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Identification of Swelling Potential in Low-Plasticity Clay Soil Using the Free Swell Index Method

Ilham Yunus [1*], Zulfadli Ibrahim [2], Humairah Annisa [3], Indah Nur Afiah [4], Mentari S. Sitorus [5]

[1,3] Department of Civil Engineering, Universitas Lamappapoleonro, Soppeng
[2,4,5] Department of Civil Engineering Education and Planning, Universitas Negeri Makassar, Makassar
*ilham.yunus@unipol.ac.id

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Abstract

Expansive behavior of clay soil poses potential risks to geotechnical structures due to volume changes caused by water absorption. Although low plasticity clay (CL) generally exhibits lower swelling potential than highly plastic clay, its swelling characteristics still require evaluation. This study investigates the swelling potential of low plasticity clay using the Free Swell Index (FSI) method. The clay soil sample was obtained from an embankment material of a road project along the Tello River, Makassar. Basic physical properties were determined through laboratory testing, including grain size distribution and Atterberg limits, to classify the soil based on the Unified Soil Classification System (USCS). The FSI test was conducted by comparing soil volume changes in distilled water and kerosene. The results indicate that the soil is classified as CL with a plasticity index of 16% and a liquid limit of 38%. The measured FSI values range from 19% to 52.5%, with most samples exhibiting very low to low swelling potential, and only one sample showing moderate swelling. These findings confirm that low plasticity clay has limited swelling potential and that FSI is one of effective method for determining swelling behavior in CL soils for geotechnical applications.

Keywords: Low-Plasticity Clay, Swelling Potential, Free Swell Index

1. INTRODUCTION

One of the most crucial properties of clay soil is its expansive behavior, which is the tendency of soil to undergo volume changes due to water absorption (Annisa et al., 2024). This phenomenon can cause serious problems for the stability of foundations, roads, and other infrastructure built on top of it (Nelson & Miller, 1997; Yunus et al., 2024). In low plasticity clay, the degree of expansion is generally smaller than in high plasticity clay, but it still has significant technical implications, especially in saturated conditions or in repeated wet-dry cycles.

The Free Swell Index (FSI) method is widely used to identify the swelling tendency of clay soils. FSI can be considered a simple and quick method for measuring the swelling potential of clay soils based on changes in soil volume when submerged in water without applying external loads (Forouzan, 2016; Medjnoun et al., 2024; Pratiwi et al., 2019). Gratchev & Saeidi (2020) showed that FSI is capable of describing the relationship between expansion properties and geotechnical parameters of soil, and can be used for rapid estimation of the expansion potential of compacted soil. Han et al. (2021) also confirmed that FSI is a reliable indicator for assessing expansive behavior and, in this study, it was even applied to evaluate the effectiveness of soil improvement with calcium carbonate precipitation. Meanwhile, El Kady et al. (2022) demonstrated that FSI can be used not only under normal conditions but also to evaluate changes in the characteristics of expansive soils submerged in salt water, thus confirming the flexibility of this method in various environmental conditions. Furthermore, Zamin et al. (2021) expanded the understanding of the relationship between geotechnical parameters, mineralogy, and soil expansion behaviour, while also confirming that the use of FSI is highly relevant for assessing the stability of expansive clay soils in the field.

Low plasticity clay (CL), characterized by a low plasticity index (PI), is the focus of this study due to its specific properties. Research shows that soils with this PI typically exhibit lower swelling-shrinking behavior than highly plastic soils; for example, kaolin exhibits lower water affinity and minimal expansion when hydrated (Ihekweme et al., 2021). This reflects the less reactive mineral composition of low plasticity clays, which can reduce expansion, in contrast to expansive clays such as montmorillonite, which are known to have high expansion potential (Hadi et al., 2021).

The expansion behavior of clay soils is greatly influenced by their mineralogical composition and internal structure. Clays containing montmorillonite tend to expand significantly due to their layered structure and high cation exchange capacity (Segad et al., 2010). Conversely, low-plasticity clays dominated by kaolinite minerals show minimal expansion due to their more stable physicochemical properties, which limit their capacity for volume change due to water absorption (Manjate et al., 2020). In this context, mineral composition and its interaction with water greatly influence the expansion of clay soils.

