The estimation of parameter compaction values for pavement subgrade stabilized with lime

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Abstract. The type of soil material, field control, maintenance and availability of funds are several factors that must be considered in compaction of the pavement subgrade. In determining the compaction parameters in laboratory desperately requires considerable materials, time and funds, and reliable laboratory operators. If the result of soil classification values can be used to estimate the compaction parameters of a subgrade material, so it would save time, energy, materials and cost on the execution of this work. This is also a clarification (cross check) of the work that has been done by technicians in the laboratory. The study aims to estimate the compaction parameter values i.e. maximum dry unit weight ($\gamma_{d\text{ max}}$) and optimum water content ($W_{opt}$) of the soil subgrade that stabilized with lime. The tests that conducted in the laboratory of soil mechanics were to determine the index properties (Fines and Liquid Limit/LL) and Standard Compaction Test. Soil samples that have Plasticity Index (PI) > 10% were made with additional 3% lime for 30 samples. By using the Goswami equation, the compaction parameter values can be estimated by equation $\gamma_{d\text{ max}} = -0.1686 \log G + 1.8434$ and $W_{opt} = 2.9178 \log G + 17.086$. From the validation calculation, there was a significant positive correlation between the compaction parameter values laboratory and the compaction parameter values estimated, with a 95% confidence interval as a strong relationship.

1. Introduction
The strength of pavement construction depends on the characteristic and carrying capacity of the subgrade. The effort which is required to increase the carrying capacity of basic soil is compaction. Laboratory compaction test is determined by conducting Proctor Compaction Test on several soil samples with varying moisture content. The result obtained is the Parameter Value of Compaction which is maximum dry unit weight ($\gamma_{d\text{ max}}$) at the time of optimum water content ($w_{opt}$). Whereas the field compaction test is obtained by Sand Cone Test or Dynamic Cone Penetrometer Test which yielded the maximum dry unit weight ($\gamma_{d\text{ max}}$) value in field [1]. In determining the compaction parameters in laboratory desperately requires considerable materials, time and funds, and reliable laboratory operators. If the result of soil classification values can be used to estimate the compaction parameters of a subgrade material, so it would save time, energy, materials and cost on the execution of this work. This is also a clarification (cross check) of the work that has been done by technicians in the laboratory [2]. This study was used the Goswami equation to estimate the value of laboratory compaction parameters (maximum dry unit weight and optimum water content) of soil mixed with 3% lime.
2. Literature Review
Subgrade is the basic soil at the bottom of the pavement layer. Soil compaction is a mechanical process whereby the amount of soil composed of solid particles, water and air that reduced by their volume by using a load. For field compaction, generally heavy equipment is used such as Three Wheel Roller, Tandem Roller, Pneumatic Tired Roller (PTR) and others. Generally vibratory roller is used for compaction of subgrade, while in laboratory, the method which is used by hitting it using a hammer. Compaction testing in the laboratory has two methods: Standard Proctor Test and Modified Proctor Test [1].

The physical properties of the soil (index properties) show the soil conditions and type of the soil. In general there are five laboratory tests of subgrade material before the compaction test [1] i.e. Moisture Content Test, Specific Gravity Test, Atterberg Limit Test, Sieve Analysis Test and Soil Classification (USCS and AASHTO).

Several studies in estimating soil compaction values (maximum dry unit weight and optimum water content) have been widely developed. The studies used several geotechnical parameters, such as: plastic limit, liquid limit, specific gravity, compaction energy, particle size distribution analysis and soil classification. The study determining the relationship between compaction parameters with one or several value of the geotechnical parameters for variety of soil types [3, 4, 5, 6, 7, 8, 9].

