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Expansive Soil Swelling Test of Small Scale Laboratory Model on Sambungmacan Soil, Central Jawa

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Keywords

Expansive Soil; Pressure; Swelling

Abstract

Soil is one of the most important elements in any civil engineering work, almost all construction activities are related to soil. One of the most common soil problems is expansive soil. This type of soil has a high potential to expand when compared to other types of soil. This research aims to find out how expansive the tested soil is and how it reacts when wetting. The test in this research is experimental, where the expansive soil test is modeled in a rectangular test box with a soil volume of 0.08 m3. The swelling and expansion pressures were measured using proving rings and dials, each totaling five units. The expansive soil used came from Sambungmacan Subdistrict, Sragen Regency, Central Java. The results of the property index test of Sambungmacan soil have a plasticity index percent value of 49.33% and a liquid limit (LL) of 90.16%. The test results showed that the maximum swelling reached 28.3% of the initial soil height of 200 mm and the maximum soil swelling pressure reached 103.23 kPa with a moisture content of 22.62%. The maximum pressure that occurs in each proving ring is at an average moisture content of 31.81%. The results of this study also show the effect of every 1% moisture content will produce a percent soil swelling of 0.40% to 1.08% and the average percentage of swelling pressure that occurs is in the range of 4.65 kPa to 10.26 kPa at every 1% swelling.

1. INTRODUCTION

The term used for soils that have a high potential for expansion and shrinkage due to changes in moisture content is called expansive soil, (Sudjianto, 2015) this type of soil has a behavior that will expand when soil conditions are wet and will shrink when soil conditions are dry, so these soils are often called shrinkage or mobile soils. Expansive soils are dominated by fine-grained clay and silt. Expansive soil according to (Hardiyatmo, 2017) is very sensitive to water due to the presence of montmorillonite mineral content, this mineral will cause the soil to expand when it comes into contact with water. Clays or silts that do not contain the mineral montmorillonite will not swell as much as those that do.

In the country, the problem of expansive soils exists in almost all regions from Sabang to Merauke, there are no reports of losses that are detailed, based on the results of surveys and research conducted by the Bina Marga dan Departemen Pekerjaaan Umum, the majority of the damage that occurs on several roads in Java is caused by expansive soil problems (Mochtar, 2000). One example of road damage is in East Java, particularly in the Soko area of Ngawi Regency, which is the main road connecting Central and East Java, the most dominant damage according to (Sudjianto, 2007) on the road section occurred due to expansive soil problems on the basic soil with very high swelling potential. An example of road body damage that also occurred was mentioned in research (Marcel, 2022), namely on Jl. Raya Timur, Sambungmacan District, Sragen Regency. Road damage in the Sragen area has been well-known since the Dutch colonial era, It was noted that the newspaper during the Dutch colonial period that had highlighted the damage to the road was De Locomotief in a report on December 4, 1935, calling Solo-Sragen the worst road in Vorstenlanden (Duhri, 2021).

One way to minimize the negative impact of expansive soil is to check the soil type first before building on it. To prevent post-construction failure of civil engineering structures due to increasing urbanization and industrialization associated with expansive soils, It is very important to evaluate the parameters and characteristics of soil strength before the construction process is carried out. (Das et al., 2011; Bell, 2014l; Puppala dan Pedarla, 2017; Christopher dan Chimobi, 2019). (Chen, 1975) stated that to understand the development of expansive soils, there are two parameters used to measure the quality of expansive soil development, namely swelling potential and swelling pressure, in line with this statement (Diana et al., 2020) stated that one of the ways to check the soil that can be done is to calculate how much the ground surface rises and the pressure caused by expansive soil. Research related to expansive soils is still being conducted because there is no appropriate method to solve this problem, Based on the current literature, most researchers research mixing expansive soil with certain materials so that the expansiveness of the soil is reduced, such as research conducted (Alazigha, 2018; Pooni, 2019; Jalal, 2020; Blayi, 2020). The calculation of expansive soil swelling potential is mostly done using an oedometer, Research that uses an oedometer in measuring expansive soil swelling includes (Ferdiansyah et al., 2012) which examines the effect of adding water content on vertical direction pressure, (Al, 2017) in research on the effect of field moisture content and air-fly ash ratio on the strength and swelling of expansive soil, (Arbianto, 2020) researched the prediction of soil swelling with clay content.

