Civil Engineering Dimension
https://ced.petra.ac.id

# Prediction of Soil Expansivity with Direct and Indirect Method in Banten Region, Indonesia

**Cikmit, A.A.[1], Sudisman, R.A.[1]*, Damayanti, A.[1], and Rizki, B.[2]**
[1] Department of Civil Engineering, Faculty of Infrastructure Planning, Universitas Pertamina,
Jl. Teuku Nyak Arief, Simprug, Kebayoran Lama, South Jakarta 12220, INDONESIA
[2] Construction Department, PT. Jaya Obayashi,
Jl. Pancoran Timur II No. 3, Pancoran, South Jakarta 12780, INDONESIA

DOI: https://doi.org/10.9744/ced.26.1.1-10

***Article Info:***
Submitted: Aug 10, 2023
Reviewed: Aug 22, 2023
Accepted: Oct 31, 2023

***Keywords***:
expansive soil,
expansion index (EI),
swelling potential.

***Corresponding Author:***
**Sudisman, R.A.**
Department of Civil Engineering, Faculty of Infrastructure Planning, Universitas Pertamina, Jl. Teuku Nyak Arief, Simprug, Kebayoran Lama, South Jakarta 12220, INDONESIA
Email:
rangga.as@universitaspertamina.ac.id

## Abstract

Expansive soils are widespread in Indonesia, particularly in Banten Province, causing extensive road damages. The study aimed to predict the soil expansivity of soil subgrade along the damaged road segments in Malingping, Cikeusik-Cibaliung, and Labuan districts. Indirect and direct expansivity predictions were employed to determine soil swelling potential. Indirect expansivity prediction was conducted based on various criteria using the Atterberg limit and grain size distribution. Direct expansivity prediction was conducted using an oedometer apparatus to measure the expansion index according to ASTM D-4829. A dynamic cone penetration test was also conducted to measure CBR values. Various indirect methods showed inconclusive results of swelling potentials, low to very high. The direct method provided more conclusive results, Expansivity Index = 100-167 and swelling values = 9%-18%, thus, categorized as expansive clay (high to very high swelling potential). CBR values were 1.49%-5% which is lower than minimum provisioned CBR (6%).



## Introduction

Indonesia, a tropical country with high-intensity rainfall and a long dry season, faces a variety of infrastructure challenges caused by the problematic soils. The problematic soils, such as expansive soil, dispersive soil, collapsible soil, and liquefiable soil [1], are distributed geographically over a wide area in several regions of the nation. Expansive soil, categorized as one of the problematic soils, has volumetric instability, meaning the soil volume fluctuates depending on the moisture content. Expansive soil swells as the moisture increases and shrinks as the moisture decreases in cyclic behavior in relation to the weather. The cyclic swell-shrink characteristic of expansive soil causes damage to road structures, light buildings, and other infrastructure [2].

Expansive soils are composed mainly of minerals that can actively react and absorb the adjacent moisture, thus causing destruction to infrastructure. Clay minerals such as smectite and montmorillonite are responsible for the swell behavior in expansive soils [3]. Their characteristics are defined as low bearing capacity, high settlement, excess deformation, and high absorbability of water [4]. The clay minerals cause volumetric instability in expansive clay soil that has destructive impacts on construction, including cracks in buildings, cracks or bumps on roads, cracks on walls, differential settlement followed by excessive deformation and rotation in abutments, damage to retaining walls, and other issues [5]. Several other studies [6-10] reported the types of road damage and the root cause analysis of road damage in diverse regions.

**Note** : Discussion is expected before July, 1st 2024, and will be published in the "Civil Engineering Dimension", volume 26, number 2, September 2024.
**ISSN** : 1410-9530 print / 1979-570X online
**Published by** : **Petra Christian University**

There are various methods to determine the expansivity of clay soil, which are generally classified into two types: indirect and direct methods. The indirect method is mostly used for practical purposes because the analysis only requires basic physical indices such as the Atterberg limits and grain size distribution analysis [11]. The universally used indirect methods are soil activity value analysis, Van der Merwe's criteria, and Chen's criteria. Among various methods of determining the expansivity of clay soils in practice, the indirect method is still the most favorable method due to its fast, less expensive, and easy-to-conduct tests required in the analysis. The direct method uses actual measurement to identify the soil expansivity, which requires recording the swelling value and the rate of swell. Due to its complexity and the time-consuming tests required in the direct test, the direct method is still a less preferred choice in the classification of soil expansivity. Although research has been comprehensively conducted and reported the effectiveness [12] and the discrepancy [13] among the indirect methods, less research has been done in comparing the two methods to identify the expansivity of residual soils in Indonesia.

