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Experimental studies on hydraulic conductivity of different straw fiber cement treated muds

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KEYWORDS
Rice straw
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ABSTRACT
Hydraulic conductivity characteristics of mud treated by rice straw fiber and cement were investigated by falling head permeability tests. The experimental results indicated that the water conductivity significantly decreased by the inserting of either cement or rice straw fiber. Comparing with cement-treated mud, the addition of rice straw fiber considerably reduced the water conductivity of the mud composite. Moreover, empirical equations were revealed to predict the value of hydraulic conductivity for the modified-mud.

1 Introduction

Dredging is necessary for rivers and canals in the Mekong Delta due to annually heavy sedimentation and erosion. An enormous volume of mud has been disposing of that is asking more disposal sites and transportation fees. The dredged mud takes a long time to reuse because of its extremely high-water content [1-5]. Right after dredging, it could not be directly used as foundation medium or construction materials without any improvement of its adverse properties. Besides, the dredged mud is mainly transported to landfills with high cost or illegal dumping. As consequence, there are burdens for environmental control and management. Moreover, the delta has been affecting by climate change, such as sea level rising, saltwater intrusion, and upstream developments. Dykes are being built to control these influences to maintain irrigation systems in the delta [6]. As a result, it needs much soil to build dykes. Therefore, if the dredged mud is recycled to build the dykes, it will be able to solve the problems of high transportation costs, illegal dumping, and lack of landfills.

The improvement of mechanical characteristics of dredged mud by the inclusion of fiber and binding materials has been studied and applied in Japan [2]. By using the method, mud was modified by adding paper fragments and cement. The modified mud revealed some advantages: high compressive strength, low permeability, high durability in repeated drying and wetting, and low brittleness [3]. Although the method is considered as a suitable procedure to recycle the dredged mud in the Mekong Delta, it has exposed several difficulties for directly applying: increasing paper fragment costs and its availability in the delta. Also, agricultural by-products such as rice straw (RS) are urgently becoming environmental problems. Annually, the estimated available quantity of RS in the Delta is around 26.2 million tons, in which 20.9 million tons are burned directly on rice fields [7]. The practice not only contributes to air pollution and global warming also affects human health. Thus, managing RS is a challenge and an opportunity to utilize the available resource and reduce agriculture's climate footprint. Therefore, RS is considered as a suitable material for mud recycling instead of the paper fragments.

Soil hydraulic conductivity, also known as permeability coefficient, is how easily water can pass through a soil medium. It is one of the essential fundamental processes in geotechnical and geoenvironmental engineering, especially in the case of dyke engineering. Theoretically, the soil permeability follows Darcy's Law. In laboratory, there are two methods to find the coefficient: constant head test and falling head test. In this study, the hydraulic conductivity of the rice straw – cement – mud composite was investigated by carrying out falling head tests. Moreover, empirical functions will be developed to predict the hydraulic conductivity of the modified mud.

2 Materials and procedures

2.1 Materials

Straw fiber cement treated mud is a combination of rice straw fibers, cement, and mud materials. The principles of the composite materials are described in Figure 1.

Figure 1-a imitated the normal phase of mud. Typical mud contains much free water then the soil particles can freely move as a "fluid". Rice straw fibers were added as described in Figure 1-b into the mud to absorb the free water, significantly reduce the plasticity, and control shrinkage during cement hydration. Moreover, the fibers could reduce the cement-treated matrix's brittleness and increase compaction strength [8-13] . The adding cement worked as a binding material to connect the soil particles and rice straw fibers. By the hydrated reaction, the compaction strength of the treated mud could be increased.

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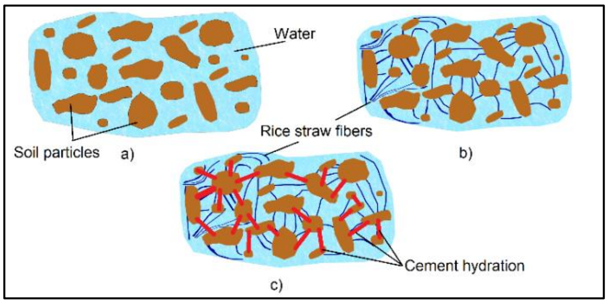

Figure 1. Principles of rice straw fiber-cement-reinforced sludge.

