

# Effect of moisture dilution rate on ground improvement materials using rice husk ash

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**ABSTRACT:** The 2024 Noto Peninsula Earthquake that occurred on January 1, 2024 caused liquefaction damage in many areas in the Hokuriku region, especially in Ishikawa Prefecture, and even in 2025, restoration of detached houses has been delayed. One of the reasons for this is that the cost of liquefaction countermeasures for narrow areas tends to be high, and residents must bear a large proportion of the cost themselves. On the other hand, rice is widely cultivated in Japan, and most rice husks are incinerated. Geopolymers are used in the field of concrete engineering. Geopolymer is a solidified material produced by the condensation polymerization reaction of alkaline solution and active filler and is used as an alternative to cement. Based on previous studies, we considered the possibility of utilizing rice husk ash as a geopolymer. However, geopolymers have not been applied to geotechnical engineering for a long time, and there are no regulations on the mixing ratio of geopolymers. In the geotechnical field, strength is not required as much as in the concrete field, and therefore, cost reduction and improvement of permeability can be expected by increasing the moisture content. In the field of geotechnical engineering, the use of concrete is also being studied. In addition, since the geotechnical engineering field does not require as much strength as the concrete engineering field, cost reduction and improvement of permeability can be expected by increasing the water content. Needle penetration tests were conducted on geopolymer-amended soil with rice husk ash, and the results showed that the target strength could be met even if the concentration of alkali solution was diluted. From the test results, an evaluation formula for uniaxial compressive strength using alkali concentration was proposed.

**KEYWORDS:** liquefaction countermeasures, rice husk ash, geopolymer, needle penetration test

## 1 INTRODUCTION

The 2024 Noto Peninsula Earthquake that occurred on January 1, 2024 caused liquefaction damage in many areas in the Hokuriku region, especially in Ishikawa Prefecture, and even in 2025, restoration of detached houses has been delayed. One of the reasons for this is that the cost of liquefaction countermeasures for narrow areas tends to be high, and residents must bear a large proportion of the cost themselves. There are various liquefaction countermeasure methods, but we wondered if there were any that would be more cost-effective in the future than the chemical injection and cement solidification methods that have been used in existing countermeasures. In Japan, rice cultivation is very popular, and rice husks are discharged as surplus biomass, much of which is incinerated. Geopolymers are utilized in the field of concrete engineering. Geopolymer is a solidified material produced by the condensation polymerization reaction of an aqueous alkaline solution and active filler and is used as an alternative to cement. Based on previous studies, we considered the possibility of utilizing rice husk ash as a geopolymer. However, geopolymers have not been applied to geotechnical engineering for a long time, and there are no regulations on the mixing ratio of geopolymers. In the geotechnical field, strength is not required as much as in the concrete field, and therefore, cost reduction and improvement of permeability can be expected by increasing the moisture content. In the field of geotechnical engineering, the use of concrete is also being studied. In addition, since the geotechnical engineering field does not require as much strength as the concrete engineering field, cost reduction and improvement of permeability can be expected by increasing the water content.

## 2 TEST SPECIMEN

Tohoku silica sand No. 6 was used as the soil sample for the geopolymer-amended soil. The active filler was rice husk ash from Toyama Prefecture, which was ground and sieved through a 2 mm sieve. Rice husk ash was selected due to its high silica and alumina content and the stable supply available in Japan, a rice-growing country. Two alkali solutions were compared: water glass No. 3 and 0.2% lime water. A 5% sodium hydroxide

solution was used as a reaction accelerator. The test samples were subjected to physical property tests in accordance with the Japan Society of Geotechnical Engineers. Table 1 shows the physical property test results of the sand. Figure 1 shows the grain size distribution of the sand. Figure 1 shows that the sand used in this study is close to having a single grain size.

Table 1. Physical properties of Northeast Silica Sand No. 6.

Soil particle density $\rho_s$ (g/cm <sup>3</sup> )	2.61
Natural water content ratio $w$ (%)	0.065
Maximum particle size $D_{max}$ (mm)	0.85
Average particle size $D_{50}$ (mm)	0.31
Maximum void ratio $e_{max}$	0.84
Minimum void ratio $e_{min}$	0.54
Coefficient of Equality $U_c$	3.50
Coefficient of curvature $U_c$	1.90

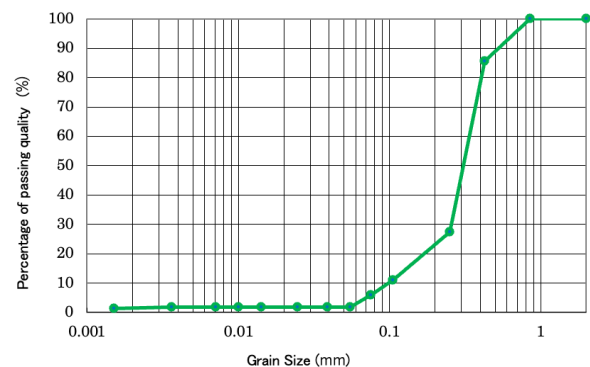


Figure 1. Particle size distribution of Northeast silica sand No. 6.

