Strength Characteristics of Cement-treated Peat in Sumatera Island, Indonesia

Hirochika Hayashi[1], Takahiro Yamanashi[1], Hijiri Hashimoto[1],
Eddie Sunaryo[2], Fahmi Aldiamar[2], Maulana Iqbal[2] and Dea Pertiwi[2]
[1]*Civil Engineering Research Institute for Cold Region (CERI), Sapporo, Japan*
[2]*Institute of Road Engineering (IRE), Bandung, Indonesia*
E-mail: hayashi@ceri.go.jp

ABSTRACT: When constructing road embankment over peat, ground improvement is needed to avoid problems such as bearing capacity failure and excess post-construction settlement. The cement stabilization technique is one of the new proven ground improvement which can greatly improve ground in a short period of time. In this study a series of laboratory testing using unconfined compression test on peat mixed with some type of cements with different chemical compositions, including a special cement which contains large amount of SO_3 than other type of cement, was conducted. The tested peat was collected in a site at Dumai in Sumatera Island, Indonesia. As a result, the cement stabilization has considerable potential to improve strength for the peat from very soft to stiff and hard consistency.
Keywords: ground improvement, cement stabilization, peat, unconfined compression strength, modulus of elasticity.

1. INTRODUCTION

Fibrous and highly organic peat, which is very soft and problematic soil, is widely distributed in Southeast Asian Countries. Especially in Indonesia, extremely large peat deposit is found in Sumatera, Java, Kalimantan and Papua (IRE, 2001). Peat hinders implementation of construction project, due to its unique engineering properties.

When constructing road embankment over peat, ground improvement is needed to avoid problems such as bearing capacity failure and excess post-construction settlement. The cement stabilization technique is one of the new proven ground improvement which can greatly improve ground in a short period of time (CERI, 2017). However, there is a possibility that organic material included in peat hinders the solidification of cement. The unexpected effect may leads to insufficient strength of cement-treated peat against the required strength. The problem should be solved by exercising various type of cement to increase the quality of soil stabilization works and give more contribution in practical works.

In this study a series of unconfined compression tests on peat mixed with several type of cements composed of different chemical compositions, including a special cement for ground improvement produced in Japan was conducted as a fundamental research. This composition can become a hint of future development of local cement in Indonesia.

2. METHODOLOGY

A laboratory mixing test was performed on Dumai peat with ordinary and special cement commercially available in Japan for cement stabilization in order to clarify their effect on the peat and confirm the suitability of implementation this technology in Indonesia, especially with similar condition with Dumai peat.

2.1 Soil Property of Peat tested

Peat sample for the laboratory test was collected from Dumai, Sumatera Island, Indonesia. (Figure 1). Table 1 shows engineering soil properties of the peat sample which resulted high water content of over 700%, ignition loss of over 95% and low pH value of 3.4. The peat included a lot of organic materials such as Bitumen and Humic acid that known to hinder the solidification of cement (e.g., Okada et al, 1983; Noto, 1991; Hayashi and Nishimoto, 2005). The physical and chemical properties of the peat are difficult soil condition for cement stabilization.

2.2 Cement used

Three types of cement (Portland cement, blast–furnace slag cement and a special cement) were used as the binder. Table 2 shows chemical composition of these cements. The Portland cement and the slag cement were produced according to Japanese Industrial Standard. The special cement (product name: ET201) was commercially developed for stabilizing highly organic soil by a Japanese cement company. The feature of ET 201 is that it includes more sulfur trioxide (SO_3) and has greater specific surface area as compared to the ordinary cements.