This research uses a test box to see the pressure reaction and swelling of expansive soil, the soil used in this research is the soil from the Sambungmacan area of Sragen district, Central Java province (7º21’43,874” ; E 111º7’15,627”), the soil of this area was chosen because based on the results of the property index test in the laboratory showed a liquid limit value (LL) of 90.16% and a plasticity index (PI) of 49.33, based on previous literature on expansive soil classification, that expansive soils are characterized by high liquid limit values (LL) and (PI) (Hardiyatmo, 2017). The purpose of this research is to see the development reaction and swelling pressure that occurs when expansive soil is wetting with a method that is still rarely used, namely using a proving ring to determine the value of the development pressure that occurs.

1.1 Expansive Soil Identification

Identification of expansive soils is usually done in the laboratory by conducting swelling tests, mineralogy tests, and chemical analyses and their correlation with classification and soil index properties. According to (Thomas, 1998) there are two ways to identify the expansion-shrinkage of expansive clay soils, namely direct identification, and indirect identification. (Noormalasari, 2000) also mentioned that there are three methods to identify the shrinkage of expansive clay soil, firstly direct measurement method, secondly indirect and lastly mineral identification. The direct measurement method is carried out by actual testing of the swelling including mineralogical identification, while the indirect measurement method involves physical properties and soil classification to predict shrinkage swell, both methods according to (Snethen, 1975) can be combined into one.

1.2 Correlation of Swelling with Atterberg Limits

The potential of soil to release and withdraw water depends on the initial moisture content of the soil and the moisture content relative to the moisture content of the consistency boundaries, such as the plastic limit, liquid limit, and shrinkage limit (Hardiyatmo, 2017). Through the Atterberg limit test, the plasticity index (PI) and liquid limit (LL) values can be determined. The classification of the degree of Swelling based on the Atterberg boundaries of several researchers is shown in table 1.

Table 1. Classification of Atterberg boundaries concerning the degree of swelling *(Hardiyatomo, 2017)*

Degree of Swelling	Plasticity Index (PI)	Shrinkage Index	Shrinkage Indeks (Ranganathan, 1984)	Liquid Limit (LL) Ladd dan Lambe (1961)
	(Raman; V. Dakshanamurthy, 1973)			
Low	<12	<15	<20	20 – 35
Medium	12 – 23	15 – 30	20 – 30	35 – 50

High	23 – 32	30 – 60	30 – 60	50 – 70
Very high	>32	>60	>60	70 - 90
Extra high				>90

2. RESEARCH METHODS

The test was conducted at the Soil Mechanics Laboratory of Sebelas Maret University Surakarta using the experimental method. This research was carried out in three stages, namely preparatory work, testing (wetting and reading of proving ring values), and analysis of test results. The testing standards used are ASTM (American Society for Testing and Materials) and SNI (Indonesian National Standard) standards. Experimental methods using proving rings to measure the swelling pressure of expansive soils like this are still rare, Expansive soil testing is generally carried out using an oedometer, even (Diana et al., 2020) in their research summarized more than fifty literature from all over the world related to measuring soil expansiveness using an oedometer. So far there is no standardized procedure or test method for calculating soil expansiveness so there are often different results because it is done in various ways (Hardiyatmo, 2002).

The soil used in this study was taken in a disturbed state (disturbed sample) on the soil surface to a depth of 50 cm, the soil sample was then dried by drying in the sun. The soil was then pounded and sieved with sieves number 4, 10, and 40 respectively, the soil that passed sieve number 4 was used for swelling testing in the test box. The volume of dry soil used in this test is 0.08 m3 with a weight of 104.46 kg.

Before wetting the soil, the property index, initial moisture content, dry weight content, and initial CBR value of the soil in the test box were tested. The proving ring used was first calibrated to determine the value of the Load Ring Constanta (LRC) on each proving ring used. Wetting is carried out only on one side of the box, the wetting process in this test lasts for 53 days until all pressure and development values at each proving ring point have not increased in value anymore and tend to decrease.

2.1 Tools and Materials

The tools and materials used during the research were as follows:

Table 2. Tools and materials

No.	Alat		Materials
	Properties index test	Test Box Set	
1	Soil moisture content tester ASTM D2216-71	Test box	Soil
2	Soil-specific gravity tester ASTM D854-00	Anchoring Portal	Water, distilled water
3	Liquid limit and plastic limit tester ASTM D4318	Set of proving ring	Sand
4	Shrinkage limit tester SNI 4144:2012		Stone
5	Oven, scales, thermometer, and desiccator		

2.2 Test Box Display

The test box used is made of iron, rectangular with dimensions as shown in Figure 1. The front and back sides of the box are 2 cm thick acrylic membrane, and both sides of the box are held by iron strip plates transversely and longitudinally. The dimensions of the test box used in this test are 120 cm long, 50 cm wide, and 98 cm high.