### 3 TEST CONDITIONS AND PROCEDURES

#### 3.1 Percentage of geopolymer improved soil

In this study, the mix proportions of geopolymer mortar with fly ash as the active filler, as developed by Terai (2019), were used as a reference. Terai aimed to develop geopolymer materials using wasabi soil as the aggregate. Terai used fly ash as the active filler and water glass as the alkaline solution. He examined whether geopolymers made with these materials could be used in construction. The authors followed this formula, replacing the active filler with rice husk ash. Additionally, the authors attempted to observe the effect on strength by adding water in arbitrary proportions. The standard formulations for this study are shown in Table 2.

Table 2. Physical properties of Northeast Silica Sand No. 6.

Soil sample	Geopolymer modifier		
Tohoku Silica Sand No. 6	Active Fillers	Alkaline solution	
	Rice husk ash	Water glass or Lime water	Sodium hydroxide solution
49	34	12	5

#### 3.2 Specimen preparation method and curing conditions

In a bowl, the materials shown in Table 2 were mixed with an arbitrary amount of water. The mixture was kneaded by hand until it was uniform. Then, the mixture was packed into a plastic mold (50 mm in diameter and 100 mm in height) in three layers, with each layer tamped to remove air and solidify the material. After preparing the specimens, they were air-cured in a curing room at 20°C and 70% RH for a specified period of 7 to 168 days.

### 4 NEEDLE PENETRATION TEST

The needle penetration test involves penetrating soil or rock with a needle, measuring the penetration length and load, and determining the slope of the penetration from the relationship between the two. This method primarily targets soils and soft rocks, including solidified soil, that can be penetrated by a needle. As previously mentioned, GP is a modified soil and is considered a highly disturbed sample; therefore, there is concern that its strength may be underestimated by uniaxial compression tests. The needle penetration test does not involve specimen failure and can be repeated on the same specimen. Therefore, strength changes over time can be confirmed with less error from specimen to specimen. The needle penetration tester used in this study is shown in Figure 2.

During the test, the penetration length ( $L$ , in mm) and penetration load ( $P$ , in N) are recorded when the penetration length reaches 10 mm or the maximum penetration load is reached. To derive the needle penetration gradient ( $NP$ ), substitute the values of  $L$  and  $P$  obtained from the penetration test into equation (1). The average value of the three tests is used as the  $NP$  of the specimen.

$$NP = P/L \quad (1)$$

where  $NP$ : Needle penetration slope (N/mm)  
 $P$ : Penetration load (N)  
 $L$ : Needle penetration length (mm)



Figure 2. Full view of needle penetration tester

Figure 3 illustrates the correlation between the needle penetration gradient ( $NP$ ), which is obtained from the needle penetration test, and the uniaxial compressive strength of specimens prepared under identical conditions. The conversion formula shown in equation (2) was derived from the figure. The converted uniaxial compressive strength ( $q_{ue}$ ), calculated from this equation, is used hereafter. Equation (2) was used for the lime-water case, as well as the water-glass case.

$$\log q_{ue} = 0.174 \cdot \log NP + 2.57 \quad (2)$$

where,  $q_{ue}$ : converted uniaxial compressive strength (kN/m<sup>2</sup>),  
 $NP$ : needle penetration slope (N/mm)

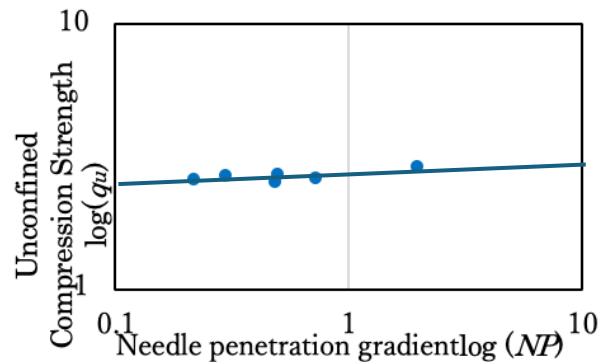


Figure 3. Relationship between needle penetration gradient and uniaxial compressive strength

