New Relationship between Linear Shrinkage and Shrinkage Limit for Expansive Soils

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Abstract. In Indonesia's engineering practice, a standard laboratory test method to describe the characteristics of expansive soils is the shrinkage limit (ASTM). Expansive soils are problematic soils that have shrinkage and swelling history due to changing water content on a particular clay mineral type (i.e., montmorillonite). Another method rare using in general practice in our country is the linear shrinkage (British Standard). The last test is easier and faster to obtain than the shrinkage limit method. Some researchers proposed swelling potential classification for expansive soils using a specific range of shrinkage limits or linear shrinkage. This research aims to give a new relationship between both methods using available laboratory test results database. There were two sets of data: first, complete laboratory data (i.e., 124 samples of shrinkage limit and linear shrinkage); and second, only Atterberg limits (i.e., liquid limit and plastic limit) results (i.e., 86 samples). For the latter database, shrinkage limit and linear shrinkage use previous researchers' empirical equations. Then, these two datasets are compared and give a similar trend. The results show that if increasing of shrinkage limit is followed by decreasing of linear shrinkage. This result may help geotechnical engineers to obtain the linear shrinkage directly from our proposed Equation and shrinkage limit value. Hence, our research has a contribution to know the characteristics of the expansive soil (i.e., swelling potential).

1. Introduction

Linear shrinkage in a laboratory test is rarely used in engineering practices in Indonesia. The standard way is shrinkage limit as one of Atterberg limits. Linear shrinkage and shrinkage limit (mercury) is the methods used in this study. The purpose of this study is as follows.

a. to determine the relation between linear shrinkage and shrinkage limit,

b. to determine the swelling potential of a soil sample using linear shrinkage and shrinkage limit value by using Altmeyer's method (1955),

c. to get the result using Whitlow's (1995) and Budhu's (2011) methods to estimate linear shrinkage and shrinkage limit from available Atterberg limit data

2. Literature Review

Expansive soil is a type of soil that undergoes significant volume changes caused by the constant change of water content inside the soil. There are plenty of cases of damages that expansive soil does to building foundations, floors, and walls, such as cracks. A movement of the soil causes this kind of failure because of the volume changes.
Expansive soil has a particular clay mineral type (i.e., montmorillonite) that can absorb an amount of water, which causes the soil to swell. The more water that the soil absorbs, the more expansion will happen to the soil. If expansive soil has little contact with water, then the foundations will lose the support required from the soil due to the massive shrinkage.

3. Methods

Linear shrinkage is a test method to determine the shrinkage of soil in a linear dimension with water content equal to or more than the liquid limit (LL) of the designated soil. On the other hand, the shrinkage limit test with mercury is a test method aimed to determine the value of a shrinkage limit and shrinkage ratio of soil.

3.1. Determination of Expansive Soil

Table 1 presents the value of linear shrinkage and shrinkage limit. To determine the degree of soil expansion, the linear shrinkage and the shrinkage limit value in this table will be used to determine the zone of critical, marginal, and non-critical volume change.

| Linear Shrinkage | Shrinkage Limit | % Expansion | Volume Changes |
|------------------|-----------------|-------------|----------------|
| >8               | <10             | >1.5        | Critical       |
| 5–8              | 10–12           | 0.5–1.5     | Marginal       |
| <5               | >12             | <0.5        | Non-critical   |

3.2. Determination of Shrinkage Limit and Linear Shrinkage with Equations

The estimation of linear shrinkage (LS) by using the value of the plasticity index (PI) uses Equation (1).

\[ \text{PI} = 2.13 \times \text{LS} \]  \hspace{1cm} (1)

To estimate the shrinkage limit (SL) by using the liquid limit (LL) and PI uses Equation (2).

\[ \text{SL} = 46.4 \left(\frac{\text{LL} + 45.5}{\text{PI} + 46.4}\right) - 43.5 \]  \hspace{1cm} (2)

There are two types of data: the actual data (known value of LS and SL), and data with one unknown value, either linear or shrinkage limit. The unknown value uses either the Whitlow's or the Budhu's equations.

