THE SEAWATER AND FRESHWATER INFLUENCE ON EXPANSIVITY BEHAVIORS OF CLAY MINERALS

PENGARUH AIRLAUT DAN AIRTAWAR TERHADAP DAYA KEMBANG SUSUT MINERAL LEMPUNG

Dian Agus Widiarso[1], Nurakhmi Qadaryati[1], Wiyatno Haryanto[2]

[1]Department of Geological Engineering, Universitas Diponegoro, Jl. Prof. Soedharto, SH., Tembalang, Semarang, Indonesia
[2]Indonesian Society of Geotechical Engineering, Jakarta, Indonesia

Corresponding author: dianagus@lecturer.undip.ac.id

(Received 07 July 2021; in revised from 22 July 2021; accepted 22 September 2021)

ABSTRACT: Semarang City subsurface geology is characterized by an intercalating of loam-silt and clayey units. The behavior of clay materials are their expansivity potency of their volume when in contact with water. Some problems in the presence of tidal flooding appears when the seawater ingress to the shoreland that causes severe damage to infrastructures. This research attempts to reveal the influence of both seawater and freshwater on the expansivity behaviors of the clayey materials based on its mineral composition. In order to observe expansivity potency of clay minerals, 28 samples from four drill hole samples were soaked in seawater and freshwater for twenty-four hours. The initial volume of each samples were then compared with the samples volume after being soaked.X-Ray Diffraction (XRD) analysis was also conducted on selected samples to determine their mineral composition. The ANOVA test was then introduced to distinguish the influence of certain mineral types and composition to the clay expansivity behaviors. Confidence level and alpha (α) are about ninety-five percent and about five percent, respectively. The result of this research has proven that montmorilonite is clay mineral type that is most affected by expansivity behaviors when immersed in seawater and freshwater compared to kaolinite and illite minerals.

Keywords: Clay minerals, montmorillonite, expansivity, seawater, freshwater, tidal flooding.

***ABSTRAK**: Kota Semarang tersusun dari satuan lanau dan lempung. Mineral lempung memiliki sifat kembang susut dari segi volumenya ketika mengalami kontak dengan air. Permasalahan yang timbul akibat terjadinya peristiwa banjir pasang di perkotaan, adalah masuknya air laut menuju ke pantai dan daratan yang dapat merusak infrastruktur. Penelitian ini bertujuan untuk menunjukkan dampak yang ditimbulkan oleh air tawar maupun air laut terhadap kembang susut mineral lempung berdasarkan komposisi mineralnya. Untuk mengamati perubahan volume dalam mineral lempung, sebanyak 28 sampel dari empat sampel sumur bor direndam dalam air tawar dan air laut selama 24 jam. Kemudian volume awal setiap sampel dibandingkan dengan volume sampel sesudah dilakukan perendaman. . Uji X-Ray Diffraction (XRD) juga dilakukan pada sampel pilihan untuk mengetahui komposisi mineral sampel tersebut. Uji ANOVA dengan tingkat kepercayaan 95% dan alpha (α) 5% diterapkan untuk mengetahui pengaruh tipe dan komposisi mineral lempung tertentu terhadap kembang susut yang terjadi. Penelitian ini berhasil membuktikan bahwa montmorilonit merupakan jenis mineral lempung yang paling terpengaruh oleh sifat kembang susut di daerah penelitian ketika direndam dengan air tawar dan air laut, dibandingkan dengan kaolinit dan ilit.*

***Kata Kunci:** Mineral lempung, montmorilonit, kembang susut, air laut, air tawar, banjir pasang*

INTRODUCTION

In general, a clayey material is an important part of the soil, which mostly involves chemical weathering of rock-forming minerals and will change in some engineering behaviors when it contacts seawater (Aksoy et al., 2008). Some research on mineralogical and geotechnical approaches in coastal areas with a predominance of clay lithology has been performed widely in several countries. For example Veerasingam et Al.(2014) studied mineralogy and geotechnic for a construction planning in Lianyungang – a region of China that requires some investigative data regarding the origin of rocks, and some geotechnical studies of the clay minerals onsite by Liu et al. (2011). Similar case from the Changi project in Singapore within Quaternary sediment, which are composed of soft marine clay recognized as problematic soil for geotechnical engineering purposes (Bo et al., 2015). The major decision in construction process involves selecting a suitable site with the best soil conditions (Manimaran et al., 2019).