Various studies have also confirmed the effectiveness of FSI in measuring the development characteristics of clay soil. By directly observing the increase in volume in a controlled water environment, this method is able to predict the potential for development in field conditions (Aniculaesi et al., 2013). Furthermore, the correlation between Atterberg parameters, particularly the liquid limit (LL) and plasticity index (PI), and expansion potential reinforces the reliability of FSI as a geotechnical assessment tool (Manjate et al., 2020).

Although FSI has been widely applied to expansive soils, systematic studies on its use in low-plasticity clay soils (CL) are still limited. Furthermore, the prevailing classification of swelling potential is generally focused on high-plasticity soils, so its validity for CL needs to be reviewed. Therefore, this study is important to evaluate the swelling potential of CL soils using the Free Swell Index method and to examine its relationship with plasticity parameters as a basis for more accurate geotechnical planning.

2. METHODS

A. Materials and Sample Preparation

The study focused on clay soil collected from an embankment soil from a road project along the Tello River, Makassar from STA+300 – STA+500. A No. 40 (0.425 mm) sieve and sieve shaker were used to separate fine soil particles according to test standards. For the free swell index test, distilled water and kerosene were used as immersion media. A 100 ml cylindrical measuring cup was used as a container in the process of immersing the soil in water and kerosene to measure the change in volume directly. The soil drying oven served to remove the initial moisture content in the samples so that uniform oven-dry soil conditions were obtained before testing. A precision digital scale was used to weigh the samples with a high degree of accuracy to ensure data accuracy. In addition, laboratory equipment such as soil scoops and spatulas were used to facilitate the soil sample handling process during preparation and testi

B. Experiment Procedure

The experiment procedure was designed to identify potential swelling on low plasticity clay (CL) through the Free Swelling Index (FSI) method, based on IS 2720-40. The testing sequence included sample collection, physical characterization, and free swelling test.

The sample for this experiment used disturbed specimens, obtained from embankment soil for a road construction project along the Tello River. The samples were stored in plastic bags to maintain natural air and moisture conditions. The soil was then air-dried and the soil was sieved using a No. 40 sieve or 0.425 mm. Finally, the samples were dried in an oven at a temperature of 105–110 °C for ±24 hours.

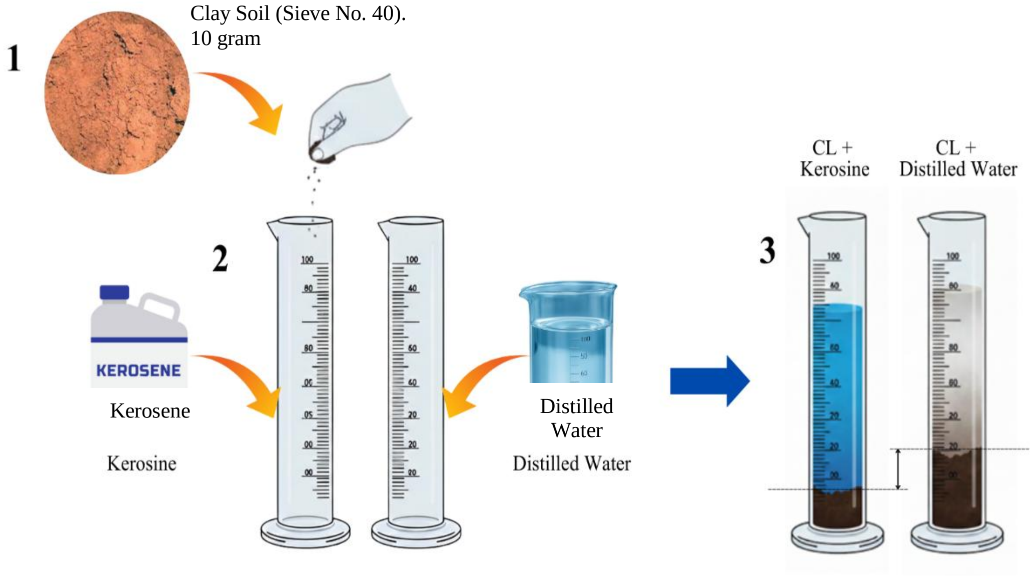

Figure 1 Experiment Procedure for Free Swell Index Method

Before the main testing is carried out, basic soil characteristics testing is first conducted to obtain data on physical properties of soil. The tests conducted included natural moisture content (ASTM D2216), soil specific gravity (ASTM D854), sieve analysis and hydrometer (ASTM D422) for particle size distribution, and Atterberg limits (ASTM D4318) to determine liquid limit, plastic limit, and plasticity index. The results of these tests form the basis for soil behavior analysis, particularly in relation to evaluating development potential using the Free Swell Index method.