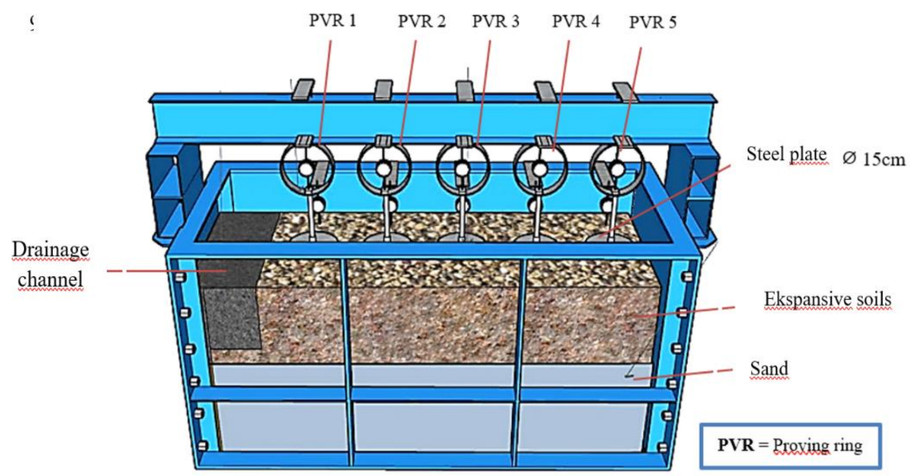


Figure 1. Assembled test box circuit

The configuration of the proving ring and dial placement points is set with the same distance between the first point and the next point, the configuration view is illustrated in Figure 2.

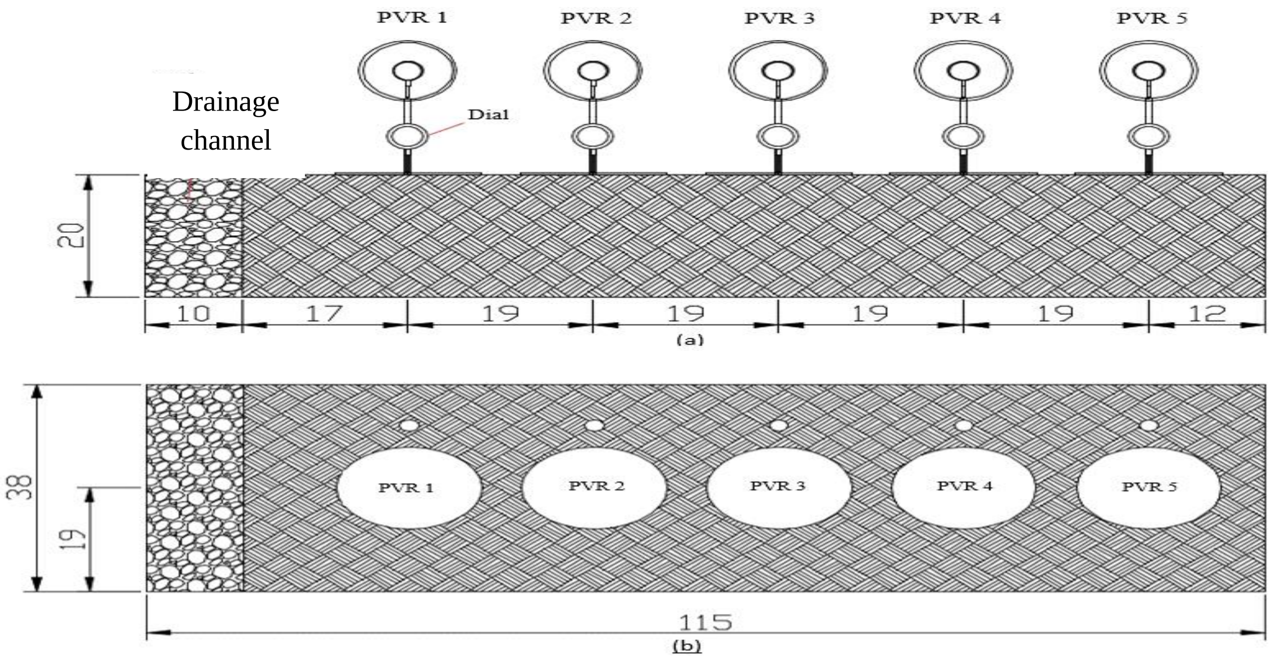


Figure 2. Configuration of proving ring and dial placement, (a) front view (b) top view

