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PRELIMINARY LABORATORY STUDY ON EXPANDABLE GROUND ANCHORS FOR EXPANSIVE SOIL

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ABSTRACT: Expansive soil is one of the problematic soil types due to its potential to swell highly when moisture content increases and shrink when moisture decreases. The soil exhibits mechanical behavior that is highly sensitive to changes in natural moisture content influenced by environmental factors such as infiltration and evaporation. It has the potential to damage civil structures such as road pavement and lightweight buildings. An alternative method to overcome this phenomenon is the use of ground anchors, a structural element installed into a soil or rock layer to withstand the tension load. An expandable ground anchor is proposed as an alternative to overcome the drawback of a helical anchor. Wings are installed in such a way that additional passive pressure is developed. The study was firstly conducted by performing anchor pullout capacity tests on a dense sand layer, followed by a swelling test of expansive soil, and finally, the performance test of ground anchor to withstand swelling pressure using three different sizes of steel box anchor prototypes, 4 cm × 4 cm × 30.5 cm, 5.5 cm × 5.5 cm × 30.5 cm and 7 cm × 7 cm × 30.5 cm. A series of anchor pullout capacity tests were conducted on a 90 cm dense sand layer, continued by a swelling test of 25 cm expansive. The result indicates that an expandable anchor can significantly withstand the swelling of expansive soil.

Keywords: Expansive soil, Expandable ground anchor, Pullout capacity

1. INTRODUCTION

Expansive soil is one of the problematic soil types due to its potential to swell highly when moisture content increases and shrink when moisture content decreases [1,2]. Civil structures such as buildings, bridges, and pavements laying on this very sensitive soil will be influenced and tend to be easily damaged when repeated infiltration and evaporation occur.

According to the Indonesian Ministry of Energy and Mineral Resources, expansive soil is very easily found in Indonesia. It is available on every main island, such as Sumatra, Java, Kalimantan, Sulawesi, and Papua [3]. Expansive soils in Central Java province are found in various locations, especially in the districts of Semarang [4], Purwodadi [5], Kudus, Cepu [6], and Sragen [7]. The map of expansive soil distribution is shown in Fig.1.

There are various methods to solve expansive soil problems, such as chemical stabilization [8,9,10,11,12,13], geosynthetics [14], and ground anchors. In some cases, the use of chemical stabilization, such as cement, lime, and fly ash, may cause potential health risks [15]. The effect of creep on long-term performance is a main concern in the use of geosynthetics [16]. Those methods may not be suitable, and consequently, the ground anchor method can be the alternative solution.

Two types of ground anchors were commonly used: helical ground anchor [17] and granular pile anchor/GPA [18,19,20]. A comparative study between helical and GPA indicated that GPA was more effective for expansive soil due to the higher contribution of soil resistance surrounding GPA compared to that offered by helical ground anchors [21]. According to the authors, passive pressure develops during the expansion of an expandable wing. It contributes to the additional passive pressure surrounding the anchor. This situation is not found in helical ground anchors.

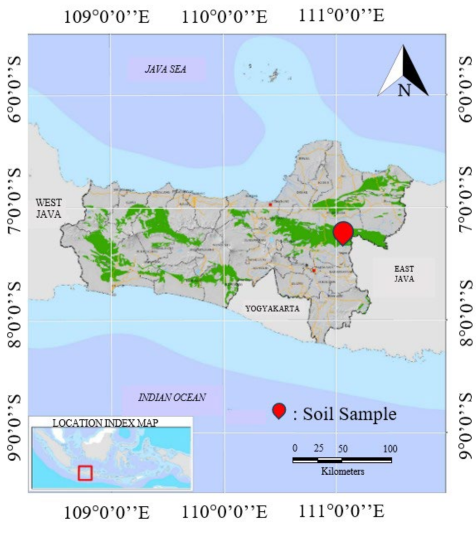

Fig.1 Expansive soil (green colored) map of Central Java [3]

This paper presents the result of a preliminary study of ground anchors in the laboratory using some different sizes of steel box anchor prototypes embedded into an expansive soil layer. Expandable wings are installed in such a way that additional passive pressure is developed. The type of anchor is quite similar to that anchor proposed by Kono [22,23]. However, instead of a cylinder shape, the anchor in this study is designed as a box shape. The study was first conducted by performing anchor pullout capacity tests on dense sand layers, a swelling test of expansive soil, and finally, a performance test of ground anchor to withstand swelling pressure. The results and discussion are presented below. In the future, an expandable anchor might be a promising method to overcome problems related to expansive soil.

