Distribution of bulk unit weight of residual soils from the Northern Malaysia

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Abstract. A total of 284 bulk unit weight data were obtained from soil samples collected from 29 failed slopes and 10 stable slopes in Penang Island and Baling, Kedah. Both study areas are located in the Northern Malaysia. Field bulk density tests were performed at all the locations where disturbed soil samples were also collected to determine the other basic important properties of the residual soils. The highly variable values of bulk unit weight are due to the high complexity and variable formation of the residual soils. The objective of this research is to determine the best-fit distribution of the highly variable values of bulk unit weight of the soil taken from the stable slopes and failed slope especially in Northern Malaysia. This research also aims to determine the mean value of bulk unit weight of residual soils. The bulk unit weight data was tested based on Kolmogorov-Smirnov method using SPSS software, to check the normality of the data distribution. The best-fit distribution for the variation of bulk unit weight of the residual soils taken in the Northern Malaysia was normal distribution. The mean value was found to be 17.30 kN/m³. The range of bulk unit weight found here is within the range that was found by the earlier researchers.

1. Introduction
Slope failures always occur during rainy seasons between the months of November to February yearly, which can kill people and causing damage to properties. Slope failure is also known as landslide, failed slope, slip, slump, mudflow, and rock fall. These terms are used to describe the movements of soil and rock materials under the pull of gravity as explained by [1]. Generally, denser or stiffer soils will have a higher value of bulk unit weight but loose and weak soils generally have lower value of bulk unit weight. Stable slope consisting of dense or stiff soils has high resistance against erosion and higher shear strength. They are less likely to fail than those with loose, weak soils and a lower shear strength. As reported by [2] that the formation of residual soils occurs under varying environmental conditions.

According to [3] the bulk unit weight for Malaysian residual soils is between the range of 15.0 to 23.0 kN/m³ while [4] found that the range of bulk unit weight for Malaysian residual soils is between 13.0 to 20.0 kN/m³. The overall range of bulk unit weight found by earlier researchers is between 13.0 to 23.0 kN/m³. The earlier researchers found that the strength parameters would be in the form beta or normal distributions depending on the types of soils, soil basic properties, the number of data available and soil homogeneity as mentioned by [1], [5] and [6]. Reference [7] studied on the three main and commonly available soils in Hong Kong and concluded that most of the basic soil properties, including...
bulk unit weight are approximately normally distributed. As stated by [8], in order to get accurate
distribution types and their properties, the number of data must be between 100 to 200. Many continuous
data are approximately normally distributed. Nothing in this real world can perfectly match the exact
mathematical shape of a normal distribution but in many continuous data, they are more or less in the
form of bell-shaped distribution as explained by [9]. It is intuitive that in many instances the bulk of
population is near the center, with a lower probability of extremes at the higher and lower ends. The
probability density function (PDF) of normal distribution is given by [10] and is defined as equation 1.

\[
 f(x) = \frac{e^{-(x-\mu)^2 / 2\sigma^2}}{\sigma \sqrt{2\pi}}
\]  

(1)

Where e and π are the numerical constant number that is equal to 2.718 and 3.14 respectively, f(x) is
the probability density function (PDF)(−∞ < x < ∞; σ > 0), x is the data, u is the mean σ is the
standard deviation.

2. Geology and field tests

2.1. Geology of study areas

Residual soils are formed from the weathering of their parent rocks and they remain at the place where
they are weathered and formed [11]. The distributions of the tropical residual soils are very closely
related to the distribution of the various parent rock types in Peninsular Malaysia. The rock formations
in Peninsular Malaysia as explained by [12] can be classified into three major groups, namely the alluvial
sediments, sedimentary and igneous rocks. The alluvial sediments and deposits are mainly consisting of
sandy materials, marine clay including inter-beded clayey and sandy river deposits, generally loose to
dense, or soft to very stiff soil materials. The common sedimentary rocks include quartzite, shale,
mudstone, sandstone, limestone and some meta-sedimentary rocks such as schist and phyllite. Igneous
rocks consist mainly of granitic bodies with minor intermediate to basic rocks and granitic rock is
abundantly found in Peninsular Malaysia.

