Statistical correlations between pressuremeter modulus and SPT- N value for glacial tills

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT:
This paper presents a correlation between the pressuremeter modulus (E_{PMT}) and standard penetration test (SPT) –N value for glacial tills in the Greater Toronto Area (GTA). 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 SPT- N value and E_{PMT} for glacial tills with different textures, such as silty clay, clayey silt, silty sand, sandy silt, sand and silt. The literature review shows that there is very limited information available about correlations between E_{PMT} and SPT- N value for glacial tills. In this paper, correlations between SPT -N value and E_{PMT} is suggested.

RÉSUMÉ:
Cet article présente une corrélation entre le module pressiométrique (EPMT) et la valeur N de l'essai de pénétration standard (SPT) pour les tills glaciaires dans la Région du Greater Toronto (RGT). Cette étude repose sur les résultats des investigations géotechniques compréhensives pour le projet Eglinton Crosstown Light Rail Transit (LRT) à Toronto. Cette étude a porté principalement sur les corrélations statistiques entre la valeur N de SPT et EPMT pour les tills glaciaires avec des textures différentes, tels que l'argile silteuse, le silt argileux, le sable silteux, le silt sableux, le sable, et le silt. La revue de la littérature montre qu'il y a très peu d'informations disponibles sur les corrélations entre EPMT et la valeur N de SPT pour les tills. Dans cet article, les corrélations entre la valeur N de SPT et EPMT sont suggérées.

1 INTRODUCTION

Statistical correlations between in-situ soil testing results and soil parameters are increasingly used during various stages of geotechnical engineering work.

Many geotechnical design parameters for soil can be derived from the SPT. The SPT is a well-established method for soil investigation. As many forms of the test are in use worldwide, standardization is essential in order 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 a distance of 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.

In addition, 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 (Menard1965). 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 in order 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}).

In this study, an attempt was made to develop a correlations between uncorrected SPT-N values with E_{PMT} for glacial till in the Greater Toronto Area (GTA) based on the soil investigation for the Eglinton Crosstown LRT Project, Canada. 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

Estimation of the pressuremeter modulus, E_{PMT}, from SPT –N value has been studied by a few researchers in the past (Briaud 1992 and Ohya et al. 1982). Attempted correlations have usually been weak because of the differences in the methods and uncertainties involved in the tests. Even though, they are widely used in practice to get an idea about the level of the geotechnical parameters used in the design. One linear relationship with zero intercept was proposed by Briaud (1992) for the E_{PMT} from SPT-N value for sands, while one non-linear relationship was proposed by Ohya et al. (1982) on the basis of data obtained from alluvial and dilluvial deposits in Japan. Both researches indicated the wide scatter of data. Further non - linear relationships between SPT and E_{PMT} for sand and clay were proposed by Bozbey (2010) for data measured during an extensive geotechnical investigation conducted in Istanbul, Turkey. In glacial tills, there is a study conducted by Yagiz (2008), the linear relationship with intercept between the corrected SPT-N values (N_{cor}) with E_{PMT} in Gumusler country, 10 km north of the city of Denizli, Turkey.

Currently, there is no such relationship available for glacial tills in the GTA. This study is based on an extensive site investigation conducted for the Eglinton Crosstown LRT project for the Toronto Transit Commission and Metrolinx.

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 Toronto area acquired at least three glacial and two interglacial periods from the published geological data (Karrow 1967 and Sharpe 1980). The geological history of the Toronto area has included several advances and retreats of glaciers of Illinoian and Wisconsinan ages (Karrow and White 1998). The glacial tills in this area were generally deposited during the early to late Wisconsinan period, represented by the Sunnybrook, Seminary, Meadowcliffe, Newmarket and Halton tills (Sharpe 1999). 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). However, the behaviour of glacial tills in southern Ontario is not fully understood.

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). The recorded maximum boulder size founded in Toronto so far has been about 3m in the maximum dimension. Boulder volume ratios (total boulder volume per volume of excavated earth material) BVR of 0.12% and 0.17% for interglacial deposits and glacial tills respectively have been recommended for TTC subway projects such as the Sheppard Subway (S.J. Boone and J.N. Shirlaw 1996) and the Toronto – York Spadina Subway extension (S.J. Boone and J. Westland 2008).