2.3 Measurement of Soil Swelling Pressure Value

Measurement of swelling pressure is carried out to determine the value of soil pressure that occurs. This pressure value is calculated using equation (1), by multiplying the reading value of the load dial reading (LDR) by the load ring constant (LRC) of each proving ring and then dividing by the area of the plate used, so that the swelling pressure value is obtained,

$$k = \frac{q}{A} \quad (1)$$

exolanation:

q = LRC * LDR *proving ring (kN)*

A = Penetration Plate Surface Area (mm^2)

k = Swelling Pressure

3. RESULTS AND DISCUSSION

3.1. Soil Property Index Test Results

The results of the property index test on Sambungmacan soil are shown in Table 3 below,

Table 3. Soil property index test results

Properties	Value	Units
Initial moisture content, w	3,3	%
Specific gravity, Gs	2,273	-
Liquid limit, LL	90,16	%
Plastic limit, PL	40,83	%
Plasticity index, PI	49,33	%
Shrinkage limit, SL	22,70	%
Percent of soil grains passing the No.200 sieve	78,44	%
Percent of soil grains retained on sieve No.4	4,28	%
Percent clay fraction 0.002 mm, C%	4,91	%
Optimum moisture content, w_{opt}	27,8	%
Maximum dry volume weight, γd max	1,28	gr/cm^3
Unified system soil classification	(MH)	
Development (oedometer)	14,02	%
Pressure Development (oedometer)	89,5	kPa

Based on the results of this test, the value of PI 49.33% and LL 90.16% is obtained, which means that Sambungmacan soil falls into the category of very high swelling degree.

3.2 Graph of swelling value and swelling pressure during the test

Based on the results of testing for 53 days, the pattern of soil swelling that occurs as shown in Figure 3, it can be seen that the reaction of soil swelling, when filled with water, has different swelling values in each proving ring area.

