Correlation between Plasticity Index and Methylene Blue Value to Determining Soil Classification

Andrias Suhendra Nugraha1, Paulus P. Rahardjo2, Bigman M. Hutapea3, and Imam A. Sadisun4
1 Doctoral Candidate of Civil Engineering, Universitas Katolik Parahyangan and Lecturer of Civil Engineering Department, Faculty of Engineering, Universitas Kristen Maranatha, Indonesia
2 Professor of Geotechnical Engineering, Faculty of Engineering, Universitas Katolik Parahyangan, Indonesia
3 Associate Professor of Geotechnical Engineering, FTSL, Institut Teknologi Bandung, Indonesia
4 Associate Professor of Engineering Geology, FITB, Institut Teknologi Bandung, Indonesia

Email: andrias.snugraha@gmail.com

Abstract. Most soil classification systems developed for geotechnical engineering purposes are based on simple index properties such as grain size distribution and plasticity. In Indonesia, the use of the methylene blue value, VBS, is still rarely used, compared to Atterberg limits that commonly used to determine the value of the plasticity index, PI. Therefore, this study aims to gain a correlation between PI and VBS. Coarse-grained soil with fines (clay and silt) contents varies from 12.36% to 29.45% are used of this study. The linear correlation between PI and VBS produces a linear equation with a coefficient of determination, $R^2 = 0.854$ for $0.62 < VBS < 2.39$. The PI obtained from the correlation to VBS that combined with the sieve analysis results can then be used for soil classification based on the Unified Soil Classification System (USCS).

1. Introduction
Soil classification is used to determine certain soil types that suitable for an application of the geotechnical construction, such as: embankment, subgrade material, and drainage material. Varies type of soils with similar properties can be classified into classes or groups and subclasses according to soil behavior. For geotechnical engineering purposes, most of soil classification systems that developed are based on simple index properties such as grain size distribution and plasticity. Plasticity index, PI, is obtained from the Atterberg limits test, which is the difference between liquid limit, LL, and plastic limit, PL [1]. When carrying out LL and PL tests, man-mad error that easily occurred [2], can impact on the subjectivity of PI values. To solve this condition, other parameters from other methods that are universal, fast and reliable are needed as a comparison for the determination of PI [3]. Another parameter for comparison with PI is methylene blue value (valeurs de blu du sol, VBS). VBS is obtained from methylene blue test [4], [5], [6]. This test was developed in France, where initially, this test was carried out to determine the suitability of granular material in making concrete by detecting clay content from granular material [7]. The spot method is more common for the test and is a simplified type of titration technique [7], [8]. This study aims to obtain a correlation between the PI and VBS. The results of these correlations can be used to determine soil classification.
2. **Method**

The standard test for sieve analysis is based on ASTM D 422. Determination of Atterberg limits (LL and PL) refers to the standard ASTM D 4318. The standard for methylene blue test is based on NF P 94-068. The test results are then analyzed to obtain a correlation between PI and VBS. The soil classification is based on the Unified Soil Classification System (USCS) [9], [10].

2.1. **Plasticity Index**

The plasticity index, PI [1] is calculated using the following equation:

\[
\text{PI} = \text{LL} - \text{PL} 
\]  

Test of LL and PL are shown in Figure 1.

![Figure 1. (a) Test of liquid limit, LL (b) Test of plastic limit, PL](image)

2.2. **Methylene blue value (Valeurs de blue du sol, VBS)**

The methylene blue test standard refers to NF 94-068 [4] or NF EN 933-9 [5]. Figure 2 shows the methylene blue test equipment and Figure 3 shows the flow chart of the methylene blue test with the spot method conducted in this study.

![Figure 2. Methylene blue test equipments](image)
A certain amount of methylene blue solution is added in a certain volume in the suspension of fine-grained soil to calculate the methylene blue value, VBS, then the clay particle suspension adsorbs methylene blue and the total amount of methylene blue adsorbed is used to obtain VBS. The following equation expresses the value of VBS [4]:

\[ VBS = \frac{B}{m_0} \times C \times 100 \]

where:
- \( VBS \) = methylene blue value (gram of blue per 100 grams of dry material, g/100g)
- \( B \) = mass blue added (solution at 10 g/liter)
- \( C \) = volume of blue, \( V_d \) (cm³) x 0.01
- \( m_0 \) = proportion of the fraction 0/5 mm in the fraction 0/50mm (%)

Athanasopoulou and Koralos [11] stated the correlation between plasticity index and volume of dye or volume of blue, \( V_d \) (cm³) by the following equation:

\[ PI = 1.20 V_d + 5.79 \text{ for } 6 < V_d < 27.5 \]  