Banten Province is one of the regions with tremendously expansive clay soil issues, according to Indonesia's problematic and potentially expansive clay distribution map [14]. The road damages (shown in Figure 1) are extremely destructive and occur in many types, such as local settlements, alligator cracks, rutting, and wavy failures on Banten National Road. The type of damages was most likely caused by the volumetric instability of the subgrade. Prior research conducted by Affandi reported that the majority of the tested soil samples met the very high expansiveness criteria [15]. However, the analysis of the study was limited to the prediction and classification of the expansivity ratio based on limited data without quantifying the value of the expansivity.

This study aimed to determine the soil expansivity of soil subgrade along the damaged road segments in Malingping, Cikeusik-Cibaliung, and Labuan districts using the direct and indirect method. Expansive soils from four locations were observed; field investigation and a series of laboratory tests were conducted to identify the soil expansivity and further compare the compatibility of the two methods. The indirect expansivity prediction was performed based on different available criteria using the Atterberg limit values, activity ratio, and grain size distribution. The direct expansivity prediction was conducted by performing free swell tests and expansion index (EI) tests per the ASTM D-4829 standard [16].

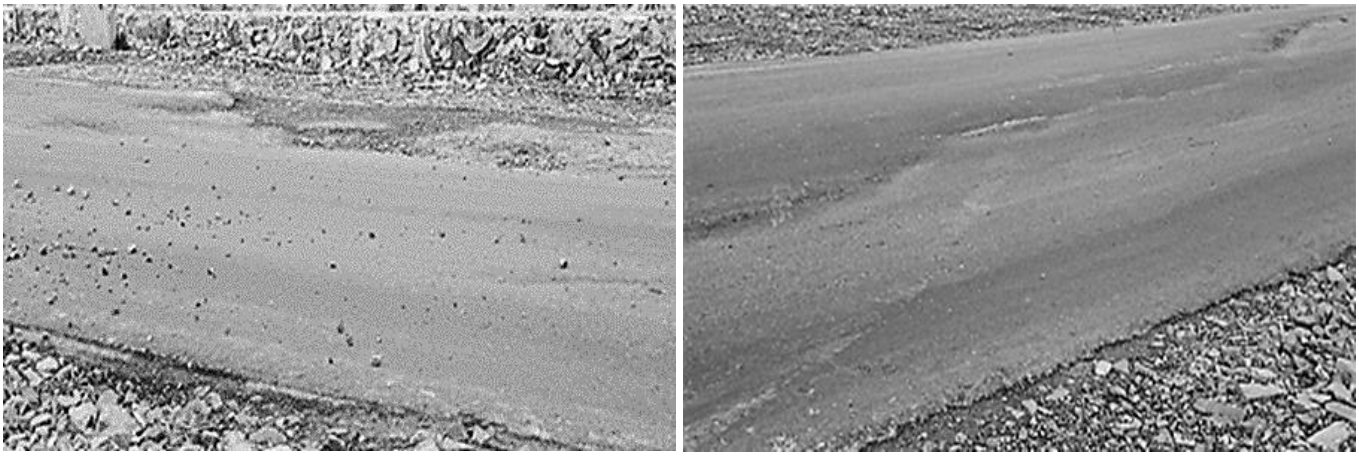

**Figure 1.** Rutting (left) and Wavy (right) Condition on Labuan National Road, Banten Province

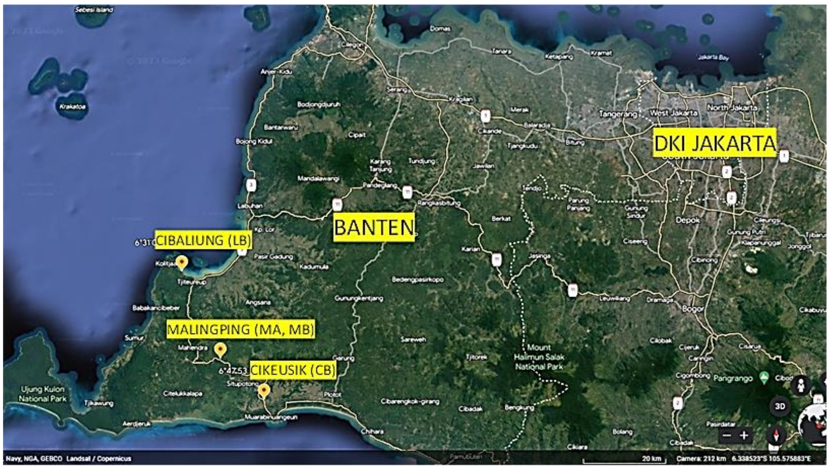


**Figure 2.** Observed Study Locations

## Materials and Method

Soil samples were collected from several locations in Pandeglang District, Banten Province, Indonesia. The observed locations were Malingping subdistrict, Cikeusik subdistrict, and Labuan subdistrict, and the MA, MB, CB, and LB samples were named, respectively (shown in Figure 2). The study started with field investigations i.e., a dynamic cone penetration test (DCPT) and a hand boring. The DCPT was carried out and converted into the California Bearing Ratio (CBR) value of the soil subgrade of the road construction. The measurement of the CBR value was intended to compare the stiffness of the initial and current conditions of the soil subgrade. The initial CBR value of the soil subgrade was predicted based on the minimum CBR value of rigid road construction, i.e., 6% [17]. Soil samples were obtained using a hand-boring apparatus at various depths from 0 m to -5 m below the surface.

