Comparison Between Soil Modulus Based On Standard Penetration Test And Pressuremeter Test- A Case Study Of Under Ground Ahmedabad Metro

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Abstract. A pressuremeter is a tool to identify the strength and stiffness parameters of soil at in-situ condition. The Pressuremeter test (PMT) is getting more popular in recent days for assessment of in-situ strength for many geotechnical design applications. However, its use for C–ϕ Soil (mixed soil with considerable fraction of silt, clay and sand) in India is not common. For design and construction of Ahmedabad Metro series of Pressuremter tests were conducted using Menard Pressuremeter (GA Type with Nx Probe outfit for C–ϕ Soil). However, alternatively preliminary investigation has been carried out using Standard Penetration Test (SPT N-Value) to evaluate the strength and stiffness properties of subsoil layers. Present study aims to correlate Pressuremeter test results with Standard Penetration Test based on the measured field data. It also highlights the use of Creep Deformation Factor that has been in practice for determination of soil Elastic modulus(E_s) from Pressuremeter Modulus (E_m) and compares with the values derived from the Standard Penetration test (using popular empirical correlations). The study highlights that estimation of Elastic modulus of soil is significantly influence the design of underground structures and retaining structure. The study will help practitioner to appropriate soil modulus for the similar subsoil conditions and append the present state of knowledge for the correlations between Presssuremeter tests and SPT N-values for determination of strength and stiffness of soil.

Keywords: Menard Pressuremeter; SPT-N Value; Elastic Soil Modulus; Ahmedabad Metro UG

1. Introduction

Soil investigation comprises of field and laboratory or both. No matter how one can try there is always a doubt that sample is undisturbed or not?. There for designer always suggest a in-situ test to validate the laboratory test results and to avoid the disturbance caused to the sample. SPT (standard penetration test) and PMT (Pressuremeter test) among the most favored one. SPT is Very low cost test and routine part of every Geotechnical investigation in India and as well as most of the country. However, PMT is comparatively costly and seldom performed in the Geotechnical projects. There for it is necessary to establish a correlation between SPT-N value and PMT. Study also focus on the use of creep deformation factor to evaluate soil Elastic modulus(Es) from Pressuremeter Modulus (Em).Relation between soil Elastic modulus(E_s) and Pressuremeter Modulus (E_m) is given as,

$$E_s = \frac{Em}{\alpha} \qquad (1)$$

Briaud (1992) further researched the issue and listed a number of reason contributing to the differences observed between the measured pressuremeter modulus (E_m) and soil elastic modulus (E_s) , namely,

- Drilling and installation of probe may cause soil disturbance near the borehole wall;
- Above expression assumes an infinite long cylinder, whereas PMT testing pressurizes a finite length of the borehole , thereby introducing errors in the determination of pressuremeter modulus (E_m);
- PMT testing exerts a load for several minutes while actual foundation loading act for a much longer periods;

- Tension may develop near borehole walls, which may result in degradation of the average modulus;
- Soil anisotropy may be present , thereby the measured horizontal moduli may be different than vertical moduli needed for the analysis.

Present study aims to establish correlation between N_{60} and both E_m and E_s based on the investigation carried out at Ahmadabad underground metro. The Correlation has been established for the sandy clay and clayey soil.

2. Standard Penetration Test And Pressuremeter Test

The Standard Penetration Test was developed in the late 1920s. The test consists of driving the standard split barrel sampler a distance of 460 mm into the soil at the bottom of the boring, counting the number of blows to drive the sampler the last two 150 mm distances (to obtain the Number) using a 63.5 kg driving hammer falling free from a height of 760 mm (IS-2131-1981). The boring log shows refusal if 50 blows are required for any 150 mm increment,100 blows are obtained for a 300 mm increment or 10successive drops produce no advance. SPT data have been used in correlations for unit weight, relative density, angle of internal friction and unconfined compressive strength. However, it is recommended the measured N value is standardized by multiplying it by the ratio between the measured energy transferred to the rod and 60% of the theoretical free-fall energy of the hammer as N60(Bowles.J.E,1997).

