# Assessing performance of a Geo Probe

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## Abstract

This study is carried out for assessing the performance of a geo probe for determining ultimate bearing capacity and shear strength of soft soils. Experimental work was carried out on 4 different types of soft soils with two trials for each sample. The tests were conducted at UTHM RECSESSS research centre. Geo Probe comprised of a cylindrical hollow PVC pipe of 50mm for internal diameter and 100mm for the external diameter in filled with foamed concrete of 1200kg/m$^3$ density. The performance of the probe was assessed based on ratio of ultimate bearing capacity over undrained shear strength in particular study of soil. Commonly, ultimate bearing capacity by five times the undrained shear strength is accepted in case of soft soils. The tests conducted for the geo probe showed that the ratio of ultimate bearing capacity over undrained shear strength for the tested samples varies from 1.0 to 6.0 for different loading which shows the performance of the geo probe is acceptable and useful for determining the ratio of ultimate bearing capacity, $q_u$ and the undrained shear strength, $S_u$.

## Keywords

geo probe, soft soil, ultimate bearing capacity, undrained shear strength

## 1. Introduction

A considerable part of the land is consisted of soft and clay soil which needs careful attention for development over it. Soft soils are commonly organic, wet, unconsolidated surficial deposits that are integral parts of the wetland systems [Bujang and Huat, 2006]. Organic soils are highly compressible (Ushaa, 2006) and organic which also has low shear strength for accommodating loading from the upper side. In case of soft soil such as clay, any error in parameter assumptions can cause extreme settlement which can be very dangerous. For construction in soft soil, several factors influence the method of the construction such as characteristics of the soil, construction material equipment required, available time location of structures and drainage requirement (Kogure et. al. 1993). Construction of the foundation is complicated because the soft soil is weak to lateral movement when it is subjected to vertical load. For construction works of soft soils, it is very important to determine ultimate bearing capacity, $q_u$ and the undrained shear strength, $S_u$ prior to design and construction. For these calculations, Ling et. al. (2014) proposed a new geo probe. This study used geo probe for conducting experimental work on various types of soft soil to assess the performance of the probe based on ratio of ultimate bearing capacity and the undrained shear strength.

## 2. MATERIAL AND METHOD

### 2.1 Site Preparation

This study aimed to assess the performance of a Geo probe on soft soil. For that, test of the probe was carried out on various types of soils around UTHM area located at the RECESS research center as shown in figure 1. Site preparation was done by digging out a hole until the ground water level of the soil to have a reluctantly soft soil figure 2. Experimental work was performed on samples from various types of soils such as clay and sand as shown in figure 3 and figure 4.

**Figure 2: Test site at RECESS**

**Figure 2: Geo Probe on test site**

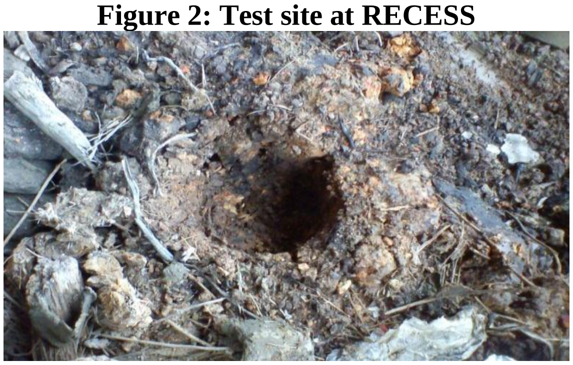

**Figure 3: Clayey soil sample at RECESS**

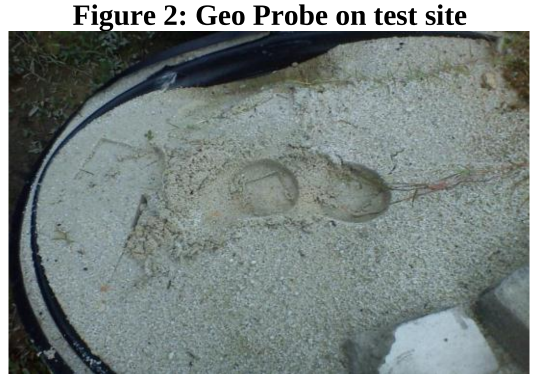

**Figure 4: Sand sample at RECESS**

### 2.2 Vane Shear Test

Vane shear test is an in-situ geotechnical testing used to estimate the undrained shear strength. Vane shear test apparatus consist of four blades which are firmly attached to the high tensile. This apparatus comes with different sizes that are use for variable of soils to take the unit shear strength of the soil. Procedure for vane shear test is consisting of 3 steps as:

- ❖ The apparatus was pushed into the soft soil, ensuring the apparatus is acting vertically to the ground.
- ❖ The vane was rotated at a constant rate of 0.10 per second by suitable equipment.
- ❖ When the soil shears, the force on the torsion device will be released and the pointers will register the maximum vane shear strength.

