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Properties of Laterite Soils from Sources Near Nibong Tebal, Malaysia

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Keywords

Laterite soil,
Maximum dry density,
Parameter correlations,
Plastic limit,
Plasticity index.

Abstract

Laterite soils sourced from the interior have been used as fill and construction materials in development projects over the soft coastal quaternary deposits in the Northern States of Peninsular Malaysia. However, studies carried out on these materials have not properly summarized their engineering properties that they can be used as aid for future works. Data from tests involving 17 samples from Nibong Tebal area which were part of a larger collection were analysed. The Maximum Dry Densities (MDD) due to the modified proctor tests carried out on the samples ranged between 1.36Mg/m^3 and 2.05Mg/m^3, while the optimum moisture content (OMC) ranged between 10% and 28.8%. The MDD was found strongly correlated against the OMC and the Plastic Limit (PL), while moderately correlated against the Plasticity Index (PI). The MDD against the rest of investigated parameters were found poorly correlated. The OMC was found strongly correlated against PL and moderately correlated against PI. Other OMC correlations were poor. Furthermore, the laterites of Nibong Tebal, were found to consist on the average, 10.96% gravel, 45.94% sand, and 43.10% fines. The average particle size (D50) was 0.17mm. The average coefficients of uniformity (CU) and conformity (CC) were 150.32 and 0.98 respectively. The average liquid limit (LL), PL, and PI were 55.68%, 35.22%, and 20.40% respectively. Most of the laterites fall under the SC and SM classifications according to the USCS system and A-5 and A-7-6 classifications according to the AASHTO system, which indicate suitability for fill and construction materials.

1. Introduction

Laterite is a residual material and could exist in rock or soil form, as shown in Figure 1. Laterite soils can be found in various terrestrial landscapes including the foot slopes, the gently undulating country, and the hill summits [1]. Laterite soils are known to be very resistant to erosion and such can be demonstrated by the nature of its properties such as high shear strength, low infiltration capacity, and low clay content making it an excellent geotechnical building material [1]. The main elements of a laterite are Ni, Fe, Ti, Si, V, Zr, and Al, which are present in the form of hydroxides and/or oxides [2]. A laterite soil is usually full of cavities and pores, and contains a very large quantity of iron, as indicated by the yellow and red ochre [3]. The actual chemical compositions of a laterite nevertheless are a function of where the material has been sourced.

Laterite soils are popular building material in Malaysia and in many other countries throughout the world [7]. The construction of highways, dams, airfields, embankments, foundations, and landfill caps usually make use of laterites where resistance against loads or protection against infiltration are provided for very well. Generally, the problems that have arisen in a laterite structure were mainly due to the insufficient treatment particularly with regard to compaction.

Key geotechnical properties such as the maximum dry density (MDD) and optimum moisture content (OMC) should be noted before going on with the next step in the construction procedure. The MDD of a stabilized soil is normally the most important information referred to in determining the quality of a fill [8]. The relative compaction is the term describing the quality of a compacted soil relative to the condition at MDD; it is a performance indicator of a stabilized fill. A superior fill is one with high MDD and high relative compaction which would be normally interpreted as one with high shear strength, great stiffness, lower compressibility, and low permeability. However, in carrying out the related modified proctor test, the previously compacted soil should not be reused as doing so would significantly give a greater MDD that does not reflect the real value in the field [9].

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A large amount of research has been carried out in the last 2 decades on the properties of laterites from places around the world. However, the results from these studies have not been properly summarized particularly with the Malaysian scenario; it would have been easier to predict an individual soil properties after knowing its specific key information. The aim of this research was to determine the properties of laterites sourced from borrow sites near the Engineering Campus of Universiti Sains Malaysia in Nibong Tebal, Malaysia. The focus of the current presentation is on the identification of relationships that relate MDD to various key parameters particularly the OMC, the Atterberg limits, and the particle sizes.