2. RESEARCH SIGNIFICANCE

The expandable ground anchor was perhaps first conducted around the sixties. Recently, another type of expandable ground anchor was also proposed by Kono et al [22]. However, the issue of expansive soil was not considered in their study. The information on expandable ground anchors to overcome the effect of swelling of expansive soil is still relatively rare and needs more studies. The information resulting from this study will be useful for enriching the understanding of ground anchor performance.

3. MATERIAL & METHODOLOGY

In general, this study consisted of four main tests, all of which were conducted in the laboratory except for soil sampling. Initially, a pullout capacity test of the ground anchor prototype was performed using dense sand as soil medium. The test was conducted in two conditions; 1) allowing the wings to remain closed and 2) forcing the anchor to expand during pullout loading. Secondly, a free swelling test of expansive soil was conducted to obtain its expansivity by increasing its moisture content. Steel cylinder 75 cm in diameter and 40 cm in height was utilized. The next test was the swelling pressure test using a similar steel cylinder. The pressure due to swelling was measured using 3 proving rings installed in some particular places on the soil surface; 1 proving ring in the center, and the rest 2 are 25 cm from the center attached to the rigid hollow steel. Finally, the anchor performance to withstand swelling pressure was investigated both with and without anchor expansion. The detail of each step is presented in the following section.

3.1 Soil Preparation

Two types of soils granular (sand) and expansive fine-grained (clay) were utilized. Both were then identified to obtain index properties and classification. The sand was easily purchased in the market, meanwhile, expansive soil was taken from Sambungmacan, Sragen Regency, Central Java (red pin in the Fig. 1). The index properties as well as shearing tests of soil were conducted based on ASTM [24,25,26, 27] as listed in Table 1.

Table 1 Soil properties test code

Code	Test
ASTM D854	Specific Gravity
ASTM D422	Particle size analysis of soil
ASTM D2487	Unified Soil Classification System
ASTM D3080	Direct Shear Test of Soils Under Consolidated Drained Conditions

3.2 Ground Anchor Prototype

The ground anchor prototype consists of three components: the main body, wings, and rod. Main body is the main structure of the anchor, at which rod and wings are attached. Wings can be closed and opened to ensure the anchor is expandable. The anchor is expanded when the pullout load is applied. The aim of wing expansion is to mobilize passive pressure surrounding the anchor. The function of the rod is to connect the main anchor with the loading device. The 3D models of the anchor prototype are shown in Fig. 2 whereas the details are listed in Table 2.

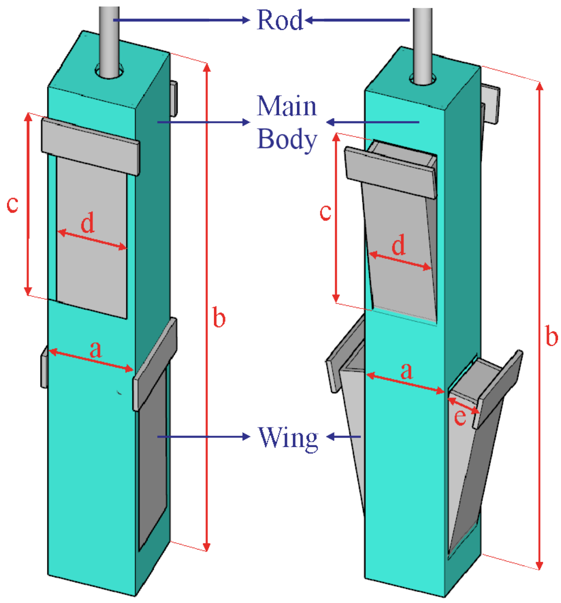

Fig. 2 Anchor prototype model

Table 2 Dimension of expandable anchor

Anchor	a (cm)	b (cm)	c (cm)	d (cm)	e (cm)
4 cm	4	30.5	10	26	1.5
5.5 cm	5.5	30.5	10.2	26.5	2
7 cm	7	30.5	10.5	27.6	2.5

