Application to the separation of disaster waste using rotary crushing and mixing method

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ABSTRACT

The 2011 off the Pacific Coast of Tohoku Earthquake and accompanying tsunami presented various geotechnical engineering issues. This paper discusses the separation of disaster waste. As a result, it is evident that the rotary crushing and mixing method can enhance the effectiveness of the separation process where soil and waste that is firmly attached to the waste or debris are ground down and pulverized (granulated) using power-driven chains to carry out the intended separation.

Keywords: the rotary crushing and mixing method, disaster waste, separation, pulverize, strike

1 INTRODUCTION

The disaster waste produced by tsunami waves accompanying the 2011 off the Pacific Coast of Tohoku Earthquake contained large quantities of soil and slurry as well as waste. In the initial stages of post-earthquake period, the local authorities had difficulty in disposing of unprecedentedly large quantities of disaster waste. As a result of application of existing technologies in the field through trial and error, technology was established for disposing of large-scale disaster waste. Disaster waste was completely disposed in part of Fukushima Prefecture, and in Miyagi and Iwate Prefectures in March 2014, a target set by the national government (Ministry of the Environment, 2014).

Discussions had been made on the application of the rotary crushing and mixing (RCM) method to the separation of disaster waste in view of its record of soil improvement using various types of soil materials (Nakajima, N. et al. 2004). As a result, the method was found to be effective for increasing the separation accuracy because it involves the striking of soil particles off the waste using the striking force of chains to separate soil particles from the waste and crush soil particles (Kadowaki, M. et al. 2012).

This paper describes a disaster waste separation approach using the RCM method and presents two case studies of application of the method to actual disaster waste separation work, specifically, restoration of farmland and crushing and separation of disaster waste.

2 OUTLINE OF ROTARY CRUSHING AND MIXING METHOD

The rotary crushing and mixing method (RCM) involves simultaneous crushing (grinding) of soil materials with rapidly rotating flexible chains in a cylinder, and uniform mixing of the fines with additives. It is applicable to high-water-content cohesive soil as well although the type of soil was difficult to handle for soil improvement (Nakajima, N. et al. 2012). The method is outlined in Figure 1. The mixing device is composed of cylindrical casing and motor sections. The impact chains attached to the rotational axis at the center of the casing rotate at high speed. The striking force of rotating chains pulverizes the soil into fines. The grain size of crushed material can be adjusted by varying the number of rotations. The casing is equipped with a device for enforced scraping of attached material to prevent cohesive soil from being attached to the interior of the casing.

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3 APPROACH TO DISASTER WASTE SEPARATION

Disaster waste is classified into flammable, non-flammable and soil particles. Of soil, undersize muck (Iwate prefectural government. 2013) (soil containing large quantities of waste wood and other flammable waste that is hardly usable as reconstruction material, and is used as cement material or disposed in landfill) or soil-mixed muck (Iwate prefectural government. 2013) (soil obtained as reconstruction material by separating non-flammable or flammable mixtures that is poorly usable and is disposed in least controlled or controlled landfill sites) is of lower quality than required as reconstruction material, and therefore is appropriately treated or disposed of. It is hoped that soil produced as disaster waste will be studied in various fields and utilized as reconstruction material. Against such a background, this paper describes an approach to the verification of separation accuracy owing to the pulverizing effect of the RCM method in the case where the 20-mm sieve used in the field for separation was replaced with a 9.5-mm sieve while soil produced as disaster waste was used after rough separation (Nakajima, N. et al. 2013).

3.1 Material used

Used as the soil produced as disaster waste in the test was roughly separated undersize soil passing a 40-mm sieve (non-flammable or flammable mixture including tsunami sediment, referred to as undersize soil below). Adopted as additives for increasing separation accuracy and making effective use of materials were concrete dust passing a 9.5-mm sieve, created by crushing the concrete muck with a maximum size of 150 mm of no use that was produced as disaster waste, and blast-furnace cement type B for stabilization and insolubilization. Table 1 lists the physical properties of the undersize soil and concrete dust. Natural water content was obtained by measuring samples containing waste and pieces of wood after separation. Soil particle density, grain size, consistency and hydrogen exponent were obtained where waste and pieces of wood were manually removed. Loss on ignition is the value where the material was classified using a 0.85-mm sieve and pieces of wood were removed. It is nearly equal to 6% (Edited by JGS. 2009), the loss on ignition in the Kanto loam.