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 1.

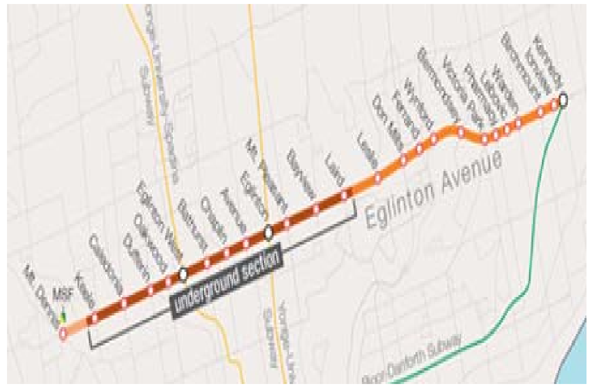

Figure 1. Crosstown route map
(http://www.thecrosstown.ca/the-project)

A series of laboratory and in-situ tests were conducted in advance at the above stations. The in-situ tests included SPTs, field vane shear tests, 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 E_{PMT} in this paper for the following stations such as Kennedy, Birch mount, Warden, Victoria park, Bermondsey, Wynford, Donmills, Leslie, Laird, Bayview, Mount Pleasant, Yonge, Avenue, Chaplin, Bathurst, West portal, Oakwood, Dufferin, Caledonia, Keel and Mount Dennis. The pair of readings (SPT-N and E_{PMT}) for clayey silt is not available from these tests in this study.

4 CORRELATION BETWEEN SPT-N VALUE AND E_{PMT}

The statistical analysis was carried out in this paper to investigate the relationship between uncorrected SPT-N value and E_{PMT}. The first step is to collect the pairs of PMT test data and SPT-N value at the same depths in the same test area. The processing of these data is one of the challenging works in the geotechnical design. Reliability of an analysis result is mostly defined by the accuracy of selected data rather than the method used for the analysis. Therefore, the selection of the most representative parameters for a site is the key to a successful design. With that in mind, in order to evaluate the correlation between SPT-N values and E_{PMT} more accurately, the compiled data were filtered by using the following methodology:

(1) The SPT's often reached refusal, i.e. blow count (N) values were greater than 100 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 100 or more than 100. The SPT-N values greater than 100 were disregarded.
(2) The data situated far from the trend line was discarded by visual inspection compared to other data.
(3) In such cases the same SPT-N value was associated with different values of E_{PMT} and this pair of readings was omitted.

Apparently more theoretical study is needed to develop a sound rationale to filter the data.

4.1 General Range of SPT-N and E_{PMT} for Different Types of Soils and All Soils

The range of SPT-N and E_{PMT} values were determined for both groups in which all of the data were collected from in-situ tests and in which the data were filtered.

4.1.1 Range of SPT-N Value

The range of SPT-N value of cohesive soils and cohesionless soils are shown in the Figure 2 and 3 respectively. Further range, the mean and standard deviation of SPT-N value for different types of soil and all soil for all data and filtered data are shown in the Table1.

4.1.2 Range of E_{PMT} Value

The range of E_{PMT} value of cohesive soils and cohesionless soils are shown in the Figure 4 and 5 respectively. Further range, the mean and standard deviation of E_{PMT} value for different types of soil and all soil for all data and filtered data are shown in the Table2.

4.2 Correlation between SPT-N and E_{PMT} Value

(a) Low Plasticity Cohesive Soils

The correlation between SPT-N value and E_{PMT} have been plotted for low plasticity cohesive soils in both original data and filtered data formats, as shown in Figure 6. The correlation functions were determined for both cases in which all the data were included and in which the data were filtered. The correlation functions and correlation coefficients are given in Table 3. The filtered data analysis provides a much improved correlation coefficient compared to all original data analysis.

