Statistical Correlations between ultimate bearing capacity (q_u) and SPT- N value for glacial tills

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ABSTRACT:

This paper presents a statistical analysis of the correlation between the ultimate bearing capacity (q_u) and standard penetration test blow count (SPT-N) for glacial tills in the city of Toronto. The (q_u) values were derived from conventional Terzaghi’s bearing capacity equations. This study is based on the results of a comprehensive geotechnical investigation for the Eglinton Crosstown Light Rail Transit (LRT) project in Toronto. This study focused primarily on the statistical correlations between (q_u) and SPT-N value for glacial tills with different textures, such as silty clay, silty clay till and clayey silt, clayey silt till and sandy silt, sandy silt till and silty sand, silty sand till. In this paper, the correlation equations between SPT – $(N)_{60}$ values and (q_u) are suggested for glacial tills. Additionally, the bearing capacity derived from Terzaghi’s bearing capacity equation compared with capacity derived from Menard bearing capacity equation from pressuremeter test (PMT) and suggested Menard bearing capacity factor for Toronto glacialtill.

Résumé

Cet article présente une analyse statistique de la corrélation entre la capacité portante ultime (q u) et le nombre de coups d'essai de pénétration standard (SPT-N) pour les tills glaciaires de la ville de Toronto. Les valeurs (q u) ont été dérivées des équations de capacité portante conventionnelles de Terzaghi. Cette étude est basée sur les résultats d'une enquête géotechnique approfondie pour le projet Eglinton Crosstown Light Rail Transit (LRT) à Toronto. Cette étude s'est concentrée principalement sur les corrélations statistiques entre (q u) et la valeur SPT-N pour les tills glaciaires de différentes textures, comme l'argile limoneuse, le till argileux limoneux et le limon argileux, le till limoneux argileux et le limon sableux, le till limoneux sableux et le sable limoneux, till de sable limoneux. Dans cet article, les équations de corrélation entre les valeurs SPT – (N) 60 et (q u) sont suggérées pour les tills glaciaires. De plus, la capacité portante dérivée de l'équation de capacité portante de Terzaghi par rapport à la capacité dérivée de l'équation de capacité portante de Menard à partir d'un test pressiométrique (PMT) et du facteur de capacité portante suggéré de Menard pour le till glaciaire de Toronto.

1. INTRODUCTION

Statistical correlations between in – situ soil testing results have become more and more popular during the site investigations especially for being practical and economical. Hence, estimation of geotechnical parameters from in – situ test results was a significant place in the geotechnical design practice. In this study also statistical correlation between standard penetration test blow count (SPT – N value) and ultimate bearing capacity (q_u) was performed. The ultimate bearing capacity derived from conventional Terzaghi’s bearing capacity equations. The bearing capacity derived from Terzaghi’s bearing capacity equation compared with capacity derived from Menard bearing capacity equation from pressuremeter test (PMT) and suggested Menard bearing capacity factor for Toronto glacial till.

The SPT is a well-established method for soil investigation. As many forms of the test are in use worldwide, standardization is essential to facilitate the comparison of results from different investigations, even at the same site (Thorburm 1986). In this paper, SPT was performed in accordance with the ASTM D 1586 method. This means that the test was standardized using a 50 mm O.D. split spoon sampler, driven into the soil with a 64 kg weight having a free fall of 760 mm auto hammer was used exclusively on the project. The blows required to drive the split –barrel sampler 305 mm, after an initial penetration of 152 mm, is referred to as the SPT –N value. This method has been accepted internationally and is useful in field investigation.

The pressuremeter test (PMT) is becoming more popular in Ontario for site investigation and geotechnical design especially in estimating soil properties for foundation design. Louis Menard developed the pre – bored PMT device and considered it to be one of the most precise testing methods available for almost any type of soil (Menard 1965). In this paper the PMT was performed accordance with procedure B, volume – controlled loading, as outlined in the ASTM D 4719-00, Pre – bored PMT was completed using a TEXAM unit. The basic idea behind the PMT is the expansion of a cylindrical sleeve in the ground to monitor the relationship between the pressure and the deformation. Two parameters determined in the Menard PMT method are the limit pressure (P_L) and the pressuremeter modulus (E_{PMT}).