### 5 TEST RESULTS

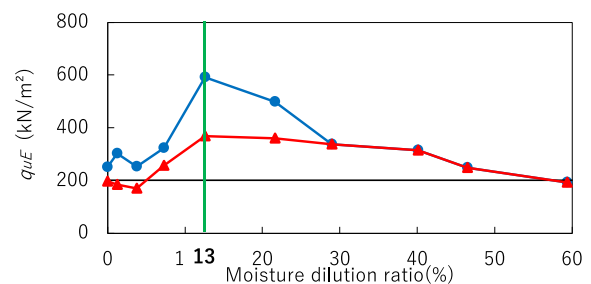


Figure 3. Relationship between moisture dilution rate and converted uniaxial compressive strength at 28 days of curing

Of the many liquefaction countermeasure methods, this study considers applying the improved ground to the permeation solidification method. In liquefaction countermeasure methods, the uniaxial compressive strength is typically set to approximately 100 kN/m<sup>2</sup> and the liquefaction strength ratio (RL), which is the stress ratio at a repetition rate (Nc) of 20, is set to approximately 0.4 to 0.6 (Coastal Technology Research Center, 2020). However, for structural measures, such as settlement control, the main improvement requires a uniaxial compressive strength of 200 kN/m<sup>2</sup> or greater. In this study, the target strength was set at 200 kN/m<sup>2</sup> because settlement control is important in liquefaction countermeasures for detached houses.

Figure 3 illustrates the correlation between water dilution rate and converted uniaxial compressive strength ( $q_{uE}$ ) after 28 days of curing. The water dilution ratio is the mass of water added divided by the total mass of geopolymer-improved soil. The target strength was achieved in all cases where water glass was used. Strength reached its peak at 13% water dilution in all cases. The lower strength at lower water dilutions may be due to the water absorbency of the rice husk ash, which inhibits the penetration of alkali components. Sato et al. (2014) reported that insufficient hydration reaction occurred when cement-improved soil mixed with bamboo was stirred due to the bamboo's water absorbency, which made the soil brittle. The same phenomenon is thought to have occurred in this case. The decrease in strength at high water dilution may be due to a decrease in the concentration of the alkaline solution.

Up to this point, the results have been organized using the water dilution ratio. However, this ratio is not versatile because it is based on a standard formula that mimics Terai's formula. If experiments are conducted using a different standard, it will not be possible to compare the types and concentrations of alkaline solutions. Therefore, the results were organized using a new water-alkali molar ratio (W/A) (Equation 3), which is expressed as the ratio of the molar ratio of the alkali component to the molar ratio of water. Using the molar ratio allows us to quantitatively evaluate the properties of the solution. When the water dilution ratio is 13%, the W/A ratio is 33 for water glass and 243 for lime water.

$$\frac{W}{A} = \frac{\text{Molar ratio of water}}{\text{molar ratio of alkali Component}} \quad (3)$$

This section estimates the strength improvement after infiltration. When rice husk ash was used, the strength peaked at a water dilution ratio of 13%. Since a lower geopolymer amendment viscosity is advantageous for penetration tests, we consider the range of water dilutions above 13% ( $W/A = 33$  for water glass and  $W/A = 243$  for petroleum petrochemical water). Figure 4 illustrates the correlation between the water-to-alkali molar ratio and the converted uniaxial compressive strength of the alkaline solution in water glass. Figure 5 depicts the correlation between the water-to-alkali molar ratio and the converted uniaxial compressive strength in lime water after 7 and 28 days of curing. The figures demonstrate an inverse proportional relationship in both cases. Next, we derive approximate equations from the figures. Typically, strength is measured 28 days after solution penetration, but we also propose a case in which the curing period until solidification is short.

In this case, the strength peaked at a 13% water dilution rate. Since solutions with low viscosity are more advantageous for penetration tests, cases with water dilution rates higher than 13% were used in this study. The water-glass case had a W/A ratio of 33, and the petrochemical water case had a W/A ratio of 243. In both cases, the converted uniaxial compressive

strength decreased as the water-to-alkali molar ratio increased (i.e., as the alkali concentration decreased).

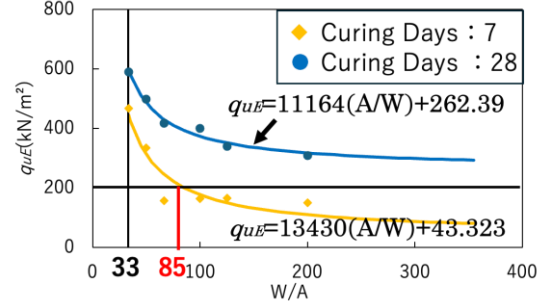


Figure4. Relationship between crown-pile uniaxial compressive strength and water-cement ratio in water-glass at 7 and 28 days of curing time.