3.3 Pullout Capacity Test

The pullout capacity test of the anchor was conducted on a dense sand layer. An anchor was placed 2 cm above the base plate of the steel cylinder. The sand was then poured and compacted layer by layer to attain the targeted thickness of 90 cm, bulk density (γ_b) of 18.44 kN/m^3, and internal friction ϕ of 40°. A pullout load with a rate of 0.7 cm/minute was applied using a hydraulic jack. During the pullout test, load versus displacement was recorded until a maximum displacement of 17.5 cm. The test was conducted on the anchor in both unexpanded (closed wing) and expanded, of which every single test was repeated three times. The setup of the anchor pullout capacity test is shown in Fig. 3.

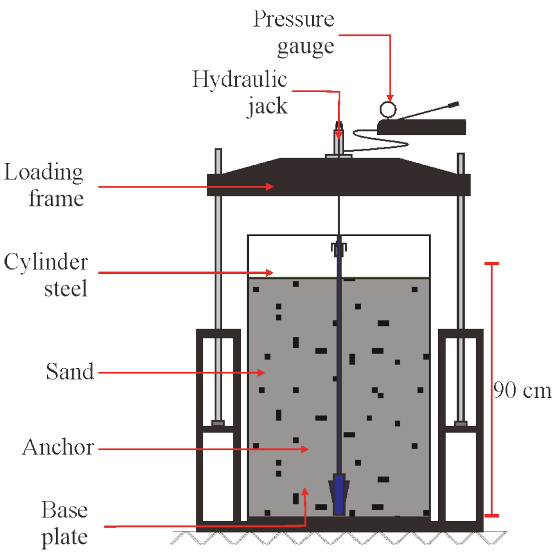

Fig. 3 Ground anchor pullout test setup

The ultimate pullout capacity of the anchor was interpreted from the load versus displacement curve using the tangent method [28]. This method is considered the simplest interpretation among various other recognized methods. It is determined simply by drawing two straight lines of the initial and the final tangent. The intersection point of two lines indicates the ultimate value of anchor pullout capacity as illustrated in Fig. 4.

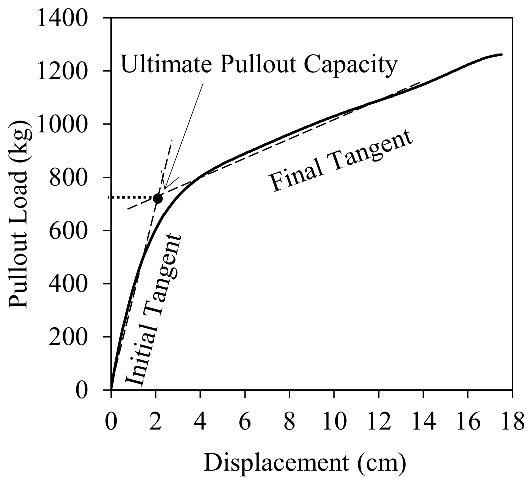

Fig. 4 Tangent method for interpreting displacement vs pullout load

3.4 Swelling Test

Two types of swelling tests were conducted to investigate the swelling potential and swelling pressure. The objective of the swelling potential test was to measure the maximum swelling at a given moisture content. A 25 cm thickness of expansive soil was placed into a steel cylinder 75 cm in diameter and 40 cm in height. The initial moisture content was determined around 5% above its shrinkage limit. It was conducted by adding a particular amount of water per day through four perforated PVC pipes. On the soil surface, a rigid steel plate disk was placed, and 5-dial gauges were installed on it. The swelling was then recorded every day until the targeted soil moisture content reached approximately 50% to obtain a curve relating moisture content and swelling. The setup of the test is shown in Fig. 5.

