A study on geotechnical properties of recycled geomaterial from tsunami-related sediments

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ABSTRACT

Due to the 2011 off the Pacific Coast of Tohoku Earthquake, a large scale tsunami hit the Pacific coast area of the Tohoku and North-Kanto Regions, Japan. As a result of the earthquake and the subsequent tsunami, the tsunami-related sediments of about 900,000 tons were generated in Kesennuma City, Miyagi Prefecture. Therefore, the tsunami-related sediments had to be properly treated from the viewpoint of being recycled as non-toxic geomaterials and certainly utilized as embankments or filling materials in reconstruction projects. Additionally, it was required that they were quickly treated in order to preserve the living environment of local inhabitants and to improve the public health. In a disaster waste management project by the Miyagi prefectural government in Kesennuma (Kesennuma treatment area), the treatment (soil modification, separation, immobilization, etc.) and recycling of tsunami-related sediments were completed in about one year. This paper summarizes the outline of the treatment of tsunami-related sediments and describes the geotechnical properties of recycled geomaterials in the Kesennuma treatment area.

Keywords: the Great East Japan Earthquake, disaster waste, tsunami-related sediment, recycle, immobilization, compaction, embankment

1 INTRODUCTION

Due to the Great East Japan Earthquake, which had a magnitude of 9.0 (in the Richter scale), a large scale tsunami hit the Pacific coast area of the Tohoku and North-Kanto Regions, Japan. In some tsunami-flooded areas, a large amount of marine sediments were mixed with other disaster wastes and deposited onshore after the inundation phase. The sediments are referred to here as “tsunami-related sediments”.

The guideline on the treatment and utilization of tsunami-related sediments was issued from the Ministry of the Environment Government of Japan (MOE, 2011). In addition, the notice on the utilization of recycled materials in public works was issued from MOE in order to promote the recycle of tsunami-related sediments as well as other disaster wastes (MOE, 2012). The fundamental concept in the notice is as follows: if non-toxic materials are recycled from tsunami-related sediments and other disaster wastes, the recycled materials are not regarded as wastes and they can be utilized in public works for the restoration and reconstruction from the Great East Japan Earthquake.

In a disaster waste management project by the Miyagi prefectural government in Kesennuma (Kesennuma treatment area), intermediate treatments (collection, transportation, temporary storage, separation, crushing, incineration, etc.) were carried out according to the above guideline and notice, and the treatments for all disaster wastes of about 1,650,000 tons were completed by March, 2014. The tsunami-related sediments of about 900,000 tons were treated by separation to each material (wood, plastic, metal, concrete, glass, ceramics, soil, etc.) and other intermediate treatments. As a result, they were recycled as useful materials for embankments and fillings.

This paper summarizes the outline of the treatment of tsunami-related sediments and describes the geotechnical properties of the recycled materials from the tsunami-related sediments in the Kesennuma treatment area.

2 AMOUNT OF TSUMANI-RELATED SEDIMENTS IN KESSENNUMA TREATMENT AREA

In the Kesennuma treatment area, the amount of tsunami-related sediments was estimated with 41,000 tons at first. However, it increased to 890,000 tons for the reason that the Kesennuma municipal government consigned additional treatment of tsunami-related sediments to the Miyagi prefectural government in April, 2013.

For the purpose of dealing with a large amount of tsunami-related sediments properly, some experiments were carried out in laboratories and in fields to establish an optimum treatment procedure (specifically, procedure to achieve both separation accuracy and
separation efficiency simultaneously) and suitable quality control method. Moreover, a treatment capacity was enhanced by adding more treatment facilities at any time. As a result, a series of treatment works for the tsunami-related sediments were completed in about one year (Fig. 1).

Fig. 1. Change in the amount of tsunami-related sediments treated in the Kesennuma treatment area.

### 3 FLOW FOR RECYCLING OF TSUNAMI-RELATED SEDIMENTS

#### 3.1 Overview

In the Kesennuma treatment area, a flow for recycling of tsunami-related sediments was established as shown in Fig. 2.

As a preparation for a series of treatments, leachate concentrations of toxic substances included in the tsunami-related sediments were examined, and they were sorted in accordance with the test results.

In case the leachate concentrations of toxic substances were lower than the environmental criteria for soil, geotechnical properties were improved just after the processes of soil modification and separation. In the soil modification process, the tsunami-related sediments, which were roughly sieved by employing skeleton buckets with the opening sizes of 100-150 mm, were mixed with soil modifying materials in order to enhance the accuracy and efficiency of the succeeding fine separation.