The pressuremeter measures the in situ lateral deformation characteristics of ground at a particular depth. It was Kogler in the 1930s who developed the idea of installing equipment to the desired depth and measuring the deformation properties (Kogler 1933). However difficulties arose in using and interpreting the results of the equipment developed by Kogler. The equipment was later developed by Menard (1957) as the ‘‘Menard Pressuremeter’’.Advances in the analysis and interpretation of pressuremeter tests have taken place in parallel with the development of the equipment and there has been an increasing use of pressuremeter both in design and research. The pressuremeter consists of two parts: the read-out unit and the probe which is inserted into the borehole. The probe consists of three independent cells, a measuring cell and two guard cells. Once the probe is at the desired depth, the guard cells are inflated and the measuring cell is pressurized with water, which exerts a pressure on the borehole wall. As the pressure increases in the measuring cell, the borehole walls deform. The pressure within the measuring cell is held constant for about 60 s and the increase in volume required maintaining the constant pressure is recorded.

A typical curve is given in Fig. 1. The initial volume of the cavity is identified as point A, at which the pressure increases linearly with strain. The pocket wall will unload elastically during pre-boring and respond elastically on reloading once the membrane is in contact with the wall. This will continue until the ground adjacent to the probe yields at point B. The limit pressure (P_L) corresponding to point C, is defined as the pressure which is required to double the initial volume of the cavity and it represents the stiffness of the ground. On the other hand, the Menard modulus or pressuremeter modulus (EM) is an initial elastic modulus taken from the slope AB which is identified from the curve as the limits of the elastic response. The slope AB is a function of the shear modulus of the annulus and gives the modulus as;

$$E_m = 2(1 + \mu)(V_0 + V_m)\frac{\Delta P}{\Delta V} \qquad (2)$$

Where μ is the Poisson’s ratio, V_o is the initial volume of the probe, V_m is the mean volume on the slope AB, ΔP is the change in Pressure during loading and ΔV is change in volume of probe during loading. It is not necessary that every time we achieve double the initial volume criteria for deciding the limiting pressure in that case we have to extrapolate the data according to the procedure given in the general memorandum of interpretation and application of pressuremeter test results to foundation design,

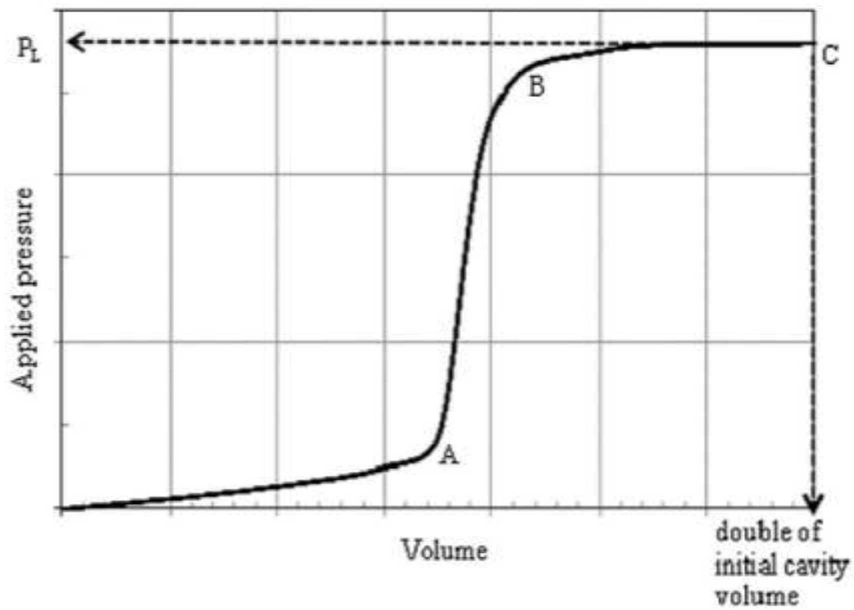

Figure 1 A Typical Pressuremeter Test Curve

3. Geology Of The Study Area

Ahmadabad is located on the banks of the River Sabarmati in the northern part of Gujarat and the western part of India. It is located at 23.03°N 72.58°E spanning an area of 205 km². The average elevation is 53 meters. There are 2 main lakes located in the city limits – the Kankaria lake, and the Vastapur lake. Kankaria lake, located in Maninagar, is an artificial lake developed by Qutb-ud-din Aybakin 1451. It also has an aquarium and a zoo. In the middle of the lake is an island palace named Naginawadi, built during the Mughal era. The city is located in a sandy and dry area. Except for the small hills of Thaltej-Jodhpur Tekra, the entire city is almost flat. The Sabarmati bifurcates the city into eastern and western parts, connected by five bridges, two of which were constructed after independence. Though the river is perennial, it gets dried up in the summer, leaving only a small stream of water flowing. The water table in the city may vary between 25 – 30 m depending on the season.