3.2 Test details

In the test, a rotary crushing and mixing machine and a floor-type vibratory sieving machine were used. In the test, a designated amount of undersize soil and a designated combined amount of undersize soil and additives were crushed using the rotary crushing and mixing machine and mixed. Then, the materials were classified using a vibratory sieving machine with openings of 9.5 and 19 mm, equivalent to the size in the field, and passing masses of classified materials were measured. In each case, the wet mass of sample was set at 50 kg and the time of separation by the vibratory sieving machine at 30 seconds. Table 2 lists test cases. In case B, undersize soil was separated solely by the vibratory sieving machine without using a rotary crushing and mixing machine. In cases T300, T500 and T900, the number of rotations of chains were set at 300, 500 and 900 rpm, respectively while handling undersize soil, and then the material was classified using the vibratory sieving machine. The pulverizing effect of the rotary crushing and mixing machine was verified in the above four cases. Then, tests were conducted in cases D20, C03, C05 and C10 in which additives were applied at a number of rotations considered fit for separation based on the results in cases T300, T500 and T900. In case D20, concrete dust was added to undersize soil at a wet mass ratio of 20%. In cases C03, C05 and C10, slag-furnace cement type B was added to undersize soil at a wet mass ratio of 3, 5 and 10%, respectively. In these cases, the effect of pulverizing was verified for varying additives and at varying percentages of additives. The effect of pulverizing was evaluated using an index referred to as the percentage of separation.

The percentage of separation was calculated using equation (1). The amount of additives is subtracted in the equation as they were assumed to pass a 9.5-mm sieve because both concrete dust and cement had a maximum grain size of 9.5 mm or less.

Table 1. Physical properties of undersize soil and concrete dust.

| Parameter                      | Undersize soil | Concrete dust |
|-------------------------------|----------------|---------------|
| Soil particle density ρc (g/cm³) | 2.644          | 2.719         |
| Natural water content w (%)   | 22.0±27        | 9.8           |
| Grain size                    |                |               |
| Maximum grain diameter Dmax (mm) | 53             | 26.5          |
| Silt fraction (0.005mm or less) | 53             | 28            |
| Clay fraction (0.005 to 0.075mm) | 16             | 12            |
| Sand fraction (0.075 to 2mm)  | 4              |
| Plastic limit wp (%)          | 31.6           | -             |
| Plasticity index Ip             | 22.6           |               |

Classification of soil material

Silty gravelly sand
Sandy gravel mixed with fine particles

Chemical
Loss on ignition Li (%) 6.7  7.3
pH 8.5 11.4

Table 2. Test cases.

| Machines for separation | Vibratory sieving machine | Rotary crushing and mixing machine and vibratory sieving machine |
|-------------------------|---------------------------|---------------------------------------------------------------|
| Additives               | None                      | Concrete dust Cement                                          |
| Test case (No.)         | T300                      | T500 T900 D20 C03 C05 C10                                   |
| Percentage of additives (%) | 0 0 0 0 20 3 5 10        |

Percentage of separation (%) = Amount passing the sieve (kg) - additives (kg) / Mass remaining in the sieve (kg) - additives (kg) (1)
3.3 Test results

Table 3 lists test results and Figure 2 shows the percentage of separation. It was verified that using the rotary crushing and mixing machine increased the percentage of separation by approximately 15 percentage points above the case using the vibratory sieving machine only. The percentage of separation increased with the increase in the number of rotations of chains. It was, however, found that pieces of wood and waste were crushed, passed the 19- and 9.5-mm sieves and were mixed with undersize soil when the number of rotations was set at 900 rpm. It was also recognized that when the number of rotations was 300 and 500 rpm, pieces of wood were broken and waste was cut into large fragments but remained at the sieve. Then, 900 rpm was considered to produce excessive striking energy for separation, and the number of rotations was set at 500 rpm in view of the mixing characteristic in cases D02, C03, C05 and C10 with additives.