(a) (b) (c)

Figure 1. Example of various forms of laterite: (a) block (b) coarse grained and (c) fine grained [4-6]

2. Materials and Method

2.1. Soil Samples and Tests

Data of 17 soil samples were analysed. These were part of a larger information currently kept in the geotechnical repository of University Sains Malaysia (USM). The laterite soil samples were sourced from sites nearby the USM Engineering Campus in Nibong Tebal, which could be considered representatives of supplies from the surrounding areas of North Perak and South Kedah. The soil samples were mainly provided by contractors involved in constructions, who have sought testing services provided by the geotechnical laboratory. The tests carried out on these samples – sieve, hydrometer, Atterberg limits, and modified Proctor – were the common ones in the practice of site preparation.

2.2. Sieve and Hydrometer Analyses

The sieve and hydrometer analyses were carried out according to the British Standard – BS1377 - in order to describe the grain size distributions [10]. Prior to the sieve analysis, the soil sample was placed in an oven for 24 hours in order to rid the moisture retained after room drying. The dried soil was shaken using a stack of mechanical sieves arranged with decreasing opening sizes from top to bottom, with a pan placed at the very bottom to collect the part of sample that passed through the finest aperture – 0.063mm. The mass of soil retained in each sieve and pan was weighed and recorded.

The sieve analysis was carried out on the whole sample while the hydrometer analysis was carried out on portion of the sample with smaller particle sizes, i.e. <2.00mm. Note that by the British Standard, soil particles >0.063mm are termed coarse grained, while those <0.063mm are termed fine grained. The dividing size in the American Standard is instead 0.075mm [11]. Based on the results of sieve and hydrometer analyses, a plot of percentage passing against particle size was created with the size presented by the abscissa and in logarithmic scale. The curve is called the particle size distribution (PSD). The diameters at 10% passing (D10), at 30% passing (D30), at 50% passing (D50), and at 60% passing (D60) were determined from the PSD curve. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) were determined according to the Eq. (1) and Eq. (2).

$$Cu = \frac{D60}{D10} \tag{1}$$

where, D60= diameter corresponding to 60% passing and D10= diameter corresponding to 10% passing

$$Cc = \frac{D^2 30}{D60\, D10} \tag{2}$$

where, D30= diameter corresponding to 30% passing

The hydrometer analyses were carried out only in cases where the amount of soil collected by the pan being >12%. The hydrometer analysis was carried out following the completion of the sieve analysis. Sodium hexametaphosphate, a dispersing agent, was added to an amount of distilled water and the solution was used to disperse the fine particles, which otherwise could not be scattered due to the clay content [11-13]. The suspension was topped up to amount to 1000ml and the measuring cylinder was shaken well to ensure all mixtures were mixed together. When truly mixed the measuring cylinder was placed on the bench and a hydrometer was placed in the soil suspension. The hydrometer measured the specific gravity of the suspension in the vicinity of its bulb, which decreased with increasing sedimentation and time. The hydrometer was designed to give the amount of soil in grams, although the soil was still in a suspension [11]. Thus the hydrometer gradation was read against time; with time the hydrometer increased in its submergence. The weight percentage of soil finer than those surrounding the bulb was determined for each particle size considered. Further discussion particularly on the calculation will not be covered in this paper as it can be found in other sources [11].

2.2. Atterberg Limit Tests

The Atterberg Limits tests, also known as consistency limit tests, were carried out according to the British Standard – BS1377 - in order to describe the critical moisture contents of a laterite soil and identify the soil behaviour associated with the changing moisture content [10]. The Atterberg limits tests were only carried out on clayey soils as with the presence of clay minerals and some moisture, the soils can be reformed without crumbling [11]. There were two main tests carried out namely the liquid limit (LL) test and the plastic limit (PL) test. In this study, the fall cone method was used to determine the LL, which involved a series of tests on samples with various moisture contents. The LL was defined as the moisture content when the penetration needle, which weighed 0.78 N, would penetrate a distance of 20 mm in 5 seconds, when allowed to drop from a position above the contact point [11-14]. A semi logarithmic curve was plotted relating moisture content to the cone penetration. The moisture content matching the 20mm penetration was the LL. For the PL, the moisture content was determined at which the soil began to crumble, when rolled into threads of approximately 3 mm diameter. The test was performed by repeated rolling of the soil threads, by hand, on a glass plate. The plasticity index (PI) was determined by subtracting the LL by the PL. The limits were given in percentage (%).