Based on geological setting, Semarang City is a part of the Holocene sediment which is composed of a river, flood-plain, swamp, tidal, and coastal deposits (Thanden et al., 1996). The sediment is characterized by intercalating of a dominant loam-silt and clay units and constituted normally consolidated clays with a soft and very soft consistency (Widiarso et al., 2019). This city is the capital city of Central Java Province, located in a large coastal deposit area with significant environmental issue. One problem such as tidal flooding in which the seawater ingresses frequently to the shoreland area during a high tide period (Wahyudi, 2007), causes serious damage in infrastructures and residential areas (Marfai and King, 2008; Muslim et al., 2019). The quality of the circumference decreases due to being influenced by tidal flooding (Sulaksana et al., 2019). One of the most important goals of disaster management teams is to protect the assets and infrastructures of the community from natural disasters such as floods (Darani and Bashiri, 2018).

Based on previous research, it was explained that claystone which has montmorillonite mineral composition more than 72% may indicate a reduction in the expansivity of the clay material when mixed with seawater, conversely, it exhibits less expansive when mixed with freshwater (Elmashad and Ata, 2014). Supporting that study result, other studies explained that the clay minerals such as kaolinite, chlorite, and mixing of other clay minerals have a lower reaction (low reactivity) than montmorillonite mineral when mixed with seawater (Aksoy et al, 2008). Therefore, the authors intend to present this research to study the influence of seawater and freshwater on the expansivity behaviors of clay materials based on particular mineral composition.

Clay Minerals Overview

Soil is defined as a constituent mineral with or without organic material left over from plants and fauna that are weathered, structured, and textured. It is useful as a construction material in various kinds of civil engineering works. As addition, the land also functions as a support for building foundation (Das, 2008). Based on the cohesivity, soils can be distinguished as cohesive and non-cohesive soils, fine-grained or coarse-grained soils (Bowles, 2015).

The abundance of clay minerals in the soils varies greatly, influenced by various things, including the type of origin rock, weathering, and diagenesis process, which cause variations both vertically and laterally. The most influential factor that determines soil types is the particle size distribution (Kaream et al., 2020). Clay materials with particle sizes smaller than 0.002-mm can be divided into three subgroups of clay minerals, are kaolinite, illite, and montmorillonite (Dunn et al., 1980).

Tidal Flood

Tidal flood is a flood that inundating the lowland areas on the coast, including estuaries and deltas, resulting in salty/brackish groundwater (Marfai, 2004). The underlying problem of tidal flooding affecting shoreland and coastal area is that the land level is lower than the high tide level. Furthermore, human activities include excessive groundwater extraction, dredging on the shipping lines, coastal reclamation, etc., are some factors contribute the tidal flooding.

METHODS (AND MATERIALS)

The research area is in Semarang City, especially on the alluvium and flood plains as referring to the Geological Map of Magelang and Semarang, Java (Thanden et al., 1996). The soil mechanics laboratory tests are performed on 28 clay soil samples, selected from 4 (four) drill hole samples (BM01, BM03, BM04, and BM05 in Figure 1). The depths of the drill hole samples are 60m, 40m, 30m, and 30m, respectively. The samples were then soaked d in seawater and freshwater for twenty-four hours. The samples volume were measured prior and after the soaking test. During the time, we observed the changes in their volumetric parameters. The difference of the lithologic volume is a product of the reduction between a final volume and the initial volume. The freshwater and seawater used in the soaking tests have been analyzed in terms of chemical and physical properties in Groundwater Utilization Sector, Geological Agency, Ministry of Energy and Mineral Resources, Bandung. (Table 1).