4. Site Description

The Data used in this study were obtained from 7 exploration boreholes that were drilled as a part of a soil investigation program for Ahmedabad Metro UG. Figure 2 below present the route of the East-West Corridor: Thaltej Gam to Vastral Gam for Ahmedabad metro UG and Figure 3 below present the subsurface profile of the boreholes, where pressuremeter test has been carried out. Site consist of silty sand in the upper layer, lying above the sandy clay medium to stiff with low plasticity, lying above the consolidated stiff clayey strata. The depth of boring ranges between 20 to 25 m in the region where PMT has been carried out. The ground water table was below 30 m at the location near by testing area, which was observed constantly through installed piezometer nearby location.

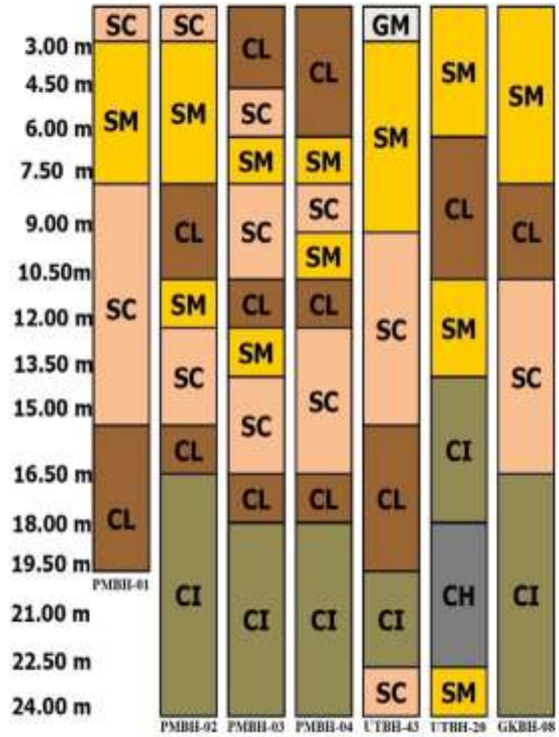

Figure 2 Route of Ahmedabad Metro UG

Figure 3 Bore log Profile

5. Methodology

A biggest problem was to carry out the pre bored pressuremeter test in soil that one has to maintain the borehole diameter at the location of PMT. Investigation were carried using rotary drilling with bentonite mud circulation technique so that caving may not occur during the drilling. Drilling bit of size 72-74 mm has been adopted so that we can achieve a borehole diameter around 76-80 mm which is accepted according to ASTM – D 4719.For conducting a PMT a fresh borehole has been drilled around the vicinity of previous borehole location where SPT has been conducted, but the distance should not increase more then 5-7 m. A donut hammer has been used for the standard penetration test (SPT-N) and test has been carried out according to IS2131–1981. In the Field , the hammer is positioned over the top of the drill rod and blows are applied at the rate of 30-40 blows per minute. A rope twice wrapped around the cathead is used to lift the hammer. The Observed SPT-N value is converted to N60 values based on the recommendation given in the Bowles.J.E(1997). The donut hammer used provides approximately 40 % of the free fall energy to the drill stem and therefore the energy correction factor for 60 % of the free fall energy is 0.66. PMT has been carried out at Crown and bottom portion of tunnel alignment as it subjected to larger strain compare to the central line of the tunnel alignment. Figure 4 below shows the variation of SPT-N with depth and Figure 5 below shows the variation of N_{60} with depth.

