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Estimation of Undrained Shear Strength of Soil using Cone Penetration Test

By

Nwobasi, Paul Awo

Department of Technology and Vocational Education

Ebonyi State University, Abakaliki

And

Egba, Ernest Ituma

Department of Technology and Vocational Education

Ebonyi State University, Abakaliki

Abstract

This paper shows the determination of undrained shear strength based on cone resistance from cone penetration test for clayey soil. The test was carried out on ten different suspected clayey soil sites at Ebonyi State College of Education, Ikwo. The cone factor which is the most important for reliable estimation of undrained shear strength from cone penetration was evaluated considering the plasticity index of the soil. The result showed that the cone factor ranges from 11.26 at plasticity index of 12.7 to 16.19 at plasticity index of 30. The result showed an increasing trend. The result also showed quantity of combined clay and silt in the sites. The researcher recommends that the concerned bodies and organizations should insist on the use of the results of soil tests such as the cone penetration test for soil properties determination in the foundation designs of structures to avert structural foundation failures

Keywords: Soil Investigation, Cone Factor, Cone Resistance, Cone Penetration Test, Undrained Shear Strength

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Introduction

The cone penetration test (CPT) is a method used to determine the geotechnical engineering properties of soils and delineating soil stratigraphy. Mayne (2007) said that the cone penetration test soundings can be used either as a replacement (in lieu of) or complement to conventional rotary drilling and sampling methods. Teh (1987) disclosed that the earliest use of the cone penetrometer in form of a static sounding probe in soil investigation can be attributed to the Swedish State Railway around 1917. However, it has undergone tremendous development in recent years as an in-situ site investigation tool. Cone penetration test is the most used method of in-situ soil testing (Brouwer, 2007). Without disturbing the ground, it provides information about soil type, geotechnical parameters like shear strength, density, elastic modulus, rates of consolidation and environmental properties.

Soil is a useful building material because it has the shear strength that can itself and other loadings. Conversely, the same material may become so weak that it can no longer support itself and it will fail. Geotechnical engineers must be able to predict the loading on a soil, its strength and determine whether it will be safe or how to modify it to make it safe especially in the case of building construction.

By definition, solid materials possess shear strength. They can resist applied shear and normal stresses. The maximum shear stress a body is able to resist is its "shear strength." A factor of safety against failure exists if the applied stress is less than the shear strength. When sheared, a soil starts from an initial condition and ultimately reaches the steady-state condition (Joseph, 2012). The shear strength of a soil is a function of: the particle shape, the gradation of the soil, the soil density, the amount and types of fines, the pore pressure and how the rate of loading affects it.

The undrained shear strength is one of the most important parameters in clayey soils. Undrained shear strength can be determined through several approaches: direct method in terms of vane shear test, simple shear test, and triaxial test and indirect empirical equations utilizing in-situ tests (CPT and Dilatometer Test (DMT)). The empirical equation using CPT is a powerful and simple method but subject to cone resistance influenced by various soil characteristics. Thus many researchers have presented their empirical methods and provided cone factors (Jamiolkowski, Lancellotta, Tordella, and Battaglio, 1982; Lunne, Eidsmoen, Gillespie, and Howland, 1986; Rad and Lunne, 1988; Lee, 1997; Chang, Lee, Jung, and Kim, 2001; Chung, Back, Ryu, and Kim, 2003; Anagnostopoulous, Koukis, Sabatakis, and Tsiambaos. 2003; Park, Kim, Kim, and Lee, 2007).

Young and Daehyeon (2010) presented a rational way of developing the correlation of undrained shear strength based on the cone resistance from the Cone

Penetration Test for clayey soils. The field cone penetration test program included CPT, the index test, the one dimensional test and the triaxial test. The cone factor, which is most important for reliable estimation of undrained shear strength from cone resistance, was evaluated considering the plasticity index of soils. The cone factor was influenced by the test method that was used for obtaining the undrained shear strength. The isotropic Consolidated Undrained Compression Test (CIUC) for shear strength assessment was used to effectively reflect in-situ strength. Following the field cone penetration test program, clayey soils from nine sites in Indiana was investigated. Based on the results from the test program, the cone factor ranges from 8.0 at plasticity index of 7.9 to 12.1 at plasticity of 20.0 for Over Consolidated (OC) clays. This result parallels the increasing trend of the cone factor as the plasticity index increases, which was reported by some researchers, while other researchers showed the decreasing trends. He suggested an equation for estimating cone factor for better geotechnical design.