The limit pressure (P_L) used to calculate the bearing capacity. The Eq 1 has been formulated by Louis Menard to calculate the bearing capacity for footings or caissons. Calculating the bearing capacity by using this equation considered as a reliable method (Baguelin et. al., 1978). Still geotechnical engineers use this equation (Sols Soils, 1975).

$$q_u - \sigma_v = K (P_L - \sigma_h) \qquad [1]$$

Where q_u - Ultimate bearing capacity

σ_v – Overburden pressure

P_L - Limit pressure from PMT

σ_h - Horizontal pressure at rest and

K – Bearing capacity factor.

The horizontal at rest pressure is necessary for this calculation. This can be estimated from PMT.

To correlate the ultimate bearing capacity (q_u) with SPT- N values, the ultimate bearing capacity (q_u) calculated by using Terzaghi's conventional bearing capacity equation as shown in Eq 2. During the calculation of the ultimate bearing capacity (q_u), it is assumed that all the foundation characteristics are the same (Foundation length L = 1 m, Foundation width B = 1 m). By this way, only the bearing capacity of glacial soil is the decisive. In this study, the bearing capacity values (q_u) were not divided by safety factor. Because, according to the importance of the project, safety factor can be changed by engineer (Tosun, 1988).

$$q_u = cN_c + qN_q + 0.5B\gamma N_\gamma \qquad [2]$$

Where q_u - Ultimate bearing capacity

c – Soil cohesion

q – Vertical stress acting at the elevation of the base of foundation

B – Width of foundation or least plan dimension of the foundation

γ - Soil unit weight

N_c N_q N_γ - Dimensionless bearing capacity factors

In this study dimensionless modification factors for foundation shape, inclination, depth and tilt and ground slope are not considered.

In this study, an attempt was made to develop correlations between SPT- N values with ultimate bearing capacity (q_u) for Toronto glacial tills based on the extensive site investigation program and laboratory test conducted for the Eglinton Crosstown LRT Project in the city of Toronto. As emphasized by Phoon and Kulhawy (1999), local correlations that are developed within a specific geologic setting generally are preferable to generalized global correlations because they are significantly more accurate.

2. LITERATURE REVIEW

The literature review was conducted on statistical correlation between SPT- N and ultimate bearing capacity (q_u) in this paper. Information available from specific research studies on statistical correlation between SPT- N and ultimate bearing capacity (q_u) are few, as only a few researchers have studied for clay and sand even rare for Toronto glacial tills. Such information, as it was considered very valuable, is presented in this section.

The correlation equation suggested by Menard for clay and sand are given below in the Table 1.

Table 1. Correlation equation for clay and sand

Soil type	Correlation equation (q_u) (kPa)
Clay	180 N
Sand	436 N

3. ENGINEERING BACKGROUND

The site is situated along Eglinton Avenue from the existing Kennedy subway station in the east to the Mount Dennis station in the west, in Toronto, Ontario, Canada.

The glacial till deposits in Toronto can be divided into low plasticity cohesive glacial tills (silty clay to clayey silt glacial till) and cohesionless glacial tills (sandy silt to silty sand glacial till) (Manzari et al. 2014). As shown in Figure 1, this type of soil can be described as high variability materials in both horizontal and vertical axis, and it normally contains complex non-linear stress-strain characteristics (Baker et al. 1998). In addition to that, the tills consist of a heterogeneous mixture of gravel, sand, silt, and clay size particles in varying proportions. Cobbles and boulders are common in these deposits (Robert et al. 2011). However, the behaviour of glacial tills in southern Ontario is not fully understood.

Figure 1. Typical glacial till (Source-Mark Clark, (http://www.free-stockillustration.com)

The proposed Eglinton Crosstown LRT is approximately 33 km in length and located approximately 7 km north of Lake Ontario. There are 25 proposed stations along the alignment as shown in Figure 2.

