Study of Behaviour Swelling Potential of Expansive Soil on Swelling Test with Cycles of Loading and Unloading

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| Submitted: July 02, 2024 | Revised: July 03, 2024 | Accepted: December 28, 2024 |

| Published: January 03, 2025 |

ABSTRACT

Expansive soil has the characteristic to swell and shrink that are capable to cause crack on the highways surface. The swell and shrink behaviour of expansive soil are influenced by several factors, one of those is surcharge. Surcharge in highways road are traffic loads. To determine the form of behaviour caused by surcharge on expansive soil, the number of loading and unloading were performed on the oedometer test with the swelling pressure as the maximum stress of each cycles. The purpose of this study to investigate the behaviour of swelling potential of expansive soil of each cycles. The results shown that the sample with lowest moisture content exhibited the largest swelling in primary phase and the lowest in secondary phase. The initial swelling potential presented that sample with lowest moisture content did not always swell larger than the sample with higher moisture content. As the number of loading and unloading cycles increased, the swelling potential of all the samples performed similar behaviour. The most significant change of swelling potential occurred from zero to first cycle. After first cycle, the difference of swelling potential tended to similar. This indicated that all the samples tended to reach the stable conditions. The most influence factors that caused swelling potential decreased with increasing number of cycles were the threshold stress and the swelling pressure. The threshold stress caused expansive soil experienced irreversible deformation. While the swelling pressure caused larger swelling in the beginning of the unloading phase due to repulsive force.

Keywords: expansive soil; oedometer test; swelling potential; cycles of loading; unloading.

INTRODUCTION

Highway construction in Indonesia is increasing rapidly every year. According to Ministry of Public Works and Housing, the highways length has increased in the last 10 years (Figure 1). The increasing number of highways in Indonesia influences the availability of the land of soil. Soil is the basic material as the main foundation of the highways. However, there is a possibility that the soil as the foundation of the highway is problematic clay.

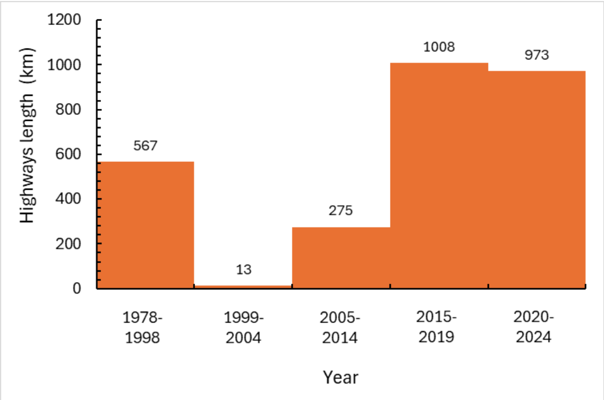

Figure 1. The development of the higways length in Indonesia since 1978 until 2024 Source: (Ministry of Public Works and Housing, 2020, 2024)

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0272-0280
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Based on the map of problematic clay soils in Indonesia, these soils are spread across all major islands in Indonesia (**Figure 2**). One of the problematic soils that pose a challenge to the highways construction in Indonesia is expansive soils. Expansive soils have charcartericstic to expand and shrink due to the content of expansive minerals such as montmorillonite. This mineral is excessively absorb the water. As a result, expansive soils can cause highways to be damaged and destroyed due to expansion-shrinkage (Asri et al., 2021). However, the expansive mineral is not one of the causes of swelling in the expansive soil.

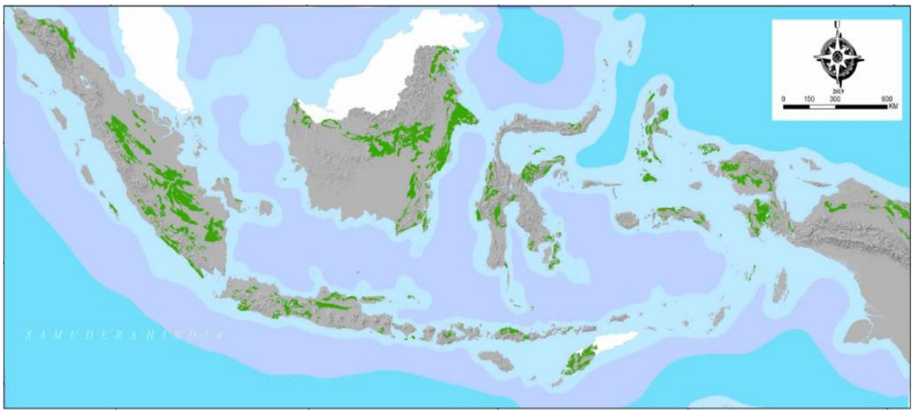

Figure 2. The map of problematic clay in Indonesia Source: (Pramudyo et al., 2019)