2.4. Modified Proctor Test

The Modified Proctor tests in this study were carried out based on the British Standard [9]. An approximately 4% water, by mass, was added to the dry sample, as a start. The soil and water were thoroughly mixed before compacted into the test mould. The soil was compacted in 5 layers using 4.5kg manual rammer. Each layer was compacted with 25 blows from a height of 457 mm. The result was recorded, in terms of the moisture content versus the dry density. Consecutive tests were repeated but with increasing moisture contents until an obvious peak dry density was achieved. The moisture content corresponding to the peak dry density was the OMC. The tests were repeated for the various soil samples.

2.5. Soil Classification

Two soil classification systems were used: the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS) [11]. Both classification systems are based on the grain size distribution and plasticity of the soil [11]. Also, both differentiate the coarse grains against the fine grains by the No. 200 sieve, which size is 0.075mm. The British Standard however recognizes the 0.063mm size as the dividing line, which is not significantly different from the 0.075mm used by AASHTO and ASTM. There is an additional classification procedure for the AASHTO system where the group index (GI) was incorporated in a bracket after giving the soil name. Generally, the quality of soil for the purpose decreases with increasing GI value. The GI is calculated based on the Eq. (3)

$$GI = (F_{200}-35)\,[0.2+0.005(LL-40)] + 0.01(F_{200}-15)(PI-10) \quad (3)$$

where, F_{200} = percentage passing through the No. 200 sieve

Just to note, the AASHTO classification system has been commonly used for highway construction purpose while the USCS has been more commonly employed in general geotechnical work.

2.6. Correlations

In statistical analysis, a correlation is said to exist when the variables are found to have a reasonable linear relationship [15]. The Microsoft Excel software was used in this study in order to evaluate the correlation of a linear relationship between any two variables. The R-square (R2) is used to evaluate the veracity of the correlation. The closer R2 value is to 1, the greater proportion of variance is said to be accounted for by the model, or the stronger is the correlation, thus more acceptable. A very small R^2 value indicates the lack of legitimacy for the correlation to exist or that the correlation is weak or poor. In this study, a correlation is considered strong if $R^2>0.5$, moderate if $0.5>R^2>0.1$, and poor if $R^2<0.1$.

3. Results and Discussion

The results of testing 17 samples by various methods are given in Table 1. The percentages of gravel, sand, silt and clay were determined from the PSD curves and the respective size definitions. The USCS specifies fines – silts and clays together – as being <0.075mm in size, sands as being 0.075mm to 4.75mm in size, and gravel as being 4.75mm to 76.2mm in size. On the other hand, the AASHTO specifies fines – silts and clays together – as being <0.075mm in size, sands as being 0.075mm to 2.00mm in size, and gravel as being >2.00mm in size. The British Soil Classification System however was used in the categorization of Table 1 for gravel, sand, silt, and clay contents [16]. The range, average, and standard deviation (SD) of each parameters are also included. The average amounts for gravel, sand, and fines for the laterites were found 10.96%, 45.94%, and 43.10% respectively.

D_{50} was found to range between 0.02mm and 0.40mm, averaging 0.17mm, indicating the fine nature of the laterites. The parameter D_{50} is an indication of the OMC; such was mentioned by the literature where it states that OMC decreases with increasing D_{50}, but the associated correlation was found poor by this current study [17]. C_U was found to range between 20.00 and 352.94 indicating a large range of particle sizes. C_C ranged between 0.03 and 6.00, but most were <1.0, thus indicating uniformity or distribution that is not well graded. The average LL, PL, and PI were 55.68%, 35.22%, and 20.40% respectively indicating moderate clay contents. The range of MDD and OMC were 1.36 to 2.05Mg/m3 and 10.0 to 28.8%, averaging 1.62Mg/m^3 and 20.57% respectively. According to Table 1, most of the soils fall under the SC and SM classifications under the USCS system and A-5 and A-7-6 soil group classification under the AASHTO system.