Table 1. The results of chemical analysis of fresh water and seawater sample

Type of Water	Indicators (mg/L)					
	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Cl^{-}	SO_4^{2-}
Seawater	315	749,5	248,5	7293,5	13393,9	246,5
Freshwater	25,4	6,4	6	19,1	14,4	1

X-Ray Diffraction (XRD) tests were performed on the similar samples as the soaking test. The purpose of this analysis is to determine the clay mineral type of the samples. The results were then processed by using X-pert Highscore and Siroquant software. The software is used to obtain the quantitative data on the diffraction pattern of a sample. ANOVA was then performed to observe the effect of mineral types and composition on the clay mineral expansivity. It is also used as an analytical tool to test the hypothesis by assessing whether there are any differences among the groups. Hypothesis testing is performed at a ninety-five percent confidence level and alpha (α) five percent.

RESULTS AND DISCUSSION

The result of the soaking test is shown in Table 2, it is observed that 3 samples were broken after soaking in both seawater and freshwater (BM 05-2, BM 05-5, BM 05-6). Therefore, these three samples were not taken into account for statistical ANOVA test. In addition to these three samples, one sample BM 05-3 was also broken after soaking in freshwater. Meanwhile, the result of XRD (X-ray diffraction) analysis in the clay mineral compositions is demonstrated in Table 3.