Sudjianto, 2015 mentioned there were several factors affecting the swelling of expansive soil, one of them was surcharge. The amount of load carried by expansive soil affects the swelling. According to Huang et al., 2019 and Sudjianto, 2015, the load increased by the deacreasing swelling potential. In reality, the magnitude and timing of traffic loads on the highways are various. To determine the form of behaviour caused by traffic loads on expansive soil, the number of loading/unloading are performed on the oedometer test.

The previous studies have done with different method. Cui et al., 2013 and Habibbeygi & Nikraz, 2018 applied the number of loading and unloading with the maximum stress increased by increasing number of cycles. The results shown that swelling potential tended to decrease and constant by increasing number of cycles. While Zeng et al., 2019 implemented the same maximum stress of each cycles. The result presented that the swelling potential decreased by increasing number of cycles. From these two studies, it can be concluded that the maximum stress value influenced the behaviour of swelling potential of the soil expansive soil. Based on the review of previous journals, there is no research that discusses the applied of maximum stress can return expansive soil to its initial condition. This maximum stress is called swelling pressure Sridharan et al., 1986. Therefore, in this research will discuss the behaviour of swelling potential of expansive soil by applying the number of loading and unloading cycles and the maximum stress equal to the swelling pressure of each cycles.

RESEARCH METHODS

Materials

The expansive soil was used in this research located from Meikarta, West Java Province. The method of retrieval sample by dredging the surface of the soil from the wild plants and sedimatation layer. After the soil'surface cleared, collect the expansive soil horizontally with a width of 0,5 cm and a depth of 0,5 – 1,2 m. The collected expansive soil was taken to lab to be tested the properties index and standar proctor test. The index properies of the expansive soil was secondary data from (Putri, 2022). Based the result of Atterberg limit, the expansive soil Meikarta was categorized as CH or clays of high plasticity (USCS) and very high swelling (All - Rawas & Goosen, 2006).

Sample test preparation

The soil was obtained in Meikarta in the form of bulk and quite hard. The bulk of the soil needed to be destroyed with a hammer. The smaller soil size was sieved with sieve No. 4 or 4,75 mm. Check the initial water content refers to ASTM D2216-19, 1999. The initial condition for each samples for this research with the same dry unit weight (1,53 gr/cm^3) and initial stress (±10 kPa). The three variation of initial moisture contents (10%, 15%, and 20%) were used in this research and every variations had two samples. The purpose that every samples have two test was to compare each sample to the other. This condition was required to compare for every variations of initial moisture contents.

Table 1. Initial conditions of Meikarta soil for this experiment

Parameter	Values					
Water content	10%		15%		20%	
Sample	1	2	3	4	5	6

After the value of initial moisture content was found, create of each samples with new moisture contents according to Table . Weight every sample expansive soils by 500 grams. Calculate the additional water to be mixed with the soil. Add gradually the water into the soil and mix thoroughly well. Put them into the plastic bag and let the sample rest overnight in order to reach maximumly homogeneity. After 24 hours, check the new moisture content every samples with the same method checking initial moiture content. If the new moisture contents of samples as planned, the samples were ready to be compacted. On the contrary, add the water with the same method earlier.

To compact samples directly inside the oedometer ring, measure the diameter and height of each oedometer rings by vernier caliper and weight by digital scale with accuracy level of 10^{-2}. Compaction method were done directly in the oedometer ring due to samples with moisture content below optimum were too dry, so it was not possible to compact the soil with standar proctor. If the samples were compacted with the standar proctor, when the soils were extruded from the mold, the compacted soils would collapse. Since there was not a standard of compacting soil directly inside the oedometer ring, the compaction method in this research slightly referred to standar proctor test by compacting the soil's samples into three layers. After calculating and scaling the weight every samples, divide the weight of the samples into three parts. Compact every parts of soil inside the oedometer ring gradually.