Later, a set of laboratory tests was conducted on the collected soil samples. Soil samples were subjected to physical index tests, swelling tests, and expansivity index tests. Soil samples were then classified based on their expansivity using two methods: indirect and direct [18]. Skempton [19], Seed et al. [20], Chen [21], Snethen et al. [22], William's chart [23], and SNI 03-6795-2002 [24] criteria were considered for the indirect method of identification. Besides, the free swell and expansion index tests were conducted to directly determine the soil expansivity value. The results of the indirect and the direct methods were analyzed and discussed.

### Field Investigation

The field soil investigation was conducted using a dynamic cone penetration (DCP) to measure the CBR value of soil subgrade. The number of blows needed to penetrate certain depths was recorded and converted to a CBR value. In this study, the initial stiffness of the soil subgrade which is denoted by the CBR was assumed to be equal to or greater than 6%. The value is the minimum CBR value required for rigid pavement construction, as provisioned by Bina Marga [17]. The change in the CBR value of the soil subgrade from the initial to current conditions was analyzed to characterize the effect of expansivity on the soil subgrade. Figure 3 shows the activities of DCP testing along the observed locations.

**Figure 3.** Dynamic Cone Penetration (DCP) Test at the Observed Location

The DCP test was performed using an 8 kg hammer and 57.5 cm height of free fall. The cone used in this study was 20 mm in diameter and 30° of angle. The depth of measurement was limited to 97 cm under the ground surface. Soil sampling was carried out at the observed locations using a hand-bore apparatus at various depths from 0 to 5 m. The water level was found at -2 to -4 m under the ground surface. Disturbed samples were collected and put into containers, and the undisturbed samples were taken using Shelby tubes and preserved in the tubes with both ends covered with paraffin. Figure 4 shows the activities performed in soil sampling.

**Figure 4.** Soil Sampling Locations in Malingping (top), Cikeusik Cibaliung (middle), Labuan (bottom)

## Laboratory Test

Laboratory tests included the determination of natural water content, soil-specific gravity, volume weight, Atterberg limits, grain size distribution, free swell, and expansion index of the soil samples. The undisturbed samples were used in all the tests except for the grain size distribution test. In the indirect method, the values of the plasticity index, liquid limit, and percentage of clay fraction were used to predict the level of expansivity, whereas in the direct method, the expansion index directly quantified the expansivity value.

### *Indirect Expansivity Identification*

There are many available criteria to identify and characterize expansive soils without measuring the actual swelling value. Among those criteria are the liquid limit (Table 1) proposed by Chen [21], the plasticity index (Table 2) proposed by Snethen et al. [22], and the shrinkage limit (Table 3) proposed by Holtz and Gibbs [25]. In Indonesia, a criterion was provisioned in SNI 03-6795-2002 [24] to identify the swelling potential based on plasticity index and suction measurement (Table 4).

**Table 1.** Soil Expansivity Criteria Identified by Liquid Limit [21]

| Liquid limit (%)s | Degree of expansion |
|---|---|
| < 30 | Low |
| 10 - 20 | Medium |
| 20 - 35 | High |
| > 35 | Very High |

**Table 2.** Soil Expansivity Criteria Identified by Atterberg Limit [22]

| Liquid Limit (%) | Plasticity Index (%) | Swelling Potential (%) | Degree of expansion |
|---|---|---|---|
| > 60 | > 35 | > 1.5 | High |
| 50 - 60 | 25 - 35 | 0.5 - 1.5 | Medium |
| < 50 | < 25 | < 0.5 | Low |

**Table 3.** Soil Expansivity Criteria Identified by Shrinkage Limit [25]

| Degree of expansion | Shrinkage limit (%) |
|---|---|
| Low | > 13 |
| Medium | 8-18 |
| High | 6-12 |
| Very High | >27 |

**Table 4.** Soil Expansivity Criteria Identified by Atterberg Limit and Suction Test SNI 03-6795-2002 [24]

| Degree of expansion | Liquid Limit (%) | Plasticity Index (%) | Original Suction Test (kN/m$^2$) |
|---|---|---|---|
| High | > 60 | > 35 | > 4 |
| Medium | 50 – 60 | 25 - 35 | 1.5 - 4 |
| Low | < 50 | < 25 | < 1.5 |

Another indirect method that is widely used in practice to predict the expansivity of clay soils is the activity ratio. The method required parameters such as clay fraction (CF) and plasticity index (PI) [19-20]. Originally proposed by Skempton [19], the activity ratio can be determined by the following equation:

$$Activity = PI/CF \tag{1}$$

where PI, which was later modified by Seed [20] as follows:

$$Activity = PI/(CF\text{-}10\%) \tag{2}$$

Skempton's activity ratio can be correlated with the level of swelling potential based on Table 5 and compared with Seed's activity ratio. William [23] determined the activity ratio by using the relationship between clay fraction and plasticity index.