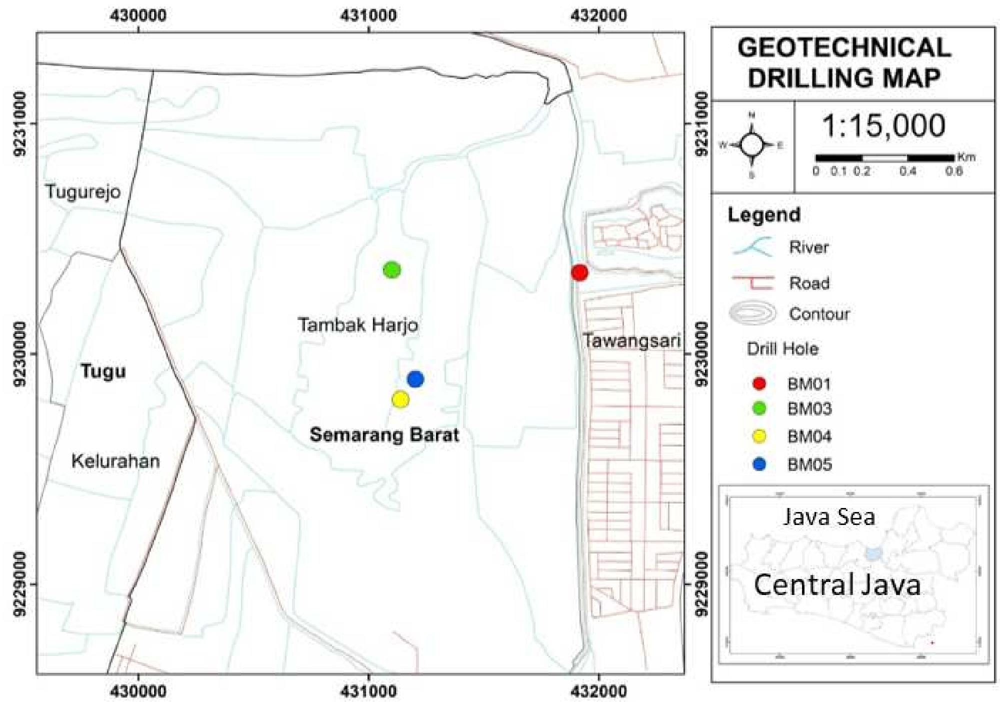

Figure 1. Geotechnical Drilling Map

Table 2. Test parameters of soaking

No	Code	Depth	Soaking in Sea Water		Soaking in Fresh Water	
			Initial Volume (cm³)	End Volume (cm³)	Initial Volume (cm³)	End Volume (cm³)
1	BM 01-1	5 - 6	166	263	133	120
2	BM 01-2	11 - 12	113	140	113	148
3	BM 01-3	15 - 16	113	159	113	135
4	BM 01-4	23 - 24	113	119	107	159
5	BM 01-5	25 - 26	90	453	90	509
6	BM 01-6	31 - 32	73	145	84	428
7	BM 01-7	41 - 42	113	127	113	137
8	BM 01-8	51 - 52	106	133	106	136
9	BM 01-9	59 - 60	129	154	129	145
10	BM 03-1	5 - 6	113	176	113	206

11	BM 03-2	11 - 12	73	122	113	161
12	BM 03-3	15 - 16	109	168	113	183
13	BM 03-4	21 - 22	107	139	140	190
14	BM 03-5	25 - 26	127	468	127	171
15	BM 03-6	29 - 30	113	144	106	146
16	BM 03-7	39 - 40	159	200	172	170
17	BM 04-1	5 - 6	113	146	113	176
18	BM 04-2	11 - 12	99	129	99	154
19	BM 04-3	15 - 16	109	134	109	166
20	BM 04-4	21 - 22	95	117	79	76
21	BM 04-5	25 - 26	95	142	79	956
22	BM 04-6	29 - 30	113	662	113	708
23	BM 05-1	5 - 6	113	108	55	163
24	BM 05-2	11 - 12	104	broken	104	broken
25	BM 05-3	15 - 16	132	190	112	broken
26	BM 05-4	21 - 22	119	468	79	179
27	BM 05-5	25 - 26	119	broken	119	broken
28	BM 05-6	25,5 - 26	98	broken	95	broken

Statistical Test on Soaking in Seawater

The independent variables in the statistical test with ANOVA were the mineral content in the sample, which are kaolinite, montmorillonite, and illite. Statistical tests were carried out by observing changes in the sample volume before and after soaking without considering the soil water content. The coefficient of significance value (α) is determined at 0.05. The significance or probability column of the ANOVA test results indicate the level of significance. The significancevalue (sig value) is used as a cut-off model to determine if the independent variable affects or does not affect the dependent variable. The independent variable is considered to affect the dependent variable if the sig value is lower than 0.05.

Table 3. Percentage of identified mineral from XRD analysis

No	Code	Depth	Identified minerals (%)			
			Quartz	Kaolinite	Illite	Montmorillonite
1	BM 01-1	5 - 6	54.97	40.56	4.47	0
2	BM 01-2	11 - 12	57.33	35.09	7.58	0
3	BM 01-3	15 - 16	59.69	39.54	0	0.76
4	BM 01-4	23 - 24	42.35	48.53	9.12	0
5	BM 01-5	25 - 26	29.48	43.98	0	26.54
6	BM 01-6	31 - 32	28.47	40.95	0	30.58
7	BM 01-7	41 - 42	35.71	0	63.77	0.52
8	BM 01-8	51 - 52	40.48	13.42	33.55	12.54
9	BM 01-9	59 - 60	28.54	44.23	0	27.23
10	BM 03-1	5 - 6	47.26	20.15	31.70	0.89
11	BM 03-2	11 - 12	48.36	17.41	33.18	1.04
12	BM 03-3	15 - 16	47.98	22.34	28.34	1.35
13	BM 03-4	21 - 22	43.62	33.87	0	22.51
14	BM 03-5	25 - 26	27.03	0	60.36	12.61
15	BM 03-6	29 - 30	23.82	47.83	0	28.35
16	BM 03-7	39 - 40	28.06	44.60	0	27.34
17	BM 04-1	5 - 6	72.61	0	26.11	1.27