The swelling test in this research referred to ASTM D4546-08, 2008. Method C. When the sample's soil reached the initial height or swelling pressure, unload the stress by half from the pervious stress. Similar during loading phase, dial reading of new lower stress was done every 24 hours. When the samples reached initial stress (10 kPa), the samples has finished one cycle. The cycle was performed five times. After the test, samples were put out from oedometer test and drying in the oven for 24 hours.

RESULT AND DISCUSSION

Result of Initial Swelling on Meikarta's Expansive Soil

Swelling Strain vs Time

According to Dakshanmurthy, 1978 and Sridharan & Gurtug, 2004, the initial swelling deformation consisted of three phase, they were initial, primary, and secondary (**Figure 3**). Based on the result of initial swelling potential and log time of Meikarta's expansive soil in **Figure 4**, the swelling behaviour were similar with Dakshanmurthy, 1978. To accommodate analyzing initial swelling behaviour of expansive soil, the primary and secondary swelling were illustrated by two coefficients of swelling. They were defined in the following formula:

$$A_2 = \frac{\Delta L_2/L_0}{\Delta lg T_2}$$

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0272-0280
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$$A_3 = \frac{\Delta L_3/L_0}{\Delta lgT_3}$$

Where A_2 and A_3 are the swelling coefficients of primary and secondary swelling, respectively. ΔL_2 and ΔL_3 are the axial displacement due to primary and secondary swelling, respectively. L_0 is the initial height of the soil. ΔlgT_2 and ΔlgT_3 are the time required to swell in primary and secondary phase, respectively. The details of paraneters for calculating swelling coefficients in primary and secondary phases every samples are provided in **Figure 5.**. **Figure 6** shows the relation between swelling coefficients in primary and secondary phases and moisture content under same initial conditions (same dry density and initial stress). The results present that the peak value of the swelling coefficients in primary phase was 12,41 when the moisture content was 10%. While the peak value of of the swelling coefficients in secondary phase was 0,31 when the moisture content was 20%. Based on these results there was a contradiction behaviour in primary swelling and secondary swelling. The primary swelling coefficient increased with decreasing moisture content. While the secondary swelling coefficient increase with increasing moisture content. Therefore, the swelling behaviour in primary and secondary phase were not linear. These behaviour were different from the previous research by Huang et al., 2019, while the swelling behaviour in primary and secondary phase were linear.

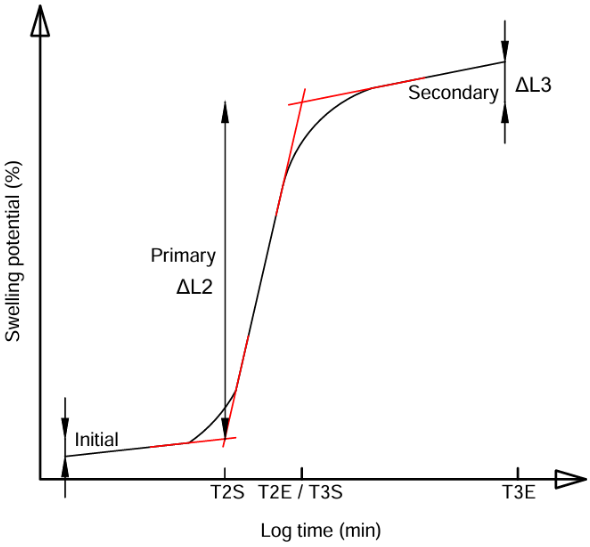

Figure 3. Three phase of initial swelling Source: (Dakshanmurthy, 1978)

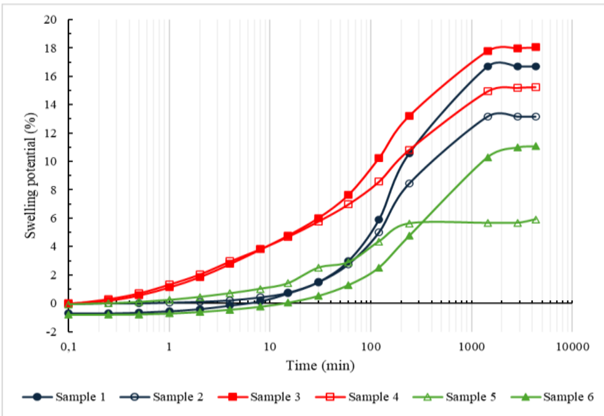

Figure 4. The deformation due to initial swelling of Meikarta's expansive soil with variation moisture contents