For the Free Swell Index test as shown in **Figure 2**, 10 grams of dry soil sample that has passed the No. 200 sieve (0.075 mm) is weighed, then placed in two 100 ml measuring cups. The first measuring cup is filled with distilled water, while the second measuring cup is filled with kerosene to a volume of 100 ml. Both samples are left for approximately 24 hours until the soil reaches a stable condition. After that, the final volume of soil in each measuring cup is read. The FSI value is then calculated using the equation:

$$\textbf{FSI (\%)} = \left(\frac{\textbf{Vd - Vk}}{\textbf{Vk}}\right) \textbf{x 100} \quad (1)$$

Dimana:

Vd = Volume of soil in measuring cylinder poured with distilled water (cm^3)

Vk = Volume of soil in measuring cylinder poured with kerosine (cm^3)

Potential swelling can also be grouped based on its swelling index value, as shown in Table 1

Table 1 Correlation Between Swelling Index and Swelling Potential (Nelson & Miller, 1997)

Swelling Index (%)	Swelling Potential
0 – 20	Very Low
21 – 50	Low
51 – 90	Moderate
91 – 130	High
> 130	Very High

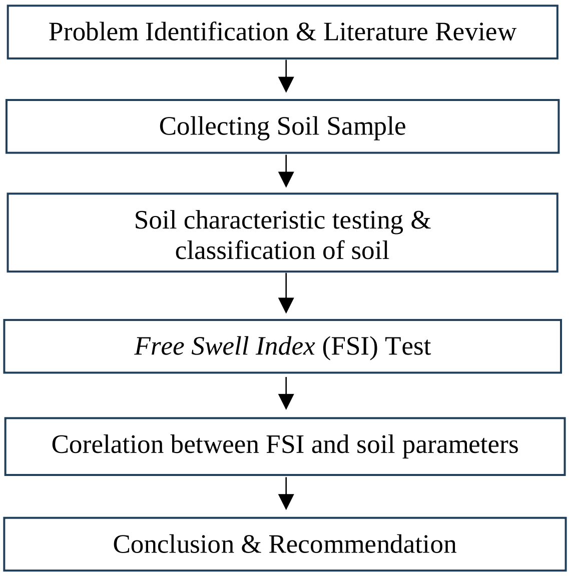

Figure 2 Research Flowchart for Identification on Swelling Potential of Clay Soil Low Plasticity Using Free Swelling Index Method

3. RESULT AND DISCUSSION

A. Physical Properties

The characteristics of the materials used in this study examined by laboratory tests. The clay soil tests included specific gravity, unit weight, sieve analysis, and Atterberg limits. The results are presented **Table 2**.

Table 2 Characteristics of Soil

Experimental Properties		Result	Unit
Specific Gravity		2.55	-
Unit Weight		1.85	gr/cm^3
Moisture Content		18.4	%
Atterberg Limit	LL	38	%
	PL	22	
	PI	16	

Table 2 above depicts the results of laboratory testing, presenting the physical properties of the soil. The results show that the specific gravity was 2.55, the unit weight was 1.85 g/cm^3, and the natural moisture content was 18.4%. The Atterberg limit test results showed

a liquid limit (LL) of 38% and a plastic limit (PL) of 22%, resulting in a plasticity index (PI) of 16%. This PI value indicates that the soil is classified as clay with low to moderate plasticity.

B. Gradation of Soil

Sieve analysis was conducted to determine the particle size distribution of the soil sample used in this study. The gradation characteristics obtained from this analysis provide insight into the proportion of coarse and fine particles within the soil. The results of the sieve analysis are summarized in **Table 3** and illustrated in the grain size distribution curve shown in **Figure 4**.