Vane shear test was performed according to soil investigation procedure BS 1377 as shown in figure 5 and 6.

Figure 5: Vane Shear Test

Figure 6: Vane Shear Test

## 3. EXPERIMENTAL WORK

The scaled down geo probe was tested on site to obtain the value of $q_u/S_u$ ratio which is commonly mentioned that qu is 5 times higher than Su for soft soil. The test was repeated twice on every site to find similarity and to get an average reading of the test. Experimental work was carried out into two stages which is testing for the tip resistance which will be used to calculate the bearing capacity and skin resistance which is for undrained shear strength. The testing procedure adopted for this work is as follows.

### 3.1 Tip Resistance

Test for tip resistance was performed by following process:

- ❖ As the movement was only the bearing probe, a paper is stick to the upper of the bearing probe and the initial distance between the loading plate and upper end of the pile was recorded. The upper end of the pile will be the marking to the paper.
- ❖ The instrumented pile was set vertically on the soft soils and the depth of the initial penetration of the pile is recorded.
- ❖ The bearing plate was tested by loading it with 10kg every session and the settlement of the bearing plate is recorded. The testing continues after 5 minutes to wait until the movement of the instrument stopped. With increasing the loading by 10kg every session and the depth of settlement was recorded as shown in figure 7 and figure 8.

Figure 7: Loading the instrumented pile

Figure 8: Recording the settlement of the pile

### 3.2 Skin Resistance

Test for Skin resistance was performed by following process:

- Marking was done on the outer section of the pile by every 50mm starting from the lowest part of the pile.
- The instrumented pile was set vertically on the soft soils and the depth of the initial penetration of the pile was recorded.
- The pile was tested by loading it with 10kg every session and the settlement of the bearing plate is recorded. The testing continued after 5 minutes waiting until the movement of the instrument was stopped. With increasing the loading by 10kg every session and the depth of settlement was recorded.

## 4. RESULTS AND DISCUSSION

For assessing the performance of the probe, 4 tests were conducted on different types of the soil samples. Each test consisted of 2 trials. The findings of the tests are presented and discussed in the following sections.

### 4.1 Test 1: Sand Soil

First test was carried out on sand sample. Vane shear test showed that sand sample gave a value of 10kpa to 12kpa which as an average of 11kpa. The test involved two trials. The penetration or the settlement for tip resistance is in the range of 4mm to 18mm and for skin resistance is of 2mm to 8mm which is shown in table 1 and table 2.

**Table 1: Experimental data (First trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kN/m$^2$) | Penetration (mm) | Cumulative (mm) | $Au$ (m$^2$) | $Su$ (kN/m$^2$) |
| 0 | 0 | 0 | 39 | 0 | 0 | 39 | 0.01225 | 0 |
| 10 | 0.0981 | 4 | 43 | 20.02040816 | 3 | 42 | 0.01319 | 7.43481 |
| 20 | 0.1962 | 4 | 47 | 40.04081633 | 2 | 44 | 0.01382 | 14.1937 |
| 30 | 0.2943 | 12 | 59 | 60.06122449 | 4 | 48 | 0.01508 | 19.5164 |
| 40 | 0.3924 | 8 | 67 | 80.08163265 | 6 | 54 | 0.01696 | 23.1305 |
| 50 | 0.4905 | 16 | 83 | 100.1020408 | 4 | 58 | 0.01822 | 26.9191 |
| 60 | 0.5886 | 12 | 95 | 120.122449 | 8 | 66 | 0.02073 | 28.3875 |

**Table 2: Experimental data (Second trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kN/m$^2$) | Penetration (mm) | Cumulative (mm) | $A_u$ (m$^2$) | $S_u$ (kN/m$^2$) |
| 0 | 0 | 0 | 43 | 0 | 0 | 43 | 0.01351 | 0 |
| 10 | 0.0981 | 2 | 45 | 20.02040816 | 2 | 45 | 0.01414 | 6.93916 |
| 20 | 0.1962 | 4 | 49 | 40.04081633 | 3 | 48 | 0.01508 | 13.0109 |
| 30 | 0.2943 | 6 | 55 | 60.06122449 | 5 | 53 | 0.01665 | 17.6752 |
| 40 | 0.3924 | 10 | 65 | 80.08163265 | 4 | 57 | 0.01791 | 21.9131 |
| 50 | 0.4905 | 14 | 79 | 100.1020408 | 3 | 60 | 0.01885 | 26.0218 |
| 60 | 0.5886 | 18 | 97 | 120.122449 | 7 | 67 | 0.02105 | 27.9638 |