(b) Cohesionless Soils

The correlation between SPT-N value and E_{PMT} have been plotted for cohesionless soils in both original data and filtered data formats, as shown in Figure 7. The correlation functions and correlation coefficients are given in the Table3. The filtered soil data analysis shows that there was weak correlation relationship between SPT-N and E_{PMT} where the correlation coefficient (R^2) is 0.33. It gave a conservative bias in the data analysis. After filtering, the sand, silt, sandy silt, silty sand, sandy silt till and silty sand till have 12, 6, 8, 4, 7 and 4 pairs of data respectively. These were not enough pairs of readings to create the correlation between parameters. Further these data would not provide reasonably good representation of the whole data. Due to that predicted correlation equations have to be cross checked with similar project in the same type of soil such as sand, silt, sandy silt, silty sand , sandy silt till and silty sand till to make it more valid in the correlation equation.

Table1. Summary of SPT-N value for different types of
soils

Soil type	Range of SPT-N value All data (Filtered data)			
	No of data	Range	Mean	Standard deviation
Cohesive soils				
Silty clay	32 (25)	8-97 (8-89)	40 (37)	26(24)
Silty clay till	26(18)	5-97 (5-53)	32 (24)	24(14)
Clayey silt till	20 (13)	6-152 (6-72)	46 (33)	36 (20)
All soils	78 (56)	5-152 (5-89)	39 (32)	28 (21)
Cohesionless soils				
Sand	22(14)	21-150 (21-98)	65(60)	31(25)
Silt	12 (9)	8-123 (8-92)	65(53)	37(29)
Sandy silt	14 (11)	8-97 (8-97)	56 (53)	27(28)
Silty sand	21(9)	50-127 (50-97)	69 (70)	24(19)
Sandy silt till	8 (7)	34-93 (34-93)	58(59)	20(22)
Silty sand till	5(4)	46-63 (46-63	52(53)	7(7)
All soils	82(54)	8-150 (8-98)	63(58)	28(24)