The mud was imitated based on the particle size distribution of actual mud samples taken in the Mekong delta. The results exposed that clay and silt could be mixed to make the imitated mud. The mud was decided to apply instead of actual mud because of the difficulties of bringing a large amount of actual mud into Japan. Figure 2 and Table 1 show the grain size distribution and physical properties of the clay, silt, and imitated mud respectively.

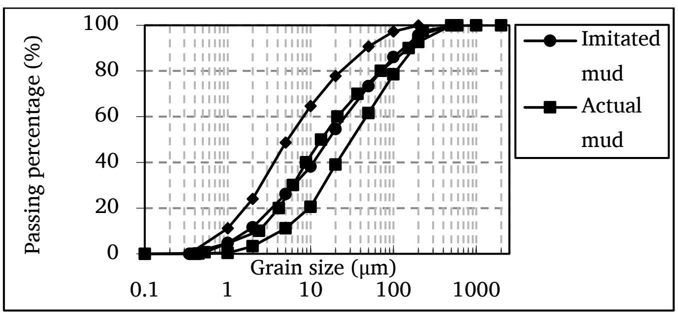

Figure 2. Particle size distribution of sludge.

Table 1.

Properties of soil materials.

Properties	Imitated mud	Clay	Silt
D_{50} (μm)	17.2	4.6	25.2
Dry density (kg/m^3)	2467	2741	2313
Liquid limit (*LL*, %)	46.1	53.8	47.9
Plastic limit (*PL*, %)	29.4	11.0	-
Plastic index (*PI*, %)	16.7	42.8	-
Optimum water content (%)	28.4	-	-

Figure 3. Rice straw fibers.

Table 2.

Rice straw fiber properties.

Properties	Values	Unit
Water absorption	290 - 310	(%)
Bulk density	30 - 50	(kg/m^3)
Moisture	3 - 6	(%)
Length	13.2 ± 6.3	(mm)
Width	0.2 ± 0.1	(mm)
Tensile strength	4.2 - 246.2	(MPa)

The rice straw fibers were extracted from Japanese rice straw. Figure 3 and Table 2 show the photograph and physical properties of the fibers, respectively. Rice straw fiber samples were tested to determine their length and width by image processing. Moreover, its tensile strength also was investigated.

2.2 Procedures

To investigate the effects of altering rice straw fibers, cement, and initial water content, falling head permeability tests were carried out. The testing conditions are shown in Table 3. In the table, *w*, *C*, and *RS* stand for imitated mud water content, cement content, and rice straw fiber content, respectively. The procedure for the experiment is described as follows:

- The imitated mud was mixed with rice straw fibers and cement by the conditions shown in Table 3. The mixture was securely cured in seal plastic box at 20 ± 3^{0}C in 3 days. After that, 5 cm in diameter and 5.1 cm in height specimens were made by compaction method.

- The specimens were soaked into tab water in 24 hours followed by 7 days curing at 20 ± 3^{0}C.

- The falling head tests were carried out.

Table 3.

Testing conditions I.

w (%)	*C* (kg/m^3)	*RS* (kg/m^3)	*w* (%)	*C* (kg/m^3)	*RS* (kg/m^3)
40	10	0, 10, 25	70	40	20, 40, 50
	20	0, 10, 25		50	20, 40, 50
	30	0, 10, 25		60	20, 40, 50
60	35	0, 10, 21, 30	80	45	0, 10, 18, 40, 50
	40	0, 10, 30		55	18, 40, 50
	50	0, 10, 30		65	18, 40, 50

In the meantime, an empirical function to determine the after curing apparent water content of the mixture, w_{ac}, was developed and calibrated by using dimensional analysis and unconfined compressive test results. Table 4 shows the testing conditions for the calibration. The procedure to carry out the unconfined compressive test is described as follows.

- Make modified mud by mixing imitated mud, rice straw fibers, and cement.

- Cure the mixture at 20 ± 3^{0}C in 3 days.