The highest MDD of 2.05 Mg/m3 corresponds to the lowest OMC of 10.00%, which were both for Sample 14. Generally, the best fill would be one with the highest MDD, thus in this case was also one with the least OMC.

The soil samples were classified according to the AASHTO and USCS systems. By USCS method, most of the laterites were classified as clayey sand (SC) followed by silty sand (SM). BY AASHTO method, most samples fall under the desirable material categories with low GI values.

Table 1. Index properties of laterite samples from Nibong Tebal area

Sample	Gravel, % (>2.0mm)	Sand, % (0.06mm-2.0mm)	Silt, % (0.002mm-0.06mm)	Clay, % (<0.002mm)	Average particle size D_{50}, mm	Coefficient of uniformity Cu	Coefficient of conformity Cc	Liquid Limit, %	Plastic Limit, %	Plastic Index, %	Maximum dry Density (MDD), Mg/m3	Optimum Moisture Content (OMC), %	USCS	AASHTO
1	0.00	66.90	33.1		0.21	76.47	3.17	29.5	12.92	16.58	1.76	16.00	SC	A-2-4(0)
2	14.30	54.90	30.8		0.19	20.00	0.59	34.70	23.64	11.06	1.59	19.70	SC	A-2-6(0)
3	39.30	12.80	35.47	12.43	0.12	-	-	71.50	56.25	15.25	1.37	28.80	GM	A-2-7(0)
4	21.30	42.30	27.43	8.97	0.21	187.50	0.30	71.50	61.90	9.60	1.37	28.09	SM	A-5(0)
5	0.90	61.30	27.67	10.13	0.21	180.00	0.12	56.70	52.78	3.89	1.36	28.80	SM	A-5(0)
6	0.50	41.20	43.39	14.91	0.02	-	-	56.00	51.52	4.45	1.45	27.30	MH	A-5(0)
7	1.00	46.20	41.3	11.5	0.04	-	-	46.00	40.91	5.09	1.53	21.70	ML	A-5(1)
8	1.10	56.90	33.59	8.41	0.19	162.50	0.54	43.50	38.89	4.61	1.54	23.00	SM	A-5(0)
9	2.30	47.90	39.61	10.19	0.07	146.67	0.08	44.20	39.23	4.97	1.50	22.20	SM	A-5(1)
10	0.80	62.70	30.35	6.15	0.18	144.44	6.00	56.20	33.33	22.87	1.56	24.60	SM	A-7-5(0)
11	23.10	30.80	37.88	8.22	0.20	352.94	0.16	58.50	22.50	36.00	1.75	14.00	SC	A-7-6(1)
12	19.60	42.60	30.21	7.59	0.31	133.33	0.03	70.00	25.00	45.00	1.72	17.00	SC	A-7-6(0)
13	14.63	42.80	33.43	9.14	0.25	108.33	0.11	73.50	31.65	41.85	1.70	17.62	SC	A-7-5(0)
14	22.93	29.99	41.66	5.42	0.09	291.67	0.61	31.80	16.67	15.13	2.05	10.00	SC	A-6(1)