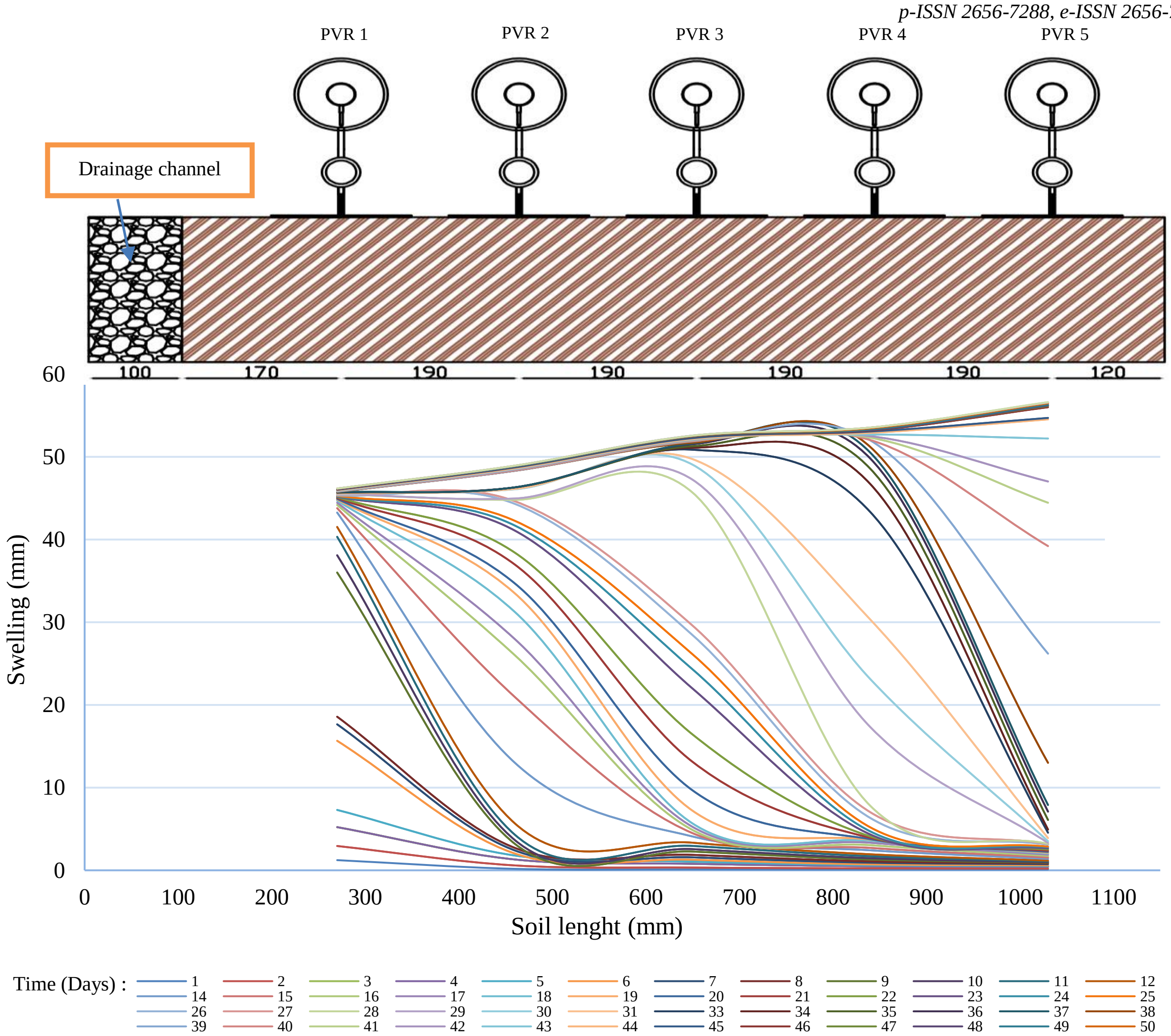


Figure 3. Swelling soil pattern

Figure 3 shows that the highest swelling is at the furthest point from the wetting area, the maximum swelling value in each proving ring is shown in Table 4.

Table 4. Maximum swelling value on each proving ring

Proving ring	Initial soil height	Swelling (mm)	Percent swelling (%)	Water content (%)
1	200	46,16	23,08	62,58
2	200	48,92	24,46	59,96
3	200	52,55	26,28	58,06
4	200	53,53	26,77	56,04
5	200	56,6	28,3	55,23
Average		51,55	25,78	58,37

Furthermore, Figure 4 shows the pattern of swelling pressure that occurs during soil wetting. The pressure value in each proving ring area is different, the highest pressure occurs in proving ring area 2 and the lowest in proving ring area 1.