- Make 5 cm in diameter and 10 cm in height specimens by compaction method.

- Cure the specimens at 20 ± 3 ^{0}C in 7 days.

- Carry out the unconfined compressive tests.

Table 4.

Testing conditions II.

w_{ini} (%)	C (kg/m^3)	RS (kg/m^3)
20	10	10
25	10	10
30	10	10
35	10	10
40	10	10

3 Results and discussions

Basically, dry soil density is significantly affected by water content in the soil. Peak value on the soil compaction curve indicates the maximum dry density of soil, ρ_{dmax}, and respect to the optimum water content, w_{op}. Therefore, the rice straw fiber cemented mud mixture may have similar characteristics. Figure 4 shows the mass changing of rice straw fibers, cement, and free water components in the mixture.

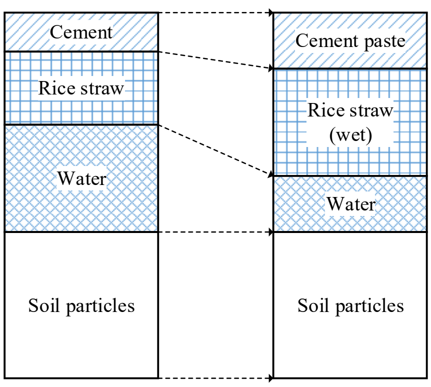

Figure 4. Mass changing in modified mud.

Eq. 1 described the volume of imitated mud.

$$V_{soil} = V_s + V_w = \left(\frac{1}{\rho_s} + \frac{w_{ini}}{100\rho_w}\right) m_s \quad (1)$$

Where V_{soil} is volume of imitated mud; V_s is volume of soil particles; V_w is volume of water; m_s is mass of soil particles; m_w is mass of water; ρ_s is density of soil particles; ρ_w is density of water; w_{ini} is initial water content of imitated mud.

Eqs. 2 & 3 indicate the mass of rice straw fibers and cement in modified mud, respectively.

$$M_{rs} = V_{soil} \times A_{rs} = \left(\frac{1}{\rho_s} + \frac{w_{ini}}{100\rho_w}\right) m_s \times A_{rs} \quad (2)$$

$$M_c = V_{soil} \times A_c = \left(\frac{1}{\rho_s} + \frac{w_{ini}}{100\rho_w}\right) m_s \times A_c \quad (3)$$

Where A_{rs} is amount of rice straw fiber in kg/m^3; A_c is amount of cement in kg/m^3; M_{rs} is mass of rice straw fibers; M_c is mass of cement.

Eq. 4 was withdrawn based on the 300 % water absorption of rice straw fibers and 25 % water absorption of cement hydration [14].

$$w_{ac} = 100\frac{m_w - 3M_{rs} - 0.25M_c}{m_s} = \left(1 - \frac{3A_{rs} + 0.25A_c}{\rho_w}\right) w_{ini} - \frac{300A_{rs} + 25A_c}{\rho_s} \quad (4)$$

When the w_{ac} was set to equal to the w_{op}, the dry density of the modified mud could reach maximum value. As a result, the w_{ini} turned into optimum initial water content, w_{opini}. The w_{opini} is expressed in Eq. 5. Using the Eq. 5, the optimum initial water content of the rice straw fiber cemented mud could quickly obtain.

$$w_{opini} = \frac{w_{op} + (300A_{rs} + 25A_c)/\rho_s}{1 - (3A_{rs} + 0.25\text{A}_c)/\rho_w} \quad (5)$$

To validate Eqs. 4 & 5, compaction tests were carried out with mixing conditions in Table 4. By using the Eq. 5, the value of w_{opini} was calculated as 30.72 %.