The tsunami-related sediments were then cured for 0.5-1 days, and they were sieved by employing trommel screens or shaking screens with the opening size of 10-20 mm. As a result, the tsunami-related sediments were classified into waste mixtures and soil portions. The waste mixtures were additionally separated to each material manually or mechanically, while the soil portions were improved in geotechnical properties through the process of the mechanical stabilization using some coarse-grained materials such as recycled crashed stones from concrete wastes (denoted as "RC-40" in Fig. 2). The manual separating was also regarded as an important process as those to properly separate the combustible wastes from the waste mixtures and to reduce the ignition losses of recycled materials, from the viewpoint of mechanical and physicochemical stabilities.

On the other hand, in case the leachate concentrations of heavy metals such as arsenic, fluorine and boron exceeded the environmental criteria in some of the tsunami-related sediments, it required an additional treatment of immobilization after the processes of soil modification and separation. The treatment of immobilization was carried out for the soil portions classified from the tsunami-related sediments. After it was ensured that the leachate concentrations were reduced to the environmental criteria in the soil portions, they were blended with the coarse-grained materials.

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<table>
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<th>Date (month/year)</th>
<th>Treatment amount (10^3 tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2012-11/2013</td>
<td>0</td>
</tr>
<tr>
<td>12/2013</td>
<td>50</td>
</tr>
<tr>
<td>1/2014-11/2014</td>
<td>200</td>
</tr>
<tr>
<td>12/2014</td>
<td>500</td>
</tr>
<tr>
<td>1/2015-11/2015</td>
<td>1,000</td>
</tr>
</tbody>
</table>

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Fig. 2. Flowchart for recycling of tsunami-related sediments in the Kesennuma treatment area.
In the following section, the soil portions with the maximum particle size of 10-20 mm are described as "tsunami-related soils".

3.2 Soil modification and immobilization

In case the water contents of the tsunami-related soils were high, it was considered that they would have aggregated each other or adhered to other disaster wastes during sieving. Moreover, it was expected that the accuracy and efficiency of the fine separation would decline appreciably. Therefore, the soil modifying materials were mixed with the tsunami-related sediments before the separation process.

Field tests were carried out in order to evaluate the separation accuracy with several soil modifying materials. In a series of tests, a finger screen (6 m³ class) was used as a screening machine. Sieves with the opening sizes of 20 mm and 50 mm were installed in the finger screen, and the tsunami-related sediments, which were roughly sieved and mixed with soil modifying materials, were separated into three fractions (fine, medium and coarse fractions) by employing the screen. Fig. 3 shows the grain size distributions of the medium fractions. The results indicate that the percentage passing the fraction finer than 20 mm was decreased into about 20 %, with the use of the lime-based or gypsum-based material. It was confirmed that separation accuracy of the medium fractions was significantly improved by applying the soil modification with the lime-based or gypsum-based material.

![Fig. 3. Grain size distributions of the medium fractions separated from the tsunami-related sediments.](image)

The treatment of immobilization was conducted using a dry magnesia-based material. The material was mixed with the tsunami-related soils at a specified ratio with some field samples in the laboratory experiments. In fields, preliminary experiments to evaluate the immobilizing effect were also conducted employing the mixing machines shown in Photo 1.

In the actual work, the tsunami-related soils of 900 m³ were immobilized at a time, and the samples were obtained for leaching tests. As shown in Fig. 4, the leachate concentrations of arsenic, fluorine and boron were maintained within an allowable range in all the samples.

![Photo 1. Mixing machines for the immobilization treatment](image)

![Fig. 4. Change in the leachate concentrations of heavy metals in the tsunami-related soils after the treatment of immobilization.](image)

3.3 Mechanical stabilization

Fig. 5 shows the grain size distributions and the Standard Procter compaction curves as typical geotechnical properties of tsunami-related soils.

The Ministry of Land, Infrastructure, Transport and Tourism, Japan (MLIT) presented the appropriate geotechnical properties of recycled materials from tsunami-related sediments as well as other disaster wastes in order to utilize them for the embankments of residential developments (MLIT, 2012). However, the grain size distributions in some of the tsunami-related soils deviated from the appropriate range (Fig. 5(a)).

The compaction curves indicated that the tsunami-related soils with the ignition loss higher than 10% resulted in the remarkably lower maximum dry densities and resulted in the high air contents such as about 15% at the optimum water contents (Fig. 5(b)).