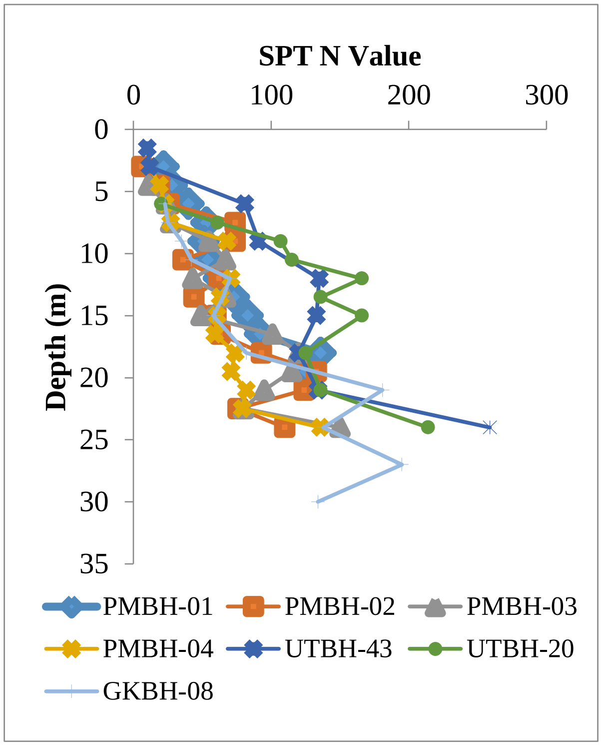

Figure 4 SPT N value vs Depth

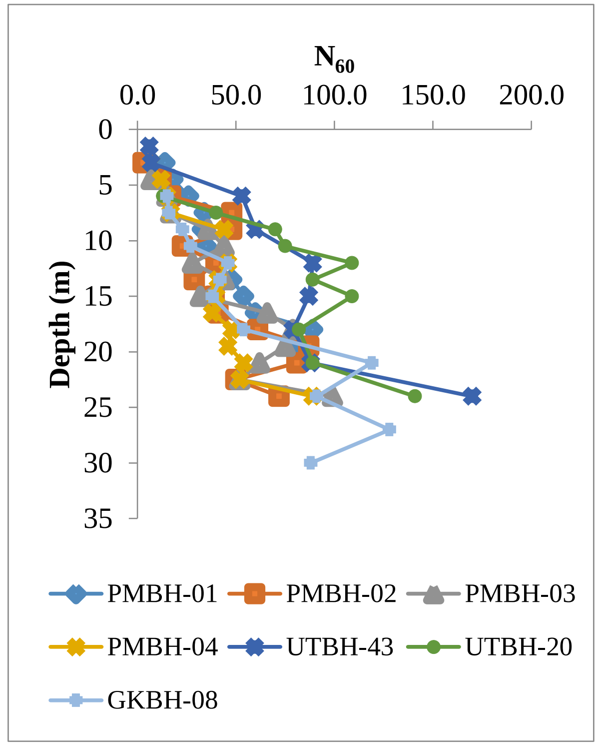

Figure 5 N_{60} vs Depth

6. Analysis

A creep deformation factor has been finalized as per the ratio of E_m/P_L as per the Table E.3, Annexure E, Eurocode 7 part 2.Table 1 shows the procedure to finalize the value of creep deformation factor. Derived value has been directly used for calculating the soil elastic modulus(E_s).Figure 6 below shows the variation of limiting pressure with N_{60} and Figure 7 below shows the variation of pressuremeter modulus (E_m) with N_{60}.

Table 1 Deciding a Creep Deformation Factor

Sr.No	BH-ID	Depth (m)	Pressuremeter Modulus (E_m) in Mpa	Limiting Pressure (P_L) in Mpa	E_M/P_L	Type of soil	Value of α
1	PMBH-01	7.3	31.4	1.15	27.3	SM	0.67
2		11.5	31.2	1.6	19.5	SC	0.5
3		16	37.9	1.9	19.95	SC	0.5
4	PMBH-02	11	85.4	4.95	17.25	CL	1
5		14.5	67.1	3.43	19.56	SC	0.5
6		18	56.7	2.65	21.4	CI	1
7	PMBH-03	11	37.6	2.03	18.52	SC	0.5
8		15	30.1	1.725	17.45	SC	0.5
9		19.5	90.6	3.93	23.05	CL	1