**Table 5.** The Soil Expansivity [19]

| Activity | Swelling Potential |
|---|---|
| < 0.75 | Nonactive |
| 0.75 - 1.25 | Normal |
| > 1.25 | Active |

### *Direct Expansivity Identification*

Although the indirect method is popular and convenient for predicting the soil expansivity, a study conducted by Sridharan et al. implied that the indirect method based on the index properties of soils statistically overestimates the actual swelling potential [26]. Therefore, the direct method, i.e., expansion index, was conducted in comparison to the results of the indirect method.

In this study, the expansion index was performed based on ASTM D-4829 [16]. The soil samples were previously filtered using a 4.75 mm sieve and dried at a temperature of 60±2°C. The initial saturation of the samples was set at 50±1% and calculated using the following equation:

$$S = (w.Gs.\alpha_d)/(Gs.\alpha_w\text{-}\alpha_d) \tag{3}$$

where $w$ is moisture content (%), $Gs$ is specific gravity, $\alpha_d$ is the dry unit weight (kN/m$^3$), and $\alpha_w$ is the unit weight of water. The moisture content of the soil samples should then be adjusted to 50±1% saturation. If this condition cannot be met, the degree of saturation ranges from 40 to 60%. For the initial dial reading ($D_1$), the height of the specimen inside the oedometer was recorded after being loaded with 6.9 kPa for 10 minutes. The specimen was then immersed for 24 hours in distilled water. After 24 hours, or when the rate of change in the dial is less than 0.005 mm/hour, the final dial reading ($D_2$) is recorded.

The results of the test can be determined by the value of the expansion index, depending on the initial saturation conditions. At saturation of 50%, the value of EI was determined by Equation 4, and at saturation of 40-60%, the EI value was determined by Equation 5.

$$EI_{meas} = \Delta H/H_1 \text{ x}1000 \tag{4}$$

$$EI_{50} = EI_{meas} – (50 – S_{meas}).(65 + EI_{meas})/(220 – S_{meas}) \tag{5}$$

where $\Delta H$ is the change in height (cm), $D_2 – D_1$, $H_1$ is the initial sample height (cm), $D_1$ is the initial dial reading (cm), $D_2$ is the final dial reading (cm), $EI_{meas}$ is the expansion index, $S_{meas}$ is the degree of saturation (%), and $EI_{50}$ is the estimated expansion index. The swelling potential can be classified into levels based on the expansion index shown in Table 6.

**Table 6.** Classification of Swelling Potential from Expansion Index Value [16]

| Expansion Index, EI | Potential Expansion |
|---|---|
| 0 - 20 | Very Low |
| 21 - 50 | Low |
| 51 - 90 | Medium |
| 91 - 130 | High |
| > 130 | Very High |

## Results and Discussion

### Dynamic Cone Penetration Test

Dynamic cone penetration tests (DCPT) were conducted to record the depth of penetration per blow of soil subgrade at several observed locations. Table 7 shows the results of the dynamic cone penetration test conducted on the soil subgrade at the observed locations. Then, the ratio of penetration to blows was converted to a CBR value. Results showed that the CBR value of the soil subgrade of the pavement had a range of 1.49%–5%, excluding 16.27% (Malingping B).

For rigid pavement in Indonesia, the construction must comply with the minimum standard criteria of 6% CBR for rigid pavement [17]. With the assumption that all the highway construction has complied with the provision, therefore, the initial CBR value of studied area was 6% or larger. Based on the DCPT results, there is a significant change in the CBR value from 6% to 1.49%, which indicates that the stiffness of the soil subgrade has significantly degraded. It is likely that the shrink-swell characteristic of the expansive soil altered the soil structure and reduced the CBR value of the soil samples. The expansive clay soils absorb large amounts of moisture during the saturation process, thus resulting in an increase in void ratio. The increase of void ratio weakens the soil structure and results in a lower bearing capacity. The reduction of CBR result which related to the characteristic of the expansive soil can be also found in another study conducted by Muntohar [18].