Chen (2001) evaluated the undrained shear strength of Klang clay from cone penetration test. He presented the shear strength from vane shear test and cone resistance of cone penetration tests from three sites located on Klang clay. He compared and correlated the results so as to establish an empirical relationship between the shear strength and the cone resistance. An empirical cone factor in the range of 5 to 12 was obtained. He evaluated the shear strength of Klang Clay from the cone factor value. He also compared the obtained cone factor values with the cone factor values of other known soft clays. He discovered that in general the cone factor value of Klang clay is at the lower boundary of the published cone factor values.

In this paper, the cone penetration test was carried out on ten different suspected clayey soil sites at Ebonyi State College of Education, Ikwo for purposes of determining soil properties.

Materials

The penetrometer assembly consists of a mantle cone and friction sleeve cone both of which give point resistance and friction resistance of the soil formation, sounding tubes which transmit downward thrust to the cone, an outer tube which shields the test from friction resistance and is used to advance the cone for test readings and to retrieve the cone, a load cell which transmits vertical thrust to a hydraulic oil-filled chamber that activates bourdon-tube gauges, and the bourdon-tube gauges which read direct hydraulic pressure.

Method

The test consists basically of advancing the cone and friction sleeve into the soil at a steady rate and recording the values on the gauge corresponding to the cone resistance and sleeve resistance respectively. Ten randomly selected positions in the site (labeled sample 1 to sample 10) were considered. Again, undisturbed soil specimens were collected from each of the selected positions using samplers and Shelby tubes for triaxial and index laboratory tests. The tubes containing the samples were labeled and sealed with candle wax to prevent loss of moisture. The undrained shear strength from the triaxial test was used to relate these findings to the results from the CPT and this relation was classified with the plasticity index from the index tests.

Results

Summary of the index test result is shown in table 1. The index test result contains the percentage of gravel, san clay and silt combined natural moisture content, liquid limit plastic limit and plastic index. Table 2 shows the overburden stress and the undrained shear strength. The cone factor and plastic index are correlated and shown in table 3. And figure 1 is the graph of cone factor against plasticity index.

Table 1. Summary of Index Test Result

Sample	Gravel (%)	Sand (%)	Combined Clay and Silt (%)	Natural Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	69.88	6.82	23.30	17.30	50.00	25.00	25.00
2	63.83	6.82	29.32	12.10	51.00	31.70	19.30
3	44.15	3.25	52.60	20.10	57.00	40.20	16.80
4	23.95	9.59	66.46	17.00	50.00	28.60	21.40
5	58.53	6.4	35.07	21.10	51.00	30.00	21.00

6	12.81	4.27	82.92	20.70	55.00	28.60	26.40
7	27.17	1.85	70.98	19.10	55.00	25.00	30.00
8	22.23	1.85	72.21	19.70	46.00	33.30	12.70
9	62.64	8.59	28.77	16.90	62.00	35.80	26.20
10	24.33	9.24	66.43	20.10	50.00	28.60	21.40

Table 2. Summary of Triaxial Test Result

Sample	Overburden stress (KN/M^2)	Undrained Shear Strength (KN/M^2)
1	115.00	206.00
2	122.00	208.00
3	78.00	138.00
4	82.00	124.00
5	47.00	143.00
6	66.00	150.00
7	102.00	147.00
8	92.00	114.00
9	87.00	144.00
10	105.00	183.00

Table 3. Summary of Cone Factor and Plasticity Index

Sample	Cone Resistance (KN/M^2)	Cone Factor	Plasticity Index (%)
1	3156	14.76	25.00
2	2855	13.14	19.30
3	1793	12.42	16.80
4	1785	13.74	21.40
5	1995	13.62	21.00
6	2340	15.16	26.40
7	2481	16.19	30.00
8	1375	11.26	12.70
9	2261	15.10	26.20
10	2435	13.74	21.40