The percentage of separation is evidently higher in cases with additives than in the case where only the vibratory sieving machine was used. No outstanding difference was observed from case T500 with no additives. In separation, when additives are mixed such as consolidation agents, the material to be improved generally tends to have lower water content and separation accuracy increases. In this study, however, no improvement in separation accuracy was recognized owing to the application of additives. The percentage of separation may have been affected because the properties of soil produced as disaster waste and the type of waste varied from test case to test case and because the amount of additives was insufficient to increase separation accuracy. Crushing by the RCM method was, however, considered effective for maintaining steady separation accuracy even without additives.

Table 3. Test results.

| Machines for separation | Vibratory sieving machine | Rotary crushing and mixing machine | and vibratory sieving machine |
|------------------------|---------------------------|-----------------------------------|------------------------------|
| Test case (No.)        | B            | T900 | T900 | T900 | D20 | C03 | C05 | C10 |
| Percentage of separation (%) | B | 59.5 | 74.0 | 74.0 | 74.0 | 89.6 | 89.6 | 89.6 | 92.1 |
| 9.5-mm sieve            | 91.2         | 91.2 | 91.2 | 91.2 | 89.0 | 89.0 | 89.0 | 89.0 | 92.1 |
| 19-mm sieve             | 73.0         | 73.0 | 73.0 | 73.0 | 87.9 | 87.9 | 87.9 | 87.9 | 83.1 |

4 CASE STUDIES

4.1 Restoration of farmland

The work for removing disaster waste from farmland in the Town of Shichigahama (phase 4) aimed at separating soil with a maximum grain size of 20 mm or less from roughly separated soil for backfilling and soil removal to restore fields where farming was possible. Table 4 outlines the farmland restoration work. Figure 3 gives the state of fields nearly one month from the incurrence of damage. It shows that various waste and slurry deposited in large quantities in the fields right after the disaster. Then, large waste particles were roughly separated using skeleton buckets and other devices. Treated in the project was the roughly separated soil particles with a size of approximately 100 mm mixed with disaster waste piled in the fields.

Table 4. Outline of farmland restoration.

| Project | Work for removing disaster waste from farmland in the Town of Shichigahama (phase 4) |
|---------|------------------------------------------------------------------------------------|
| Owner   | Miyagi prefectural government                                                      |
| Objective | Restoration of farmland                                                              |
| Construction period | August 2012 through June 2013                                                      |
| Scale of work    | Disaster waste separated and disposed: 86,200 m³                                   |
| Soil treated    | Roughly separated disaster waste                                                   |
| Improved quality | Grain size D ≤ 20 mm                                                                |

Fig. 2. Percentage of separation.

Fig. 3. Fields right after the earthquake disaster.

Fig. 4. Soil to be treated.
method was adopted in separation as part of the total work to increase separation efficiency by pulverizing high-water-content soil and uniformly mixing it with mountain sand. Soil was separated at the site by developing a plant system combining the RCM method and a vibratory sieving machine with a 20-mm sieve.

Water content increase due to rainfall or frost was sometimes of concern during the work. A mean percentage of soil passing the sieve exceeded 90%. The fields have been improved to a stage where rice cropping is possible (Figure 5).