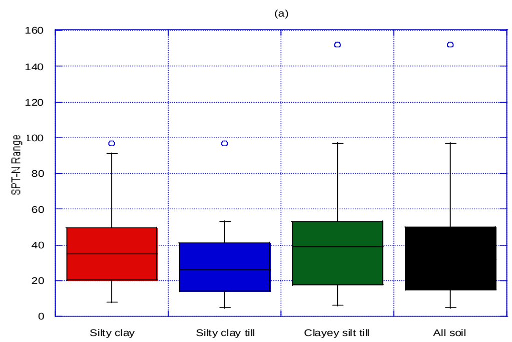

Figure 2(a).Range of SPT-N value for all data

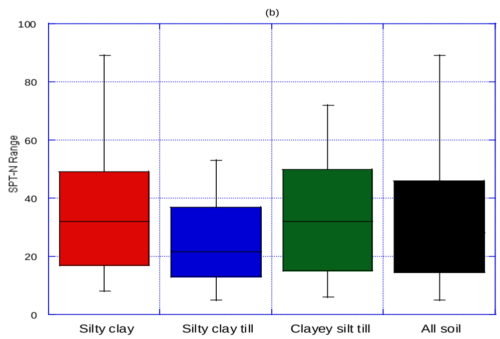

Figure 2(b).Range of SPT-N value for filtered data

Figure 2.Range of SPT-N value for cohesive soils

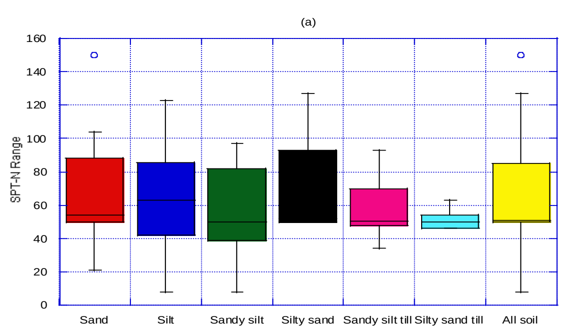

Figure 3(a). Range of SPT-N value for all data

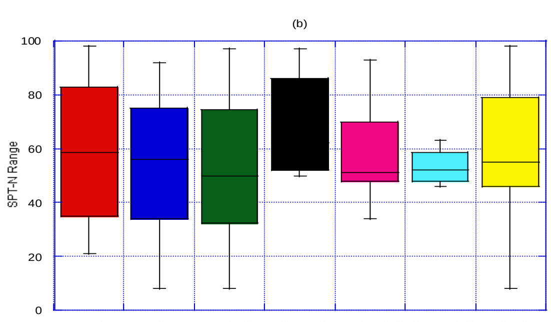

Figure 3(b). Range of SPT-N value for filtered data

Figure 3. Range of SPT-N value for cohesionless soils

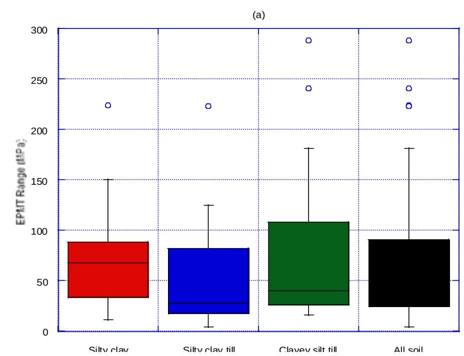

Figure 4(a). Range of E_{PMT} value for all data

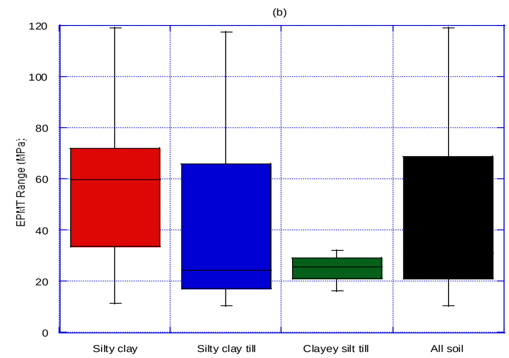

Figure 4(b). Range of E_{PMT} value for filtered data

Figure 4. Range of E_{PMT} value for cohesive soils

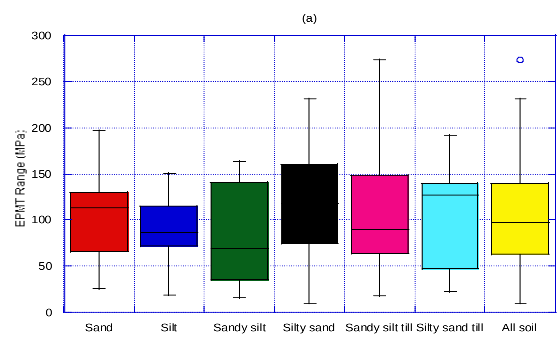

Figure 5(a). Range of E_{PMT} value for all data

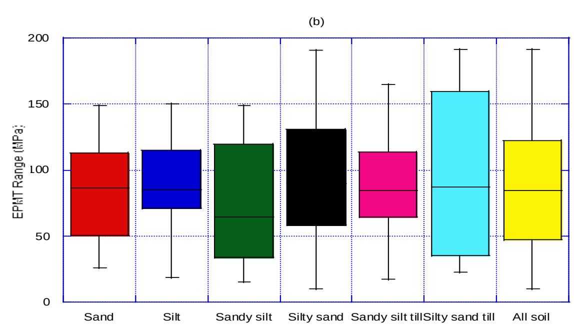

Figure 5(b). Range of E_{PMT} value for filtered data

Figure 5. Range of E_{PMT} value for cohesionless soils

Table 2. Summary of E_{PMT} value for different types of soils

Soil type	No of data	Range	Mean	Standard deviation
	Range of E_{PMT} value(MPa) All data (Filtered data)			
Cohesive soils				
Silty clay	32(24)	11- 224 (11-119)	70(56)	47(28)
Silty clay till	26(18)	4-223 (10-117)	50(39)	51(32)
Clayey silt till	20(9)	16-288 (16-32)	78(25)	78(6)
All soils	78(51)	4 -288 (10-119)	66 (45)	58(29)
Cohesionless soils				
Sand	21(13)	26-197 (26-149)	104(83)	46(41)
Silt	24(21)	19-150 (19-150)	90(89)	34(36)
Sandy silt	14(11)	15-163 (15-149)	83(75)	55(50)
Silty sand	21(9)	10-231 (10-191)	117(95)	58(57)
Sandy silt till	8 (7)	18-273 (18-165)	112(89)	79(49)
Silty sand till	5(4)	23- 192 (23-192)	106(97)	69(77)
All soils	93(65)	10-273 (10-192)	101(87)	52(45)