In this study, the content of additive cement (cement ratio, *CR*), defined in Equation (1), were 20%, 30%, 40% and 50%. Where, W_C is the dry weight of the cement and W_P is the wet weight of peat.

$$Cement\ Ratio\ (\%) = (W_C / W_P) \times 100 \quad (1)$$

Figure 1 Location of sampling site

Table 1 Engineering Soil Properties of Peat Sample

Specific gravity Gs		1.51
Natural water content Wn (%)		769
Iginition loss Li (%)		95.2
PH		3.4
Degree of decomposition (von Post)		H3-H4
Content of organic material (%)	Bitumen	8.3
	Humid acid	56.2
Unconfined compression strength UCS (kPa)	No. 1	7.3
(undisturbed sample before stabilization)	No.2	12.8

Table 2 Chemical Composition of Used Cement

Type of Cement	Specific surface area (cm^2/g)	Chemical Composition (%)					SAC ratio
		SiO_2	Al_2O_3	CaO	SO_3	Others	
Ordinary Portland	3310	21.1	5.7	63.9	2.1	7.2	0.12
Blast Furnance Slag	3810	26.0	8.7	55.4	1.8	8.1	0.19
Special Cement (ET201)	6250	22.6	8.2	49.8	12.5	6.9	0.42

SAC ratio = $(Al_2O_3+SO_3)/CaO$

2.3 Test Procedure

According to the "Practice for Making and Curing Stabilized Soil Specimens without Compaction" (JGS 0821-2009: JGS, 2016), a standard defined by the Japanese Geotechnical Society, specimens 5 cm in diameter and 10 cm in height were made as follows. First, peat and cement slurry with W/C (W: weight of water, C: dry weight of cement) of 0.6 for each CR were poured into an electric mixer (Fig. 2) and mixed well for 10 minutes. Next, the mixture was put in a mold in three layers, without compaction. Then, the specimens were tamped to avoid voids.

The unconfined compression test (JGS 0511-2009: JGS, 2015) was conducted after 7 days and 28 days of laboratory curing at a temperature of 20°C.

Figure 2 Electric mixer used in this study

3. RESULTS AND DISCUSSION

3.1 Strength of Cement-treated Peat

Figure 3 shows a typical result of the unconfined compression test on undisturbed peat before stabilization (original peat), stabilized peat using Portland cement and ET 201 of *CR* = 50% after 28 days curing. For the original peat, no clear peak in the stress-strain curve was found and the unconfined compression strength (compression stress at failure: *UCS*) was very low. The result is a typical mechanical behavior of peat (Noto, 1991; Huat et al., 2014). Meanwhile, the stress-strain curve of the stabilized peat was characterized by significant higher *UCS* and smaller axial strain at failure as compared with the original peat. The results show that the cement stabilization has considerable potential to improve strength for the peat from very soft consistency (*UCS*<24 kN/m^2) to stiff consistency (*UCS* ranges from 96-192 kN/m^2) for Portland cement and hard consistency (*UCS*>383 kN/m^2) for ET 201 according to Terzaghi and Peck (1967).

Figure 4 (a) and (b) show the relationship between the CR and the UCS of stabilized peat after 7 and 28 days curing respectively. The UCS of stabilized peat increased with the increase of the CR. It should be noted that the UCS of stabilized peat varied depending on type of cement. In cases in which Portland cement and slag cement were used, the UCS was approximately 100 kN/m2, even at CR = 50%, and it was low improvement effect. It is thought that the unexpected effect is caused by hindering cement solidification of the organic materials included in peat.

When ET 201, a special cement containing large amounts of SO_3 and has greater specific surface area was used, the UCS after 28 days curing besides CR = 20% was higher than that using the ordinary cements. Hayashi and Nishimoto (2005) conducted a series of laboratory tests on stabilized Japanese peat with different types of cement. They pointed out chemical reactions for increasing the UCS of stabilized peat with a special cement containing large amounts of SO_3 as follows. The SO3 in a special cement is contained as gypsum (CaSO4). A typical reaction, in which a hydration product is produced through the binding of gypsum and a large amount of water, is shown below.