		Primary							Secondary						
Sample	**Wc**	**ΔSP0**	**ΔSP1**	**ΔSP**	**ΔL0**	**ΔL1**	**ΔL**	**Coefficient**	**ΔSP0**	**ΔSP1**	**ΔSP**	**ΔL0**	**ΔL1**	**ΔL**	**Coefficient**
1	**10%**	-0,70	16,71	17,41	57,00	1440,00	1,40	12,41	16,71	16,71	0,00	1440,00	4320,00	0,48	0,00
2		0,32	13,10	12,78	57,00	1300,00	1,36	9,41	13,10	13,16	0,06	1300,00	4320,00	0,52	0,11
3	**15%**	1,21	18,05	16,84	15,00	1390,00	1,97	8,56	18,05	18,05	0,00	1390,00	4320,00	0,49	0,00
4		2,40	15,20	12,80	21,00	1550,00	1,87	6,85	15,20	15,26	0,06	1550,00	4320,00	0,45	0,12
5	**20%**	0,34	5,73	5,39	9,00	216,00	1,38	3,91	5,73	5,91	0,18	216,00	4320,00	1,30	0,14
6		-0,67	10,95	11,62	43,00	1750,00	1,61	7,22	10,95	11,07	0,12	1750,00	4320,00	0,39	0,31

Figure 5. Recapitulation of primary and secondary swelling cofficents

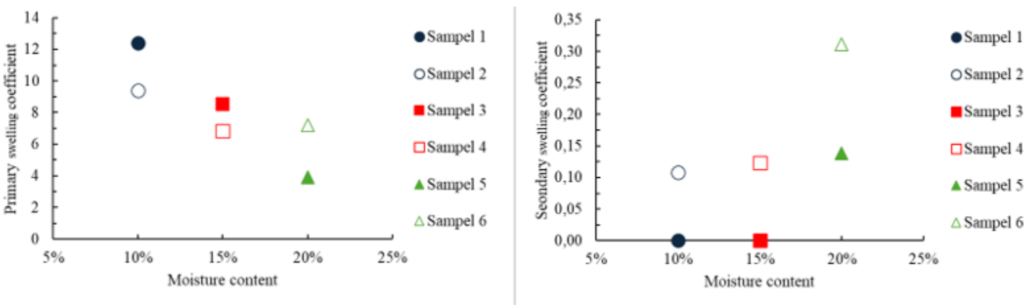

Figure 6. Relation of coefficient of swelling and initial moisture content. a) primary swelling. b) secondary swelling

Initial Swelling Potential vs Moisture Content

Based on the results of swelling test the initial swelling of Meikarta's soil in **Figure 7**, the lowest swelling potential were 5,91% and 11,07% with the initial moisture of both of samples were 20%.. While the samples with lower optimum moisture content, the highest value of the swelling potential was 18,05% when sample moisture content was 15%. The second highest of the swelling potential was 16,71% when sample moisture content was 10%. This unusual result of swelling potential were affected by the contradiction swelling behavour in primary and secondary phase. When samples with 10% moisture content had the highest swelling in primary phase, the behaviour of swelling changed when the sample entered the secondary phase of swelling. It had the lowest swelling in that phase.

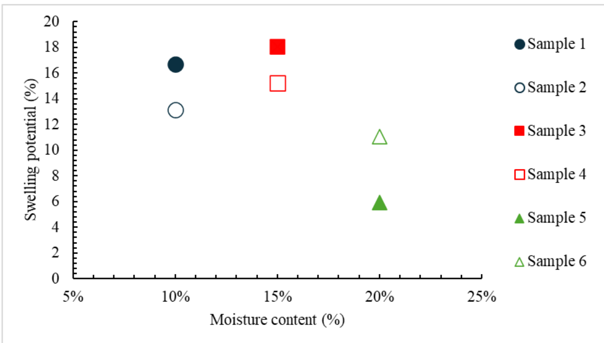

Figure 7. Relation between initial swelling potential and initial moisture content

This swelling potential behaviour similar to the result of research by Huang et al., 2019, the highest swelling potential occurred on the samples with 15% moisture content (the lowest was 10,10%). Huang et al., 2019 mentioned that regarding the initial moisture content, there was a threshold value when the swelling potential increased with increasing moisture content. At the certain moisture content, the swelling potential started to decrease. Accordingly, the samples with lowest moisture content did not always swell with the highest swelling potential. The other reason of this behaviour

pISSN 2302-4240
eISSN 2655-2086
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occurred was during samples preparation. Since it was not possible to compact the soil with standar proctor for sample with lower than optimum moisture content and there was not a standar to compact soil's samples directly inside the oedometer ring, the compaction method influenced the samples swelling behaviour, especially samples below optimum moisture content.