From tables 1 and 2, it is seen that the cumulative depth at 60 Kg loading on proble achieved for the tip resistance is 95mm and 97mm and the same for skin resistance is 66mm and 67mm. The ultimate bearing capacity, qu gives a higher gradient than undrained shear strength, Su. The ratio of ultimate bearing capacity over the undrained shear strength gives an average value of 2.15 for first trial and 2.57 for second trial as presented in table 3 and table 4.

**Table 3: Data of $q_u/S_u$ Ratio (First Trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 40 | 16 | 7 | 2.28571 |
| 45 | 27 | 11.8 | 2.28814 |
| 50 | 36 | 17 | 2.11765 |
| 55 | 46 | 21.8 | 2.11009 |
| 60 | 56 | 27 | 2.07407 |
| 65 | 66 | 32 | 2.0625 |

**Table 4: Data of $q_u/S_u$ Ratio (Second Trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 45 | 25 | 8.5 | 2.94118 |
| 50 | 35.5 | 12.5 | 2.84 |
| 55 | 46 | 18.5 | 2.48649 |
| 60 | 56 | 24 | 2.33333 |
| 65 | 66.5 | 29.5 | 2.25424 |

### 4.2 Test 2: Clay Soil

Test 2 was carried out on clayey soil. Visual observation highlighted that the sample taken was red brownish cohesive soil. Shear strength of the soil obtained through vane shear apparatus ranged from 20kpa to 23kpa. Penetration that resulted from the loading applied to the probe was in the range of 2mm to 10mm for tip resistance as shown in table 5 and table 6

**Table 5: Experimental data (First trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kg/mm$^2$) | Penetration (mm) | Cumulative (mm) | $A_u$ (m$^2$) | $S_u$ (kN/m$^2$) |
| 0 | 0 | 0 | 20 | 0 | 0 | 20 | 0.00628 | 0 |
| 10 | 0.0981 | 5 | 25 | 20.02040816 | 1 | 21 | 0.0066 | 14.8696 |
| 20 | 0.1962 | 3 | 28 | 40.04081633 | 2 | 23 | 0.00723 | 27.1532 |
| 30 | 0.2943 | 2 | 30 | 60.06122449 | 4 | 27 | 0.00848 | 34.6958 |
| 40 | 0.3924 | 8 | 38 | 80.08163265 | 3 | 30 | 0.00942 | 41.6349 |
| 50 | 0.4905 | 10 | 48 | 100.1020408 | 5 | 35 | 0.011 | 44.6089 |
| 60 | 0.5886 | 83 | 131 | 120.122449 | 3 | 38 | 0.01194 | 49.3045 |

**Table 6: Experimental data (Second trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kg/mm$^2$) | Penetration (mm) | Cumulative (mm) | $A_u$ (m$^2$) | $S_u$ (kN/m$^2$) |
| 0 | 0 | 0 | 23 | 0 | 0 | 23 | 0.00723 | 0 |
| 10 | 0.0981 | 4 | 27 | 20.02040816 | 2 | 25 | 0.00785 | 12.4905 |
| 20 | 0.1962 | 6 | 33 | 40.04081633 | 4 | 29 | 0.00911 | 21.5353 |
| 30 | 0.2943 | 2 | 35 | 60.06122449 | 2 | 31 | 0.00974 | 30.2189 |
| 40 | 0.3924 | 4 | 39 | 80.08163265 | 3 | 34 | 0.01068 | 36.7367 |
| 50 | 0.4905 | 8 | 47 | 100.1020408 | 6 | 40 | 0.01257 | 39.0327 |
| 60 | 0.5886 | 5 | 52 | 120.122449 | 4 | 44 | 0.01382 | 42.5812 |

There is a drastic increase of the penetration which was 83mm, this can be said that there was a void section in between the soil at the below of the pile that causes the failure of the soil when it is loaded with 60kg of load. Cumulative penetration that is recorded for tip resistance is 131mm and 52mm. For the skin resistance the penetration of the soil is in the range of 1mm to 6mm and cumulative penetration of 38mm and 44mm as shown in the table 5 and table 6. The $q_u$ over $S_u$ ratio for both trial is in average of 1.09 and 1.68 as shown in table 7 and 8 which almost the same and prove that the results taken are acceptable.