Sample	Gravel, % (>2.0mm)	Sand, % (0.06mm-2.0mm)	Silt, % (0.002mm-0.06mm)	Clay, % (<0.002mm)	Average particle size D_{50}, mm	Coefficient of uniformity Cu	Coefficient of conformity Cc	Liquid Limit, %	Plastic Limit, %	Plastic Index, %	Maximum dry Density (MDD), Mg/m3	Optimum Moisture Content (OMC), %	USCS	AASHTO
15	14.86	47.71	31.3	6.13	0.40	-	-	67.50	16.93	50.57	1.85	15.21	SC	A-7-6(0)
16	6.72	37.40	44.42	11.46	0.02	-	-	85.50	43.48	41.02	1.71	18.05	CH	A-7-6(0)
17	2.90	56.63	29.79	10.68	0.19	-	-	49.90	31.11	18.79	1.77	17.70	SM	A-7-5(0)
Average	10.96	45.94	43.10		0.17	150.32	0.98	55.68	35.22	20.40	1.62	20.57	-	-
Range	0.00 – 39.30	12.80 –66.90	30.80 – 58.30		0.02–0.40	20.00 – 352.94	0.03 – 6.00	29.50 – 85.50	12.92 – 61.90	3.89 – 50.57	1.36 – 2.05	10.00 – 28.80	-	-
SD	11.12	13.26	7.74		0.10	88.38	1.78	15.65	14.28	15.67	0.18	5.45	-	-

4. Correlations of MDD Against other Parameters

The correlations of MDD against other parameters are given in Table 2. The correlation of MDD versus OMC was found to be the most legitimate with highest R^2, followed by MDD versus PL. With $R^2>0.5$, the correlations of MDD against OMC and against PL were considered strong. With $0.5>R^2>0.1$, the correlation of MDD against PI was considered moderate. The correlations of MDD versus D50, C_U, C_C, and LL were found to be lacking legitimacy due to the low values of R^2, thus they were poor or unacceptable. Thus the attempt to relate MDD to any of the D_{50}, C_U, C_C, and LL could not be legitimized by statistical evidence based on the available data so far. The curves of MDD versus OMC, PL, and PI are given in Figures 2, 3, and 4.

Meanwhile, the correlations of OMC versus the rest of the parameters are given in Table 3. The correlation of OMC versus PL was considered strong while the OMC versus PI was moderate. The curves of OMC versus PL and versus PI are given in Figures 5 and 6.

Table 2. Correlation of MDD against other parameters

Correlation	R^2	Equation
MDD vs OMC	0.931	MDD = -0.033OMC + 2.293
MDD vs PL	0.734	MDD = -0.011PL + 2.010
MDD vs PI	0.317	MDD = 0.007PI + 1.485
MDD vs D_{50}	0.061	MDD = $0.458D_{50}$ + 1.543
MDD vs LL	0.047	MDD = -0.003LL + 1.763
MDD vs C_U	0.039	MDD = $0.0003C_U$ + 1.584
MDD vs C_C	0.002	MDD = $0.005C_C$ + 1.617