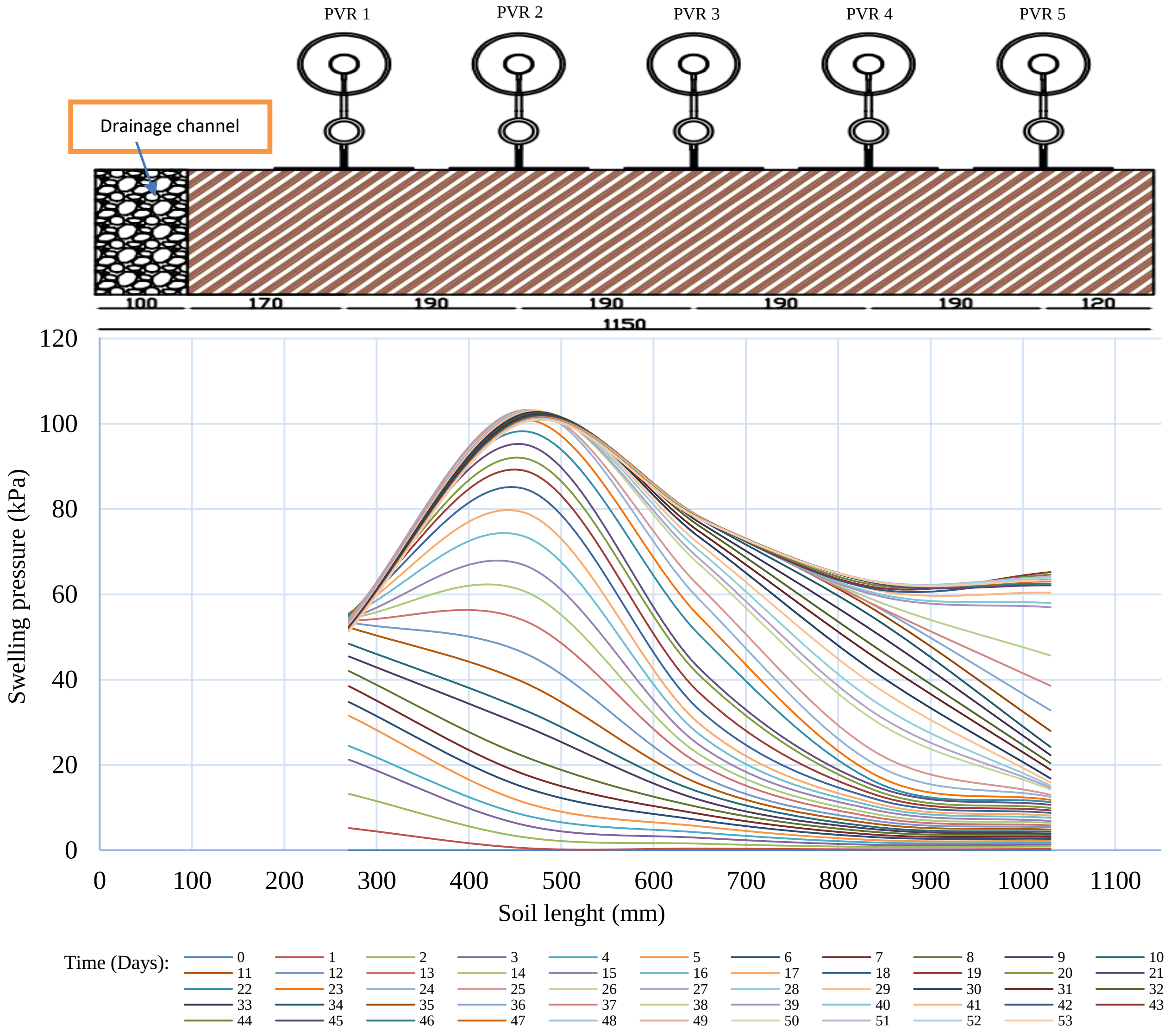


Figure 4. The Pattern of soil swelling pressure

The values of maximum swelling pressure, moisture content, and the time that occurs when the maximum pressure is due to the wetting process are shown in Table 5.

Table 5. The maximum swelling pressure value

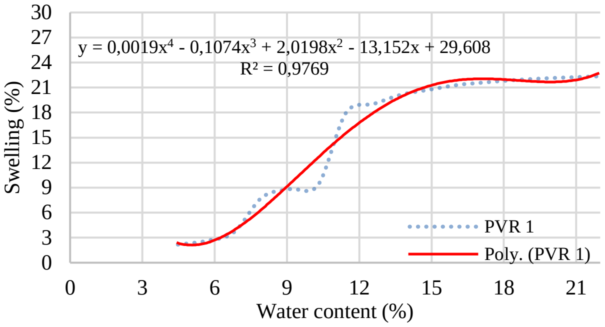
Proving ring	Max swelling pressure (kPa)	Water content (%)	Time of day-
1	55,51	21,9	18
2	103,23	22,62	24
3	78,23	33,42	35
4	62,93	47,53	48
5	65,22	33,59	43
Average	73,02		

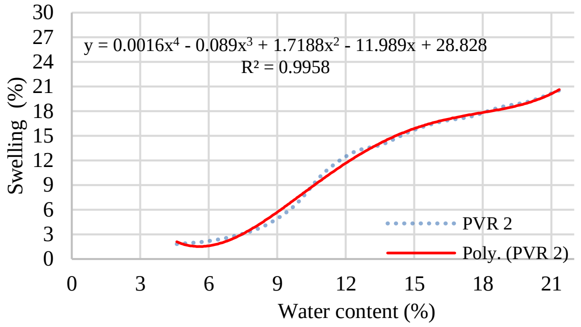
3.2 Relation of percent swelling to water content

The relationship of how much percent swelling occurs when the water content increases every percent, relation is drawn based on the situation when the proving ring area starts to be touched by water flow until it reaches the maximum swelling pressure in each proving ring,