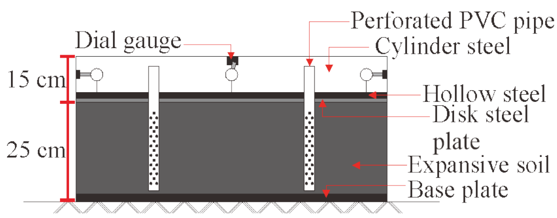

Fig. 5 Free swelling test scheme

Along with the free-swelling test, a swelling pressure test was also conducted using the same size of steel cylinders. However, swelling of the soil was confined using a loading frame. To ensure its rigidity, the steel plate was braced with a hollow steel, on which 3 proving rings were installed. The swelling pressure was recorded every day until the targeted soil moisture content reached around 50%. The setup of the test is shown in Fig. 6.

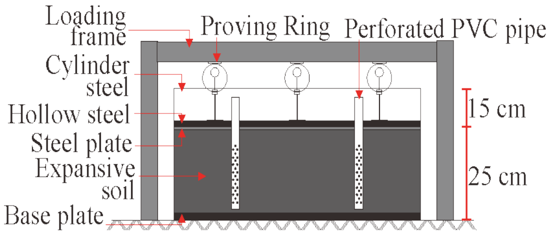

Fig. 6 Swelling pressure test setup

3.5 Anchor Performance Test on Expansive Soil

The performance test of the ground anchor to withstand swelling pressure was investigated as a continuation of the previous pullout capacity, free swelling, and swelling pressure tests. The test was quite like the free swelling test. However, in this performance test, the swelling of soil was retained by an anchor embedded into dense sand beneath the expansive soil layer. A series of tests were conducted on three various anchor prototypes; 4 cm, 5.5 cm, and 7 cm. Two soil layer, sand and expansive soil were used; sand in the bottom and expansive soil on the top. The sand was densified to obtain targeted unit weight using electric vibrator. Expansive soil layer was then placed on the top of sand layer. A plastic membrane was placed between two layer to avoid the water leakage. A rigid disk steel plate was then placed on the top of the layer. Four perforated PVC pipes were installed, and five dial gauges were attached to the cylinder wall. Water was then poured to have initial moisture content of 15 %.

For the first test, water was poured through perforated PVC to obtain 5% increase in moisture content. The swelling of soil was recorded per day and the total 8 days of observation was required for whole of the tests to obtain the targeted moisture content of approximately 50 %, when the test was terminated. The setup of the test is shown in Fig. 7.

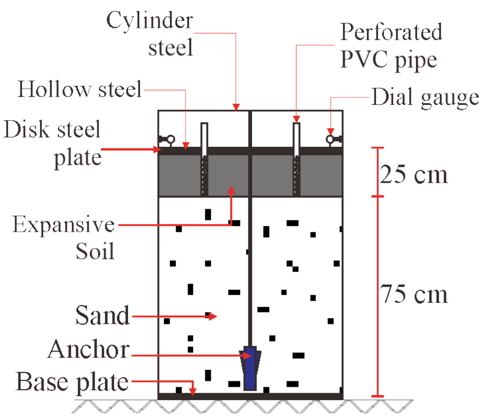

Fig. 7 The setup of anchor performance test on expansive soil

4. RESULTS AND DISCUSSIONS

4.1 Soil Properties

The physical and index properties of sand can be seen in Table 3. According to the USCS (Unified Soil Classification System), it is classified as well graded sand – silty sand (SW – SM).

Table 3 The index properties of sand

Test	Parameter	Unit	Value
Unit Weight	γ_b	kN/m^3	18.8
Specific Gravity	G_s	-	2.63
	Gravel (%)	-	0
	Sand (%)	-	90
Grain Size Analysis	Silt (%) & Clay (%)	-	10
	Cu	-	10
	Cc	-	2.24
USCS classification	-	-	SW-SM

The index property of expansive soil is shown in Table 4. According to the USCS, the soil is classified as high plasticity silt (MH). Based on its Atterberg limits (plasticity index) the clay is considered as expansive soil with a very high potential to swell (Table 5) and it has also a critical degree of expansion (Table 6).