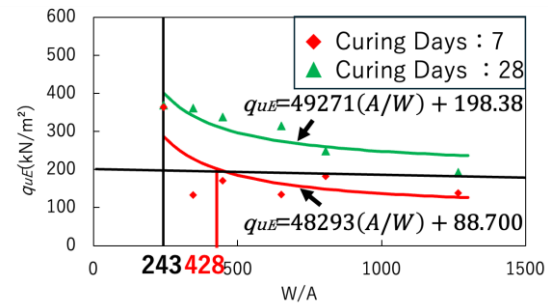


Figure5. Relationship between crown crest uniaxial compressive strength and water-cement ratio in lime water at 7 and 28 days of curing time

Figure 4 shows the conversion equations for the uniaxial compressive strength at 7 and 28 days of curing (see Equations 4 and 5).

$$q_{uE} = 13430 (A/W) + 43.323 \quad (W/A \geq 33) \quad (4)$$

$$q_{uE} = 11164 (A/W) + 262.39 \quad (33 \leq W/A \leq 85) \quad (5)$$

Figure 5 shows the conversion equations for the uniaxial compressive strength at 7 and 28 days of curing (see Equations 6 and 7).

$$q_{uE} = 13430 (A/W) + 43.323 \quad (W/A \geq 243) \quad (6)$$

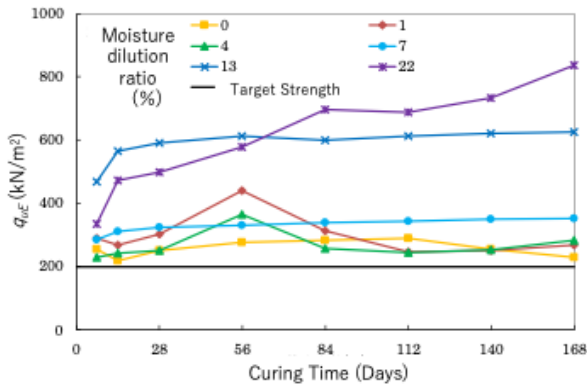
$$q_{uE} = 13430 (A/W) + 43.323 \quad (W/A \geq 243) \quad (7)$$

Typically, the 28th day, when the strength is stable, should be used. However, if you want to design based on the initial strength, you can use the equation for the seventh day of curing. Studies have shown that the target strength can be achieved if the strength falls within the following ranges:  $33 \leq W/A \leq 85$  for water glass and  $243 \leq W/A \leq 428$  for lime water.

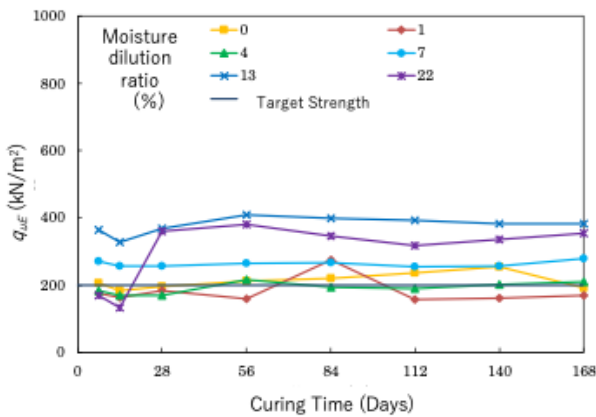
In order to introduce the new material to liquefaction countermeasures, the long-term strength behavior of the material needs to be discussed. The following figure shows the change in the strength of rice husk ash-based geopolymer-amended soil with different alkali solutions over a limited period of time, from seven days to 168 days of curing.

Figure 6 shows the relationship between converted uniaxial compressive strength and the number of curing days for each water dilution ratio. (a) illustrates the use of water glass as the alkaline solution and (b) illustrates the use of lime water as the alkaline solution. The target strength was set to 200 kN/m<sup>2</sup>, which is twice the 100 kN/m<sup>2</sup> used in many liquefaction countermeasures. The target strength was met at all water

dilution rates when water glass was used as the alkali solution. The strength of the case in which lime water was used as the alkali solution was generally lower than that of the case in which an alkali solution was used.



(a) Water Glass



(b) Lime water

Figure 6. The relationship between the converted uniaxial compressive strength and the number of curing days is shown here.

## 6 CONCLUSIONS

Needle penetration tests on geopolymer-amended soil with rice husk ash showed that the target strength could be achieved even with a diluted alkali solution. Based on these results, a formula was proposed to evaluate the uniaxial compressive strength in relation to the alkali concentration.

## 7 ACKNOWLEDGEMENTS

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