18	BM 04-2	11 - 12	64.78	28.85	0	6.37
19	BM 04-3	15 - 16	45.72	29.01	22.06	3.21
20	BM 04-4	21 - 22	50.19	49.05	0	0.76
21	BM 04-5	25 - 26	33.84	0	59.44	6.72
22	BM 04-6	29 - 30	28.04	38.10	0	33.86
23	BM 05-1	5 - 6	60.04	34.40	0	5.56
24	BM 05-2	11 - 12	48.12	25.29	24.71	1.88
25	BM 05-3	15 - 16	94.37	0	0	5.63
26	BM 05-4	21 - 22	59.62	0	0	40.38
27	BM 05-5	25 - 26	12.80	0	87.20	0
28	BM 05-6	25,5 - 26	63.55	35.81	0	0.65

Based on Table 4, it shows that the sig value is 0.024, smaller than 0.05 (α), suggests that the model passed and can be used to specify the influence of the mineral contents in samples on sample volume changes after soaked in seawater. The probability value (significance) is below 0.05, indicates all independent variables influence the dependent variable and vice versa.

Tabel 4. ANOVA test result on soaking in seawater

Model	df	Mean square	F	Sig.
Regression	3	48961.1	3.897	0.024b
Residual	20	12563.6		
Total	23			

a. Dependent variable: after soaked in seawater

b. Predictors: (constant), montmorillonite, kaolinite, and illite.

Afterwards, the F-count value (F in table 4) is then compared to the F-table parameter. The F-table is obtained by calculating the number of df (degree of freedom). The df of multiple regression consists of df1 and df2 with the following formula:

df1=k-1...(1)

df2=n-k...(2)

under following condition:

n = number of samples

k = number of independent variables

For this statistical tests, 25 samples were analyzed. As has been mentioned before, from total 28 samples, 3 samples (BM 05-2, BM 05-5, and BM 05-6) were broken after being soaked in seawater, therefore were not considered for the statistical test. The soaking test in seawater has k value = 3 and n = 25. Hence, the values of df1 = 2 and df2 = 22 are obtained. Based on F distribution table at 0.05 sig level, the F-table value is 3.443 (Nuryadi et al., 2017), which is smaller than F-count (3.897). Therefore, it can be concluded that all independent variables influence the dependent variable. The test results of the coefficient value on the soaking in seawater is displayed in Table 5.

In Table 5, t value is the benchmark to see the influence of variable (partial) by comparing their each t value to the t-table value. When the value of t-count is greater than the t-table value, denotes the variable has an impact. By calculating the number of df (degree of freedom), t-table is obtained with the following formula:

df=n–(k–1)...(3)

under the following condition:

n = number of samples

k = number of independent variables

The calculation of df (degree of freedom) = 25 – (3–1) = 23.

Based on t-table value for multiple regression df 23 at sig 0.05 is 1.71387 (Nuryadi et al., 2017). T-count value of montmorillonite mineral reveals a value of 3.303 (Table 5), which is greater than t-table value. In contrast, t-count value of kaolinite and illite are -0.375 and 0.568, respectively, which are lower than t-table (1.71387). It is concluded that montmorillonite mineral has the most influence on the changes in sample volumetric when it is soaked in seawater compared to kaolinite and illite minerals.

The sig column in Table 5 represents the significance level of each independent variable to determine whether the variables influence the dependent variable or not. When sig value is smaller than 0.05 (α), signify that there is significant impact, in contrast, when it is greater than 0.05 (α), then there is no influence at all. The result reveals that only sig value of montmorillonite mineral has a lower value than 0.05 (0.004). So, montmorillonite mineral has the most influence on changes in sample volume compared to kaolinite and illite minerals when soaked in seawater.

Statistical Test on Soaking in Freshwater

The data is processed using multiple regression analysis methods with the dependent variable is the percentage of difference between the initial volume with the sample final volume, after soaked in freshwater for

Tabel 5. Coefficient test result of soaked in seawater

Model	t	Sig.
(Constant)	1.503	0.148
Kaolinite	-0.375	0.712
Illite	0.568	0.576
Montmorillonite	3.303	0.004

twenty-four hours. The ANOVA test result shown in Table 6 with the sig value of about 0.249.