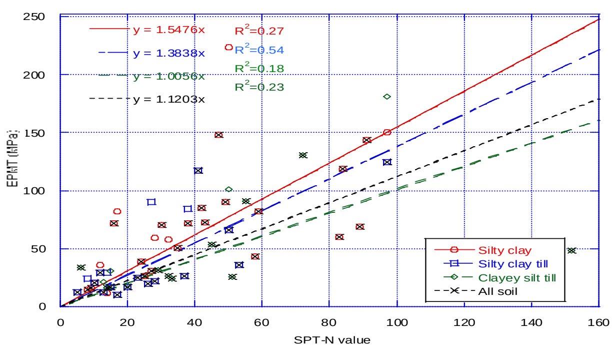

Figure 6(a). Correlation between SPT-N vs E_{PMT} for all data

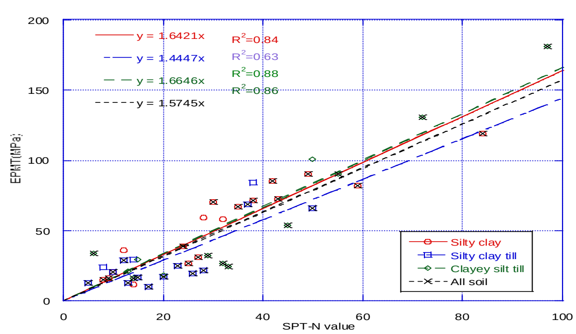

Figure 6(b). Correlation between SPT-N vs E_{PMT} for filtered data

Figure 6. Correlation between SPT-N vs E_{PMT} for cohesive soils

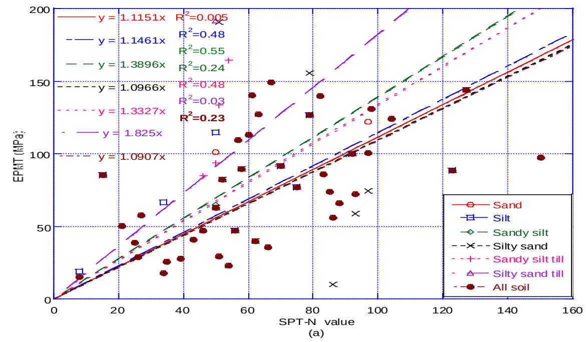

Figure 7(a). Correlation between SPT-N vs (E_{PMT}) for all data

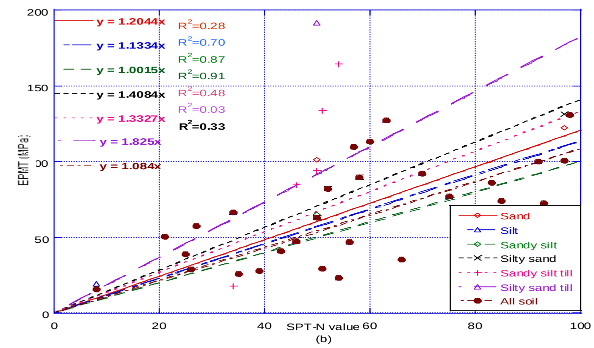

Figure 7(b). Correlation between SPT-N vs (E_{PMT}) for filtered data

Figure 7. Correlation between SPT-N vs (E_{PMT}) for Cohesionless soils

Table3 Summary of correlation between SPT-N value and E_{PMT} value for different types of soils