10	PMBH-04	12	47.5	2.3	20.65	CL	1
11		16	35.8	1.9	18.84	SC	0.5
12		20	56.1	3.05	18.39	CI	1
13	UTBH-43	15.5	41.6	2.9	14.34	SC	0.67
14		19	71.4	4.57	15.62	CL	0.67
15	UTBH-20	10.5	72.1	3.4	21.21	CL	1
16		14	91.7	5	18.34	CI	1
17	GKBH-08	7	12.3	1.3	9.46	SM	0.33
18		10.5	46	3.9	11.79	CL	0.67
19		14	15.3	1.75	8.74	SC	0.33

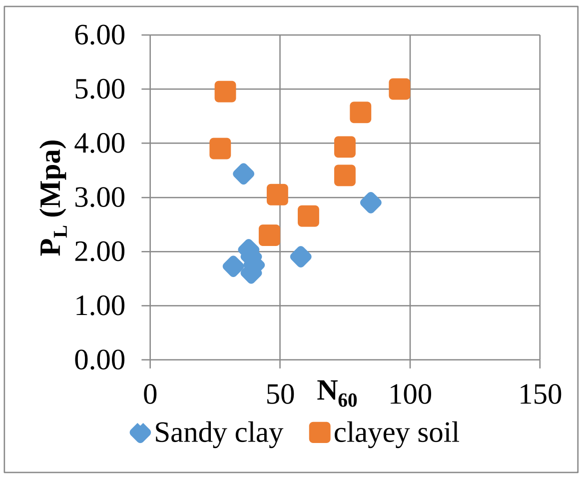

Figure 6 N_{60} vs P_L

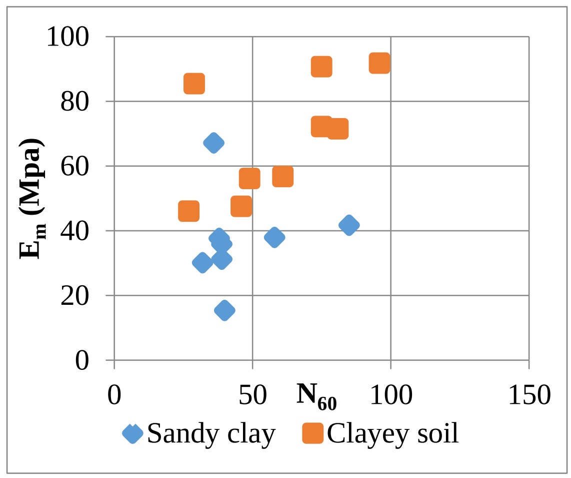

Figure 7 N_{60} vs E_m

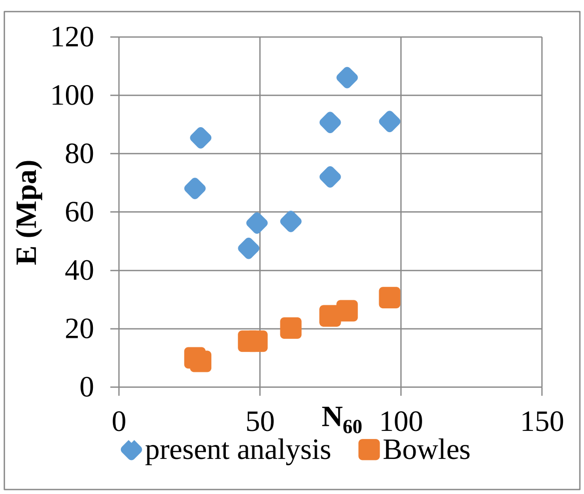

Figure 8 N_{60} vs E for sandy soil

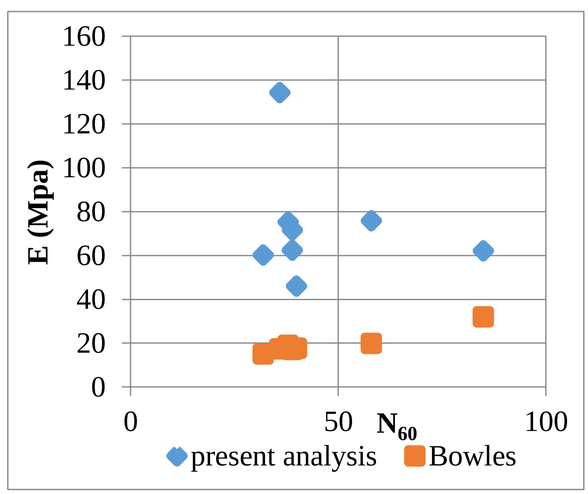

Figure 9 N_{60} vs E for clayey soil

An attempt has been made to compare the carried analysis with already existing correlation (Bowles J.E,1997), Figure 8 and Figure 9 shows the variation of soil elastic modulus with N_{60} for sandy clay and clayey soil respectively. A correlation between N_{60}, P_L, E_m and E has been derived as below,

For Sandy Clay,

$$P_L = 0.0131N_{60} + 1.5516Mpa \ , R^2 = 0.1249 \qquad [3]$$

$$E_m = 0.0742N_{60} + 33.669Mpa \ , R^2 = 0.008 \qquad [4]$$

$$E = 0.3925N_{60} + 54.25Mpa \ , R^2 = 0.069 \qquad [5]$$

For Clayey soils

$$P_L = 0.00981N_{60} + 3.166 \text{ Mpa}, R^2 = 0.0566 \qquad [6]$$

$$E_m = 0.4213N_{60} + 43.381 \text{ Mpa}, R^2 = 0.3141 \qquad [7]$$

$$E = 0.4169N_{60} + 49.842 \text{ Mpa}, R^2 = 0.2575 \qquad [8]$$

Table 2 Relation between soil elastic modulus and SPT N value

Sr. no	**BH-ID**	**Depth (m)**	**Young's modulus in Mpa**	**Young's Modulus as per Bowles (Mpa)**	**E_m (Mpa)**	**Young's Modulus as per Bowles /N_{60}**	**E_m/N_{60}**	**E/N_{60}**
1	PMBH-01	7.3	46	12	31.4	0.36	0.95	1.39
2		11.5	62.4	17.6	31.2	0.45	0.80	1.60
3		16	75.8	19.8	37.9	0.34	0.65	1.31