Figure 2. Crosstown route map (http://www.thecrosstown.ca/the-project)

A series of laboratory and in-situ tests were conducted in advance at the stations above. The in-situ tests included SPTs, FVSTs, pre-bored TEXAM PMT and seismic tests. The laboratory tests included density and moisture content measurements, grain size and hydrometer analysis, consistency (Atterberg) limit tests, consolidation tests, consolidated undrained and drained triaxial compression tests.

Based on these tests, the soil was classified as a glacial till which further classified as low plasticity cohesive glacial till and cohesionless glacial till according to the current version of TTC Geo-technical Standards (2014). In this area, the low plasticity cohesive glacial till mostly consists of the following soil types such as (i) silty clay till (ii) clayey silt till. The cohesionless glacial till mostly consists of following soil types such as (iii) sandy silt till (iv) silty sand till. The glacial tills are interbedded with silty clay, clayey silt, sandy silt, sand and silt and silty sand.

SPTs conducted near the PMTs at similar depths were selected to develop the relationship between SPT-N values and ultimate bearing capacity (q_u) in this paper for the following stations such as Allen, Avenue, Bathurst, Bayview, Bermondsey, Black creek, Caledonia, Don mill, Kennedy, Victoria Park, Warden, Wynford. The pair of readings (SPT-N and (q_u) for silty clay, silty clay till and clayey silt till was collected from these tests in this study.

Silty clay from the above stations contains 0 to 8% gravels, 0 to 39% sand, 33 to 75% silt and 16 to 64% clay size particles based on grain size analysis. The water contents are generally between 6 to 36% and unit weight is from 20.4 – 22.9 kg/m^3. Based on the Consistency (Atterberg) limits test the range of LL is 22 to 50%, PL is 12 to 37% and PI is 7 to 23.

Silty clayey till from the above stations contains 0 to 11% gravels, 13 to 42% sand, 34 to 62% silt and 16 to 35% clay size particles based on grain size analysis. The water contents are generally between 7 to 26% and unit weight is from 21.9 – 23.9 kg/m^3. Based on the Consistency (Atterberg) limits test the range of LL is 17 to 33%, PL is 10 to 27% and PI is 7 to 13.

Clayey silt till from the above stations contains 0 to 7% gravels, 27 to 44% sand, 37 to 64% silt and 14 to 27% clay size particles based on grain size analysis. The water contents are generally between 7 to 18% and unit weight is from 22.9 – 23.5 kg/m^3. Based on the Consistency (Atterberg) limits test the range of LL is 14 to 22%, PL is 10 to 16% and PI is 4 to 7. These values are shown in Table 2.

Table 2. Summary of cohesive glacial till properties

	Silty clay	Silty clay till	Clayey silt till
Gravel (%)	0 to 8	0 to 11	0 to 7
Sand (%)	0 to 39	13 to 42	27 to 44
Silt (%)	33 to 75	34 to 62	37 to 64
Clay size particles (%)	16 to 64	16 to 35	14 to 27
Water content (%)	6 to 36	7 to 26	7 to 18
Unit weight (kg/m^3)	20.4 to 22.9	21.9 to 23.9	22.9 to 23.5
LL (%)	22 to 50	17 to 33	14 to 22
PL (%)	12 to 37	10 to 27	10 to 16
PI (%)	7 to 23	7 to 13	4 to 7

4. CORRELATION BETWEEN SPT- N AND (q_u)

The statistical analysis is carried out in this paper to investigate the relationship between SPT-N value with (q_u). The first step is to collect the pairs of PMT test data and SPT-N value at the same depths in the same boreholes. The field measured SPT-N values are corrected according to the CFEM (2006). Because of the variability in equipment and operating conditions, direct use of SPT-N values for geotechnical design is not recommended. As a result, many corrections shall be done on the field SPT-N values. Those corrections are rod length, borehole diameter, sampler, energy, and overburden described in CFEM (2006). The practice in the Canada the SPT N-value measured to an average energy ratio of 60% (ERR=60%) according to ASTM D1586-11 (2014). In this study energy ratio of 60% (ERR=60%) is adopted. In case of cohesive glacial tills, overburden correction is not accommodated in this study. In these situations, the SPT-N became SPT-$(N)_{60}$.