$3CaO\text{-}Al_2O_3 + 3CaSO_4 + 32H_2O \rightarrow 3CaO\text{-}Al_2O_3\text{-}3CaSO_4\text{-}32H_2O$

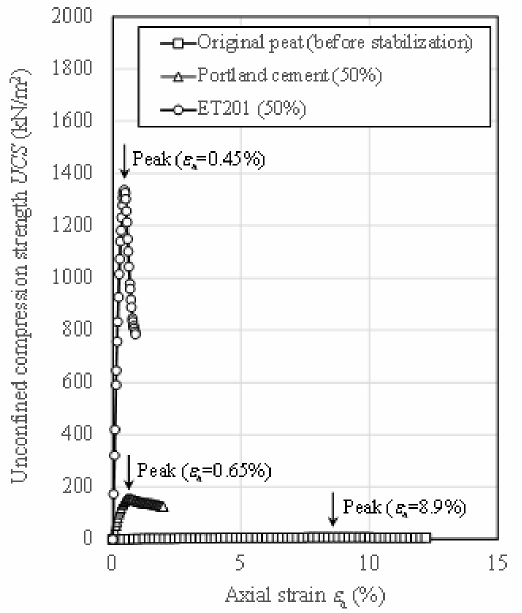


Figure 3 Typical result of unconfined compression test on original peat and stabilized peat after 28 days curing

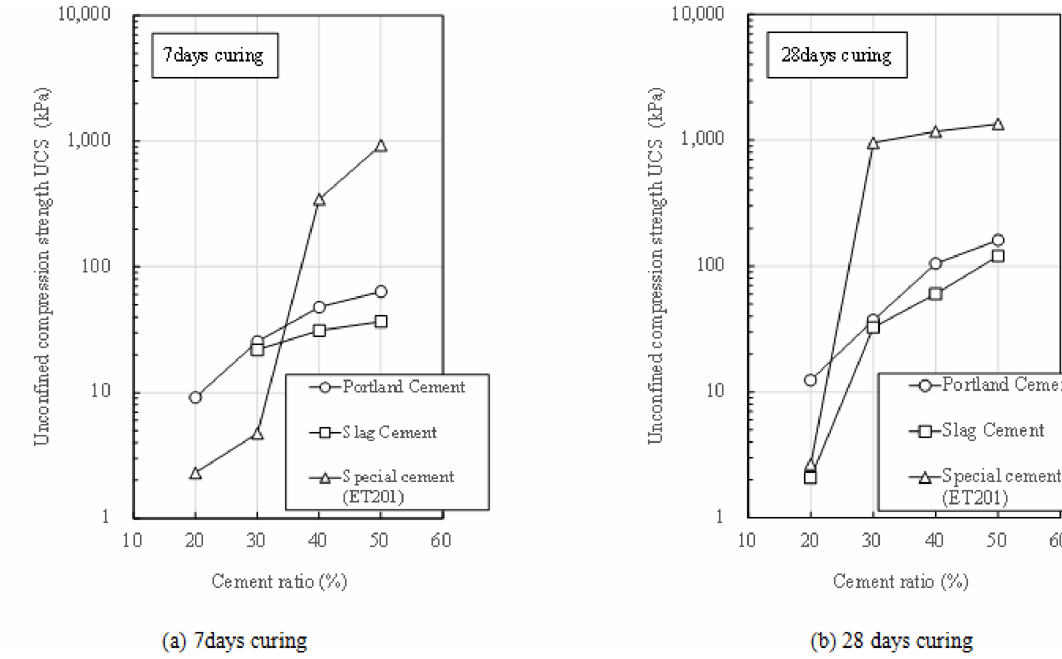


Figure 4 Relationship between Cement Ratio and UCS of stabilized peat

3CaO-Al_2O_3-3$CaSO_4$-32H_2O is a hydrogen product called ettringite (Fig. 5). It is characterized by large, needle-shaped crystals unlike ordinary hydrogen products. It binds together with a large amount of water during its formation process, which lowers the water content of the soil. It is thought that the increase in the strength of stabilized soil progresses with the entanglement of these needle-shaped crystals and peat. This reaction is also unlikely to be hindered by organic substances in the soil. This is a reason that the ET201 was effective for the peat.

In case of all types of cement, the UCS after 28 days curing increased from that after 7day curing as shown in Fig. 4. To clarify this trend, the relationship between the UCS after 7 days and 28 days is shown in Fig. 6. For most of the data except for some cases in the ET201, the UCS after 28 days curing ranged from 1.5 to 3.0 times the UCS after 7 days curing. In these phenomena, no significant difference was found due to the difference in cement type.