Factors Influencing the Initial Swelling Potential
Initial water content effect

According to Mochtar, 2011, samples with lower moisture content tend to swell larger. Expansie soil with lower initial moisture content have more capacity to absorb more water. This caused expansice soil swell larger than expansive soil with higher initial moisture content. How ever according to Figure 7, the largest swelling occurred on the samples with 15% moisture content. This indicates that samples with lowest moisture content did not always swell the largest.

Mineral and clay content

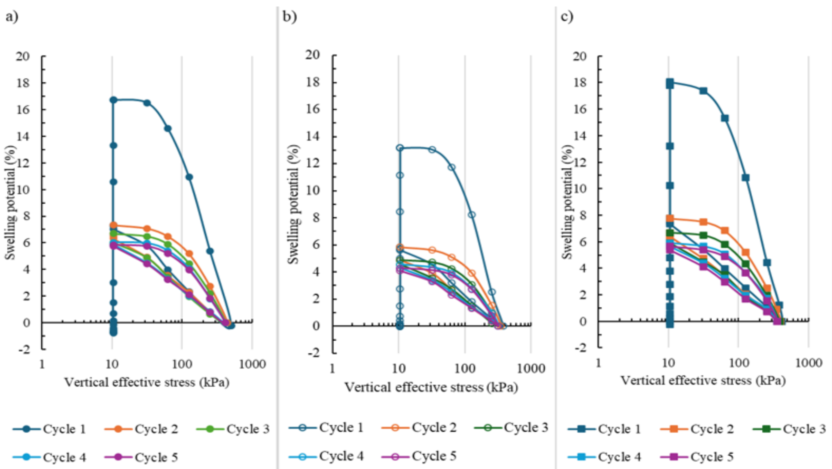
Besides initial moisture content, the other factors caused the swell behaviour were expansive mineral and clay content. Even though the samples were used all the same, however the possibility of the mineral and clay content each of the samples were different. This was proven by Reddy et al., 2020 with XRD test and sieve analysis each of samples. The results showed that each of samples had variation of percentage of expansive minerals and clay content.

Compacting method

Since there was not standard for compacting method directly inside the ring, the method influenced the swelling behaviour of expansive soil.

Result of Swelling Potential vs Number of Loading-Unloading Cycles
Swelling Potential vs Number of Loading and Unloading

Based on **Figure 5**, the curve of the swelling potential and the stress tend to smaller with increasing number of loading and unloading cycles. This behaviour influenced of swelling potential values for every variation of moisture contents tended to decrease with the increasing number of loading and unloading cycles (**Figure 10**). The most significant change was from zero to first cycles. After the first cycle, the decrease of swelling potential tended to smaller, the difference in swelling potential to the next cycles was quite similar. It was proven with the curves line after the first cycle became gentler. At the fourth cycle, the swelling potential was quite same. It was indicating all the samples was heading to be more stable. There is unique behaviour that the each of two samples with close initial swelling potential tended to converge to each other at the certain number of cycle (Sample 1 and 3, Sample 2 and 4, Sample 5 and 6). This indicates that the each pairs have the similar behaviour towards stability, even though the initial moisture contents were different, especially samples with lower than optimum moisture content.