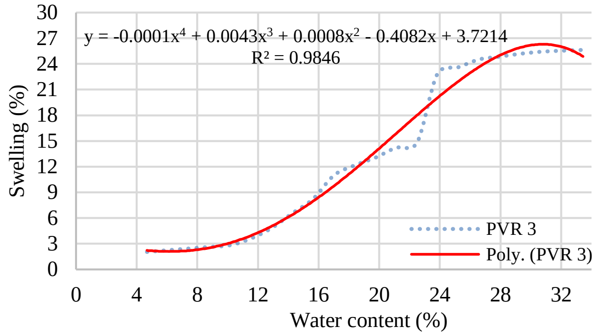
Proving ring 1

Proving ring 2

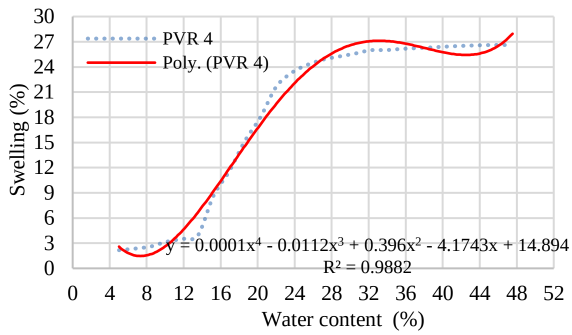




Proving ring 3



Proving ring 4



Proving ring 5

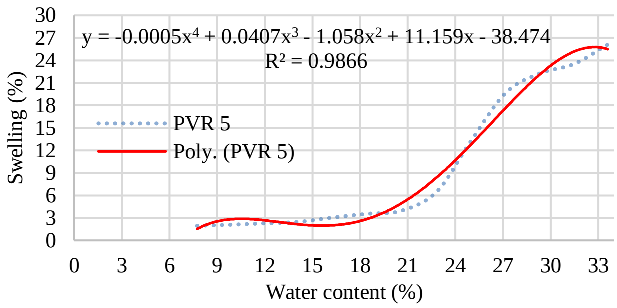


Figure 5. Relation of percent swelling to water content

Figure 5 is a graph of the relationship between the percent swelling value and water content in each proving ring, from this relation graph it can be seen that the average value of the coefficient of determination R2 from the results of the 4th-degree polynomial (quartic) regression analysis of each proving ring is close to 1, meaning that moisture content simultaneously affects the soil swelling that occurs. Based on this regression analysis, the equation of the relationship between water content and the percent of soil swelling that occurs is obtained, this equation is used to predict the percent swelling that occurs due to the effect of additional moisture content at each proving ring distance. Every 1% moisture content will cause the percentage of swelling with a value range of 0.40% to 1.08%, this result answers that the potential swelling of expansive soil is strongly influenced by changes in moisture content by the opinion (Hardiyatmo, 2017). These results can also be a reference for further research and input for previous research in predicting the effect of 1% moisture content on expansive soil swelling that occurs, most previous studies only show the effect of moisture content until maximum swelling occurs, such as research conducted (Ferdiansyah et al.,2012) and (Arbianto, 2020).

3.3 Relation of percent swelling to swelling pressure

The relation of how much swelling pressure occurs when the percent swelling increases, the relation is drawn based on the situation when the proving ring area starts to read the pressure value until it experiences the maximum swelling pressure in each proving ring, the following results, and explanations:

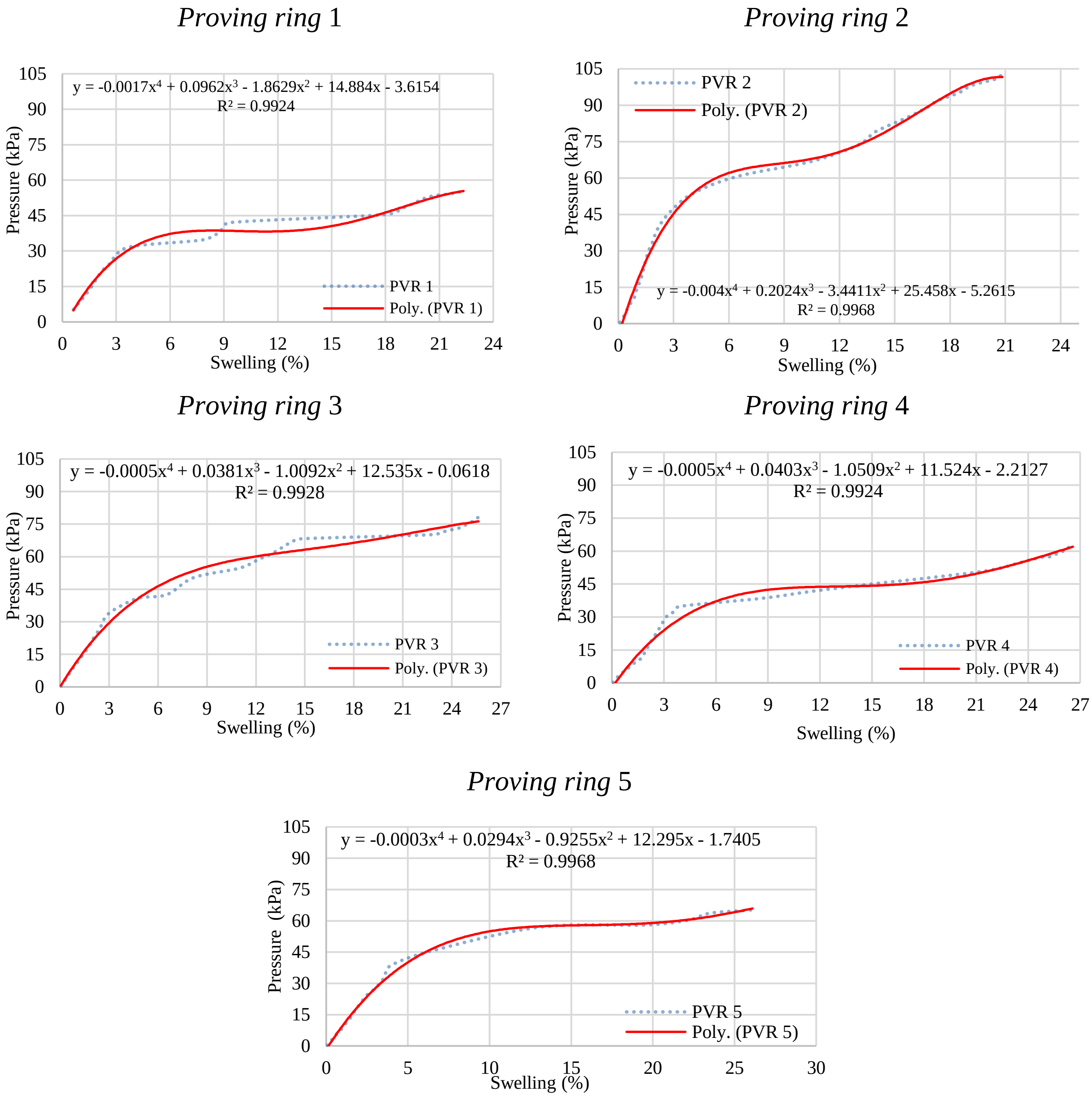


Figure 6. Relation of pressure to percent swelling

Figure 6 is a graph of the relation between the value of swelling pressure and percent swelling in each proving ring, from this relation graph it can be seen that the average value of the coefficient of determination R2 from the results of the regression analysis of polynomial degree 4 (quartic) in each proving ring is close to 1, meaning that the water content simultaneously affects the soil swelling that occurs. Based on this regression analysis, the equation of the relation between swelling pressure and the percent of soil swelling that occurs is obtained, this equation is used to predict how much swelling pressure occurs due to the influence of the percent of soil swelling at each proving ring distance. Every 1% swelling will cause swelling pressure of 4.65 kPa to 10.26 kPa in Sambungmacan soil. Similar to the relation of moisture content to swelling, the relationship of swelling to swelling pressure can also be a reference for further research and input for previous research in predicting the effect of 1% swelling on the swelling pressure that will occur.

4. CONCLUSIONS

Expansive soils will react when in contact with water. Soil exposed to water will expand and the swelling that occurs will exert pressure. Based on the classification results concerning the liquid limit (LL) and plasticity index (PI) values, it is concluded that the Sambungmacan soil is included in the expansive soil classification with a very high degree of swelling. The average swelling percentage value of this soil is 25.77%, while the mining pressure value obtained in this test is 103.23 kPa for the maximum swelling pressure value, 55.51 kPa for the lowest swelling pressure value, and the average swelling pressure is 73.02 kPa.

Based on the results of this study, it is also known that every 1% water content will cause a swelling percentage with a value range of 0.40% to 1.08% and every 1% swelling will cause a swelling pressure of 4.65 kPa to 10.26 kPa in Sambungmacan soil.

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