The estimation for the value of maximum dry unit weight ($\gamma_{d_{\text{max}}}$) and optimum water content ($w_{\text{opt}}$) can also be calculated from the model suggested by Goswami with the following equation [2]:

$$Y = m \log G + k$$

where:
- $Y$ = maximum dry unit weight ($\gamma_{d_{\text{max}}}$) and optimum water content ($w_{\text{opt}}$)
- $m$ = the slope of the curve
- $k$ = constant
- $G$ = coefficient of gradation $(1 + F) (AX1 + BX2 + CX3)$
- $X1$ = % weight retained shieve 4.75 mm
- $X2$ = % weight retained between shieve 4.75 mm and 0.075 mm
- $X3$ = % weight through shieve 0.075 mm
- $A, B, C$ = constants for shieve number
- $F$ = % fine grain

The $m$ and $k$ constants are obtained from the graph between Log $G$ with the value of the maximum dry unit weight and the optimum water content from the experimental results in the laboratory. Whereas, $F$ is fine grain percent that is determined based on percent through shieve 0.075 mm and Plasticity Index (IP) value (Table 1).

| % weight through shieve 0.075 mm | Value of F |
|----------------------------------|------------|
|                                  | IP < 10%   | IP > 10%   |
| 0 – 25                           | 0,0        | 0,0        |
| 26 – 40                          | 0,2        | 0,2        |
| 41 – 60                          | 1,0        | 1,0        |
| 61 – 85                          | 1,0        | 0,0        |
| 86 – 100                         | 1,0        | 1,0        |

3. Research Method
The samples were 30 soil samples with plasticity index (PI) >10%. The lime was lime powder (CaO) which is generally sold in the material store and pass through the sieve No. 200. Laboratory testing for
the original soil samples consists of the the index properties test and compaction test. The index properties test were moisture content test, specific gravity test, sieve analysis test, atterberg limit test, while the compaction test was standard proctor test. After 3% of lime was added [10], the samples had the same tests. Using the Goswami model, the graph of correlation between the Log G with the compaction parameter values laboratory was obtained, and then the m and k values were determined. Using the m and k values in Goswami equation, the compaction parameter values estimated were obtained. These values then were compared with the compaction parameter values laboratory. Compaction parameter values estimated were also analyzed base on the soil classifications (USCS and AASHTO). Afterward, the level of accountability was observed by the validation method, to get a positive correlation level of accountability.

4. Results and Analysis

4.1. Original soil test results in laboratory

The test results of original soil in laboratory ie. index properties values and compaction parameter values can be seen in Table 2.

Table 2. Test results of original soil in laboratory.

| Parameter                        | Average |
|----------------------------------|---------|
| Water content (%)                | 33.87   |
| Specific Gravity (SG)            | 2.65    |
| Liquid Limit (LL) (%)            | 40.29   |
| Plastic Limit (PL) (%)           | 22.88   |
| Plasticity Index (PI) (%)        | 17.41   |
| Fines (Passing No.200) (%)       | 50.39   |
| AASHTO                           | A-6 (6) |
| USCS                             | CL      |
| Maximum dry unit weight (γd<sub>max</sub>) (gr/cm<sup>3</sup>) | 1,529 |
| Optimum water content (W<sub>opt</sub>) (%) | 21.57 |

4.2. Soil + lime test result in laboratory

After the soil was mixed with lime, the laboratory tests were repeated ie. index properties tests (sieve analysis and Atterberg limit test) and standard compaction test. The test results of soil samples added with lime can be seen in Table 3. The addition of lime as much as 3% was resulted in changes of the index properties value, were decreased the Plasticity Index (IP) from 17.41% to 11.27%, Liquid Limit (LL) from 40.29% to 34.85%, Maximum Dry Unit Weight from 1.529 gr/cm<sup>3</sup> to 1,396 gr/cm<sup>3</sup>. Conversely, were increased Plastic Limit (PL) from 22.88% to 23.56%, Fines percentage from 50.39% to 53.36% and Optimum Water Content from 21.57% to 24.87%. This results was supported the previously research [10].