**Table 7.** Dynamic Cone Penetration Test Results

| Soil Samples | Blows count | Penetration (mm) | DCP (mm/blows) | CBR (%) |
|---|---|---|---|---|
| MA | 0 | 0 | 34.67 | 5.55 |
| | 3 | 104 | | |
| | 6 | 445 | 111.33 | 1.49 |
| | 9 | 772 | | |
| | 12 | 902 | 34.83 | 5.52 |
| | 15 | 981 | | |
| MB | 0 | 0 | 13.33 | 16.27 |
| | 3 | 40 | | |
| | 6 | 360 | 96.67 | 1.75 |
| | 9 | 620 | | |
| | 12 | 790 | 51.25 | 3.58 |
| | 15 | 950 | | |
| | 17 | 1030 | | |
| CB | 0 | 0 | 125.0 | 1.31 |
| | 3 | 375 | | |
| | 6 | 625 | 82.14 | 2.10 |
| | 9 | 856 | | |
| | 10 | 950 | | |

### Soil Physical Properties

Table 8 shows the physical properties of the soil samples. The natural moisture content of the samples was 34%-43%. The specific gravity of the soil samples was 2.66-2.71. The grain size distribution test results revealed the lowest clay fraction percentage of 12.3% and the highest percentage of 81.69%. The soil samples had a liquid limit

(LL) value higher than 40% and a plastic limit (PL) higher than 25%.

The plasticity index (PI) of MA, MB, CB, and LB was 36.02%, 31.89%, 15.09%, and 20.09%, respectively. Based on the soil classification of the Unified Soil Classification System (USCS) standard, MA and MB were classified as CH (high plasticity clay), CB was classified as ML/OL (low plasticity silt), and LB was classified as MH/OH (high plasticity silt). As can be seen from the result, none of the soil samples had a PI of over 40%.

**Table 8.** Physical Properties of Soil Samples

| Soil Samples | Water Content (%) | Specific Gravity | Sand (%) | Silt (%) | Clay Fraction (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) |
|---|---|---|---|---|---|---|---|---|
| MA | 40.03 | 2.67 | 0.16 | 18.16 | 81.69 | 62.08 | 26.06 | 36.02 |
| MB | 34.83 | 2.72 | 0.55 | 38.38 | 61.07 | 59.20 | 27.30 | 31.90 |
| CB | 41.25 | 2.70 | 3.43 | 84.27 | 12.30 | 44.44 | 29.35 | 15.09 |
| LB | 43.50 | 2.69 | 10.25 | 29.43 | 60.32 | 61.57 | 41.47 | 20.10 |

## Indirect Soil Expansivity Prediction

The indirect method is still more favorable than the direct test because it requires a minimum number of tests for the analysis, Atterberg limits, and grain size distribution analysis. Tables 9 and 10, and Figures 5 and 6, are the analysis results of indirect expansivity identification using previous research provisions [20, 21, 23] on the observed expansive soil samples. As shown in Table 9, MA is classified as a high to very high expansive soil, MB is classified as a medium to high expansive soil, CB is classified as a low to medium expansive soil, and LB is classified as a medium to high expansive soil. Table 10 shows the activity ratio of samples based on the Skempton and Seed equations. All samples are categorized as inactive swelling potential soil according to the Skempton Ac value [19]. However, according to the Seed Modified Ac value [20], all the samples are predicted to have high swelling potential soil.

**Table 9.** Correlation between Liquid Limit and Swelling Potential

| | LL(%) | PI (%) | Chen [21] | Snethen [22] | SNI 03-6795-2002 [24] |
|---|---|---|---|---|---|
| MA | 62.080 | 36.017 | Very High | High | High |
| MB | 59.199 | 31.899 | High | Medium | Medium |
| CB | 44.436 | 15.091 | Medium | Low | Low |
| LB | 61.570 | 20.095 | High | Medium | Medium |

**Table 10.** Identification of Activity ratio

| | MA | MB | CB | LB |
|---|---|---|---|---|
| Plasticity Index (%) | 36.017 | 31.899 | 15.091 | 20.095 |
| Clay Fraction (%) | 81.685 | 61.066 | 12.302 | 60.322 |
| Skempton [19] | | | | |
| Activity (Ac) | 0.441 | 0.522 | 1.227 | 0.333 |
| Swelling Potential | Inactive | Inactive | Inactive | Inactive |
| Seed et al. [22] | | | | |
| Activity (Ac) | 0.502 | 0.625 | 6.557 | 0.399 |
| Swelling Potential | High | High | High | High |

The results show contrasting predictions for the soil samples based on various indirect methods of soil expansivity. Figures 5 and 6 show the swelling potential of soil samples based on Seed et al. [20] and Williams & Donaldson [23]. The results in Figure 5 indicate that based on Seed's relationship between activity value and percentage of clay fraction, MB and LB are predicted as low- to medium- swelling potential soils, while MA and CB cannot be precisely predicted since the value was out of the graph. Based on the relationship between percentage of clay fraction and PI, MB and CB are predicted as medium-swelling potential soils, whereas MA and LB are predicted as low-swelling potential soils.