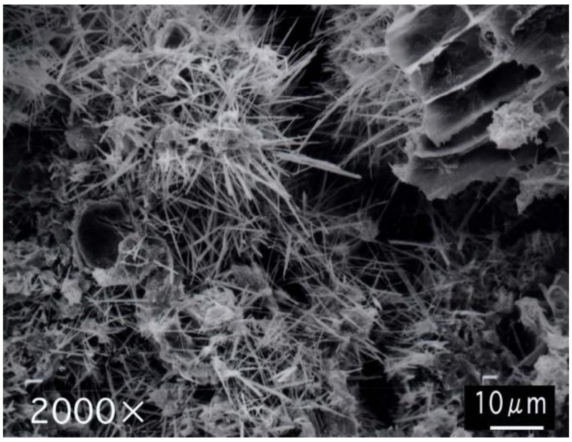


Figure 5 Ettringite, a needle-shaped hydrogen product (SEM photo of stabilized peat after Hayashi and Nishimoto, 2005)

3.2 Modulus of Elasticity of Cement-treated Peat

When analyzing deformation of ground improved by using a deep cement stabilization method by numerical modeling, it is important to accurately determine stiffness of cement-treated soil. Therefore, modulus of elasticity of the cement-treated peat is described in this Section. The modulus of elasticity (E_{50}) as defined in Equation (2) is mean stiffness in range from small strain to strain at failure, and is calculated using the stress-strain curve as shown in Fig.2. Where, unit of the E_{50} is kN/m^2, unit of the USC is kN/m^2 and ε_{50} is the axial strain at compression stress of (USC/2) (%). In analyzing static deformation of improved ground due to embankment loading, the E_{50} is often used for evaluating the stiffness of the cement stabilized soil.

$$E_{50} = ((USC/2)/\varepsilon_{50}) \times 100 \quad (2)$$

Figure 7 (a) and (b) show the double-logarithm relationship between the E_{50} and the UCS of stabilized peat after 7 and 28 days curing respectively. Without depending on the type of cement, the E_{50} increased linearly with the increase of the UCS. Kitazume and Terashi (2013) presented that a similar tendency is observed for various types of cement-stabilized clay. This relationship in this study can be approximated by Eq. (3) and (4).

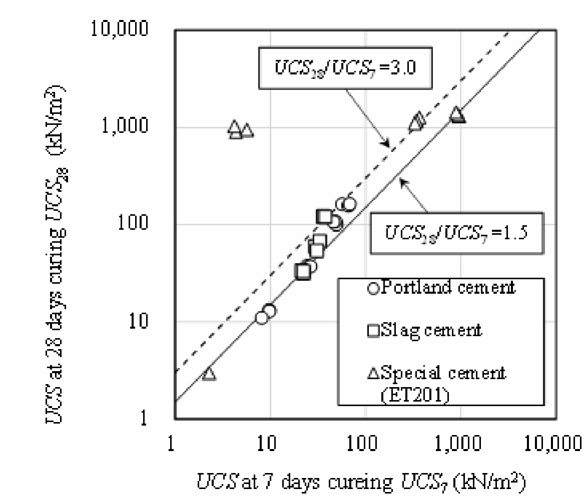
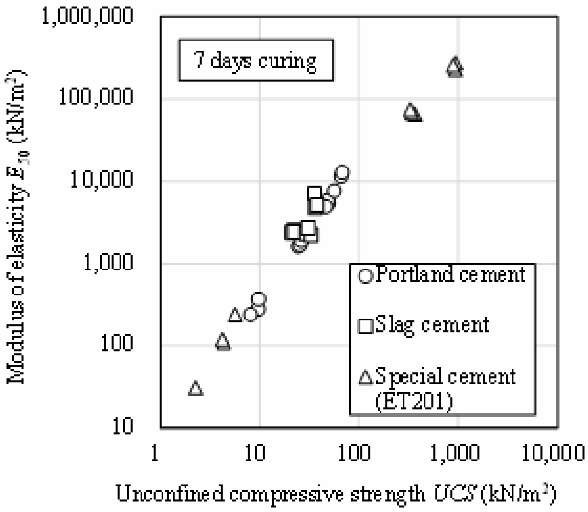