Most of the rock formations experienced extensive weathering due to the tropical climate, where the
rock formations are entirely weathered and transformed into residual soils. Based on the simplified
surface geology, the rock distributions mainly the granitic and sedimentary rocks will eventually
weathered into granitic and sedimentary residual soils as shown in figure 1. The geological map also
shows the locations of the coastal alluvial deposits. Figure 1 also shows the study areas of the selected
failed and stable slopes in Penang which is within granitic residual soil area and in Baling which is
within sedimentary residual soil zone. Figure 2 and figure 3 show the locations of the failed and stable
slopes selected in Penang Island and Baling, Kedah respectively.
2.2. Field bulk density tests

A total of 284 field bulk density data were obtained from 29 failed slope and 10 stable slopes in Penang Island and Baling, Kedah. Both are located in Northern Malaysia. A total of 247 field bulk density data were collected from failed slopes while another 37 data were collected from stable slopes. In general, as stressed by [13], all the basic properties of the residual soils including bulk unit weight found at the failed slopes and the stable slopes are approximately the same since the soil samples has been collected from the same locations and areas. Although both the basic properties of the residual soils including bulk unit weight...
bulk unit weight found at the failed slopes and the stable slopes are approximately the same, both are highly variable and it is necessary to collect bulk unit weight data from both types of slopes.

Soil sample points taken at the stable slopes and failed slopes were shown in figure 4 and figure 5 respectively. At all locations of soil sample points collected, field bulk density tests were also conducted. Disturbed soil samples were also collected to determine the other important basic soil properties of the residual soils. Disturbed soil samples were collected using hoes and hand auger. The failed slope includes the main failed section, the un-failed sections next to the failed one as well as the slopes toe and crest. A stable slope has defined as a slope, which does not show any sign of failure and is still standing until now as explained by [13]. Majority of the field bulk density tests were carried out at about 100 mm depth for both the stable slopes and failed slopes. At only two failed slope locations, the field bulk unit weight tests were also carried out at varying depths of 100, 400, 700 and 1000 mm from the slope surface. From both the failed and stable slopes, a total of 232 data were collected at depth of 100 mm in perpendicular direction to slope surface. Another 52 data were collected at varying depths from the two failed slopes. The reason of the soil samples collected at varying depths was to increase the number of data collected.

To conduct the field bulk density tests the procedures has based on [14]. At all samples points, field bulk density tests were conducted using field bulk sampler. It consists of a cylinder with a diameter of 50 mm x 230 mm long. The field bulk sampler was connected to a rod with a hammer on it, so that it can be knocked into the soil at any locations and directions. Equation 2 is used to determine the field density of soil while equation 3 is used to determine the bulk unit weight was calculated using.

\[
\rho = \frac{4W}{\pi d^2 L}
\]

\[
\gamma = \rho \times g
\]

Where, \(w\) is the weight of soil sample (kg), \(d\) is the diameter of the soil sample (m), \(L\) is the length of the soil sample (m), \(g\) is acceleration (m/s²), \(\rho\) is bulk density (kg/m³) and \(\gamma\) is bulk unit weight (kN/m³)
3. Analysis of results and discussions

3.1. The skewness and kurtosis

Skewness refers to how symmetrical is a distribution is. There are three types of skewness namely the negative and positive skewed as shown in figure 6(a), 6(b) and 6(c). Normal distribution is shown in figure 6(b). A positive skewed distribution is when it has a longer tail on the right. When the skewness value is zero, then it is normally distributed. The distribution is approximately normally distributed and almost in symmetrical shape, if the skewness is between +1 and -1 [15]. To determine the skewness in SPSS software is by using equation 4 as described by [10].

\[
S = \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} (x_i - \bar{x})^3 \tag{4}
\]

\[
K = \left( \frac{n(n+1)}{(n-1)(n-2)(n-3)} \right) \sum_{i=1}^{n} \left( \frac{x_i - \bar{x}}{s} \right)^4 - \frac{3(n-1)^2}{(n-2)(n-3)} \tag{5}
\]

Where, \(x_i\) is the monitoring data, \(\bar{x}\) is the mean value, \(s\) is the population standard deviation, \(n\) is actual number of data, \(S\) is skewness and \(K\) is kurtosis.