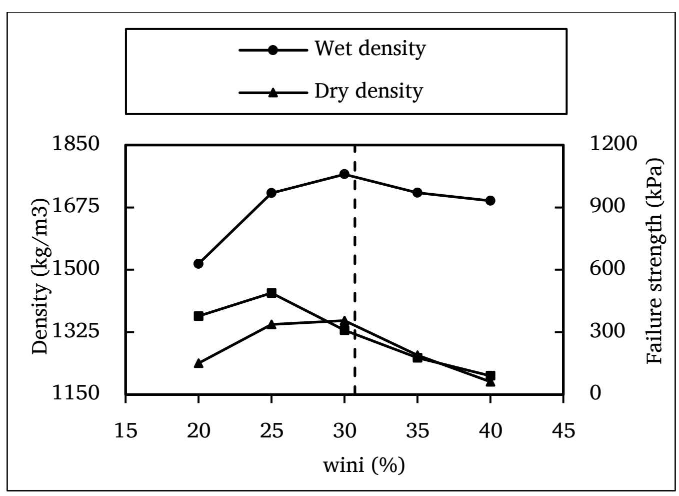

Figure 5. Correlation between modified sludge densities and failure strength.

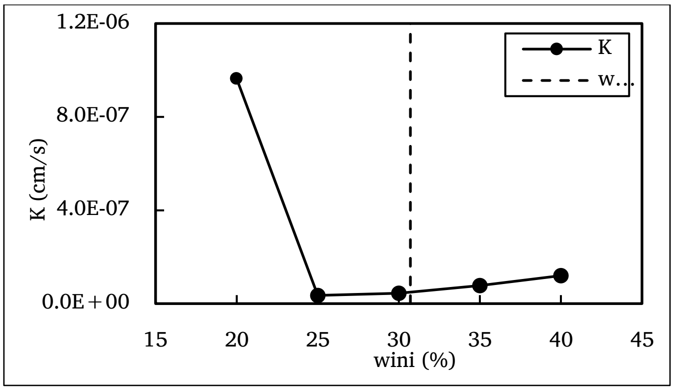

Figure 6. Correlation between permeability coefficient and initial water content.

Figure 5 shows the results of densities and failure strength of modified mud. In the figure, the dry density reached the maximum value at the maximum of wet density. However, the maximum dry density did not respect the maximum failure strength. The initial water content for the maximum failure strength was less than the initial water content at the maximum dry density. The initial water content at the maximum dry density was almost the same as the optimum initial water content w_{ini}. The results could be concluded that Eqs. 4 & 5 could be applied to determine the optimum initial water content and the water content after curing the RS fiber cement modified mud. The modified mud at the optimum initial water content was sufficiently compacted.

Moreover, Figure 6 shows the correlation of the hydraulic conductivity, *K*, and initial water content. The results indicated that along with increasing initial water content, *K*-value decreased to the minimum value at 25 % w_{ini} and then continuously increased. The *K* reached a minimum value at the initial water content respected to maximum failure strength in Figure 5. However, it did not match to maximum dry density condition. Therefore, Eqs. 4 & 5 could be used to estimate the water content after curing and determine the optimum initial water content for modified sludge.

Furthermore, the hydraulic conductivity characteristics of modified mud were investigated with the testing conditions I and shown in Figure 7. It showed that the increase of either RS fibers amount or cement amount reduced the K-value. Compared with cemented mud, the addition of RS fibers could significantly reduce the K-value better than the one with cement added only. That could be explained by the effects of cement hydration and RS fibers water absorption. First, the RS fibers and cement absorbed the free water in the modified mud. Then, the modified mud got higher compacted efficiency. Second, the cement's hydration developed "anti-seepage walls" around soil particles and RS fibers. The walls prevented the development of capillary porosity from large or well-connected pores. Also, it decreased the progression of microcracks at the interfacial transition zone between the cement paste, soil particles, and RS fibers induced by the swelling behavior of modified sludge. As a result, the K-value decreased.