Table 4 Expansive soil index properties

Test	Parameter	Unit	Value
Specific Gravity	G_S	-	2.67
	Gravel (%)	-	7.1
Grain Size Analysis	Sand (%)	-	14.4
	Silt & Clay (%)	-	78.4
	LL (%)	-	89.8
	PL (%)	-	40.8
Atterberg Limit	PI	-	49
	SL (%)	-	9.3
	LS (%)	-	26.99
Retained by sieve no. 4	-	-	4.28
USCS classification	USCS	-	MH

Table 5 Relationship between plasticity index and swelling potential of expansive soils [29]

Plasticity Index (%)	Swelling potential
0 – 15	Low
10 – 35	Medium
20 – 55	High
> 35	Very High

Table 6 Degree of expansion based on shrinkage limit and linear shrinkage [30]

Shrinkage limit (%)	Linear shrinkage (%)	Degree of expansion
< 10	> 8	critical
10 – 12	5 – 8	medium
> 12	0 – 5	noncritical

4.2 Pullout Ultimate Capacity

The purpose of the pullout loading test is to determine the ultimate pullout capacity of the anchor prototypes into a dense sand layer. It was conducted by evaluation of pullout load vs displacement curves using the method described in the previous section. The average pullout load vs displacement curves of all the tests are shown in Fig.8.

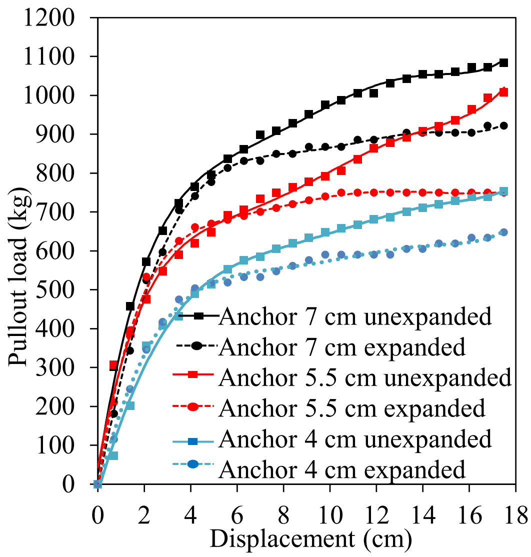

Fig. 8 Pullout capacity curves on dense sand

The pullout load vs displacement curve of the anchor 4 cm shows the relatively linear relation between loading and displacement. The curve is initially steep up to 500 kg of loading (4 cm displacement). It gradually changes to a relatively gentler, resulting an average ultimate capacity of 490 kg. The curve of the expanded anchor 4 cm is slightly steeper compared to the unexpanded anchor, resulting slightly higher average ultimate capacity of 536.67 kg. It shows that the expanded anchor contributes around 9.5 % to the pullout capacity.

Table 7 Anchor pullout capacity test results

Anchor	Wing	Ultimate Capacity (kg)	Wing Contribution (%)
4 cm	Unexpanded	490.00	9.5
	Expanded	536.67	
5.5 cm	Unexpanded	733.33	3.2
	Expanded	756.67	
7 cm	Unexpanded	776.67	4.9
	Expanded	815.00	

The result of the pullout test of the anchor 5.5 cm and 7 cm exhibits a steeper curve compared to the result of the smaller anchor. The larger the size of the anchor, the steeper the curve, and the higher the average ultimate capacity. It can also be evaluated that the wings contribute to the increase of its ultimate capacity. Table 7 shows the recapitulation of the pullout test.

4.3 Swelling Test

The purpose of conducting the swelling test is to investigate the effect of the changes in moisture content on the swelling soil (in both free swelling and swelling pressure). The result of the free swelling test is presented in Fig. 9. The initial moisture content was set to be around 15 %. Water was then flowed slowly through four perforated PVC pipes to obtain the targeted moisture content of 20 %. The thickness of the soil was then recorded using 5 Dial Gauges (DG) after 24 hours. The increase of moisture content for the next 5%/day was set up until 168 hours (7 days) to have a final moisture content of 50 %, resulting in a total swelling of 6.73 cm with an average swelling of 0.96 cm/day.

The effect of the increase in moisture content on swelling pressure was conducted according to the procedure described in previous section. The procedure of adding water to the soil to increase the moisture content is like that of the procedure for the free swelling test. The result of the test is presented in Fig. 10. The curve represents of the total force recorded from three installed proving rings. The curve indicates that the increase in moisture content causes the increase in swelling pressure. It can be seen from the curve that every 5 % the increase in moisture content causes the increase of pressure of 0.05 kg/cm^2. For the final moisture content of 50 % the swelling pressure is 0.54 kg/cm^2.