The analysis results from various indirect methods of expansivity of the samples disagree with one criterion and another. The results show similar results to those conducted by Putri et al. [13] in 2020, where the analysis results showed discrepancies in prediction among the methods. It is obvious that the analysis requires more than the physical indices and grain size distribution to determine the degree of expansivity.

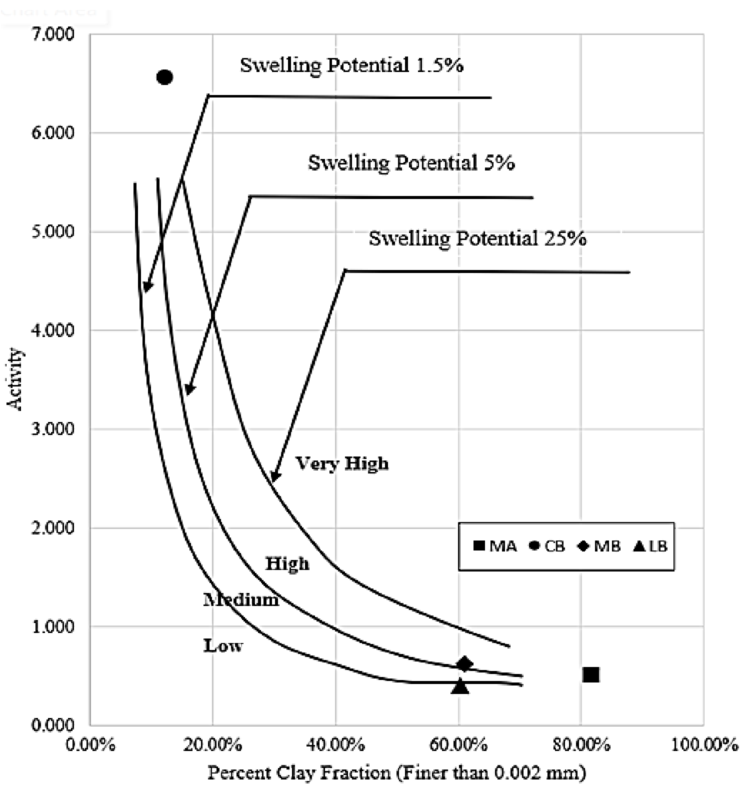


**Figure 5.** The Swelling Potential of Soil Samples Based on Seed et al. [20]

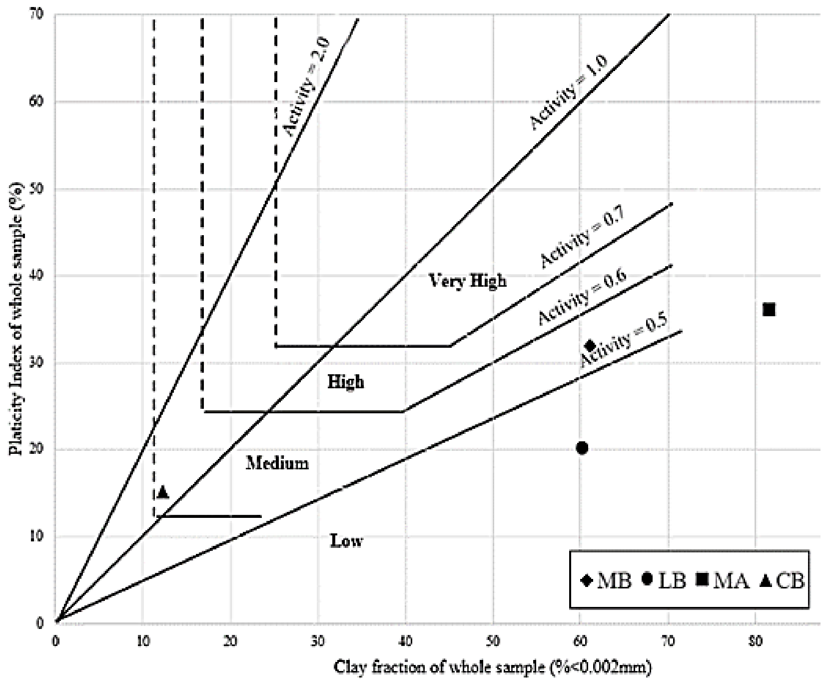


**Figure 6.** The Swelling Potential of Soil Samples based on Williams & Donaldson [23]

## Direct Soil Expansivity Prediction

The other method for determining the degree of expansivity is the direct method, which measures the actual swelling value of samples in the laboratory. In this study, the swelling value of the samples was measured using the Expansion Index Method, which complies with the American Standard Testing Method D-4829 [16]. The direct expansivity identification was carried out with initial saturation conditions of 50% ±1%. The test results are shown in Table 10. The MA, MB, CB, and LB samples yielded average EI values of 163, 135, 140, and 107, respectively, with the percentage of swelling potential being in the 9%–18% range. Samples are classified as having a high to very high potential for expansion.