4	PMBH-02	11	85.4	8.7	85.4	0.30	2.94	2.94
5		14.5	134.2	17.3	67.1	0.48	1.86	3.73
6		18	56.7	20.1	56.7	0.33	0.93	0.93
7	PMBH-03	11	75.2	18.9	37.6	0.50	0.99	1.98

8		15	60.2	15	30.1	0.47	0.94	1.88
9		19.5	90.6	24.3	90.6	0.32	1.21	1.21
10	PMBH-04	12	47.5	15.6	47.5	0.34	1.03	1.03
11		16	71.6	17	35.8	0.44	0.92	1.84
12		20	56.1	15.6	56.1	0.32	1.14	1.14
13	UTBH-43	15.5	62	32.00	41.6	0.38	0.49	0.73
14		19	106	26.1	71.4	0.32	0.88	1.31
15	UTBH-20	10.5	72	24.3	72.1	0.32	0.96	0.96
16		14	91	30.6	91.7	0.32	0.96	0.95
17	GKBH-08	7	37	6.3	12.3	0.42	0.82	2.47
18		10.5	68	9.9	46	0.37	1.70	2.52
19		14	46	17.6	15.3	0.44	0.38	1.15

7. Conclusion

Major difficulties occur in assessing appropriate soil parameters due to such factors as the degree of disturbance caused during testing, drainage conditions and levels of strains imposed during in situ testing as well as the wide variety of soil types, drilling equipment and testing conditions and procedures. In this context, correlations may help designers to evaluate, compare, interpret or cross check the soil parameters obtained from different field tests.

This study aimed to correlate Standard Penetration Test and pressuremeter data obtained during a soil investigation performed in Ahmedabad Metro UG. Empirical equations were proposed between N_{60}, E_M,E and P_L Correlations were obtained for sandy clay and clayey soils separately and R2 values were obtained. Table 2 Above shows the variation of ratio E_m/N_{60} and E/N_{60} among all the borehole it is seen from the table that the ratio E/N_{60} varies from 0.73 to 3.73 for sandy clay and 0.88 to 2.94 for clayey soil.

8. ACKNOWLEDGMENT

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