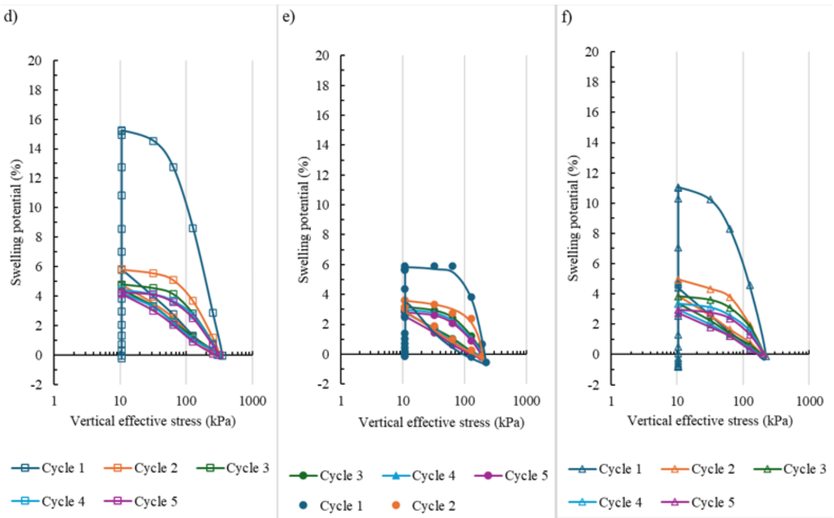


Figure 5. Graph relation swelling potential and stress. a) Sample 1. b) Sample 2. c) Sample 3. d) Sample 4. e) Sample 5. f) Sample 6

Number of Cycles	Swelling Potential (%)					
	10%		15%		20%	
	I	II	I	II	I	II
/cm3)	**1,53**	**1,53**	**1,53**	**1,53**	**1,53**	**1,53**
0	16,71	13,16	18,05	15,26	5,91	11,07
1	7,33	5,84	7,76	5,82	3,59	4,95
2	6,68	4,88	6,68	4,80	3,17	3,85
3	6,03	4,56	5,91	4,44	2,98	3,36
4	5,86	4,30	5,66	4,23	2,83	2,95
5	5,76	4,08	5,40	4,13	2,58	2,72

Figure 9. Swelling potential values in number of loading and unloading cycles

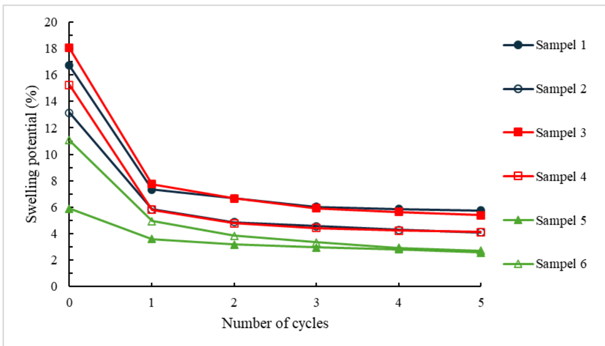


Figure 10. Graph relations swelling potential and number of loading and unloading cycles

Factors Influencing the Swelling Potential in Number of Loading and Unloading Cycles

The phenomena of the swelling potential and the swelling pressure tended to decrease by number of loading and unloading cycles were caused by the threshold stress and the swelling pressure itself. First, during loading phase, when the samples were added additional stress, the curve of compression moresteeper after passed the certain stress. According to Cui et al., 2013, this certain stress was called the threshold stress. When the samples reached the threshold stress, they experienced irreversible deformation, it means the soil could not back to the initial state or height. They were presented with steeper curve after samples passed threshold stress in every variation of moisture contents. The effect received by the samples when they passed the threshold stress, the swelling potential in the next cycle tended to decrease. In order to find the threshold stress value, it was quite similar to find a preconsolidation stress in a consolidation test. Casagandre, 1936 method was used in this research to find the threshold of each cylces.

Swelling pressure also influenced the behaviour of swelling during unloading phase. In this research, the curve of swelling tended steeper at the beginning of unloading phase. According to Cui et al., 2013, this behaviour was caused by the repulsive force when the samples reached the stress equal to the swelling pressure. Therefore, the swelling pressure influenced the swelling curve during the unloading phase.

CONCLUSION

Based on the results of this study, the following conclusions that can be drawn that the increasing number of loading and unloading cycles cause decreases of the swelling potential and the swelling pressure. The decrease value of swelling potential were caused by the threshold stress during loading phase and swelling pressure in the unloading phase. The threshold stress caused irreversible deformation of expansive soil. While the swelling pressure caused repulsive force at the beginning of unloading phase, resulting in greater swelling at the beginning of the phase.