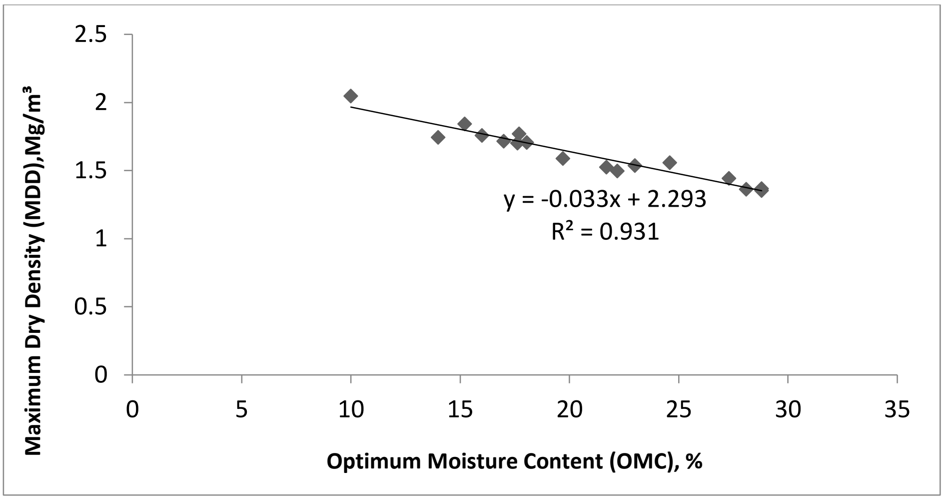

Figure 2. MDD versus OMC

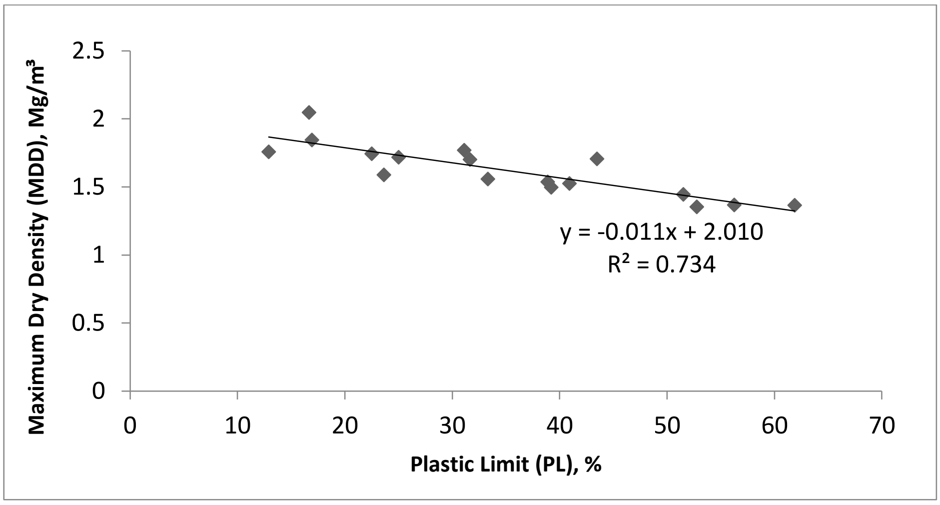

Figure 3. MDD versus PL

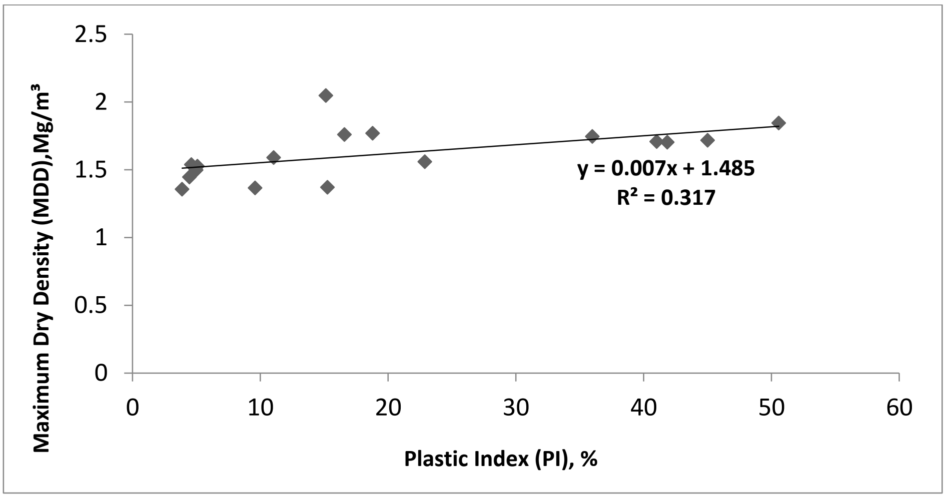

Figure 4. MDD versus PI

Table 4. Correlation of OMC with other parameters

Correlation	R^2	Equation
OMC vs PL	0.782	OMC = 0.337PL + 8.694
OMC vs PI	0.318	OMC = -0.196PI + 24.577
OMC vs D_{50}	0.059	OMC = -13.212D_{50} + 22.819
OMC vs LL	0.058	OMC = 0.084LL + 15.912
OMC vs C_U	0.063	OMC = -0.013C_U + 21.949
OMC vs C_C	0.002	OMC = 0.149C_C + 20.472