4.3 Compaction parameter values estimated by Goswami model

Using the Goswami model, from the graph of correlation between the Log G with the compaction parameter values laboratory, then the m and k values were determined as shown as Figure 1 and Figure 2. From Figure 1, there were m = -0.1686 and k = 1.8434, while from Figure 2, m = 2.9178 and k = 17.086.
Table 3. Test result of soil samples added with lime.

| No | Fines (%) | LL (%) | PL (%) | PI (%) | $\gamma_{d \text{ max}}$ (gr/cm$^3$) | $W_{\text{opt}}$ (%) |
|----|-----------|-------|--------|--------|-----------------------------------|-------------------|
| 1  | 49.52     | 37.19 | 25.33  | 11.86  | 1.401                             | 24.02             |
| 2  | 52.29     | 35.52 | 24.69  | 10.83  | 1.403                             | 24.21             |
| 3  | 54.23     | 37.17 | 24.12  | 13.05  | 1.362                             | 25.16             |
| 4  | 53.44     | 35.55 | 24.71  | 10.84  | 1.399                             | 25.51             |
| 5  | 53.10     | 34.27 | 24.37  | 9.90   | 1.396                             | 25.53             |
| 6  | 52.25     | 35.86 | 24.77  | 11.09  | 1.393                             | 25.32             |
| 7  | 47.99     | 34.30 | 24.23  | 10.07  | 1.392                             | 24.92             |
| 8  | 46.65     | 30.44 | 24.39  | 6.05   | 1.402                             | 23.97             |
| 9  | 48.38     | 34.23 | 23.25  | 10.98  | 1.384                             | 24.71             |
| 10 | 53.13     | 36.06 | 24.05  | 12.01  | 1.389                             | 25.94             |
| 11 | 56.06     | 34.72 | 24.41  | 10.31  | 1.408                             | 23.43             |
| 12 | 55.07     | 36.72 | 23.50  | 13.22  | 1.391                             | 24.53             |
| 13 | 54.92     | 34.27 | 24.04  | 10.23  | 1.392                             | 24.38             |
| 14 | 53.27     | 32.83 | 22.28  | 10.55  | 1.383                             | 25.16             |
| 15 | 55.06     | 32.24 | 22.41  | 9.83   | 1.388                             | 25.15             |
| 16 | 52.24     | 33.10 | 22.86  | 10.24  | 1.396                             | 25.69             |
| 17 | 50.61     | 40.90 | 26.52  | 14.38  | 1.406                             | 24.66             |
| 18 | 56.45     | 34.02 | 22.56  | 11.46  | 1.410                             | 24.66             |
| 19 | 56.65     | 34.50 | 21.68  | 12.82  | 1.407                             | 24.61             |
| 20 | 56.09     | 39.25 | 23.27  | 15.98  | 1.412                             | 24.67             |
| 21 | 52.65     | 33.40 | 24.30  | 9.10   | 1.386                             | 25.69             |
| 22 | 55.67     | 33.95 | 22.43  | 11.52  | 1.406                             | 24.63             |
| 23 | 51.37     | 33.21 | 23.18  | 10.03  | 1.393                             | 25.09             |
| 24 | 50.88     | 35.16 | 22.59  | 12.57  | 1.394                             | 25.04             |
| 25 | 56.36     | 32.89 | 22.40  | 10.49  | 1.398                             | 24.53             |
| 26 | 55.61     | 33.16 | 22.27  | 10.89  | 1.394                             | 25.04             |
| 27 | 53.51     | 34.05 | 23.74  | 10.31  | 1.392                             | 25.20             |
| 28 | 58.82     | 33.33 | 22.42  | 10.91  | 1.405                             | 23.69             |
| 29 | 52.52     | 38.78 | 22.42  | 16.36  | 1.387                             | 25.34             |
| 30 | 56.12     | 34.32 | 24.18  | 10.14  | 1.397                             | 25.19             |
| Avr | 53.36   | 34.85 | 23.56  | 11.27  | 1,396                             | 24.87             |

where : $\gamma_{d \text{ max}}$ = Maximum dry unit weight ($W_{\text{opt}}$) ; $W_{\text{opt}}$ = Optimum water content; Fines=Percentage of fines; LL=Liquid Limit; PL=Plastic Limit; PI=Plasticity Index

Figure 1. Correlation of maximum dry unit weight ($\gamma_{d \text{ max}}$) with Log G
Using the m and k values in Goswami equation, the compaction parameter values estimated i.e. maximum dry unit weight estimated (γ_{d max}) and optimum water content estimated (W_{opt}) were obtained as seen as Table 4. Subsequently, the soil type of the sample can be determined, which according to AASTHO classification of soil belongs to A6 and A7 class and according to USCS including class of SL, ML and CL.