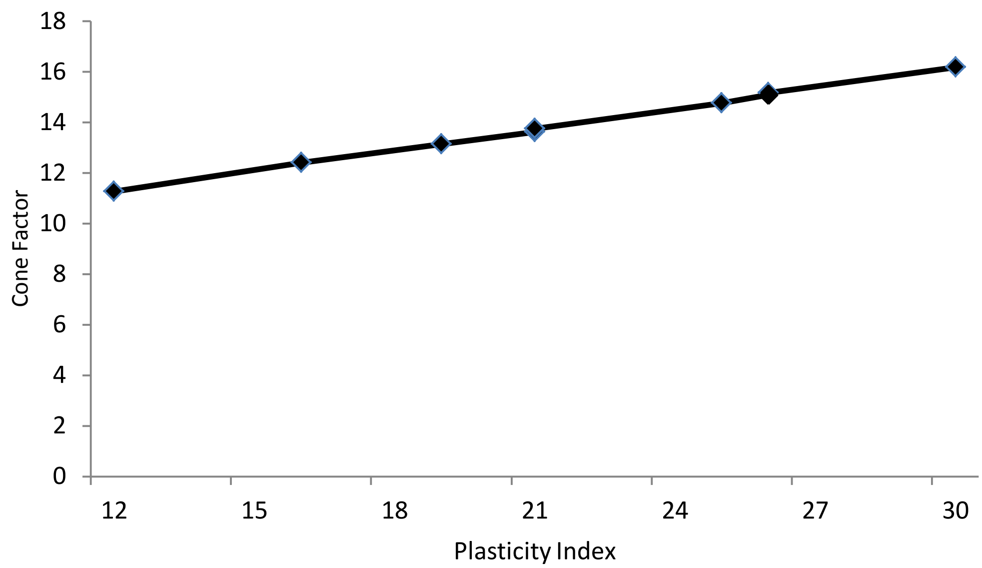

Figure 1. Graph of Cone Factor and Plasticity Index

Discussion

The undrained shear strength from the triaxial test and the overburden stress were calculated from the test and then cone factors were evaluated. Table 5 and Figure 1 show the cone factor and plasticity index for clayey soils in Ebonyi State College of Education, Ikwo. The cone factor values from the test range from 11.26 to 16.19. These results fall within the range of values reported in the international literature (Lunne, Robertson, and Pwell (1997) and are comparable with the cone factor values from 8 to 25 in clays (Jamiolkowski et al., 1982; Lunne et al., 1986; Rad and Lunne, 1988; La Rochelle, Zebdi, Leroueil, Tavenas, and Virely, 1988; Anagnostopoulous et al., 2003).S

Furthermore, these values show increasing trends and change with a plasticity index from 11.26 at plasticity index of 12.7 to 16.19 at index of 30. As presented in figure 1, these results are similar to the findings from Aas, Lacasse, Lunne, and Hoeg (1986), and Young and Daehyeon (2010) while Lunne, Eide, and Ruiter (1976) and Baligh, Vivatrat, and Ladd (1980) show the decreasing trends (Aas et al. 1986; Lunne et al., 1976; Baligh, et al. (1980). The analysis is of significance as it indicates increasing trends of cone factor with plasticity index for clayey soils in Ebonyi State College of Education, Ikwo.

Conclusion

Cone penetration test was carried out on ten different suspected clayey soil sites at Ebonyi State College of education, Ikwo. The index test and triaxial test were also carried out to assist in the determination of the properties of the soil. The study concluded that the cone factor is the most important means for reliable estimation of undrained shear strength from cone resistance. Again, the cone factor is influenced by soil type, penetration rate during the cone penetration test, and the test methods for undrained shear strength. It also revealed quantity of combined clay and silt soil in the sites. Furthermore, the results of the study showed increasing trends of cone factor with plasticity index.

Recommendation

Based on the study, the researcher recommends that more cone penetration test should be carried out within Ebonyi state to determine different soil properties for sustainable development. Again, the concerned bodies and organizations should insist on the use of the results of such test in the foundation designs of structures to avert structural foundation failures.

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