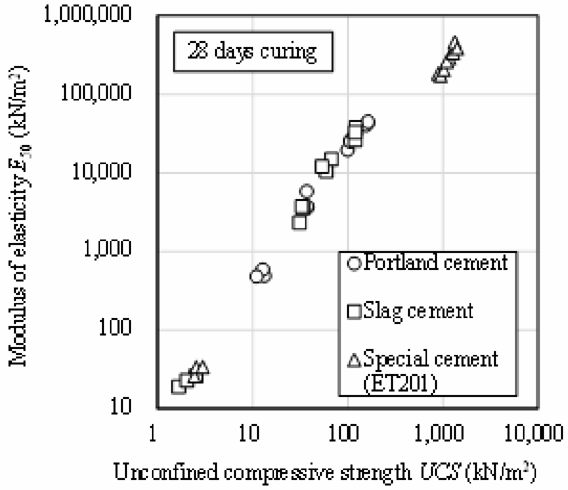
Figure 6 Relaintionship between UCS of stabilized peat after 7 days curing and after 28 days curing

In case of 7 days curing: $E_{50} = 18.0\ UCS^{1.45}$ (3)

In case of 28 days curing: $E_{50} = 13.7\ UCS^{1.49}$ (4)



(a) 7 days curing



(b) 28 days curing

Figure 7 Relationship between UCS and modulus elasticity

4. CONCLUSIONS

In this study, a series of laboratory mixing testing on peat collected at a site of Dumai in Sumatera Island, Indonesia using different types of cement was conducted. The main results can be summarized as follows:

1. The tested peat has high water content of over 700%, ignition loss of over 95% and low pH value of 3.4. The physical and chemical properties are difficult soil condition for cement stabilization.
2. In cases in which Portland cement or blast furnace cement were used, small strength enhancement from unconfined compression strength (UCS) resulted from curing time of 7 and 28 days. Stabilized peat can only achieve stiff consistency.
3. When special cement (product name: ET201) containing large amounts of sulfur trioxide or aluminium oxide was used, enhancement of high UCS result was obtained. Stabilized peat can achieve hard consistency.
4. For most of the data except for some cases in the ET201, the UCS after 28 days curing ranged from 1.5 to 3.0 times the UCS after 7 days curing.
5. Without depending on the type of cement, the modulus of elasticity (E50) increased linearly with the increase of the UCS. Based on the result, an experimental correlation between the E50 and the UCS is presented.

This study was collaboratively carried out based on “Agreement on Research Exchange and Cooperation between Civil Engineering Research Institute for Cold Region (CERI), Japan and Institute of Road Engineering (IRE), Indonesia”, in order to technically support national projects of highway construction over peat in Indonesia.

5. REFERENCES

Civil Engineering Research Institute for Cold Region (CERI). (2017) Manual for Countermeasure for Peat Soft Ground, pp.1-6. (in Japanese)

Hayashi, H. and Nishimoto S. (2005) Strength Characteristic of stabilized peat using different types of binders, Proceedings of The International conference on Deep Mixing Best Practice and Recent Advances (CD-R), Stockholm.

Huat, B. B. K., Prasad, A., Asadi, A. and Kazemian, S. (2014) Geotechnics of Organic Soils and Peat, CRC press, pp.81-95.

Institution of Road Engineering (IRE). (2001) Guideline of Indonesian Road Construction over Peat and Organic Soils

Japanese Geotechnical Society (JGS). (2016) Laboratory Testing Standards of Geomaterials, Vol.2.

Japanese Geotechnical Society (JGS). (2015) Laboratory Testing Standards of Geomaterials, Vol.1.

Kitazume, M. and Terashi, M. (2013) The Deep Mixing Method, CRC press, pp.83-84.

Noto, S. (1991) Peat Engineering Handbook, CERI, pp.102-110.

Okada, Y., Kutara, K. and Miki, H. (1983) Effect of humic acid on soil stabilization, Proceedings of the 53rd Annual Conference of Japan Society of Civil Engineers, pp.467-468. (in Japanese)

Terzaghi. K., and R.B. Peck. (1967). Soil Mechanics in engineering practice, Wiley New York p.729.