Sieve.

Sieve opening (mm)	Weight retained (kg)	Percent retained (%)

4.75	0.05	3.38
0.60	0.07	5.43
0.425	0.10	7.75
0.25	0.08	6.20
0.15	0.04	3.10
0.09	0.04	3.10
0.075	0.01	0.775
PAN	0.90	69.77

The resulting graph or plot is called the particle size distribution curve or gradation curve. Table 2 reflects the percent of particles finer. By merely looking at the shape of the graph shown in Figure 4, we can see that the soil is well graded. A well-graded soil is a soil sample that has all sizes of material present from the No. 4 sieve to the No. 200 sieve. Well graded soils are produced by bulk transport processes such as glacial till.

Table 2. Percent Finer Summary

Sieve opening	Percent Finer (%)
4.75	96.12
0.60	90.69
0.425	82.94
0.25	76.74
0.15	73.64
0.09	70.54
0.075	69.77
Pan	0

Based on the particle size distribution of the soil, one can characterize the physical properties of soil. This was used for textural classification of soil. Different coefficients derived from the gradation curve were used in reference to the different classification systems which evolved through the years.

3.2. **Effective Size**. The effective size (D_{10}) is the diameter of the particles of which 10% of the soil is finer. It is an important value in regulating flow through soil and can significantly influence the mechanical behavior of soil since the coarser fractions may not be in effective contact with each other; that is they ought in a matrix of finer particles. The higher the effective size, the better the drainage characteristics are. Based on the gradation curve, the effective size of the sample is projected to be 0.013mm. The effective size is the diameter of an artificial sphere that will approximately produce the same effect of an irregular shaped particle.

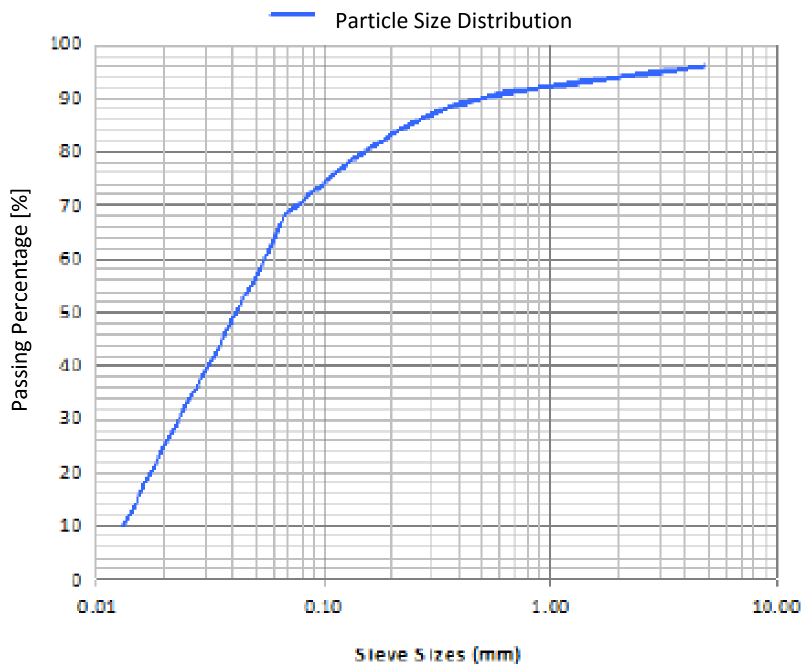


Figure 4. Particle Size Distribution Curve of the Soil Sample Reckoned from the Vicinity of the Investigation Site.

Real soil consists of a mixture of particle sizes. The selection of a soil for a particular use may depend on the assortment of particles it contains. Two coefficients have been defined to provide guidance on distinguishing soil based on the distribution of the particles.

3.3. **Uniformity Coefficient (UC)**. The uniformity coefficient (UC) is a measure of uniformity of particles. It is defined as the ratio between the diameters of the soil particles for which 60% of the particles are finer over the effective size D_{10}. In equation form,

(3.3) $$UC = D_{60}/D_{10}$$

Based on the gradation curve, D_{60} is projected to be equal to 0.055mm. Based on the earlier value of the effective size and applying the equation for the uniformity coefficient is found to be equal to 7.0. A soil that has a uniformity coefficient of less than 4 contains particles of uniform size. The minimum value of UC is 1 and corresponds to an assemblage of particles of the same size. The gradation curve for a uniform soil is almost vertical. Higher values of UC, values greater than 4, indicate a wider assortment of particle sizes. The 4.23- UC value projected only reinforces the earlier result that the soil is indeed well-graded.

3.4. **Coefficient of Curvature**. The coefficient of curvature (CC) is also known as the coefficient of gradation or coefficient of concavity. It is defined by the following formula:

$$CC = (D_{30})2/D_{10}D_{60} \quad (3.4)$$

D_{30} is defined as the diameter of the soil particles for which 30% of the particles are finer, while D_{10} and D_{60} are defined above. Following the above-captioned formula, the soil has a CC value of 1.019. This reinforces the result that the soil is well graded.