Table 3 Sieve Analysis Result

Sieve	Diameter	Weight of Retained Soil		Percent. Cummulative Retained Soil	Percent. Cummulative Passed Soil
	(mm)	(gram)	(%)	(%)	(%)
1"	25.40	0	0	0	100
3/4"	19.05	0	0	0	100
1/2"	12.70	0	0	0	100
3/8"	9.525	0	0	0	100
1/4"	6.350	0	0	0	100
4	4.750	11	2.20	2.20	97.80
10	2.000	8	1.60	3.80	96.20
20	0.850	38	7.60	11.40	88.60
40	0.425	19	3.80	15.20	84.80
60	0.250	32	6.40	21.60	78.40
80	0.180	16	3.20	24.80	75.20
100	0.150	27	5.40	30.20	69.80
200	0.075	61	12.20	42.40	57.60
PAN	-	281	56.2	98.600	1.4

The data presented in **Table 3** are further illustrated in the form of a grain size distribution curve in **Figure 4**.

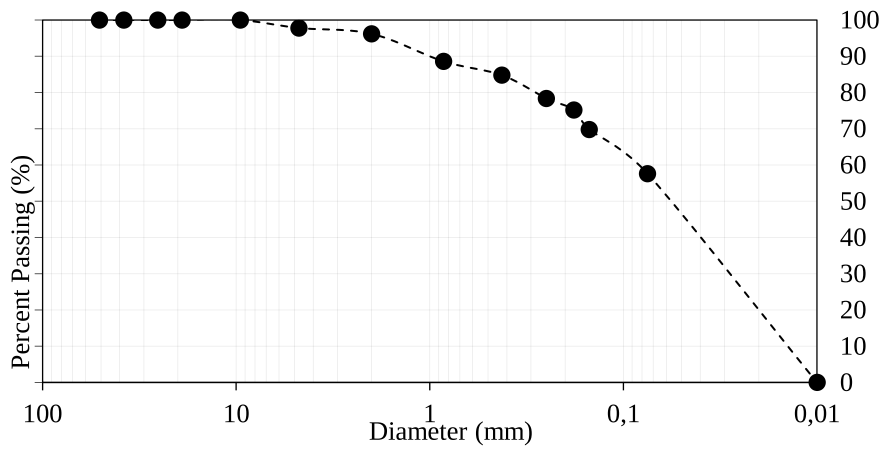

Figure 3 Grain Size Distribution Curves of Soil

The grain size distribution curve in **Figure 3**, derived from the sieve analysis results in **Table 3**, indicates that the soil is predominantly fine-grained. No particles were retained on sieves larger than 4.75 mm, confirming the absence of gravel-sized material. The curve shows a gradual decrease in percent passing within the sand-size range, indicating a limited proportion of sand particles. More than 57% of the soil passes Sieve No. 200 (0.075 mm), demonstrating the dominance of fines (silt and clay fractions). Overall, the soil particle distribution is in the fine particle range.

C. Soil Classification Using USCS

According to the result of tests, particularly sieve analysis and Atterberg Limit, the soil subsequently can be classified. This soil classified using USCS, as shown in **Figure 4**.

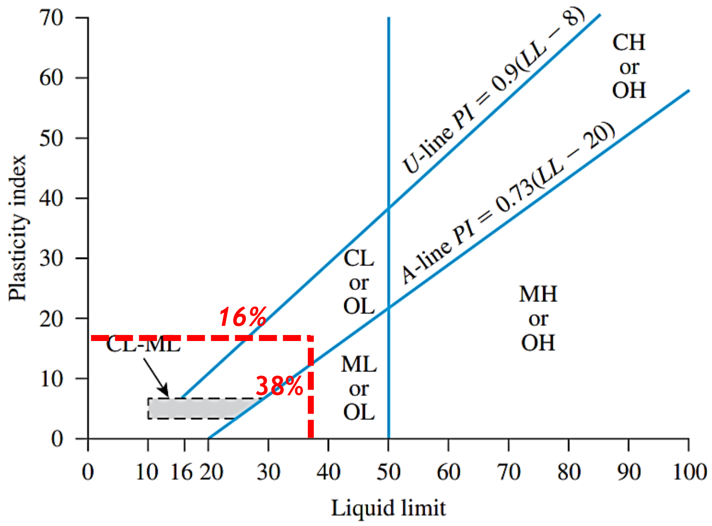

Figure 4 **Soil Classification through USCS, modified from (Das & Sobhan, 2006)**

Based on **Figure 4**, the combination of grain size with a percentage passing the No. 200 sieve exceeds 50%, and plasticity properties indicated by LL = 38% and PI = 16%, shows that the soil is classified as CL (Low Plasticity Clay) according to the USCS soil classification system. These characteristics indicate that the soil has cohesive properties, limited plasticity, and is sensitive to changes in moisture content, which can affect its mechanical behaviour.