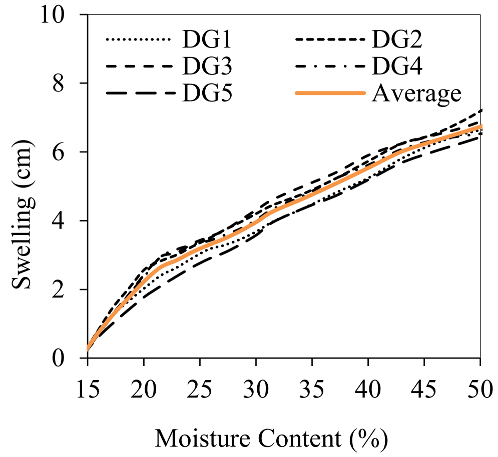

Fig. 9 Free swelling curves

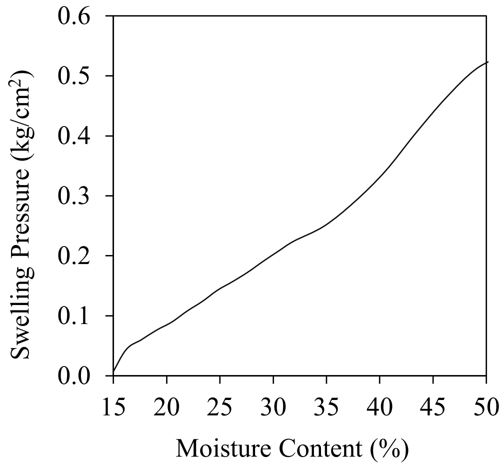

Fig. 10 Moisture content vs swelling pressure

4.4 Anchor Performance on Expansive Soil

The performance of the anchor to withstand swelling pressure due to the increase in moisture content was evaluated using a series of test. The procedure of anchorage swelling soil is described previously.

Fig. 11 illustrates the performance of the anchor both in unexpanded and expanded conditions. The green curve (the top one) illustrates the influence of moisture content increase on the swelling (free swelling). The performance of anchor 4 cm is illustrated by the blue curves, both in unexpanded (closed wing) and expanded anchor. When the soil moisture content reaches 50%, the unexpanded and expanded anchor 4 cm can reduce swelling up to 4.95 cm and 5.08 cm respectively. The red curves describe the performance of the anchor 5.5 cm. The anchor exhibits better performance as it can reduce swelling up to 5.84 cm and 5.97 cm for unexpanded and expanded conditions respectively. The highest performance is demonstrated by anchor 7 cm, as it can reduce swelling up to 5.91 cm and 6.04 cm for unexpanded and expanded conditions respectively. Table 9 summarizes the performance of the anchor to withstand swelling of the soil at 50% moisture content.

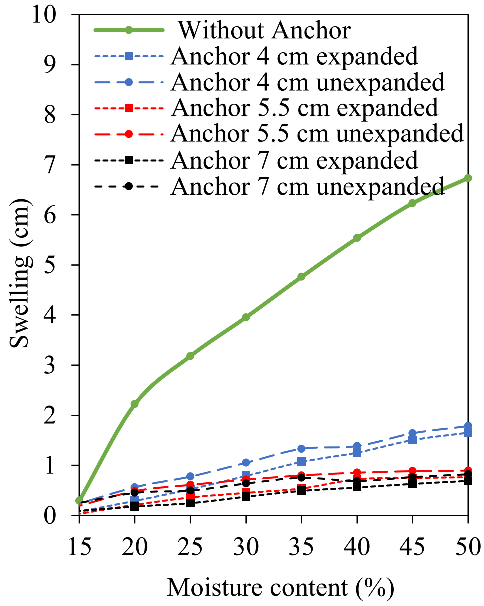

Fig. 11 Anchor performance on expansive soil

Table 9 Performance of Anchor at 50 % moisture content

Anchor	Wing	Reduced swelling (cm)	%
4 cm	Unexpanded	4.95	73.49
	Expanded	5.08	75.81
5.5 cm	Unexpanded	5.84	86.69
	Expanded	5.97	88.77
7 cm	Unexpanded	5.91	87.78
	Expanded	6.04	90.45

It can be seen from the result that the anchors demonstrate a good performance when it is embedded into the dense sand layer. It concludes that expandable anchor is a promising method as an alternative method to overcome a problem related to expansive soil.