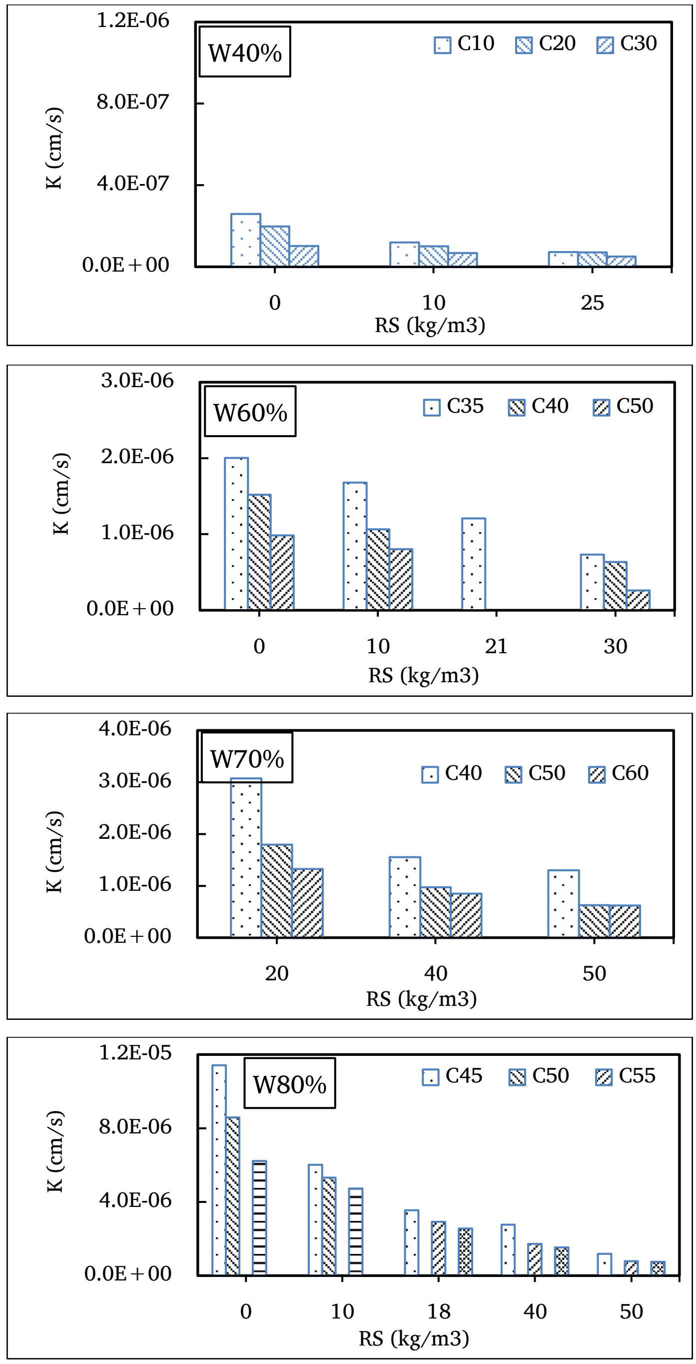

Figure 7. Hydraulic conductivity of rice straw fiber cement treated mud.

Moreover, an empirical function to show the correlation between w_{ac} and *K* was developed, as shown in Figure 8, Figure 9, and Eq. 6. In Figure 8, the *K*-value significantly decreased with decreasing of w_{ac}. For practical engineering purposes, by using the known mixing condition of RS fiber cement treated mud, the w_{ac} could be quickly calculated. Then, the hydraulic conductivity of the modified mud could quickly obtain.

$$K = 3\times10^{-16} w_{ac}^{\;5.4761} \quad (6)$$

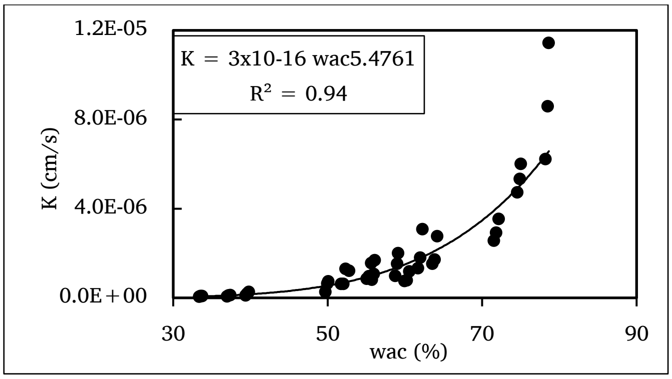

Figure 8. Emperical function of rice straw fiber cement treated mud.