**Table 11.** Expansion Index Test Results

| Soil Sample | Expansion Index | Potential of Expansion | Swelling Value (%) |
|---|---|---|---|
| MA 1 | 160.0 | Very High | 16.44 |
| MA 2 | 166.7 | Very High | 17.41 |
| MB 1 | 125.2 | High | 12.15 |
| MB 2 | 145.9 | Very High | 14.67 |
| CB 1 | 120.7 | High | 12.52 |
| CB 2 | 160.7 | Very High | 16.07 |
| LB 1 | 114.8 | High | 11.48 |
| LB 2 | 100.7 | High | 9.41 |

**Table 12.** Resume of Various Test Results

| Soil Sample | Potential of Expansion | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Indirect Method | | | | | | Direct method | |
| | Chen [21] | Snethen et al. [22] | SNI 03-6795-2002 | Ac Skempton [19] | Ac Seed et al. [20] | Williams & Donaldson [23] | Expansivity Index test | Average Swelling Value (%) |
| MA | Very High | High | High | Inactive | High | Low | Very High | 16.93 |
| MB | High | Medium | Medium | Inactive | High | Medium | High | 13.41 |
| CB | Medium | Low | Low | Inactive | High | Medium | High | 14.30 |
| LB | High | Medium | Medium | Inactive | High | Low | High | 10.45 |

Table 12 summarizes the results of various indirect methods and direct methods of soil expansivity. The results of various indirect methods of expansivity disagreed with one criterion and another. The results varied from low (not expansive) to very high for the same type of soils. Furthermore, the results of the indirect method were inconclusive, whilst those of the direct method were all high to very high expansivity. Based on the evidence found, for practical purposes, we can no longer rely on the indirect method, and the expansion index test should be conducted to verify the indirect identification results.

## Conclusions

Based on the experiments and analysis conducted on the observed soils in Banten Province, several conclusions can be drawn:

1. The CBR values obtained from DCP test results were lower (CBR = 1.49–5%) than the minimum CBR value for rigid pavement (6%). It is likely the subgrade of the road construction in the observed area has degraded in stiffness due to the swell-shrink behavior of expansive soils.
2. The indirect identification methods showed inconclusive results about the swelling potentials of the observed soils. It ranged from low to very high, using different methods of classification.
3. Based on the direct method, all the soils drawn from several areas in Banten (Malingping subdistrict, Cikeusik subdistrict, and Labuan subdistrict) were classified as expansive clay with a high- to very high- swelling potential. The EI value ranged from 100 to 167, and the percentage of swelling potential ranged from 9%–18%.
4. The analysis result showed a discrepancy among the indirect methods and differed from the direct method results (expansivity index analysis). From the evidence, the indirect method is inconclusive, and for practical purposes, the direct method should be performed to avoid misclassifying or underestimating the expansivity of clay soils.

## Acknowledgements

The Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia and the Indonesian Endowment Fund for Education (LPDP) has funded this research through the Program Riset Keilmuan 2021 grant no. 091/E4.1/AK.04.RA/2021. The authors would like to express their gratitude to the National Road Implementing Agency (BPJN), Banten Province for granting permission for field investigations and soil sampling in their area.

## References

1. Rezaei, M., Ajalloeian, R., and Ghafoori, M., Geotechnical Properties of Problematic Soils Emphasis on Collapsible Cases, *International Journal of Geoscience, 3*(1), 2012, pp. 105-110, http://dx.doi.org/10.4236/ijg.2012.31012.
2. Nelson, J.D. and Miller, D.J., *Expansive Soils Problem and Practice in Foundation and Pavement Engineering*,

