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POSSIBILITY FOR SOLIDIFICATION OF PEATY SOIL BY USING MICROBES

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ABSTRACT: Peaty soil is widely distributed in Hokkaido. Untreated, it is too soft for use as a civil engineering material. Soil solidification improvement technologies that harness the metabolism of microbes in soil have recently been gaining attention. Such research and development has proceeded within and beyond Japan. The researchers investigated a technology for peat solidification that harnesses the ability of microbes inhabiting the soil of construction sites to precipitate calcium carbonate, and consideration was given to solidifying peaty soil by harnessing the ability of those microbes. Focusing on the urease activity of microbes, which has an influence on solidification of peaty soil, a soil solidification test, in which the metabolism of microbes was utilized, and an experiment, in which the degree of solidification of peaty soil was tested, were done by using peaty soil samples from Hokkaido. The two experiments found the following. 1) Microbes that have urease activity inhabit the peaty soil of Hokkaido. 2) It is possible to solidify peaty soil by enhancing the urease activity of these microbes. 3) It is possible to evaluate the degree of urease activity in peaty soil by measuring its electric conductivity.

Keywords: Solidification, Urease activity, Peat, Electric Conductivity, Microorganism

1. INTRODUCTION

Construction in Hokkaido has the potential to involve peaty soil, because such soil accounts for 6% of the flat land in Hokkaido [1] (Fig.1). Peaty soil (Fig.2) is highly organic and soft, therefore, the strength in supporting structures such as roads and embankments is extremely small [2]. Uses of peaty soil generated from excavation works is extremely difficult, and a development of an effective improvement technique for this type of soil has been called for.

In recent years, research and development on a soil solidification technology using carbon dioxide generated by the metabolism of microbes has proceeded within and beyond Japan [3]-[6]. By applying this technology to peaty soil, it is thought that the environmental loads from conventional land improvement can be reduced. The authors have been conducting peaty soil solidification experiments using a land solidification technology that harnesses the urease activity of microbes [7]. In the soil solidification experiments, strength sufficient to allow treated soil to be transported by dump trucks (50kN/m^2) was attained after 6 months of curing [8]. An examination was done on a technique for evaluating the degree of solidification of peaty soil by using electrical conductivity as an index [9]. This report summarized the above study.

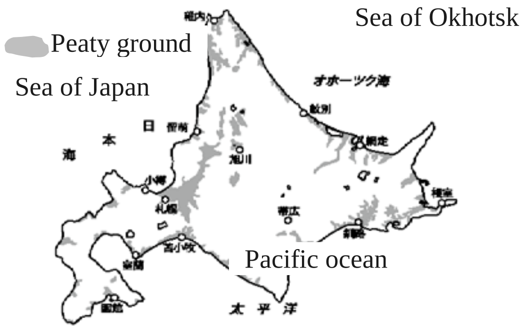


Fig.1 Distribution of peat

Fig.2 Example of peat

2. MECHANISM OF SOIL SOLIDIFICATION USING THE METABOLISM OF MICROBES

Soil improvement techniques that harness the metabolism of microbes are categorized as those involving calcium carbonate [5] and those involving silica [6]. In this experiment, soil solidification using microbes was done by using the calcium carbonate method. The calcium carbonate method utilizes calcium carbonate, which precipitates from the reaction between carbon dioxide generated by microbial metabolism and calcium source in the voids of soil, in solidification of the ground. The precipitated calcium carbonate causes soil particles to adhere to each other, which increases the strength of the soil [10].

When solidifying ground by the calcium carbonate method, urea is mixed in the soil to raise pH of the soil and supply carbon dioxide to the soil, and calcium compound is mixed as the source of calcium. The reaction mechanism of calcium carbonate method is as follows. If microbes that have urease activity inhabit in the peaty soil, the microbes hydrolyze urea ($CO(NH_2)_2$) and generate ammonia (NH_3) and carbon dioxide (CO_2). Calcium carbonate precipitates from the reaction between the carbon dioxide (CO_2) and the calcium ions (Ca^{2+}) in the pore water of the soil.