REFERENCES

All - Rawas, A. A., & Goosen, M. (2006). *Expansive Soils Recent Advances in Characterization and Treatment*. https://doi.org/https://doi.org/10.1201/9780203968079

Asri, N., Uba, A., Sudjianto, A. T., & Suraji, A. (2021). Analisis Pengaruh Variasi Kadar Air Terhadap Swelling Volumetrik Tanah Lempung Ekspansif (Studi Kasus KM 51 Ruas Jalan Tirtoyudo Kabupaten Malang). *The 4th Conference on Innovation and Application of Science and Technology (CIASTECH 2021)*, 455–462. https://doi.org/https://doi.org/10.31328/ciastech.v0i0.3341

ASTM D2216-19. (1999). *Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass 1: D 2216 ± 98*. https://doi.org/10.1520/D2216-98

ASTM D4546-08. (2008). *Standard Test Methods for One-Dimensional Swell or Collapse of Soils*. ASTM International. https://doi.org/10.1520/D4546-21

Casagandre, A. (1936). The Determination of the Pre-Consolidation Load and Its Practical Significance. *Proceedings of The International Conference on Soil Mechanics and Foundation Engineering*, *3*, 60–64.

Cui, Y. J., Nguyen, X. P., Tang, A. M., & Li, X. L. (2013). An insight into the unloading/reloading loops on the compression curve of natural stiff clays. *Applied Clay Science*, *83–84*, 343–348. https://doi.org/10.1016/j.clay.2013.08.003

Dakshanmurthy, V. (1978). *A New Method to Predict Swelling Using Hyperbolic Equation*. *9*(1), 29–38.

Habibbeygi, F., & Nikraz, H. (2018). The Effect of Unloading and Reloading on the Compression Behaviour of Reconstituted Clays. *International Journal of GEOMATE*, *15*(51), 53–59. https://doi.org/10.21660/2018.51.52643

Huang, C., Wang, X., Zhou, H., & Liang, Y. (2019). Factors Affecting the Swelling-Compression Characteristics of Clays in Yichang, China. *Advances in Civil Engineering*, *2019*. https://doi.org/10.1155/2019/6568208

Ministry of Public Works and Housing. (2020, January 24). *The Development of Highways in 1978-2019*. https://data.pu.go.id/infografis/pengembangan-jalan-tol-tahun-1978-2019

Ministry of Public Works and Housing. (2024, March 26). *Supporting the Traffic Flow of Eid 2024, 6 New Toll Roads Ready to Operate Functionally*.

https://binamarga.pu.go.id/index.php/berita/dukung-kelancaran-mudik-lebaran-2024-6-ruas-tol-baru-siap-beroperasi-fungsional

Mochtar, I. B. (2011). The Effect of Water Content Change and Variation Suction in Behavior Swelling of Expansive Soil. *International Journal of Civil & Environmental Engineering IJCEE-IJENS*, *11*(3), 1–7.

Pramudyo, T., Sollu, W. P., Hermawan, W., Defrizal, Wahyudin, Wiyono, Hasibuan, G., & Sidarta, B. (2019). *Atlas Sebaran Batulempung Bermasalah Indoneisa* (A. Sugalang, Ed.). Badan Geologi Kementrian Energi dan Sumber Daya Mineral.

Putri, C. A. (2022). Effect of Wetting-Drying Cycles on Swelling-Shrinkage Behavior and Microstructures of Tropical Residual Expansive Soil. *International Journal of Technology*. http://ijtech.eng.ui.ac.id

Reddy, P. S., Mohanty, B., & Rao, B. H. (2020). Influence of Clay Content and Montmorillonite Content on Swelling Behavior of Expansive Soils. *International Journal of Geosynthetics and Ground Engineering*, *6*(1). https://doi.org/10.1007/s40891-020-0186-6

Sridharan, A., & Gurtug, Y. (2004). Swelling Behaviour of Compacted Fine-Grained Soils. *Engineering Geology*, *72*(1–2), 9–18. https://doi.org/10.1016/S0013-7952(03)00161-3

Sridharan, A., Sreepada Rao, A., & Sivapullaiah, P. V. (1986). Swelling Pressure of Clays. *Geotechnical Testing Journal*, *9*(1), 24–33. https://doi.org/10.1520/gtj10608j

Sudjianto, A. T. (2015). *Tanah Ekspansif Karakteristik dan Pengukuran Perubahan Volume*. Graha Ilmu.

Zeng, Z. xiong, Kong, L. wei, & Wang, J. tao. (2019). The Deformation and Permeability of Yanji Mudstone Under Cyclic Loading and Unloading. *Journal of Mountain Science*, *16*(12), 2907–2919. https://doi.org/10.1007/s11629-019-5550-4