Soil improvement of tsunami sediment soil by steel slug and concrete sludge

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ABSTRACT

The most powerful earthquake, the 2011 Tohoku Earthquake, occurred on March 11, 2011. The north-eastern region of Japan have been most seriously damaged by the tsunami waves devastated the Pacific coast. Total amount of tsunami sediment was estimated around ten million ton in Miyagi, Iwate and Fukushima prefectures. It is necessary to use the tsunami sediment soil by construction materials in reconstruction works in north-eastern area in Japan. In this paper, an author proposed a reuse method of tsunami sediment soil by mixing with stabilizers, such as steel slug and concrete sludge. To improve strength of tsunami sediment, the blast furnace slug was used, however, a long time is necessary to enhance the strength of soft soil improved by blast furnace slug alone. To accelerate the hardening time, the author added concrete sludge as an alkaline irritant to awake the potential hardening effect of blast furnace slug. The strength of tsunami sediment soil improved by blast furnace slug rapidly increased by adding the concrete sludge. The improved tsunami sediment achieved the target strength for construction materials within short period and it was applicable for the construction of embankment or fill material.

Keywords: reuse, tsunami sediment, soil improvement, concrete sludge, steel slag

1 INTRODUCTION

The 2011 Tohoku Earthquake occurred on March 11, 2011. The moment magnitude of the earthquake was 9.0, the most powerful earthquake ever measured in Japan. About 19,000 are dead and missing. Three prefectures in the north-eastern region of Japan, Miyagi, Iwate and Fukushima, have been most seriously damaged. The tsunami waves devastated the Pacific coast of north-eastern district in Japan. Many cities and towns are still far from reconstruction Tsunami disaster was one of the grievous disasters in the 2011 Tohoku Earthquake. Total amount of tsunami sediment was estimated around ten million ton in Miyagi, Iwate and Fukushima prefectures (Ministry of the Environment, 2013). It is necessary to use the tsunami sediment soil as shown in Fig.1 by construction materials in reconstruction works in north-eastern area in Japan.

In this paper, an author proposed a reuse method of tsunami sediment soil by mixing with stabilizers, such as steel slug and concrete sludge. Steel slug, especially granulated blast furnace slug, was widely used to improve mechanical properties of soft soils such as dredged soil. To improve strength of tsunami sediment, the blast furnace slug was used by Horii et al. (2013). Mechanical properties are improved by mixing with steel slag, however, a long time is necessary to enhance the strength of soft soil improved by blast furnace slug alone. This means that it is impossible to reuse tsunami sediment as a construction material in a short period. To accelerate the hardening effect of the steel slag, the author added concrete sludge as an alkaline irritant to awake the potential hardening effect of blast furnace slug. The concrete sludge is a by-product of ready-mixed concrete, which is generated from the reconstruction works in Tohoku area. In this paper, it is discussed through the experimental tests whether the
tsunami sediment improved by steel slag and concrete sludge achieved the target strength for construction materials within short period.

2 TEST PROCEDURES

The unconfined compressive strength was used as an index to evaluate the soil improvement. The target strength of the improved soils was set as the second grade of treated soils (Ministry of Land, Infrastructure, Transport and Tourism, 2006) which has over 800 kN/m² of unconfined compressive strength. The second grade of treated soils is widely reused as the geotechnical material for the fill, backfill, embankment, and roadbed.

2.1 Tsunami sediment

Tsunami sediment used in this study was taken at Natori city in the southern coast of Sendai bay. Although the tsunami sediment usually includes a large amount of fisheries waste, plastics waste and wood pieces, they were removed from the tsunami sediment because of difficulty for reuse as soil material. After the intermediate treatment, the grain size distribution curve of tsunami sediment is shown in Fig.2. Tsunami sediment seems to be a sandy soil as shown in Fig.2 (a) and fine content was lost by the intermediate treatment. Natural tsunami sediment has high water content and contains fines as shown in Fig.1 (a). Therefore, substitute soil taken from construction site near my college was used as the muddy soil of tsunami sediment as shown in Fig.2 (b). It has more than 60% fine contents, liquid limit 28.2 % and plastic limit 16.2%. It was classified to the low plasticity clay.

2.2 Granulated blast furnace slug

Granulated blast furnace slug was used as a solidification material in this study as shown in Fig.3. There are iron and steel foundries in Tohoku area. It has the potential hardening effect itself and the hardening effect is mobilized with alkaline irritation in a short period. The chemical composition of granulated blast furnace slag is shown in Table 1.

| Chemical component | percentage (%) | chemical component | percentage (%) |
|--------------------|----------------|--------------------|----------------|
| CaO                | 40.59          | Na₂O               | 0.41           |
| SiO₂               | 32.97          | K₂O                | 0.40           |
| Al₂O₃              | 15.42          | MnO                | 0.37           |
| MgO                | 7.87           | FeO                | 0.34           |
| TiO₂               | 1.13           | Cl                 | 0.001          |
| S                  | 1.12           |                     |                |

![Fig. 3. Granulated blast furnace slag.](image)

2.3 Concrete sludge

The concrete sludge is a by-product of ready-mixed concrete, which is made by removing sand and coarse aggregate from the ready-mixed concrete. It has high alkalinity, so it is suitable for alkaline irritant. It is generated from the reconstruction works in Tohoku area. In this study, artificial concrete sludge was used, which is made from cement paste with the water-cement ratio of 40%. It was solidified for 48 hours, then crushed into granular material under 5 mm as shown in Fig.4.