Table 4. Compaction Parameter Values Estimated by Goswami Model.

| No | AASHTO | USCS | Fines (%) | LL (%) | PL (%) | PI (%) | γ_{d max} (gr/cm³) | γ_{d max} # (gr/cm³) | W_{opt} (%) | W_{opt} # (%) |
|----|--------|------|-----------|--------|--------|--------|-------------------|-------------------|-------------|--------------|
| 1  | A-6 (3) | SM   | 49.52     | 37.19  | 25.33  | 11.86  | 1,401             | 1,388            | 24.02       | 25.84        |
| 2  | A-6 (3) | ML   | 52.29     | 35.52  | 24.69  | 10.83  | 1,403             | 1,392            | 24.21       | 25.78        |
| 3  | A-6 (5) | CL   | 54.23     | 37.17  | 24.12  | 13.05  | 1,362             | 1,395            | 25.16       | 25.73        |
| 4  | A-6 (4) | ML   | 53.44     | 35.55  | 24.71  | 10.84  | 1,399             | 1,394            | 25.51       | 25.75        |
| 5  | A-4 (3) | ML   | 53.10     | 34.27  | 24.37  | 9.90   | 1,396             | 1,393            | 25.53       | 25.76        |
| 6  | A-6 (3) | ML   | 52.25     | 35.86  | 24.77  | 11.09  | 1,393             | 1,392            | 25.32       | 25.78        |
| 7  | A-4 (2) | SM   | 47.99     | 34.30  | 24.23  | 10.07  | 1,392             | 1,386            | 24.92       | 25.88        |
| 8  | A-4 (1) | SM   | 46.65     | 30.44  | 24.39  | 6.05   | 1,402             | 1,384            | 23.97       | 25.91        |
| 9  | A-6 (3) | SC   | 48.38     | 34.23  | 23.25  | 10.98  | 1,384             | 1,387            | 24.71       | 25.87        |
| 10 | A-6 (4) | CL   | 53.13     | 36.06  | 24.05  | 12.01  | 1,389             | 1,393            | 25.94       | 25.76        |
| 11 | A-4 (4) | ML   | 56.06     | 34.72  | 24.41  | 10.31  | 1,408             | 1,398            | 23.43       | 25.68        |
| 12 | A-6 (5) | CL   | 55.07     | 36.72  | 23.50  | 13.22  | 1,391             | 1,396            | 24.53       | 25.71        |
| 13 | A-4 (4) | ML   | 54.92     | 34.27  | 24.04  | 10.23  | 1,392             | 1,396            | 24.38       | 25.71        |
| 14 | A-6 (3) | CL   | 53.27     | 32.83  | 22.28  | 10.55  | 1,383             | 1,393            | 25.16       | 25.75        |
| 15 | A-4 (3) | CL   | 55.06     | 32.24  | 22.41  | 9.83   | 1,388             | 1,396            | 25.15       | 25.71        |
| 16 | A-4 (3) | CL   | 52.24     | 33.10  | 22.86  | 10.24  | 1,396             | 1,388            | 25.69       | 25.78        |
| 17 | A7-6 (5) | ML   | 50.61     | 40.90  | 26.52  | 14.38  | 1,406             | 1,392            | 24.66       | 25.82        |
| 18 | A-6 (4) | CL   | 56.45     | 34.02  | 22.56  | 11.46  | 1,410             | 1,395            | 24.66       | 25.67        |
| 19 | A-6 (5) | CL   | 56.65     | 34.50  | 21.68  | 12.82  | 1,407             | 1,394            | 24.61       | 25.66        |
| 20 | A-6 (7) | CL   | 56.09     | 39.25  | 23.27  | 15.98  | 1,412             | 1,393            | 24.67       | 25.68        |
**Table 4.** Compaction Parameter Values Estimated by Goswami Model (continued).