D. Potential Swelling on Low Plasticity Clay Soil

This test aims to determine the Free Swelling Index (FSI) of low plasticity clay (CL) and to classify its swelling potential, as presented in **Table 4**. The test was conducted using the Free Swelling Index (FSI) method, in which ten soil specimens were prepared and divided into two immersion media. One condition was inundated with kerosene, while the other was immersed in distilled water. The difference in the final soil volume between the two media was then used to calculate the swelling index.

Table 4 Swelling Potential

Sample	Volume of Soil in Water (ml)	Volume of Soil in Kerosin (ml)	Free Swell Index (%)	Swelling Potental
FSI-1	9,5	8,0	19	Very Low
FSI-2	10,2	8,0	27,5	Low
FSI-3	10,8	8,0	35	Low
FSI-4	11,5	8,0	43,8	Low
FSI-5	12,0	8,0	50	Low
FSI-6	11,0	8,0	37,5	Low
FSI-7	9,8	8,0	22,5	Low
FSI-8	10,5	8,0	31,3	Low
FSI-9	12,2	8,0	52,5	Moderate
FSI-10	11,8	8,0	47,5	Low

The results of the Free Swell Index (FSI) test on low plasticity clay soil showed FSI values ranging from 19% to 52.5%. Based on the criteria of Nelson & Miller (1992), most samples had expansion potential in the low category (21–50%). This can be seen from the nine samples that showed dominant FSI values below 50%, ranging from 22.5% to 47.5%. Only one sample (FSI-9) reached a value of 52.5%, thus categorised as having moderate expansion potential.

In general, these results indicate that the test soil belongs to the group of soils with low expansion potential, so the risk of swelling and shrinkage due to changes in water content is not very significant. These findings are in line with the basic characteristics of the soil, which has a plasticity index (PI) of 16% and a liquid limit (LL) of 38%, indicating low to moderate plasticity. Thus, this soil is still relatively stable against volume changes, although it still shows a tendency to expand in certain samples. These FSI results support the classification of the soil as CL (Clay of Low Plasticity) in the USCS system, with the technical implication that the soil can be used as a subgrade construction material, but still requires moisture content control to keep its swelling and shrinkage behaviour under control.

E. Discussion

The swelling characteristics of low plasticity clay soil can be interpreted by comparing the plasticity properties from the Atterberg limit tests with the swelling index measured through the Free Swell Index (FSI) test.

Based on the Atterberg limit results, the soil exhibits a liquid limit (LL) of 38%, plastic limit (PL) of 22%, and a plasticity index (PI) of 16%. According to the Unified Soil Classification System (USCS), this range of LL and PI places the soil in the category of low plasticity clay (CL). From a geotechnical standpoint, soils with PI values between approximately 10% and 20% are generally associated with limited swelling potential, as they tend to contain non-expansive or weakly expansive clay minerals.

This expectation derived from plasticity characteristics is largely confirmed by the results of the Free Swell Index test. The measured FSI values range from 19% to 52.5%, with nine out of ten samples exhibiting values below 50%, corresponding to very low to low swelling potential based on the criteria proposed by Nelson and Miller (1992). Only one specimen (FSI-9) reached an FSI value of 52.5%, which falls into the moderate swelling category. The overall consistency between the moderate PI value (16%) and the predominantly low FSI values indicates a strong correlation between plasticity and swelling behaviour for this soil. The relatively low PI limits the soil’s capacity for water adsorption and soil particle expansion, which in turn restricts excessive volumetric increase when the soil is immersed in water.

4. CONCLUSION

Based on the Free Swell Index (FSI) test results, the low plasticity clay soil exhibits predominantly low swelling potential. The measured FSI values range from 19% to 52.5%, with the majority of samples falling within the very low to low swelling categories. Only one specimen shows moderate swelling behavior. Overall, the FSI results indicate that the soil has a limited tendency to undergo volumetric expansion when exposed to water, confirming that swelling-related risks are generally low under free swelling conditions.

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