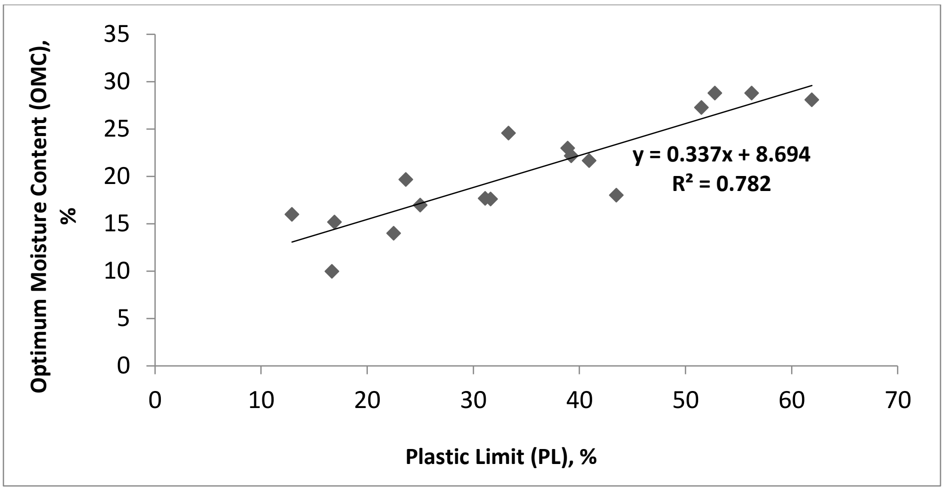

Figure 5. OMC versus PL

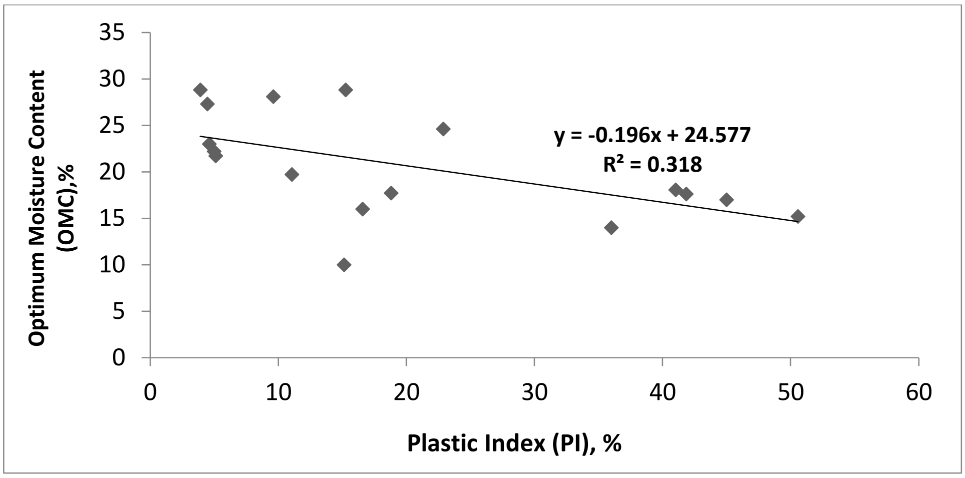

Figure 6. OMC versus PI

5. Conclusions

Based on the available data so far, the laterites of Nibong Tebal area, on the average consist of 10.96% gravel, 45.94% sand, and 43.10% fines. The average D50 is 0.17mm. The CU and CC are 150.32 and 0.98 respectively, on the average. The LL, PL, and PI are 55.68%, 35.22%, and 20.40% respectively, on the average. The MDD and OMC are 1.62Mg/m^3 and 20.57% respectively. Most of the soils fall under the SC and SM classifications under the USCS system and the A-5 and A-7-6 classifications under the AASHTO system. MDD vs. OMC and MDD vs. PL are strongly correlated, while MDD vs. PI is only moderately correlated. OMC vs. PL is strongly correlated while OMC vs. PI is only moderately correlated.

It will be now possible to predict the MDD and OMC of a laterite by simply determining its Atterberg limits. By comparing the MDD values, the quality of a laterite can also be evaluated against another. In practice, this should also affect pricing.

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