![Fig. 4. Concrete sludge.](image)
2.4 Mixing rate and preparation of specimens

Tsunami sediment is mixed with granulated blast furnace slag and concrete sludge as shown in Table 2. Sandy tsunami sediment is mixed with steel slag with mixing rate of 0, 3, and 5%, in which the strength of tsunami sediment improved by steel slag alone is evaluated. Then, as alkaline irritant, concrete sludge of 10% is mixed with sandy tsunami sediment and steel slag. Through the comparison with test results in cases of steel slag alone, the acceleration of the hardening effect of concrete sludge is evaluated.

Muddy tsunami sediment is mixed with steel slag with mixing rate of 0, 5, and 10%. Also, as alkaline irritant, concrete sludge of 5% and 10% is mixed with muddy tsunami sediment and steel slag. Mixing rate of steel slag and additive rate of concrete of muddy soil are higher than those of sandy tsunami sediment, because the muddy soil is weaker than sandy tsunami sediment.

Specimens, which have 50mm in diameter and 100mm in height, are made in the steel mold by tamping method and cured under 20 degree Celsius and 60% humidity from 0, 14, 28, and 90 days. A series of unconfined compression tests are carried out to evaluate strength characteristics of the improved tsunami sediment. All test cases in this study are shown in Table 2.

| tsunami sediment       | mixing rate of steel slag (%) | additive rate of concrete sludge (%) | cured time (days) |
|------------------------|-------------------------------|-------------------------------------|------------------|
| sandy soil             | 0                             | 0                                   | 0, 14, 28, 90    |
|                        | 3                             | 0                                   | 10               |
|                        | 5                             | 0                                   | 10               |
| muddy soil (substitute soil) | 0                         | 0                                   | 0                |
|                        | 3                             | 0                                   | 10               |
|                        | 5                             | 0                                   | 10               |
|                        | 10                            | 0                                   | 10               |

3 TEST RESULTS AND DISCUSSION

The strength characteristics of the improved tsunami sediment is evaluated by unconfined compressive strength. Effects of the mixing rate of steel slag and the cured time are discussed.

3.1 Strength of the improved sandy tsunami sediment and mixing rate of steel slag

Fig. 5 shows unconfined compressive strength of sandy tsunami sediment with mixing rate of steel slag. As the mixing rate of steel slag increases, the unconfined compressive strength increases regardless of the additive rate of concrete sludge. There are no difference between unconfined compressive strength from 0 to 28 days without concrete sludge. By adding 10% concrete sludge, unconfined compressive strength has mobilized within 14 days. Especially, without mixing with steel slag, initial unconfined compressive strength increases by adding concrete sludge.

3.2 Strength of the sandy improved tsunami sediment and cured time

Fig. 6 shows unconfined compressive strength of sandy tsunami sediment with cured period. As the cured period increases, unconfined compressive strength increases by mixing with steel slag regardless of adding concrete sludge. However, by adding 10% concrete sludge, unconfined compressive strength rapidly increases with the cured time. This is because the alkaline irritant enhances potential hardening effect of the steel slag. The concrete sludge also has hardening effect, the hydration reaction in the improved clay by concrete sludge was observed by Noguchi et al. (2012) using scanning electron microscope.

The target strength (q_u=200 kN/m^2) was achieved by mixing with 10% concrete sludge and cured more than 14 days regardless of mixing rate of steel slag as shown in Fig. 6.

3.3 Strength of muddy tsunami sediment improved by steel slag

Fig. 7 shows unconfined compressive strength of muddy tsunami sediment with mixing rate of steel slag. As the mixing rate of steel slag increases, the unconfined compressive strength a little increases without concrete sludge, however, as the additive rate of concrete sludge increases, the unconfined compressive strength increases. After 90 days, the unconfined compressive strength clearly increases by mixing steel slag without concrete sludge. The increase ratio in unconfined compressive strength after 90 days is much bigger than that after 0 day, therefore, it is
confirmed that the alkaline irritant enhances potential hardening effect of the steel slag.

3.4 Strength of muddy tsunami sediment improved by steel slag and concrete sludge

Fig. 8 shows unconfined compressive strength of muddy tsunami sediment with cured period. As the cured period increases, unconfined compressive strength increases by mixing with steel slag regardless of adding concrete sludge. In case without mixing steel slag, the increase ratio in unconfined compressive strength gradually decreases after 28 days. However, by mixing steel slag, the increase ratio in unconfined compressive strength increases until 90 days. This is because the hardening effect of steel slag enhanced by concrete sludge.

The target strength was achieved by mixing with 10% steel slag and 10% concrete sludge and cured more than 14 days, or 10% steel slag and 5% concrete sludge and cured more than 90 days.

4 CONCLUSIONS

Main conclusions in this study were summarized as follows:
1) As the mixing rate of steel slag increases, the unconfined compressive strength increases regardless of the additive rate of concrete sludge.
2) As the cured period increases, unconfined compressive strength increases by mixing with steel slag regardless of adding concrete sludge.
3) The increase ratio in unconfined compressive strength increases until 90 days by mixing steel slag because of hardening effect of steel slag enhanced by concrete sludge.
4) The improved tsunami sediment achieved the target strength for construction materials within short period by mixing with steel slag and concrete sludge with reasonable rates.

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