4. Result and Discussion

4.1. Actual Data

Data retrieved with the provided values of both linear shrinkage and shrinkage limit refer to actual data. Fig. 1 shows the actual data.
Fig. 2 shows the data with one unknown value of linear shrinkage and shrinkage limit and then calculated with either the Whitlow's or the Budhu's equations. One can use Equation 1 if the unknown value is linear shrinkage. If the unknown value is the shrinkage limit, then Equation (2) is used.

Fig. 3 shows the difference between the actual data of Turkey's soils and the calculated data by using Equation (1) and Equation (2) to estimate the value of shrinkage limit and linear shrinkage calculated. The differences between the actual and computed data are determined by evaluating the most significant deviation in percentage based on the same value of shrinkage limit and the equal value of linear shrinkage.

If based on the same value of shrinkage limit (18), the calculated data value of linear shrinkage is around 400%. If based on the same value of linear shrinkage (11%), the shrinkage limit's from calculated data value is around 225%.

Fig. 4 shows the difference between the actual data (Fig. 1) and calculated data (Fig. 2) plus the computed data of Turkey soil.
As seen in Fig. 4, based on the same value of shrinkage limit (16), the calculated data value of linear shrinkage is around 287%. If based on the equal value of linear shrinkage (11%), the shrinkage limit's calculated data value is around 159%

4.4. Zone of Volume Change (Altmeyer, 1955)

Altmeyer's table of volume change shows a zone of volume changes the level of soil made by the data collected from Turkey (Fig. 5).

From the parameter input in Table 1, there are some of the zones which are unclassified. This appearing zone may be caused by some data with two-volume change classification (i.e., critical but marginal at the same time). Another reason is that the value of linear shrinkage and shrinkage limit of this data falls on two different classifications (i.e., linear shrinkage >8 but shrinkage limit is between 10-12).
Data shown above is only Turkey's soils to represent the data better. As explained above, there are only three certain classifications (critical, marginal, and non-critical). There six more spaces that are unidentified because Altmeyer's table does not mention. Because of this classification, in terms of determining a degree of soil expansion, it is suggested to use more than one method to make a more accurate estimation of a soil's degree of expansion.

The usage of Altmeyer's method can also be justified. If a soil sample falls into two classification types, then one may use only 1 of the parameters (shrinkage limit or linear shrinkage) and desirably choose the highest risk of the degree of expansion.

4.5. Correlation between Shrinkage Limit and Linear Shrinkage

Based on all of the data retrieved, Fig. 6 shows that generally, when the linear shrinkage value is high, then the shrinkage limit value is low, and vice versa.

It is clear that if the value of linear shrinkage increases and the shrinkage limit decreases, this is critical volume change soil (Table 1). If linear shrinkage decreases and the shrinkage limit increases, it enters a non-critical soil in expansion.

Figure 5. Zone of Volume Change Based on Altmeyer’s Classification

Figure 6. Shrinkage Limit and Linear Shrinkage Correlation
As shown in Fig. 6, increasing shrinkage limit is followed by decreasing linear shrinkage.

5. Conclusion
The correlation of shrinkage limit and linear shrinkage is inversely proportional. Because if linear shrinkage has a low value, then generally shrinkage limit has a high value. The difference between actual data and calculated data in Turkey's soil is that the computed data value is four times higher at the same value of shrinkage limit (18) and 225% at the same value of linear shrinkage (11%). The difference between actual data and calculated data, in general, is that the calculated data value is higher around 287.5% at the same value of shrinkage limit (16) and 159.1% at the same value of linear shrinkage (11%). It is considered better by doing a direct measurement of shrinkage limit and linear shrinkage in a lab because the calculated method has a high deviation from the actual data. The usage of Altmeier's method to determine the expansion of soil is better to be paired with other methods to make sure the degree of expansion of soil is certain.

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