John Wiley and Sons, Inc, USA, 1992.
3. Puppala, A.J. and Pedarla, A., Innovative Ground Improvement Techniques for Expansive Soils, *Innovative Infrastructure Solution*, 2, 24, 2017, http://dx.doi.org/10.1007/s41062-017-0079-2.
4. Kempfert, H. and Gebreselassie, B., *Excavations and Foundations in Soft Soils*, Springer, Berlin-Heidelberg, 2006.
5. Wardana, I.G.N. and Suryanegara, D., Analisis Penyebab Kerusakan Rumah Sederhana yang Didirikan di Atas Tanah Lempung di Daerah Kerobokan, *Jurnal Ilmiah Teknik Sipil*, *16*(2), 2012, pp. 177-185. (*In Indonesian*), https://ojs.unud.ac.id/index.php/jits/article/view/7511
6. Muntohar, A.S., The Swelling of Expansive Subgrade at Wates-Purworejo Roadway sta. 8 127, *Civil Engingeering Dimension*, *8*(2), 2006, pp. 106-110, https://doi.org/10.9744/ced.8.2.pp.%20106-110.
7. Yahya, R.G., Kerusakan Jalan Raya Akibat Tanah Mengembang, *Jurnal Teknik Sipil Universitas Kristen Maranatha*, *11*(1), 2015, pp. 63-74. (*In Indonesian*), https://journal.maranatha.edu/index.php/jts/article/view/1400/1082.
8. Daffala, M.A. and Shamrani, M.A., Road Damage due to Expansive Soils: Survey of The Phenomenon and Measures for Improvement, *Design, Construction, Rehabilitation, and Maintenance of Bridges*, *Proceedings of GeoHunan International Conferences*, Hunan, China, June 9-11, 2011, pp. 73-80, https://doi.org/10.1061/47630(409)10.
9. Jalal, F.E., Xu, Y., Jamhiri, B., and Memon, S.A., On Recent Trends in Expansive Soil Stabilization Using Calcium-based Stabilizer Materials (CSMs): a Comprehensive Review, *Advances in Materials Science and Engineering*, 2020, pp. 1-23, https://doi.org/10.1155/2020/1510969.
10. Zumrawi, M.M.E., Geotechnical Aspects for Roads on Expansive Soils, *International Journal of Science and Research*, *4*(2), 2015, pp. 1475-1479, https://www.researchgate.net/publication/272476770_Geotechnical_Aspects_for_Roads_on_Expansive_Soils
11. Sridharan, A. and Prakash, K., Expansive Soil Characterisation: An Appraisal, *Indian National Academy of Engineering Letters*, 1, 2016, pp. 29-33, https://doi.org/10.1007/s41403-016-0001-9.
12. Dakshanamurthy, V. and Raman, V., A Simple Method of Identifying an Expansive Soil, *Soils and Foundation*, *13*(1), 1973, pp. 97-104, https://doi.org/10.3208/sandf1972.13.97
13. Putri, C.A., Prakoso, W.A., and Rahayu, W., Review of Classification Methods to Determine Expansion Degree of Expansive Soils in Indonesia, *Proceeding of 2nd International Conference on Civil and Environmental Engineering, E3S Web Conference*, Malaysia, January 6-7, 347, 2022, 03006, https://doi.org/10.1051/e3sconf/2022347 03006.
14. Pramudyo, T., et al., *Atlas Sebaran Batulempung Bermasalah Indonesia*, Badan Geologi, Bandung, 2019. (*In Indonesian*)
15. Affandi, D., Mapping Expansive Soil Characteristics on The National Road Segment in Java Island, *Proceeding of 25th Annual National Conference on Geotechnical Engineering*, Jakarta, November 9-10, 2021. pp. 361-372.
16. ASTM D4829-21, *Standard Test Method for Expansion Index of Soils*, American Society for Testing and Materials International, 2021.
17. Kementerian Pekerjaan Umum dan Perumahan Rakyat Dirjen Bina Marga, *Manual Desain perkerasan jalan no. 02/M/BM/2017*, Jakarta, 2017. (*In Indonesian*)
18. Muntohar, A.S., The Swelling of expansive subgrade at Wates-Purworejo Roadway, Sta. 8+127, *Civil Engineering Dimension*, *8*(2), 106-110, 2006.
19. Skempton, A.W., The Colloidal “Activity” of Clays, *Proceeding of the Third International Conference on Soil Mechanics and Foundation Engineering*, Zurich, 1953. pp. 57-61, Retrieved from: https://www.issmge.org/uploads/publications/1/42/1953_01_0014.pdf
20. Seed, H.B., Woodward, R.J., and Lundgren, R., Prediction of Swelling Potential for Compacted Clays, *Journal of Soil Mechanics and Foundations Division*, *88*(1), 1962, pp. 53-87, https://doi.org/10.1061/JSFEAQ.0000431
21. Chen, F.H., *Foundation on Expansive Soils.* Elsevier Scientific Publishing Company, Amsterdam, 1975.
22. Snethen, D.R., Johnson, L.D., and Patrick, D.M., *An Evaluation of Expedient Methodology for Identification of Potentially Expansive Soils.* Federal Highway Administration, Office of Research and Development, 1977.
23. Williams, A.A.B. and Donaldson, G.W., Building on Expansive Soils in South Africa: 1973-1980, *Proceeding of 4th International Conference on Expansive Soils*, Denver, 1980, pp. 834-844.
24. SNI 03-6795-2002, *Metode Pengujian Menentukan Tanah Ekspansif*. Badan Standarisasi Nasional Indonesia, 2002. (*In Indonesian*).
25. Holtz, W.G. and Gibbs, H.J., Engineering Properties of Expansive Soils, *Transactions of ASCE*, *121*(1), 1956, pp. 641-679, https://doi.org/10.1061/TACEAT.0007325.
26. Srindharan, A. and Prakash, K., Classification Procedures for Expansive Soils, *Proceeding Institution of Civil Engineers-Geotechnical Engineering*, *143*(4), 2000, pp. 235-240, https://doi.org/10.1680/geng.2000.143.4.235