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_3 + CO_2 \quad (1)$$
$$Ca^{2+} + CO_2 + H_2O \rightarrow CaCO_3 + H^{2+} \quad (2)$$

3. PROPERTIES OF PEATY SOIL

3.1 The microbes found in peaty soil

To apply the soil solidification technology using microbes to the peaty soil in Hokkaido, 3 major types of peaty soil samples were investigated for finding whether microbes usable for soil solidification inhabit in the soil. Viable microbes and ray fungi of 10^4 - 10^6 per 1g of sample were found in all of the 3 samples (Table 1). The microbe count in ordinary soil is about 10^7 - 10^9 per1g [11]. Even though the counts for the samples were less than those for ordinary soil, solidification using microbes was thought to be possible.

3.2 Urease activity of Microbes

Before conducting experiments for peaty soil solidification using the calcium carbonate method, tests were done to find the existence of microbes with urease activity in the sample peaty soil. Peaty soil samples collected at 8 locations in Hokkaido were tested for urease activity by using Christensen citrate agar [12]. Christensen citrate agar turns red if a sample contains microbes with urease activity. Fig. 3 shows the test result. All the agar plates turned red, from which it was found that microbes with urease activity inhabit widely in peaty areas in Hokkaido.

Table 1 The number of microbes that inhabit the peat (cfu/g) ( ) is kind of microbes

Sample name	Viable microbes	Ray fungi
Kushuro	$1.1x10^{-6}$ (5)	$3.7x10^{-2}$ (3)
Iwamizawa1	$2.8x10^{-5}$(7)	$1.7x10^{-2}$ (1)
Iwanai1	$3.3x10^{-4}$ (3)	-

4. EXPERIMENT METHOD

A solidification test and an estimation for urease activity, which was done by measuring electric conductivity, were done for the peaty soil samples shown in Table 2. The peaty soil samples are much higher in natural water content and ignition loss than ordinary soil is [13], and they are very low in soil particle density. Peaty soil characterized by low pH.

4.1 The soil improvement by the calcium carbonate method

A test of solidification by using microbes was done for peaty soil from Ebetsubuto. In previous solidification tests [14]-[15], the resulting soil strength was low, because the water content of the peaty soil was much higher than that of ordinary soil. For the solidification in the current experiment, the calcium carbonate method was applied to the peaty soil after reducing its water content to 336% by natural drying. The mix proportions shown in Table 3 were used for mixing

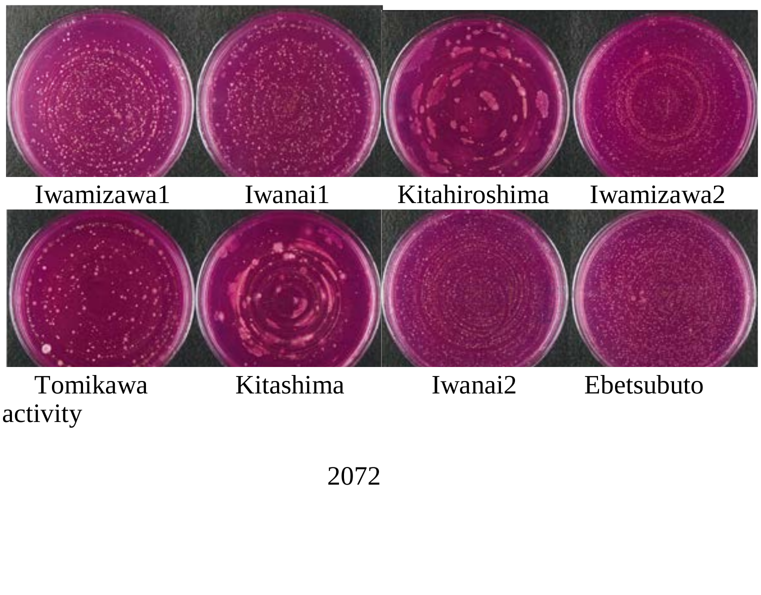


Fig.3 Test for urease activity

Table 2 Basic physical properties of the peaty soil samples

Solidification test		〇	
Estimation for urease activity	〇	〇	〇
Sample name (sampled area)	Iwanai	Ebetsubuto	Tomikawa
Water content (%)	1028.64	545.92	119.55
Soil particle density ρ_s(g/cm^3)	1.557	1.895	2.206
Ignition loss L_i(%)	93.813	56.653	39.007
pH	4.5	4.1	2.5

urea and calcium chloride in 1.5kg of peaty soil. The amount of urea was 1/10 of water in the peaty soil, and the amount of calcium chloride was 2 times of the urea [7]. It is understood that the effectiveness of microbes in soil solidification is good when the pH of the soil is neutral to weakly alkaline. To adjust the pH of soil, which would be acidic because of the large amount of calcium chloride, to be in the range of neutral to weakly alkaline sodium bicarbonate was mixed. In the experiment, a mix proportion using urease originated from sward beans (*Canavalia gladiata*) was also used to promote decomposition of urea.