Otcu et.al [12] stated the correlation between the plasticity index and methylene blue value expressed in grams of dye per kilogram of the 0/2mm fraction, MB [5] by the following equation:

\[ PI = 1.1097 MB^{0.7837} \text{ for } 31.25 < MB < 89.20 \]

where:
- \( MB \) = \( (V_1/M_1) \times 10 \) (%)
- \( V_1 \) = total volume of methylene solution added (ml)
- \( M_1 \) = mass of the experimental sample (g)
- 10 = a factor used to convert the volume of stain solution used to the mass of stain per kilogram of the mass tested
3. Results and discussion

The study of plasticity index and methylene blue value for soil classification are carried out on data obtained from laboratory test results of soils originating from areas in North Maluku, Indonesia. Table 1 shows the results of a sieve analysis of those data. It can be seen from Table 1 that the coarse-grained soil have fines (Silt and Clay) contents varies from 12.36% to 29.45%. Following the completion of sieve analysis, methylene blue test was conducted to get VBS. Also, Atterberg limits test (LL and PL) were conducted to obtain PI. Table 1 also shows the VBS and the PI of the samples.

| Sample No. | Result of Sieve Analysis | VBS (%) | PI = LL - PL (%) |
|------------|--------------------------|---------|-----------------|
|            | Gravel (%) | Sand (%) | Silt & Clay (%) |                 |
| 1          | 17.49      | 64.58    | 17.92           | 0.68            |
| 2          | 33.84      | 48.08    | 18.08           | 1.28            |
| 3          | 17.22      | 65.03    | 17.74           | 1.31            |
| 4          | 37.57      | 45.51    | 16.92           | 0.78            |
| 5          | 43.96      | 29.66    | 26.38           | 0.80            |
| 6          | 39.76      | 32.35    | 27.89           | 0.86            |
| 7          | 24.64      | 56.91    | 18.45           | 0.35            |
| 8          | 15.08      | 59.16    | 25.77           | 0.47            |
| 9          | 23.91      | 48.58    | 27.51           | 0.66            |
| 10         | 15.14      | 61.04    | 23.82           | 0.74            |
| 11         | 30.93      | 39.62    | 29.45           | 1.39            |
| 12         | 45.37      | 37.04    | 17.59           | 2.39            |
| 13         | 21.21      | 57.92    | 20.87           | 1.10            |
| 14         | 17.20      | 63.17    | 19.63           | 0.90            |
| 15         | 19.89      | 60.24    | 19.88           | 0.76            |
| 16         | 32.14      | 41.55    | 26.31           | 0.92            |
| 17         | 26.82      | 50.92    | 22.25           | 0.52            |
| 18         | 36.90      | 44.09    | 19.02           | 0.34            |
| 19         | 27.49      | 48.69    | 23.82           | 1.62            |
| 20         | 47.79      | 33.86    | 18.35           | 0.67            |
| 21         | 31.79      | 46.24    | 21.97           | 1.49            |
| 22         | 27.91      | 59.74    | 12.36           | 0.80            |
| 23         | 25.71      | 50.24    | 24.04           | 0.81            |
| 24         | 32.99      | 48.66    | 18.35           | 1.19            |
| 25         | 24.42      | 56.12    | 19.47           | 0.42            |

A plot of PI vs. VBS is presented in Figure 4. Based on the data given in Figure 4, a linear correlation between the PI and the VBS can be expressed by the following equation:

\[ \text{PI} = 17.94 \times \text{VBS} + 0.056 \quad \text{for} \quad 0.62 < \text{VBS} < 2.39 \]  \hspace{1cm} (5)

With coefficient of determination, \( R^2 = 0.854 \).

The results of the Atterberg limits test are strongly dependent on the technician. For example, to decide the number of blows to close the groove in the sample to obtain the liquid limit. Furthermore, the pressure on the operator palm hand, while roll the sample on a glass plate, affect the results, which is the plastic limit.

On the other hand, compare to the Atterberg Limits test, the methylene blue test with spot method is less dependent on the technician. This is because the procedure for conducting the methylene blue test is more natural to perform.
Table 2. Comparison of PI from Atterberg limits and PI from correlation with VBS