The second step is to calculate the ultimate bearing capacity (q_u) by using Terzaghi's conventional bearing capacity equation as shown in Eq 2 for same soil type at the same depths in the same boreholes.

Third step is to calculate the Menard bearing capacity factor (K) by using the Eq 1 for same soil type at the same depths in the same boreholes.

After calculated the ultimate bearing capacity (q_u) and corrected the SPT-N, the pair of data were collected for both SPT- $(N)_{60}$ values and (q_u) for cohesive glacial tills. To analyze more accurately, the compiled data were filtered by using the following methodology:

(1) The data situated far from the trend line was discarded by visual inspection compared to other data.
(2) The SPT's often reached refusal, i.e. blow count (N) values were greater than 50 for 300 mm or less increment when the SPT sampler hits a cobble or boulder within the glacial till. As a result, the SPT-N values were assigned values of more than 50. The SPT-N values greater than 50 were disregarded.

4.1 General Range of SPT--$(N)_{60}$ and (q_u) and K for cohesive glacial tills

The ranges of SPT- $(N)_{60}$ and (q_u) and K values are determined for cohesive glacial tills of the data are collected from in-situ tests. The ranges of $(N)_{60}$ and (q_u) and K values of cohesive glacial tills are shown in Figure 3 and 4 and 5 and Table 3 respectively. The percentages (%) marked in Figure 3 and 4 and 5 represents most of the range values that belong to the thick portion of the range diagrams.

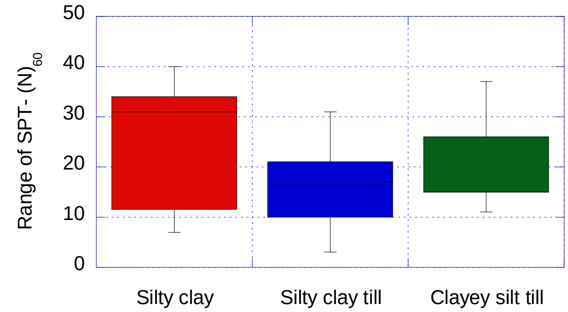

Figure 3. Range of SPT - $(N)_{60}$ values for cohesive glacial till

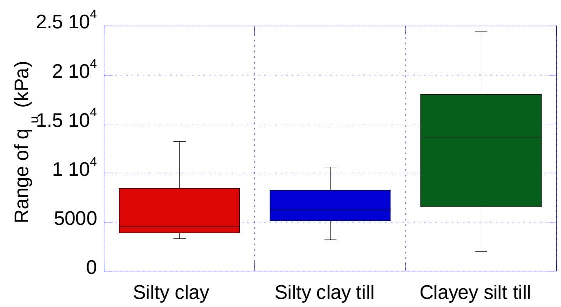

Figure 4. Range of (q_u) values for cohesive glacial till

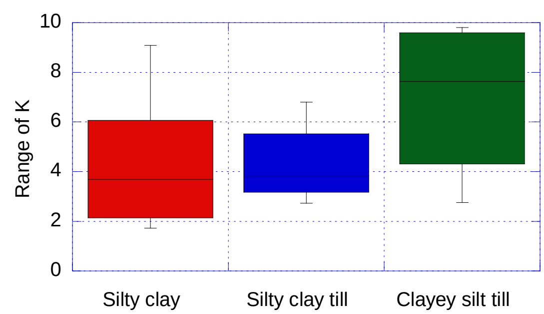

Figure 5. Range of K values for cohesive glacial till

Table 3. Approximate range of SPT--$(N)_{60}$ and (q_u) and K for cohesive glacial tills

Soil type	SPT--$(N)_{60}$	(q_u) (kPa)	K
Silty clay	7 - 40	3304 – 13 211	1.72 – 9.08
Silty clay till	3 - 31	3196 – 10 598	3.00 – 5.81
Clayey silt till	11 – 37	1992 – 24 405	2.75 – 9.80

4.2 Correlation between SPT--$(N)_{60}$ values and (q_u)

The correlation between SPT--(N) 60 values and (q_u) has been plotted for a cohesive glacial till is shown in Figure 6 and 7 and 8. In this analysis, origin liner best fit line method used. The correlation functions and correlation coefficients are given in Table 4.