Table 3 Mix proportions for solidification test

	$CO(NH_2)_2$	$CaCl_2$	$NaHCO_3$	Urease
[1]	116	232	-	-
[2]	-	-	-	-
[3]	116	232	20	-
[4]	116	232	20	3.5

For each mix proportion, specimens of 5cm in diameter and 10cm in height were created based on the method of uncompacted sample preparation specified in the Practice for Making and Curing Stabilized Soil Specimens without Compaction, of the Japanese Geotechnical Society [17]. The specimens were cured in a room at constant temperature (20°C) and humidity for 4 months. The specimens were measured for unconfined compressive strength and for precipitated calcium carbonate at the age of 1 month and 4 months. For the measurement of precipitated calcium carbonate, gas pressure of carbon dioxide (hereinafter, gas pressure) was measured. As shown in Eq. (3), when calcium carbonate is dissolved by hydrochloric acid, calcium chloride and carbon dioxide are generated. By measuring the pressure of gas generated by the dissolution of calcium carbonate, the calcium carbonate content can be determined [18].

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2 \quad (3)$$

Fig. 4 shows the flow of a peaty soil solidification experiment using the calcium carbonate method.

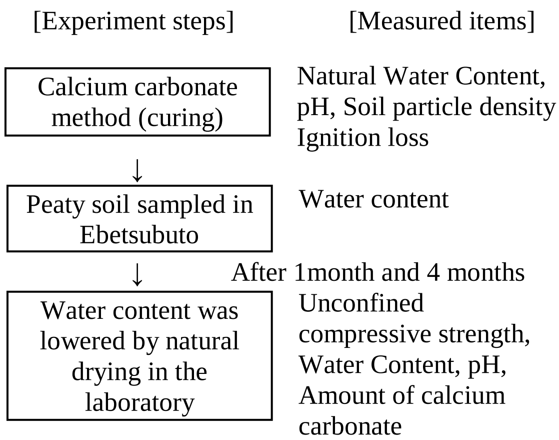
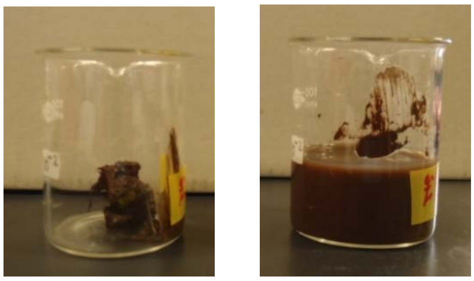


Fig.4 Flow of peaty soil solidification test using the calcium carbonate method

4.2 Evaluation of urease activity based on electrical conductivity

The authors addressed a method for evaluating the rate of urea hydrolysis [9] as a technique to estimate the degree of urease activity of the subject peaty soil. In this method, the urease activity is estimated by measuring the electrical conductivity of the peaty soil. The microorganisms were liquid cultured on Christensen citrate agar, and urea solution was added to the medium. The rate of urea hydrolysis by the microorganisms was estimated by measuring the electrical conductivity of the solution. However, isolating the microorganisms that promote solidification of peaty soil requires special knowledge and techniques that have not been considered practical for improving civil engineering materials. Therefore, the authors decided not to isolate the microorganisms but to do experiments for solidifying the peaty soil by using microorganisms naturally inhabiting the peaty soil. Hata et al. [9] used a mixture of 10ml of microbe culture solution and 40ml of urea solution to measure electrical conductivity. The authors used a suspension of 10g of peaty soil in 40ml of urea solution to measure the electrical conductivity of the soil (Fig.5), because the water content of peaty soil is very high. Fig.6 shows the procedure for measuring how the electrical conductivity of the solution increases with time.