| Sample No. | PI = LL - PL from Atterberg Limits (%) | PI = 17.94 VBS + 0.056 from correlation with VBS (%) | Absolute difference (%) |
|------------|---------------------------------------|--------------------------------------------------|--------------------------|
| 1          | 10.74                                 | 12.30                                            | 1.6                      |
| 2          | 20.28                                 | 23.07                                            | 2.8                      |
| 3          | 28.75                                 | 23.47                                            | 5.3                      |
| 4          | 17.42                                 | 13.99                                            | 3.4                      |
| 5          | 12.43                                 | 14.48                                            | 2.0                      |
| 6          | 11.50                                 | 15.46                                            | 4.0                      |
| 7          | 8.98                                  | 6.26                                             | 2.7                      |
| 8          | 10.28                                 | 8.45                                             | 1.8                      |
| 9          | 9.90                                  | 11.82                                            | 1.9                      |
| 10         | 14.56                                 | 13.37                                            | 1.2                      |
| 11         | 19.29                                 | 24.94                                            | 5.6                      |
| 12         | 49.39                                 | 42.93                                            | 6.5                      |
| 13         | 17.01                                 | 19.84                                            | 2.8                      |
| 14         | 11.23                                 | 16.29                                            | 5.1                      |
| 15         | 11.62                                 | 13.66                                            | 2.0                      |
| 16         | 17.62                                 | 16.57                                            | 1.1                      |
| 17         | 13.52                                 | 9.40                                             | 4.1                      |
| 18         | 7.63                                  | 6.16                                             | 1.5                      |
| 19         | 31.07                                 | 29.12                                            | 1.9                      |
| 20         | 17.53                                 | 12.01                                            | 5.5                      |
| 21         | 21.53                                 | 26.75                                            | 5.2                      |
| 22         | 13.08                                 | 14.42                                            | 1.3                      |
| 23         | 13.95                                 | 14.50                                            | 0.5                      |
| 24         | 20.44                                 | 21.42                                            | 1.0                      |
| 25         | 8.60                                  | 7.62                                             | 1.0                      |

2.9 (Average)
Table 2 shows the PI values obtained directly from the Atterberg Limit test and those obtained based on the correlation with VBS (Equation 5). The absolute difference between these two PI is also shown in Table 2. It can be seen from Table 2 that the average of this absolute difference is only 2.9%. Therefore, one can say that the methylene blue test can be used as an alternative method to obtain the PI of soil.

The PI value obtained from the correlation to VBS combine with the sieve analysis results (Table 1) is used to classify soil sample according to the USCS. The results are given in Table 3. It can be seen from Table 3 that for the whole tested coarse-grained soil, there are four Group Name and four Group Symbol.

| Sample No. | Soil Classification based on USCS |
|------------|----------------------------------|
| 1, 2, 4, 8, 9, 10, 11, 13,14,15,16,17,19, 21, 22, 23, 24, 25 | Clayey sand with gravel SC |
| 5, 6, 12, 20 | Clayey gravel with sand GC |
| 7, 18 | Silty, clayey sand with gravel SC-SM |
| 3 | Silty sand with gravel SM |

4. Conclusion

Plasticity index, PI is one of the most important soil parameters for conducting soil classification based on the Unified Soil Classification System (USCS). PI can be obtained through correlation to VBS, which is the result of a methylene blue test. Compare to the Atterberg limits test, the procedure for conducting the methylene blue test is more straightforward. The results of this study show that for VBS value between 0.62 and 2.39, the correlation can be expressed by a linear equation with a coefficient of determination $R^2 = 0.854$. The PI obtained from the correlation to VBS combine with the sieve analysis results can then be used for soil classification based on the USCS.

5. References

[1] ASTM D 4318-10 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, Annual Book of ASTM Standards.
[2] Zhang, X., Li, J., Shi, R., Zou, M., Wang, Y., Li, H., 2013 The liquid and plastic limit data treated system based on VC++, Proceedings of the 2nd International Symposium on Computer, Communication, Control and Automation (ISCCCA-13), Paris, France, pp.066 – 069.
[3] Seybold, C.A., Elrashidi, M.A., Engel, R.J., 2008 Linear regression models to estimate soil liquid limit and plasticity index from basic soil properties, Soil Science, Vol. 173 (1), pp.25-34.
[4] NF P 94-068, 1998 Détermination de la valeur de bleu de méthylène d'un sol ou d'un matériau rocheux par l'essai à la tache, AFNOR, France.
[5] NF EN 933-9, 1999 Part 9: Assesment of Fines–Methylene Blue Test, AFNOR, France.
[6] LCPC / GTR, 2003 Practical Manual for The Use of Soil and Rocky Materials in Embankment Construction, Paris, France.
[7] Turkos, M., and Tosun, H., 2011 The use of methylene blue test for predicting swell parameters of natural clay soils, Scientific Research and Essays, Vol. 6(8) pp.1780-1792.
[8] Chiappone, A., Marello, S., Scavia, C., Setti, M, 2004 Clay mineral characterization through the methylene blue test: comparison with other experimental techniques and applications of the method, Canadian Geotechnical Journal, Vol. 41 pp.1168-1178.
[9] ASTM D 2487-11 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), Annual Book of ASTM Standards.
[10] ASTM D 422-02 Standard Test Method for Particle-Size Analysis of Soils, Annual Book of ASTM Standards.
[11] Athanasopoulou, A and Kollaros, G., 2011 *Laboratory tests on the cleanliness of soil materials used as subgrades in pavement structures*, WIT Transactions on Engineering Sciences, Vol 72 pp.315-325.

[12] Otcu, N.U., Uzundurukan, S., Kaplan, G., 2017 *Determination of the Plasticity Index of Soils with Fine-Grained Soils Using Methylene Blue Test*, Journal of Geoscience and Environment Protection, 5pp.165-181.