Tabel 6. ANOVA test result on soaked in freshwater

Model	df	Mean square	F	Sig.
Regression	3	93014.1	1.484	0.249b
Residual	20	62688.1		
Total	23			

Dependent variable: after soaked in freshwater

Predictors: (Constant), montmorillonite, kaolinite, and illite

The value is greater than 0.05 (α), so the model is considered failed, and cannot be used to determine the influence of sample's mineral content in the changes of sample volume after being soaked in freshwater. The probability value (significance) is above 0.05, suggests not all independent variables have an affect on the dependent variable and vice versa.

Only 24 out of 28 samples were analyzed in the statistical tests after being soaked in freshwater because four samples (BM 05-2, BM 05-3, BM 05-5, BM 05 -6) were broken after being soaked. The soaking test in freshwater has a value of k = 4 and a value of n = 24, so that the values of df1 = 3 and df2 = 21 are obtained. Based on the F distribution table at the 0.05 sig level, the F-table value is 3.072 (Nuryadi et al., 2017), greater than the F-count amounting to 1.484 (Table 6). It can be concluded that not all independent variables have an influence on the dependent variable.

Table 7. Coefficient test result of soaked in freshwater

Model	t	Sig.
(Constant)	-0.012	0.990
Kaolinite	0.364	0.719
Illite	1.304	0.207
Montmorillonite	1.837	0.081

The df value for the soaking test in freshwater is = 24–(4–1) = 21. Based on the t-table value for the multiple regression df 21 at sig 0.05 is 1.72074 (Nuryadi, et al., 2017). The t-count value of the montmorillonite mineral in Table 7 shows a value of 1.837, so the montmorillonite mineral has the most influence in the changes of sample volume compared to the kaolinite and illite minerals when soaked in freshwater.

Based on a comparison of the ANOVA difference test for soaking of the clay minerals in seawater and freshwater, it is obtained that the F value is 3.897 with a sig of 0.024, while the results of soaking in freshwater, the F value is 1.484 with sig value 0.24. Hence, it is suggested that seawater has a more significant influence on the expansion process of the clay minerals compared to freshwater.

Montmorillonite is a mineral formed by two sheets of silica and one sheet of aluminium. The octahedral sheet is located between two silica sheets with the ends of the tetrahedra. Tetrahedra is mixed with hydroxyl of the octahedral sheet to form an aluminium single layer by magnesium. Due to the weak Van der Waals bonding forces (bonds due to changes in the number of electrons at any time in one part of the atomic nucleus) between the ends of the silica sheet and the lack of negative charge in the octahedral sheet, water (H_2O) and moving ions can enter and separate the layers (Ariesnawan, 2015). This, results in high swelling properties. The ionic content of seawater which is higher than that in fresh water, induces the swelling properties of mineral montmorillonite to be more developed when exposed to seawater than when exposed to fresh water.

CONCLUSSIONS

It is proven that montmorillonite mineral is the most influential in changing the volumetric expansivity of soil when the soil is soaked in seawater and freshwater compared to kaolinite and illite minerals. The montmorillonite minerals have more effect on volumetric changes when the clay minerals are immersed in seawater than when they are immersed in freshwater. This study provides an understanding that it is also necessary to have a good knowledge regarding the composition of clay minerals in the planning, especially when the land area is dominated by clay material and affected by tidal flooding. Engineering geological planning should not only observe the physical properties of lithology, they must consider the chemical properties of lithology as well.

ACKNOWLEDGEMENTS

This paper is a part of Research Development and Implementation Research (RPP) Fund Sources Apart from the Diponegoro University State Budget for the 2021 Fiscal Year. The authors are grateful to all those who have supported and helped during the research process.

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