### 4.2 Crushing and separation of disaster waste

The project for crushing and separating disaster waste in the Yamada district (phase 2) aimed at sorting disaster waste into flammable, non-flammable and soil particles through crushing and separation for appropriate treatment and disposal of waste. Table 6 outlines the project. The disaster waste was roughly separated from soil particles with a maximum grain size of 150 mm in the primary stage of disposal. Of the roughly separated particles, the mixture of flammable and non-flammable waste was sorted into a mixture of flammable and non-flammable waste with a grain size of 20 mm or larger, undersize muck with a grain size not exceeding 20 mm [5] and soil-mixed muck [5]. The mixture of flammable and non-flammable waste with a grain size of 20 mm or larger was sorted into flammable and non-flammable particles. The automatic separation system, however, had low separation accuracy because of the soil attached to the waste. Then, focus was placed on the effect of the RCM method on crushing. A process was verified of improving mixtures of flammable and non-flammable waste by striking off the soil particles attached to the waste using the force of chains to increase the separation accuracy of automatic separation systems. The plant system was composed of the RCM machine and a trommel with a 20-mm sieve. Figure 6 shows the plant system. Verifications were made by handing the mixture of flammable and non-flammable waster using either a trommel only or a system composed of the RCM machine and a trommel. The effectiveness of striking for removing the soil particles attached to the mixture was visually evaluated in the case where no additives were applied. Figure 7 shows the result of separation only with a trommel and Figure 8 shows the results in the case where a system

### Table 5. Physical properties of materials used.

| Parameter | Soil particle density $\rho_s$ (g/cm$^3$) | Natural water content $w_n$ (%) | Grain size | Maximum grain diameter $D_{max}$ (mm) | Silt fraction (0.005 to 0.075mm)% | Clay fraction (0.005mm or less)% | Grain size D≦20% | Gravel fraction (2 to 75mm)% | Sand fraction (0.075 to 2mm)% | Liquid limit $w_l$ (%) | Plastic limit $w_p$ (%) | Plasticity index $I_p$ | Consistency | Soil treated | Improved quality Grain size D≦20% |
|-----------|----------------------------------------|-------------------------------|------------|-----------------------------------|---------------------------------|---------------------------------|------------------|---------------------------|-----------------------------|-----------------------------|-----------------------------|------------------------|-------------|-------------|-----------------------------|
|           | 2.575 2.683                            | 27.3 58.1                     | 19.0       | 9.5 21 51 28 15 41 20 3 2 13 21 34 | 64.6 60.1                      | 26.2 22.7                     | 37.4 47.6       | 1.4 1.4                   | 7.5 7.1                     | 8.4 8.2                     | 7.8 7.8                   | 33.3                    | 25.7         | 7.4         | 20 mm          |

### Table 6. Outline of disaster waste crushing and separation.

| Project | Contracted work for crushing and separating disaster waste in the Yamada district (phase 2) |
|---------|-------------------------------------------------------------------------------------------|
| Owner   | Iwate prefectural government |
| Objective | Disaster waste crushing and separation |
| Construction period | December 2011 through March 2014 |
| Scale of work | Composite flammable and non-flammable waste and disposed: 90,000 tons (part of total work) |
| Soil treated | Composite flammable and non-flammable waste that underwent primary separation |
| Improved quality | Grain size D≦20 mm |

Fig. 5. Restored fields.
composed of the RCM machine and a trommel was adopted. Figure 7 and 8 clearly show that a smaller amount of soil was attached to the waste separated by the RCM method and a trommel than in the case where only a trommel was used. As a result, separation accuracy increased when the mixture of flammable and non-flammable waste crushed by the RCM method without applying additives was sorted into flammable and non-flammable particles using an automatic separator. The RCM method was therefore adopted.

In actual construction, mixtures of flammable and non-flammable waste of various shapes and properties were treated using an automatic separator. No deterioration in separation accuracy was observed owing to the steady pulverizing effect of the RMC method.

5 CONCLUSIONS

This study carried out to investigate the applicability of the RMC method to the separation of disaster waste. The conclusions are as follows.

1) As case studies of the adoption of the RMC method in construction work, the separation of disaster waste with a high water content deposited in fields, and a project that contributed to the improvement of steady separation by removing soil particles attached to waste were described.

2) In the future, large-scale waste separation and disposal will be required in preparation for the Tonankai Earthquake. Efforts are now being made to enhance the applicability of the RMC method by making better use of its features.

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