a. Peaty soil   b. Peaty soil after mixing with urea solution

Fig.5 The appearances of the samples

5. TEST RESULTS

5.1 Result of the soil improvement by the calcium carbonate method

The unconfined compressive strengths of the specimens measured at 1 month and 4 months after preparation of the specimens are shown in Fig. 7. The unconfined compressive strength is the average of the values for 2 specimens. The specimens of all mix proportions were not able to keep their shape when the frames were remove at the time of sample preparation. The unconfined compressive strength of Specimen #1, #2, and #3, which had mix proportions only with the naturally contained microbes, measured 1 month after and 4 months after specimen preparation were very small, and the strength of the specimens did show any improvement. In Specimen #4, to which urease was added, the unconfined compressive strength at 1 month after sample creation was 25kN/m^2 and that at 4 months after sample creation was 53kN/m^2. It was verified that strength of the soil increased as a result of urease addition, and the strength continued to increase with time. It was found that, by using microbes, soft soil could be improved to achieve strength sufficient for transport by dump trucks (50kN/m^2). From the test result, it was found that solidification of peaty soil is possible if the microbes activated in the soil hydrolyze urea and promote precipitation of calcium carbonate.

The relationship between the pressure of gas generated by the reaction of microbes and the unconfined compressive strength is shown in Fig. 8. The gas pressure was measured for 2 specimens created from one soil sample after its unconfined compressive strength was measured. The value in Fig. 8 is the average of the values of the two

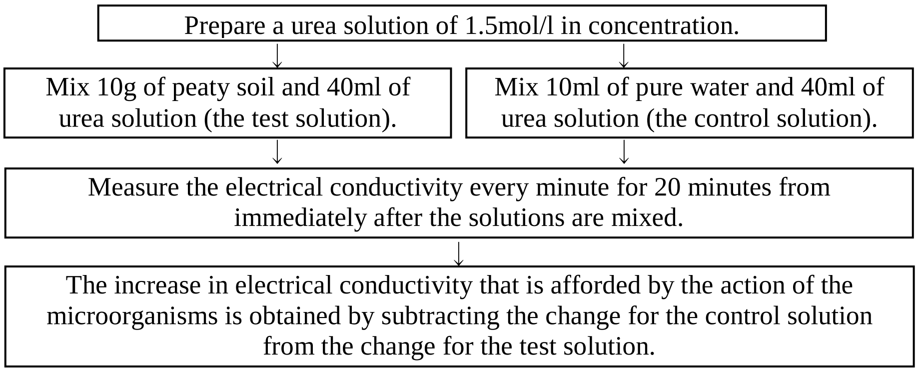


Fig.6 Estimating urease activity based on electrical conductivity
The figure in Reference #9 was partly modified and simplified.