In this paper, the expansion of the anchor is set to a single determined degree of expansion. Further study is in progress to investigate the effect of various degree of expansion on the increasing of anchor pullout capacity.

5. CONCLUSIONS

Based on the study, it can be concluded that:

1. The pullout capacity test of the anchor embedded into dense sand demonstrates the ability of the anchor to withstand tension forces. The ultimate capacity is affected by anchor size and wings.
2. The free swelling test has been conducted on high plasticity silt starting from 15% up until the final moisture content of 50 % resulting in the total swelling of 6.73 mm with an average swelling of 0.96 cm/day.
3. The swelling pressure test indicated that in every 5 %, the increase in moisture content causes the increase of pressure of 0.05 kg/cm^2, resulting in a swelling pressure of 0.54 kg/cm^2 when the moisture content reaches 50 %.
4. The performance of anchor to withstand swelling of expansive soil has been demonstrated. The anchor 4 cm can withstand the swelling up to 73.49 % and 75.81 % in unexpanded and expanded wings respectively. The bigger anchors of 5.5 cm and 7 cm show higher their capability up to 86.69 %, 88.77 %, 87.78 %, and 90.45 % in both unexpanded and expanded wings respectively.
5. It concludes that an expandable anchor is a promising method as an alternative method to overcome a problem related to expansive soil.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Mir B. A. and A. Sridharan A., Physical and Compaction Behaviour of Clay Soil-Fly Ash Mixtures, Geotech. Geol. Eng., Vol. 31, No. 4, 2013, pp. 1059–1072.

[2] Mir B. A., Some Studies on The Effect of Fly Ash and Lime on Physical and Mechanical Properties of Expansive Clay, Int. J. Civ. Eng., Vol. 13, No. 3–4, 2015, pp. 203–212.

[3] Geological Department, Atlas of Indonesian Problematic Clay Distribution, Indonesia's Ministry of Energy and Mineral Resources, 2019. pp. 14.

[4] Wardani S. P. R., Muhrozi, and Hedy R., The Problems and the Rehabilitation Work Design for Semarang-Wirosari Road (Central Java – Indonesia) on Expansive Soil, 16th International Conference on Soil Mechanics and Geotechnical Engineering, Vol.1, Issue 2, 2006, pp. 161–162.

[5] Soedarsono, Pratikso, Amalia N. A., and Rohmadoniati V., Characteristic Of Expansive Clay Soil (Case research at Bugel Village, Godong Subdistrict, Purwodadi Regency, Central Java Province), no. C, 2017, pp. 434–442.

[6] Sudjatmiko E. T., SPT and CPT Correlation of Expansive Clay in Cikarang, Indonesia, Journal of the Civil Engineering Forum, Vol. 8, Issue 3, 2022, pp. 245–256.

[7] Saputra C. A., Expansive Soil Swelling Test of Small Scale Laboratory Model on Sambungmacan Soil, Central Jawa, PENA TEKNIK: Jurnal Ilmiah Ilmu-Ilmu Teknik, Vol. 8, No. 1, 2023, p. 32.

[8] Ghobadi M. H., Abdilor Y., and Babazadeh R., Stabilization of Clay Soils Using Lime and Effect of pH Variations on Shear Strength Parameters, Bulletin of Engineering Geology and the Environment, Vol. 73, No. 2, 2014, pp. 611–619.

[9] Chenarboni H. A., Lajevardi S. H., Abasi H. M., and Zeighami E., The Effect of Zeolite and Cement Stabilization on the Mechanical Behavior of Expansive Soils, Construction and Building Materials, Vol. 272, 2021, pp. 121630.

[10] Nalbantoğlu Z., Effectiveness of Class C Fly Ash as an Expansive Soil Stabilizer, Construction and Building Materials, Vol. 18, No. 6, 2004, pp. 377–381.

[11] Nalbantoglu Z. and Tuncer E. R., Compressibility and Hydraulic Conductivity of a Chemically Treated Expansive Clay, Canadian Geotechnical Journal, Vol. 38, No. 1, 2001, pp. 154–160.