Soil type	Correlation equation (E_{PMT}) (MPa) (R^2)	
	All data	Filtered data
Cohesive soils		
Silty clay	1.55N (0.27)	1.64N (0.84)
Silty clay till	1.38N (0.54)	1.45N (0.63)
Clayey silt till	1.01N (0.18)	1.67N (0.88)
All soils	1.12N (0.23)	1.58N (0.86)
Cohesionless soils		
Sand	1.12N (0.005)	1.20N (0.28)
Silt	1.15N (0.48)	1.13N (0.70)
Sandy silt	1.39N (0.55)	1.00N (0.87)
Silty sand	1.09N (0.24)	1.41N (0.91)
Sandy silt till	1.33N (0.48)	1.33N (0.48)
Silty	1.83N (0.03)	1.83N (0.03)

sand till		
All soils	1.09N (0.23)	1.08N (0.33)

5 DISCUSSIONS

There is limited information available about the correlation between SPT-N values and E_{PMT} for sand and clay, sparse for glacial tills. This paper presents a study on the correlation between SPT-N values and E_{PMT} for glacial tills in the GTA. In addition, comparisons between this studies with the literature studies were also performed. In this study the specific twelve (12) pair of filtered data available only for sand. The developed regression line by using twelve filtered data was compared with available literature studies.

The approximate correlation between SPT-N and E_{PMT} proposed by Ohya et al. (1982) and Bozbey (2010) were plotted on the Figure 8 (a) with the studied data. In this comparison, nonlinear power best fit line was plotted for the studied filtered data due to the available nonlinear literature model. For the preliminary estimation of the E_{PMT} for the sand, the E_{PMT} can be estimated from the SPT-N value using the following relationship:

$$E_{PMT}\,(\text{MPa}) = 6.37(N)^{0.59} \qquad R^2 = 0.34 \qquad [1]$$

The predicted E_{PMT} values were calculated by using "Equation 1" and the measured E_{PMT} and predicted E_{PMT} values also presented in the Figure 8 (a).

Another comparison of the data was performed with Briaud (1992) and is plotted on the Figure 8 (b) with the studied data. In this comparison, a linear correlation with zero intercept has been used due to the available linear literature model. For the preliminary estimation of the E_{PMT} for the sand, the E_{PMT} can be estimated from the SPT-N value using the following relationship:

$$E_{PMT}\,(\text{MPa}) = 1.2N \qquad R^2 = 0.28 \qquad [2]$$

The predicted E_{PMT} values were calculated by using "Equation 2" and the measured E_{PMT} and predicted E_{PMT} values also presented in the Figure 8 (b).

Another comparison of the data performed for glacial till with Yagiz (2008) is plotted on the Figure 8 (c) with the studied data. In this comparison, linear correlation with intercept has been used due to the available linear literature model. For the preliminary estimation of the E_{PMT} for the glacial till, the E_{PMT} can be estimated from the SPT-N value using the following relationship:

$$E_{PMT}\,(\text{MPa}) = 1.15N + 7.38 \qquad R^2 = 0.84 \qquad [3]$$

The predicted E_{PMT} values using "Equation 3" and the measured E_{PMT} values also presented in the Figure 8 (c). The comparison shows that measured E_{PMT} was higher than the literature value. The reasons for this was the Toronto area glacial tills deposit consists of cobbles and boulders (Ng et al. 2011).

Further the comparison of range of E_{PMT} was performed with Briaud (1992).The E_{PMT} value for dense sand was greater than 22.5 MPa from Briaud (1992). Studied E_{PMT} range was 26 – 149 MPa. Which was higher than Briaud (1992) value. This was because the studied sand in this paper was dense to very dense with cobbles and boulders. In addition to that comparison of range of SPT-N value was performed with Canadian Foundation Engineering Manual. The SPT-N value of dense sand was greater than 50. Studied SPT-N mean value was 60.