| No | AASHTO | USCS | Fines (%) | LL (%) | PL (%) | PI (%) | $\gamma_{d_{max}}$ (gr/cm$^3$) | $\gamma_{d_{max}^*}$ (gr/cm$^3$) | $W_{opt}$ (%) | $W_{opt}^*$ (%) |
|----|--------|------|-----------|--------|--------|--------|-----------------|-----------------|-------------|---------------|
| 21 | A-4 (3) | ML   | 52.65     | 33.40  | 24.30  | 9.10   | 1.386           | 1.392           | 25.69       | 25.77         |
| 22 | A-6 (4) | CL   | 55.67     | 33.95  | 22.43  | 11.52  | 1.406           | 1.386           | 24.63       | 25.69         |
| 23 | A-4 (3) | CL   | 51.37     | 33.21  | 23.18  | 10.03  | 1.393           | 1.384           | 25.09       | 25.80         |
| 24 | A-6 (4) | CL   | 50.88     | 35.16  | 22.59  | 12.57  | 1.394           | 1.387           | 25.04       | 25.81         |
| 25 | A-4 (4) | CL   | 56.36     | 32.89  | 22.40  | 10.49  | 1.398           | 1.393           | 24.53       | 25.67         |
| 26 | A-6 (4) | CL   | 55.61     | 33.16  | 22.27  | 10.89  | 1.394           | 1.398           | 15.46       | 25.69         |
| 27 | A-4 (3) | CL   | 53.51     | 34.05  | 23.74  | 10.31  | 1.392           | 1.396           | 25.20       | 25.75         |
| 28 | A-6 (4) | CL   | 58.82     | 33.33  | 22.42  | 10.91  | 1.405           | 1.396           | 23.69       | 25.60         |
| 29 | A-6 (6) | CL   | 52.52     | 38.78  | 22.42  | 16.36  | 1.387           | 1.393           | 25.34       | 25.77         |
| 30 | A-4 (4) | ML   | 56.12     | 34.32  | 24.18  | 10.14  | 1.397           | 1.396           | 25.19       | 25.68         |

where: $\gamma_{d_{max}}$=Maximum Dry Unit Weight; $W_{opt}$=Optimum Water Content; Fines=Percentage of Fines; LL=Liquid Limit; PL=Plastic Limit; PI=Plasticity Index

According to the testing for range of validity for the compaction parameter values estimated were known that the maximum dry unit weight estimated ($\gamma_{d_{max}^*}$) obtained 95% validity range with a significant positive correlation with the maximum dry unit weight laboratory ($\gamma_{d_{max}}$). Likewise, the optimum water content estimated ($W_{opt}^*$) obtained 95% validity range also with a significant positive correlation with the optimum water content laboratory ($W_{opt}$). But, this model only used on soil types A-4, A-6, and A-7 (AASHTO) or SL, ML and CL (USCS) with 3% lime added.

5. Conclusion

From the results of laboratory testing and data analysis obtained as follows: (1) The addition of 3% lime was decreased the index properties, Plasticity Index (IP), Liquid Limit (LL) and Maximum Dry Unit Weight value and was increased Plastic Limit (PL), Fines percentage and Optimum Water Content value; (2) The compaction parameter values can be estimated by Goswami equation: $\gamma_{d_{max}^*} = -0.1686 \log G + 1.8434$ and $W_{opt}^* = 2.9178 \log G + 17.086$; (3) Estimation with Goswami Model is easier and more effective because it only requires the value of Fine; (4) Based on the soil classification, the soil samples were A4, A6, and A7 (AASHTO) or SL, ML and CL (USCS) with 3% lime added; (5) The correlation between the compaction parameter values estimated with the compaction parameter values laboratory provides a significant positive correlation with a 95% confidence range.

6. References

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