[12] Barman D. and Dash S. K., Stabilization of Expansive Soils using Chemical Additives: A Review, Journal of Rock Mechanics and Geotechnical Engineering, Vol. 14, No. 4, 2022, pp. 1319–1342.

[13] Mir B. A. and Sridharan A, Mechanical Behaviour of Fly-ash-treated Expansive Soil, Proc. Inst. Civ. Eng. Gr. Improv., Vol. 172, No. 1, 2019, pp. 12–24.

[14] Singh D. D., and Shukla S. K., Effect of Expansive Soils on Swelling Behavior of Encapsulated Sodium Bentonite of Geosynthetic Clay Liner (GCL), Materials Today : Proceedings, 2023, pp. 1-5.

[15] Xu D. M., Fu R. B., Wang J. X., Shi Y. X., and Guo X. P., Chemical Stabilization Remediation for Heavy Metals in Contaminated Soils on The Latest Decade: Available Stabilizing Materials and Associated Evaluation Methods — A Critical Review, J. Clean. Prod., Vol. 321, 2021, p. 128730.

[16] Chantachot T., Kongkitkul W., and Tatsuoka

F., Load-strain-time behavours of two polymer geogrids affected by temperature, Int. J. GEOMATE, Vol. 10, no. 3, 2016, pp. 1869–1876.
[17] Foundation Technologies Inc, Helical Ground Anchors, https://www.foundationtechnologies.com/products/chance-helical-anchors/.
[18] Khan H. A. and Gaddam K., An Experimental Study on Heave and Uplift Behaviour of Granular Pile Anchor Foundation System, IOP Conference Series: Earth and Environmental Science, Vol. 822, No. 1, 2021, pp. 1-9.
[19] Siang J. L. M., Sfoog E. H., Naji N., Yi S. S., Guntor N. A. A., and Prasetijo J., Ground Improvement using Granular Pile Anchor System: Resistance to Heave and Uplift Pressure, Indonesia Journal of Electrical Engineering and Computer Science, Vol. 19, No. 1, 2020, pp. 403–411.
[20] Nusier O., Alawneh A., and Alsuqaier A., The Efficiency of Granular Pile Anchor Foundation System in Reducing Heave of Irbid Expansive Clayey Soil: An Experimental Investigation, Case Studies in Construction Materials, Vol. 18, 2023, pp. e01846.
[21] Singh S., Laddha A., Hiranandani P., and Purohit D. G. M., A Review on Pull-out Capacity of Helical Anchors in Clay and Sand, Journal of Architecture and Civil Engineering, Vol. 3, Issue 6, 2017, pp. 24–32.
[22] Kono K., Nakahashi A., Daicho D., Fukushima N., and Fukagawa R., Stractural Simulation On an Open-Wing-Type Ground, International Journal of GEOMATE, Vol. 14, Issue 46, 2018, pp. 89–94.
[23] Johnson N. and Sandeep M. N., Ground Improvement Using Granular Pile Anchor Foundation, Procedia Technol., Vol. 24, 2016, pp. 263–270.
[24] ASTM International, ASTM D854, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, West Conshohocken, United States, 2014.
[25] ASTM International, ASTM D442, Standart Test Method for Particle-Size Analysis of Soils, West Conshohocken, United States, 2007.
[26] ASTM INTERNATIONAL, ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), West Conshohocken, United States, 2017.
[27] ASTM International, ASTM D3080, Standar Test Method for Direct Shear Test of Soils Under Consolidated Drained Condition, West Conshohocken, United States, 2011.
[28] Bhardwaj S. and Singh S. K., Experimental Study on Model Micropiles under Oblique Pullout Loads, Tunneling and Underground Construction, 2014, pp. 610–621.
[29] Chen F. H., Foundations on Expansive Soils, Elsevier Scientific, Colorado, 1979, pp. 18.
[30] Dawson R. F., Altmeyer W. T., Barber E. S., and DuBose L. A., Discussion of Engineering Properties of Expansive Clays, Transactions of the American Society of Civil Engineers, Vol. 121, No. 1, 1956, pp. 664–675.