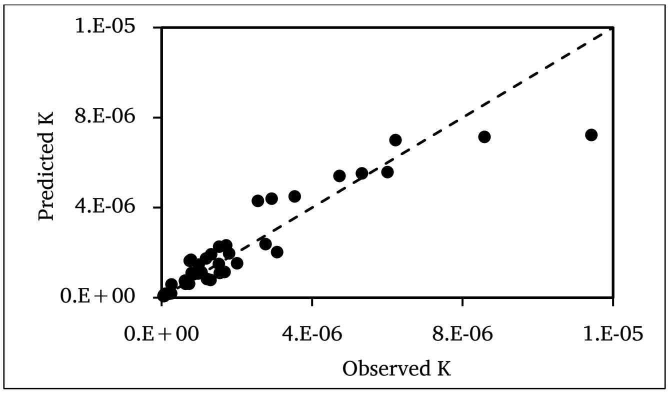

Figure 9. Correlation of observed and predicited data of *K*-value.

4 Conclusions

RS fibers and cement were applied as active soil additives to reduce the hydraulic conductivity of normal mud. Based on the experimental results, several conclusions could be drawn as follows

- An equation was developed to determine the water content after curing of the RS fiber-cement-reinforced mud, w_{ac}, based on dimensional analysis and experimental calibration.
- The increase of either RS fibers or cement amount reduced the hydraulic conductivity of the modified mud.
- The addition of RS fibers exposed better effects on the hydraulic conductivity than cement.
- An empirical function was withdrawn to estimate the value of the hydraulic conductivity based on the adding amount of RS fibers, cement, and physical characteristics of mud.

References

[1] P. T. Chien, T. Satomi, and H. Takahashi (2007). Study on sludge recycling with compaction type and placing type by rice husk-cement-stabilized soil method. *Advanced Experimental Mechanics,* (2):159-167.

[2] M. Mori and H. Takahashi (2003). A proposal of new recycling system for high-water content muds by using paper debris and polymer and strength property of recycled soils. *Journal of MMIJ,* (119):155-160.

[3] H. Takahashi (2014). *Topical Themes in Energy and Resources*. Springer: Tokyo Heidelberg New York Dordrecht London.

[4] H. Takahashi and M. Mori (2012). Creation of artificial ground by recycling tsunami sludge. *Proceedings of the 6th Symposium on Sediment-Related Disasters*, Japan.

[5] M. Mori, H. Takahashi, and K. Kumakura (2006). An experimental study on strength of fiber-cement-stabilized mud by use of paper sludge and durability for drying and wetting tests. *Journal of MMIJ,* (122):353-361.

[6] TheWorldBank (2012). Mekong Delta Transport Infrastructure Development Project.

[7] S. N. Tran and K. Ingvorsen (2014). To quantify the seasonal rice straw and its use in different provinces in the Vietnamese Mekong Delta. *Can Tho University Journal of Science,* (32):87-93.

[8] S. M. Hejazi, M. Sheikhzadeh, S. M. Abtahi, and A. Zadhoush (2012). A simple review of soil reinforcement by using natural and synthetic fibers. *Construction and Building Materials,* (30):100-116.

[9] R. MacVicar (1997). *Mechanical and physical changes associated with aging of cellulose fiber reinforced cement composites*. University of Toronto.

[10] H. W. Xiao and S. Y. Yeoh (2013). Fiber Reinforced Cement Treated Clay. *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering*, Paris.

[11] A. M. Brandt (2008). Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering. *Composite Structures,* (86):3-9.

[12] M. Maher and Y. Ho (1993). Behavior of fiber-reinforced cemented sand under static and cyclic loads. *Geotechnical Testing Journal,* (16):330-338.

[13] N. Consoli and L. A. Ulbrich (1998). Influence of Fiber and Cement Addition on Behavior of Sandy Soil. *Journal of Geotechnical and Geoenvironmental Engineering,* (124):1211-1214.

[14] P. T. Chien, T. Satomi, and H. Takahashi (2018). Study on strength characteristics of rice straw fiber-cement-reinforced sludge. *International Journal of the Society of Materials Engineering for Resources,* (23):147-151.