**Table 7: Data of $q_u/S_u$ Ratio (First Trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 20 | 8.5 | 12.5 | 0.68 |
| 25 | 26.5 | 24 | 1.10417 |
| 30 | 44.5 | 35.8 | 1.24302 |
| 35 | 63 | 47.5 | 1.32632 |

**Table 8: Data of $q_u/S_u$ Ratio (Second trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 30 | 33 | 22 | 1.5 |
| 35 | 54 | 31.5 | 1.71429 |
| 40 | 74 | 40.8 | 1.81373 |

### 4.3 Test 3: Soft Soil

Test 3 was carried out at soft soil site in area of RECESS Universiti Tun Hussein Onn Malaysian with shear strength of 1kpa and 2kpa. The soil was the combination of water and soil and the sample was in-fill to the hole taken by digging. Penetration of tip resistance was up to 150mm based on the probe design criteria. Test involved two trial and the maximum load before the tip resistance crossed e 150mm mark was recorded as 20kg. Experimental results at various loadings are presented table 9 and table 10.

**Table 9: Experimental data (First trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kN/m2) | Penetration (mm) | Cumulative (mm) | $A_u$ (m2) | $S_u$ (kN/m2) |
| 0 | 0 | 0 | 90 | 0 | 0 | 90 | 0.02827 | 0 |
| 10 | 0.0981 | 13 | 103 | 20.02040816 | 10 | 100 | 0.03142 | 3.12262 |
| 20 | 0.1962 | 42 | 145 | 40.04081633 | 15 | 115 | 0.03613 | 5.43064 |
| 30 | 0.2943 | | | 60.06122449 | 34 | 149 | 0.04681 | 6.28715 |
| 40 | 0.3924 | | | 80.08163265 | 31 | 180 | 0.05655 | 6.93916 |
| 50 | 0.4905 | | | 100.1020408 | 30 | 210 | 0.06597 | 7.43481 |
| 60 | 0.5886 | | | 120.122449 | 26 | 236 | 0.07414 | 7.93886 |

**Table 10: Experimental data (Second trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kN/m2) | Penetration (mm) | Cumulative (mm) | $A_u$ (m2) | $S_u$ (kN/m2) |
| 0 | 0 | 0 | 50 | 0 | 0 | 50 | 0.01571 | 0 |
| 10 | 0.0981 | 16 | 66 | 20.02040816 | 11 | 61 | 0.01916 | 5.11905 |
| 20 | 0.1962 | 80 | 146 | 40.04081633 | 62 | 123 | 0.03864 | 5.07743 |
| 30 | 0.2943 | | | 60.06122449 | 46 | 169 | 0.05309 | 5.54311 |
| 40 | 0.3924 | | | 80.08163265 | 43 | 212 | 0.0666 | 5.89174 |
| 50 | 0.4905 | | | 100.1020408 | 28 | 240 | 0.0754 | 6.50546 |
| 60 | 0.5886 | | | 120.122449 | 25 | 265 | 0.08325 | 7.07008 |

From table 9 and table 10, it can be seen that for skin resistance, the penetration was ranging from 10 mm to 62 mm which is higher than sandy soil. Although the penetrations increased more than the previous soil, the value still show a similar type of increase. The difference between $q_u$ and $S_u$ gradient is different from the previous soil which has the ratio between $q_u$ and $S_u$ is much higher with an average of 6.71 and 6.94 i.e. more than 5 which is commonly assumed by engineers; this could be because of the safety factors that the ratio is reduced to 5.The ratio of $q_u$ and $S_u$ for the two trials carried out are in table 11 and table 12.

**Table 11: Data of $q_u/S_u$ Ratio (First Trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 100 | 11.7 | 1.95 | 6 |
| 110 | 18.2 | 3.4 | 5.35294 |
| 120 | 25 | 3.8 | 6.57895 |
| 130 | 31.5 | 4.25 | 7.41176 |
| 140 | 38.2 | 4.65 | 8.21505 |

**Table 12: Data of $q_u/S_u$ Ratio (Second trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 80 | 17.3 | 3.35 | 5.16418 |
| 100 | 24.7 | 3.78 | 6.53439 |
| 120 | 32 | 4.2 | 7.61905 |
| 140 | 39 | 4.6 | 8.47826 |

### 4.4 Test 4: Soft Soil

Site for test 4 is similar to test 3 as the soil is dug but there is no in fill and the test was carried after the soil is dug until the ground water level to have lower soil strength. The shear strength of the soil is in the range of 19kpa to 20kpa as valued through vane shear apparatus. The penetration for tip resistance is lower than 10mm which is in the range of 2mm to 9mm where the skin resistance shows lower penetration which ranges from 2mm to 5mm. The cumulative penetration show slight difference for tip resistance which is 79mm for second trial and 89mm for first trial which is shown in table 13 and table 14.