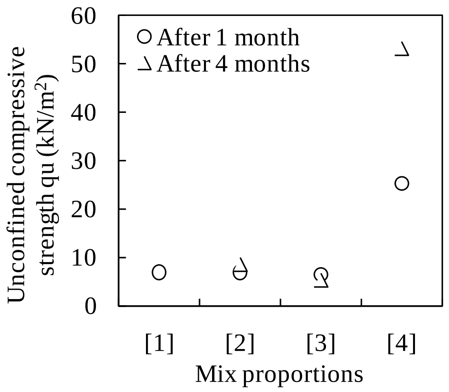


Fig.7 Unconfined compressive strength of each mix proportions

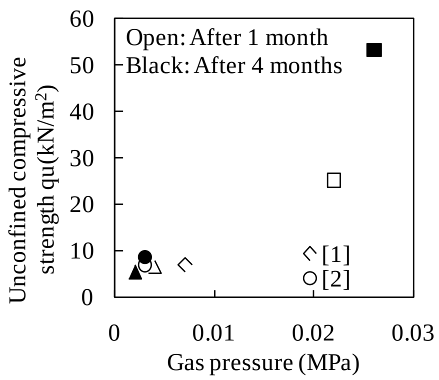


Fig.8 Gas pressure and Unconfined compressive strength

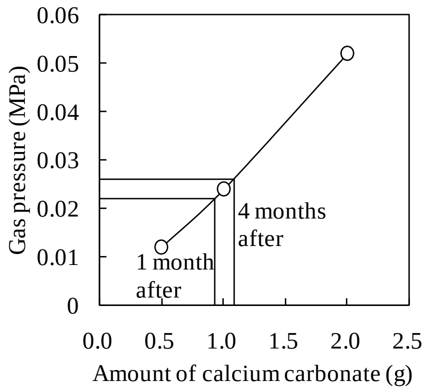


Fig. 9 Amount of calcium carbonate and Gas presure

specimens. Gas was not generated at the time of specimen preparation. Gas generation was found in the 1-month-old and 4-month-old specimens, which showed that calcium carbonate was precipitating. For specimen #4, whose strength was found to have increased at 1 month and 4 months after preparation, the gas pressure was high. Fig. 9 shows the relationship between the amount of calcium carbonate and gas pressure [7]. It was estimated that 0.9g of calcium carbonate precipitated in 10g of 1-month-old specimen #4 and 1.1g of calcium carbonate was precipitated in 10g of 4-month-old specimen #4.

5.2 Estimating urease activity based on electrical conductivity

Fig.10 shows how electrical conductivity increased with time after soil and urea solution mixing. The large increase in electrical conductivity with the passage of time indicates high urease activity. The increase in electrical conductivity with time is small in the Iwanai and Ebetsubuto samples, which means that the urease activity of these two samples is low. The increase in electrical conductivity with time is great in the

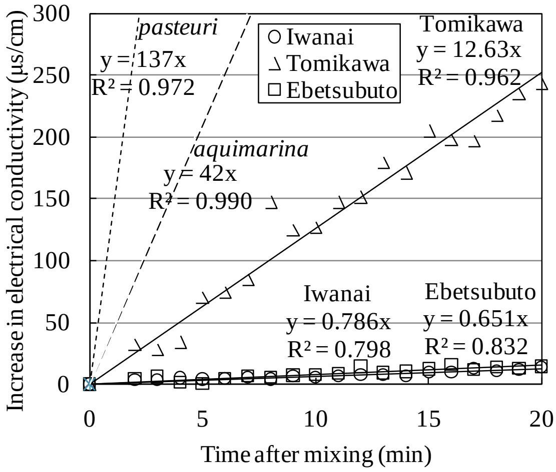


Fig.10 Time after mixing, and the increase in electrical conductivity

Tomikawa sample, which means that the urease activity of this sample is high. The urease activity of the samples varied.

Fig.10 also shows the data for increase in electrical conductivity of samples with *Bacillus pasteurii* and *Sporosarcina aquaimarina* [9].*Bacillus pasteurii* is a land bacterium whose effectiveness in ground solidification has been clarified. It is used widely in Japan and abroad. *Sporosarcina aquaimarina* is a marine bacterium with urease activity that is expected to be used in soil solidification. The rate of increase in the electrical conductivity of soil from Tomikawa was about one-tenth (1/10) that of *Bacillus pasteurii* and about one-fourth (1/4) that of *Sporosarcina aquaimarina*. The microorganisms in peaty soil from Hokkaido have lower urea activities than those of the above two types of bacteria; however, the soil from Tomikawa has relatively high urease activity. It is thought that solidification of peaty soil using the metabolism of indigenous microorganisms is possible.

The Iwanai and Ebetsubuto samples showed relatively small increases in electrical conductivity in a short test. Therefore, their electrical conductivity was measured at 1 hour and and again at 3 days after mixing, which were longer periods after mixing than for experiment by Hata et al. The measurement results are shown in Table 4. A slight increase in electrical conductivity was observed in the Ebetsubuto sample. In the Iwanai sample, the electrical conductivity increased by 340μs/cm in three days. It was thought that by setting a longer time, peaty soil could be solidified by using the metabolism of microorganisms.

Table 4 Electrical conductivity after the passage of time (μs/cm)

Sample loc.	Iwanai	Ebetsubuto
0 minutes	348	29
1 hour	388	42
3 days	686	85

6. SUMMARY

The findings in this study are as follows.

1) Microbes with urease activity inhabit in the subject peaty soil.
2) Improvement of peaty soil is possible by using the calcium carbonate method,if the urease activity of the microbes in the peaty soil is able to be enhanced.
3) The degree of urease activity is possible to be evaluated not by isolating the microbes in the peaty soil but by measuring the electrical conductivity of the soil.

7. CONCLUSION

From this experiment, it was clarified that peaty soil improvement by solidification using the calcium carbonate method was possible.In the future studies, the authors would like to clarify the relation between the urease activity of the microbes in peaty soil and the physical properties of the peaty soil, and that between the urease activity of microbes and the the strength of peaty soil.

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