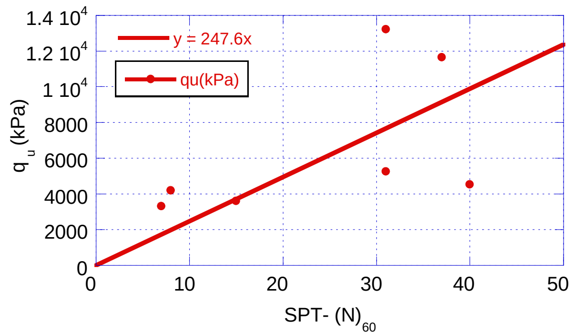

Figure 6. Correlation between (q_u) vs SPT- *(N)* *60* for silty clay

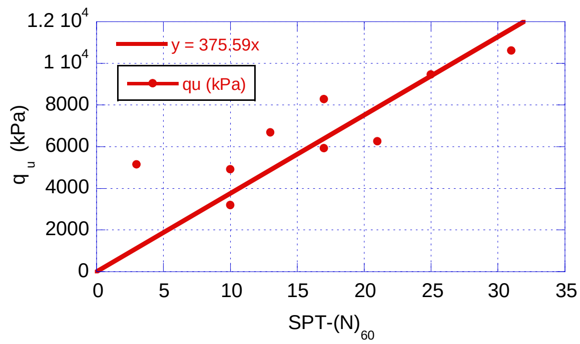

Figure 7. Correlation between (q_u) vs SPT- *(N)* *60* for silty clay till

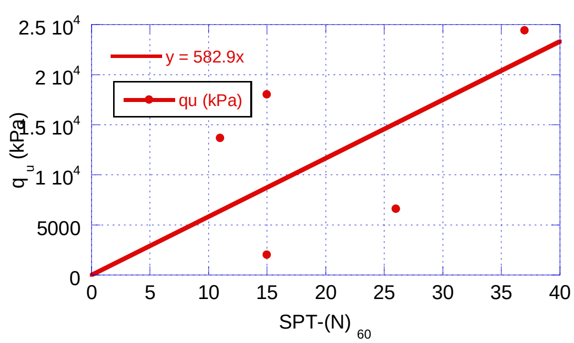

Figure 8. Correlation between (q_u) vs SPT- *(N)* *60* for clayey silt till

Table 4. Summary of correlation between SPT- *(N)* *60* values and (q_u) for cohesive glacial tills

Soil type	Correlation equation (R^2) (q_u) (kPa)
Silty clay	247.6 *(N)* *60* (0.80)
Silty clay till	375.6 *(N)* *60* (0.94)
Clayey silt till	583.0 *(N)* *60* (0.78)

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5. DISCUSSIONS

There is limited information available for about the correlation between SPT- *(N)* *60* values and (q_u) for clay and sand, sparse for cohesive glacial tills. This paper presents a study on the correlation between SPT- *(N)* *60* values and (q_u) for cohesive glacial tills in the city of Toronto.

According to literature, the ultimate bearing capacity value for clay is 180N. Studied values for ultimate bearing capacity are higher than literature. Because studied soil was cohesive glacial tills.

According to literature, the range of K value vary from 1.4 to 2.4. But studied values vary from 1.72 to 9.80. it was higher than literature. Because studied soil was cohesive glacial tills which contains gravel, cobbles, and boulders. Due to that reasons the studied value was higher than the literature. The Smith, (2006) states that the K value depends on soil type and foundation shape. Further he suggested the K value 0.8 for clay invariably and singular foundation.

6. CONCLUSION

In conclusion, the study was performed based on an intensive site investigation program conducted for the Eglinton Crosstown LRT Project in the city of Toronto. The data were collected from in-situ tests (SPT) and laboratory tests analysed statically. In this study, the linear correlation equation between SPT--(N) 60 values and (q u) were established for cohesive glacial till. Further the ranges of SPT--(N) 60 and (q_u) and K were suggested for cohesive glacial till in the city of Toronto.

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