**Table 13: Experimental data (First trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kN/m2) | Penetration (mm) | Cumulative (mm) | $A_u$ (m2) | $S_u$ (kN/m2) |
| 0 | 0 | 0 | 58 | 0 | 0 | 58 | 0.01822 | 0 |
| 10 | 0.0981 | 4 | 62 | 20.02040816 | 3 | 61 | 0.01916 | 5.11905 |
| 20 | 0.1962 | 2 | 64 | 40.04081633 | 2 | 63 | 0.01979 | 9.91308 |
| 30 | 0.2943 | 8 | 72 | 60.06122449 | 3 | 66 | 0.02073 | 14.1937 |
| 40 | 0.3924 | 6 | 78 | 80.08163265 | 3 | 69 | 0.02168 | 18.1021 |
| 50 | 0.4905 | 2 | 80 | 100.1020408 | 5 | 74 | 0.02325 | 21.0988 |
| 60 | 0.5886 | 9 | 89 | 120.122449 | 4 | 78 | 0.0245 | 24.0202 |

**Table 14: Experimental data (Second trial)**

| Loading (kg) | Force (kN) | Tip Resistance | | | Skin Resistance | | | |
|---|---|---|---|---|---|---|---|---|
| | | Penetration (mm) | Cumulative (mm) | $q_u$ (kN/m2) | Penetration (mm) | Cumulative (mm) | $A_u$ (m2) | $S_u$ (kN/m2) |
| 0 | 0 | 0 | 54 | 0 | 0 | 54 | 0.01696 | 0 |
| 10 | 0.0981 | 6 | 60 | 20.02040816 | 2 | 56 | 0.01759 | 5.57611 |
| 20 | 0.1962 | 4 | 64 | 40.04081633 | 5 | 61 | 0.01916 | 10.2381 |
| 30 | 0.2943 | 2 | 66 | 60.06122449 | 2 | 63 | 0.01979 | 14.8696 |
| 40 | 0.3924 | 5 | 71 | 80.08163265 | 3 | 66 | 0.02073 | 18.925 |
| 50 | 0.4905 | 2 | 73 | 100.1020408 | 4 | 70 | 0.02199 | 22.3044 |
| 60 | 0.5886 | 6 | 79 | 120.122449 | 3 | 73 | 0.02293 | 25.6654 |

Results show that for skin resistance the cumulative penetration is almost the same for both the trial that was carried out which is 78mm and 73mm. Further, compared to test 2, the gradient is lower which highlights that lower strength of soil will give a higher ratio of ultimate bearing capacity over undrained shear strength. Results of qu over Su ratio are presented in table 15 and table 16.

**Table 15: Data of $q_u/S_u$ Ratio (First Trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 60 | 15 | 5 | 3 |
| 65 | 34 | 10.5 | 3.2381 |
| 70 | 53 | 16.8 | 3.15476 |
| 75 | 72 | 22.5 | 3.2 |

**Table 16: Data of $q_u/S_u$ Ratio (Second trial)**

| Depth | $q_u$ | $S_u$ | $q_u/S_u$ |
|---|---|---|---|
| 60 | 25 | 9 | 2.77778 |
| 65 | 51 | 16 | 3.1875 |
| 70 | 76.5 | 22.8 | 3.35526 |

## 5. SUMMARY

The summary of all the test is carried out by comparison qu/Su ratio of all tests and trial as presented in Table 17.

**Table 17: Comparison of $q_u/S_u$ ratio for different type of soil**

| Sample | Trial | Average |
|---|---|---|
| Test 1: Sand | 1 | 2.15636 |
| | 2 | 2.57105 |
| Test 2: Clay | 1 | 1.08837 |
| | 2 | 1.676 |
| Test 2: Soft Soil | 1 | 6.71174 |
| | 2 | 6.94897 |
| Test 3: Soft Soil | 1 | 3.14821 |
| | 2 | 3.10685 |

From table 17, it can be concluded that weaker the soil will give a higher value of the qu over Su ratio. Experimental work carried out through the designed probe showed that is acceptable and useful. However, this probe is small sized and can only be used for small scale investigations. Further, it is recommended that for better results on large scale, the size of probe can be increased to real size of the spun file to determine the actual values of qu and Su at higher depth through different layers of the soil.

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