Kurtosis indicates how flat the top portion of a distribution when compared with a normal distribution as shown in figure 6(a), 6(b) and 6(c). When a kurtosis value is zero, it indicates a shape of normal distribution. A positive value of kurtosis indicates a distribution shape that is more peaked than normal distribution while a negative kurtosis value indicates a shape that is flatter than normal distribution as shown in figure 6(d), 6(e) and 6(f). A kurtosis value between -1 and +1 has considered within the acceptable limit [15]. To determine Kurtosis in the SPSS software is using equation 5 as explained by [8].

Table 1 demonstrates the distribution properties of the variation of the bulk unit weight obtained from Northern Malaysia. Both the values of skewness and kurtosis were obtained using the SPSS software. Both the values of skewness and kurtosis are between +1 and -1 showing that distribution are normally distributed as mentioned by [15]. As stated by [8], in order to get accurate distribution types and their properties, the number of data must be in between 100 to 200. In this research, there are 284 data, well above the minimum of 100 data as required.
Table 1. The distribution properties of the variation of bulk unit weight in Northern, Malaysia.

| Distribution property | No. of data (N) | Minimum (kN/m$^3$) | Maximum (kN/m$^3$) | Mean (kN/m$^3$) | Standard deviation |
|-----------------------|----------------|-------------------|-------------------|----------------|-------------------|
| Value                 | 284            | 13.80             | 20.35             | 17.30          | 13                |

3.2. Coefficient of variation (CV)

As explained by [18], the coefficient of variation (CV) is by using when comparing the distributions having different values of standard deviations and means. The ratio of the standard deviation to the mean is known as CV as below:

$$CV = \frac{\sigma}{\bar{x}}$$  \hspace{1cm} (6)

where, $\sigma$ is standard deviation and $\bar{x}$ is mean.

The CV is independent of units used. Therefore, CV is useful when comparing the distribution having different units. The distributions are considered having smaller relative variations, if the values of CV < 1. These indicate that the data are more consistent as explained by [18]. However, if the values of CV > 1, then there are wider variations of the data found. Table 1 shows the distribution properties of the variation of bulk unit weight in this study. There is only 1 value of CV shown in table 1, indicating that the data are consistent.

3.3. Goodness-of-fit test using kolmogorov-smirnov tests method

The bulk unit weight data was tested based on Kolmogorov-Smirnov method using SPSS software, to further check the normality of the data distribution. If the significant level $p > 0.05$, then the best-fit distribution as assumed the normal distribution [19].

Table 2. Normality test using kolmogorov-smirnov method.

| Distribution Property | Number of data (N) | Mean | Standard Deviation | Kolmogorov-Smirnov Z | p = Assymp. Sig. (2-tailed) |
|-----------------------|-------------------|------|--------------------|----------------------|-----------------------------|
| Bulk unit weight      | 284               | 17.30| 1.28               | 0.61                 | 0.85                        |

From table 2, normal distribution has attained for the bulk unit weight data, since $p > 0.05$. Figure 7 shows the output of the SPSS software where the histogram is normally distributed. Normal distribution curve is superimposed onto the histogram. Three types of soil in Hong Kong and concluded that the distribution of bulk unit weight was approximately normally distributed [7].
Figure 7. Normal distribution curve is superimposed onto the histogram of bulk unit weight.

4. Conclusion
Many continuous data are approximately normally distributed with the continuous data having more or less a bell-shaped distribution. The best fit distribution for the variation of bulk unit weight of residual soil was found to be the normal distribution. The bulk unit weight found in this study vary between the range of 13.80 kN/m$^3$ to 20.35 kN/m$^3$ where the mean value was found to be 17.30 kN/m$^3$. The range of bulk unit weight found in here is within the range found by earlier publications which was between 13.00 kN/m$^3$ to 23.00 kN/m$^3$.

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