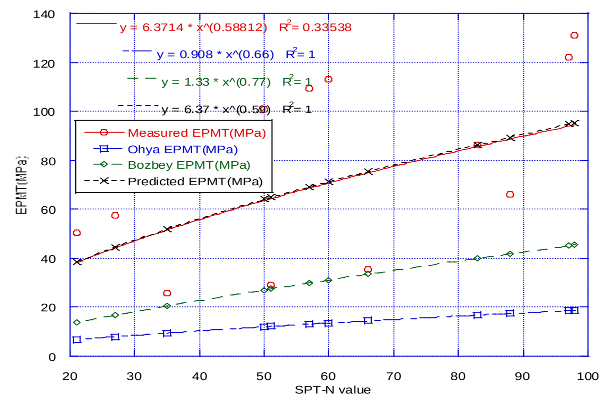

Figure 8(a). Correlation between SPT-N and E_{PMT} for sand (non-linear relationship)

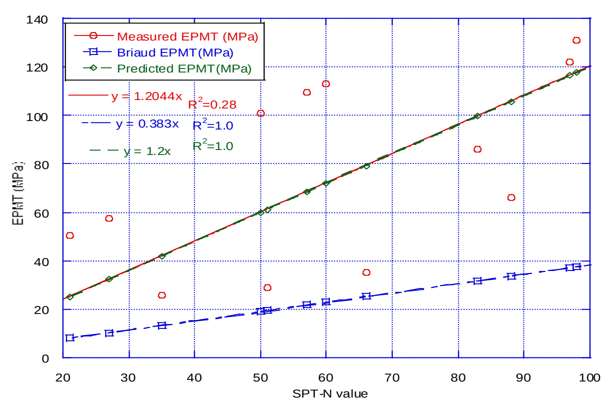

Figure 8(b). Correlation between SPT-N and E_{PMT} for sand (linear relationship)

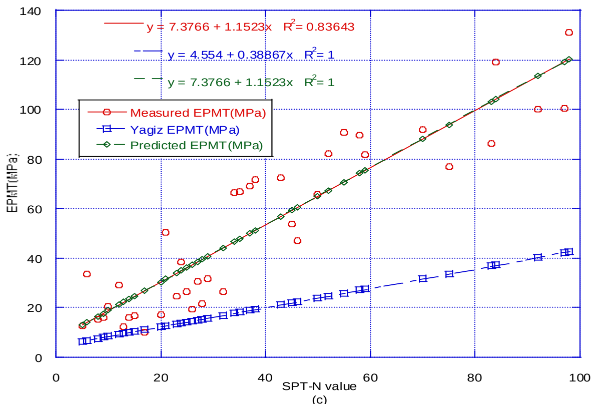

Figure 8(c). Correlation between SPT-N and E_{PMT} for glacial till (linear relationship)

Correlation between SPT-N and E_{PMT} has been investigated by Kulhawy and Mayne (1990). They concluded that more than an order of magnitude variation is possible when SPT-N value is used as the sole predictor. Based on that statement three type of correlation equations were suggested in this study (Equations 1, 2 and 3).

Briaud (1992) mentioned that the scatter in the data is considerably large which makes the correlations essentially useless in design. The scattering of the data is considerable which causes the coefficient of correlation (R^2) to be low (R^2= 0.34 for nonlinear and R^2 =0.28 for liner). The coefficient of correlation (R^2) in the scattering seems to be closer to Ohya (1982) (R^2 =0.482). The main reason for the scatter and deviation in the data can be related to borehole disturbances prior to PMT because in this project pre - bored PMT was performed. On the other hand, it can be related to heterogenous nature, type and properties of soil, field application procedures and water table fluctuation. In addition to that thorough understanding of the equipment and test procedures are required to obtain reliable results, as found in the Canadian Foundation Engineering Manual.

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 such as SPT and PMT and analysed statically. In this study, an attempt was made to develop new relationships between uncorrected SPT-N values with E_{PMT} for various type of glacial till (glacial soil). The accuracy of the evaluated correlations can be increased by more carefully performed and well controlled in - situ testing, borehole sampling and laboratory testing. In this way, some of the uncertainties can be reduced and the reliability of the correlations would be enhanced.

7 ACKNOWLEDGEMENTS

This study was performed using data generated by the Eglinton Crosstown LRT Project in Toronto. The authors would like to thank the Natural Sciences and Engineering Research Council of Canada for financial assistance and Toronto Transit Commission for granting permission to publish this paper.

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