3.5. Atterberg Limits. The Atterberg Limits is a basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, the physical and mechanical behavior of fine-grained soil is likened to four distinct states: solid, semi-solid, plastic and liquid. In each state the consistency and behaviour of a soil is different and thus so its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. The Atterberg Limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays

3.5.1. **Liquid Limit**. The liquid Limit (LL) is determined using the Casagrande Cup Method. It is determined from an apparatus that consists of a semi-spherical brass cup that is repeatedly dropped onto a hard rubber base from a height of 10mm by a cam-operated mechanism. A dry powder of the soil is mixed with distilled water into a paste and placed in the cup to a thickness of about 12.5mm.

Soil surface is smoothed and a groove is cut into the soil using a standard grooving tool. The crank operating the cam is turned at a rate of 2 revolutions per second and the number of blows required to close the groove over a length of 12.5mm is counted and recorded. A specimen of soil within the closed portion is extracted for the determination of the water content. The liquid limit is defined as the water content at which the groove cut into the soil will close over a distance of 12.5mm following 25 blows. Four or more tests at different water content are usually required for terminal blows. Table 3 shows the results of the liquid limit test done on the soil sample.

Table 3. Results of Casagrande Cup Method

Number of Blows	Water Content (%)
28	50.00
38	53.85
46	25.00
53	11.11

The values in Table 3 were then plotted with the y-axis as the water content and the x-axis being the logarithm of the number of blows. And the water content corresponding to 25 blows was extracted from the graph. Figure 5 reflects the graph of the relation between the water content and the logarithm of the number of blows.

Based on Figure 5, the water content corresponding to 25 blows was extracted to be equal to 64.89%. This was actually defined as the Liquid Limit of the soil sample by Casagrande Cup Method.

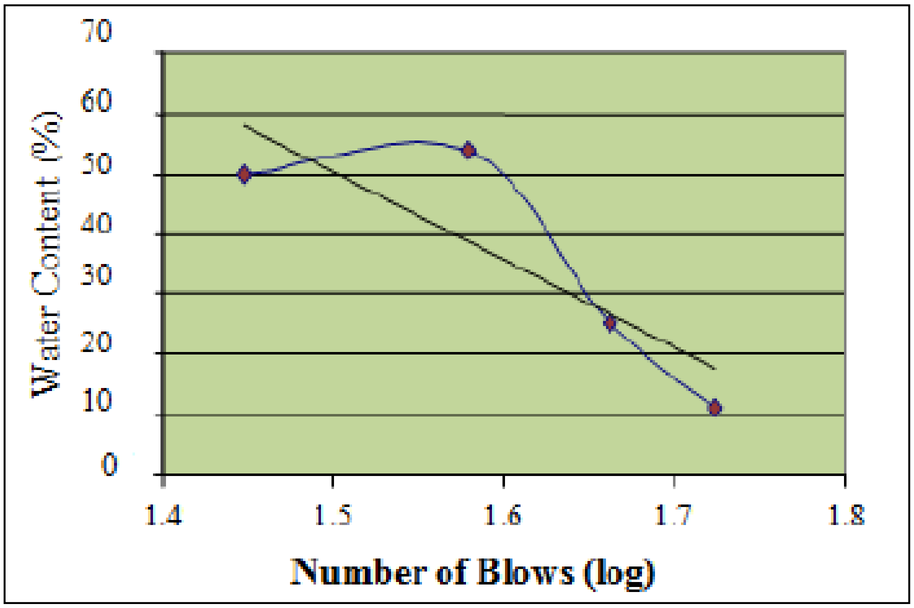


Figure 5. Graph for Liquid Limit Determination.

3.5.2. **Plastic Limit Test**. The water content at which the soil changes from a plastic to a semi-solid state is known as the plastic limit (PL). The plastic limit was determined by rolling a small clay sample into threads and finding the water content at which threads approximately 3mm in diameter will just start to crumble. At least two or more determinations were made and the average water content was used as the Plastic Limit. Table 4 shows the two tests done for the determination of the Plastic Limit. Getting the average of the two trials, it yielded that the Plastic Limit of the soil sample was 48.67%.

Table 4. Determination of Plastic Limit

Trial	Water Content
1	48.92
2	48.42

3.6. **Plasticity Index**. The range of water content over which the soil deforms plastically is known as the Plasticity Index. It is denoted as I_p and is computed using the following equation:

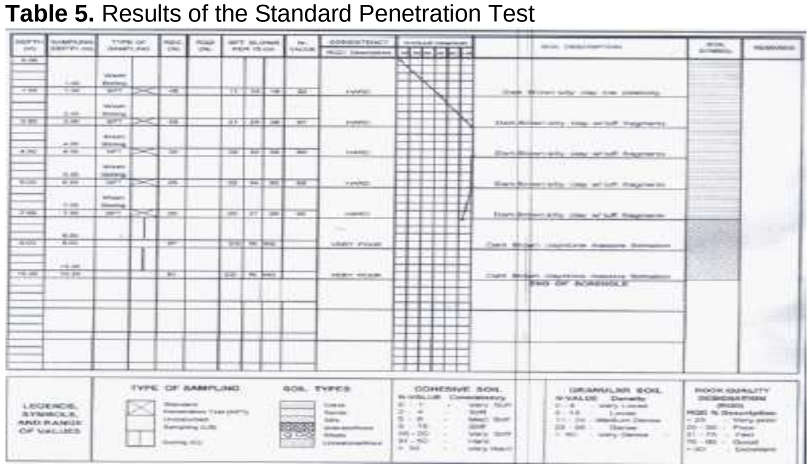
(3.5) $$I_p = LL - PL$$

Using the above-captioned equation, A 16.22 Plasticity Index of soil sample was derived. 3.7. Liquidity Index. A measure of soil strength using the Atterberg Limits is known as the liquidity index, denoted as I_l. The liquidity index is the ratio of the difference in water content between the natural or in-situ water content of a soil and its plastic limit to its plasticity index. In equation form, I_l is expressed as:

(3.6) $$I_l = (\text{Water Content in-situ} - PL)/ I_p$$

Following the above-stated equation with the natural water content to be equal to 59.80%, A 0.69 liquidity index of soil sample was derived. Table 5 shows the result of the Standard Penetration Tests (SPT) performed in rotary-wash borehole at the vicinity of Caypombo, Sta. Bulacan.

Table 5. Results of the Standard Penetration Test



The Standard Penetration Tests (SPT) were performed in rotary-wash borehole following the procedures specified in ASTM D56, at depth of 10.50m from the natural ground level.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. **Summary of Findings**

This study was conducted to investigate the heaving of soil in the vicinity of Caypombo, Sta. Maria, Bulacan. The researchers extracted soil samples in the said location and performed tests to obtain the classification, the liquid limit, plastic limit, plasticity index, and liquidity index of the soil samples. The result of the graph of the sieve analysis showed that the soil was well-graded. The soil has a coefficient of curvature value of 1.019 and uniformity coefficient of 4.23. By these results, the generalization that the soil was well-graded was reinforced.

The Liquid Limit Test was done using the Casagrande Cup Method and the water content corresponding to 25 blows was extracted to be equal to 64.89%. The Plastic Limit of the soil sample was obtained to be 48.67%. Based on the values of the liquid limit and plastic limit, the soil contained hydrated halloysite. These clay minerals were known to be expansive. The Plasticity Index of the soil sample was found to be at 16.22. The natural water content was equal to 59.80%, and it was derived that the Liquidity Index of the soil sample was 0.69. The results of the Standard Penetration Tests (SPT) showed that the soil was dark brown silty clay with low plasticity and with tuff fragments, at depth of 1.50 m from natural ground level and from 1.50 m to 7.50 m depth, respectively. At depth of 7.50 m up to 10.50 m below natural ground level, the results showed that the soil was dark brown clay stone massive formation. The log of the borehole drilled at the study site was characterized in the upper part of the section by hard low plasticity silty clay to about 1.50 m, followed by variably weathered, fractured rock. No seepage of water into drill hole was observed.

4.2. **Conclusion**

Based on the physical characteristics of the soil that were reckoned from the different tests, it is hereby concluded that the soil was well-graded. The Uniformity Coefficient of 4.23 and the Coefficient of Curvature of 1.019 reinforced the conclusion that, indeed, it was well-graded. Based on the results of the different tests done on the soil sample, it is deduced that according to AASHTO classification system, the soil was under group A-7-5. Based on Unified Soil Classification System (USCS), the soil falls under the OH subgroup. The soil was organic as manifested by the presence of peats. This was mainly attributed to the conversion of agricultural land to residential areas. It is hereby concluded that the soil present in the vicinity is silty clay. It is also concluded that the primary cause of heaving of soil in the area was the existence of highly expansive organic soil. The heaving was made worse by the poor drainage property of the soil, as manifested by the small effective size of 0.013mm.

4.3. **Recommendations**

The conclusions and recommendations presented in this study were based on the results at the point of exploration, and were subjected to conformation (to the extent possible) based on the conditions revealed during construction. Variations from the conditions portrayed, which were not indicated by the test explorations, may occur. The footing was predicated on removal of soft materials, man-made fill, and otherwise unsuitable subgrade soil and replacement with engineered fill to achieve the final grades.

It is also recommended that further chemical tests on soil be done since pesticides were predominantly used in the area due to previous agricultural activities. It is recommended that all earthworks during construction be monitored including site preparation, placement of all engineered and trench back, construction of slab and all foundation excavations. The role of this study was to provide the opportunity to observe the soil conditions encountered during construction, assess the applicability of the recommendations in relation with the soil conditions encountered, and recommend appropriate changes in design or construction methods if conditions differ from those described herein. The researchers, due to some restrictions, failed to correlate the results of standard penetration tests with the bearing capacity of the soil including its settlement characteristic. It is therefore recommended that further studies be done to correlate these parameters.

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