From the viewpoint of the applicability to embankments and fillings, the tsunami-related soils were blended with some coarse-grained materials such as RC-40 at a specified ratio in the laboratory experiments in order to improve the grain size distributions and compaction properties.

In the following section, the tsunami-related soils...
blended with the coarse-grained materials are described as "recycled geomaterials".

In addition to the laboratory tests, the embankment test was carried out, anticipating that the recycled geomaterials would be utilized in road embankments. As shown in Photo 2, a tire roller (15 tons class) was used as a roller compaction machine. The recycled geomaterials were spread in two layers of 24 cm each. Two embankments were constructed, with the number of passes set as 4 and 8 times, respectively. After roller compaction, the results of the layer thickness, in-situ density and in-situ CBR were obtained as shown in Table 1. The degree of compaction shown in the table was calculated based on the maximum dry density obtained from the compaction test by applying the Modified Proctor. Here, the maximum dry density and optimum water content through the Modified Proctor were 1.630 g/cm³ and 19.4 % respectively.

As shown in the table, in Case #2, the target value of 20 cm for layer thickness was reproduced, and the in-situ CBR was about 8 %. According to the Japanese Geotechnical Society (JGS), the in-situ CBRs of sandy soils which are used for subgrade vary in the range of 7-15 % (JGS, 2013). Thus, it may be regarded that the quality of the recycled material was equivalent to that of the sandy soil applicable to subgrade.

### 4 GEOTECHNICAL PROPERTIES OF RECYCLED GEOMATERIALS

#### 4.1 Mechanical properties

Geomaterials of about 3,000 m³ were recycled at a time, and the samples for the geotechnical tests in the laboratory were obtained.

Fig. 6 shows the mechanical properties of the recycled geomaterials. The natural water contents and the wet densities of samples compacted in the laboratory varied in the range of ordinary sandy soils. The ignition losses were mostly distributed over the range of 5-12 %. Although the about 20 % of the whole samples indicated the ignition losses higher than 10 %, the compaction properties were obviously improved since the air contents at the optimum water contents were less than 10 %. The swelling ratio, which is measured using the CBR-instrument, is generally related to the ignition loss and is used as an index of the potential of long-term settlement. As shown in Fig. 6, the swelling ratios as well as the grain size distributions and cone indices of the recycled geomaterials satisfied the qualities required for the embankments of residential developments.

Although the details are not shown in the figure, it may be noted that the coefficient of permeability resulted in the order of 10⁻³ cm/s and that the strength constants indicated the cohesion of 0-3 kN/m² and the internal friction angle of 34-39 degrees. These geotechnical properties are equivalent to those of gravelly soils or well-graded sandy soils.

#### 4.2 Chemical properties

Fig. 7 shows the histograms of the concentrations of radioactive caesium ¹³⁴Cs and ¹³⁷Cs in the recycled geomaterials. The samples with the concentrations higher than 100 Bq/kg occupied only about 10% of the whole samples, with the maximum concentration of radioactive caesium of about 250 Bq/kg. According to MOE (2012), the maximum concentration is within a low range in which the recycled geomaterials can be utilized for the embankments by applying soil covering with shielding materials such as impermeable asphalt.

Fig. 8 shows the histograms of salinity, electrical conductivity and pH of the recycled geomaterials. In some recycled materials, the values of these chemical properties exceeded the criteria for the embankments of residential developments. According to MLIT (2012), the recycled geomaterials with the salinity, electrical conductivity and pH higher than the criteria might cause the corrosion of underground pipes and the deterioration of underground structures, and it is required that such the materials are treated by salt removing and soil washing prior to the application to the embankments.

Besides, although the details are not described due to paper limitation in this paper, the leachate concentrations of heavy metals in the recycled geomaterials were lower than the environmental criteria for soil.
Table 1. Results of the embankment test.

<table>
<thead>
<tr>
<th>Case #</th>
<th>#1</th>
<th>#2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of passes (times)</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Layer thickness (cm/layer)</td>
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<td>20</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>22.8</td>
<td>20.4</td>
</tr>
<tr>
<td>Dry density (g/cm³)</td>
<td>1.576</td>
<td>1.664</td>
</tr>
<tr>
<td>Compaction degree (%)</td>
<td>96.7</td>
<td>102</td>
</tr>
<tr>
<td>In-situ CBR (%)</td>
<td>4.2</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Fig. 6. Mechanical properties obtained from laboratory tests of the recycled geomaterials.

Fig. 7. Histogram of the concentrations of radioactive caesium in the recycled geomaterials.
5 CONCLUSIONS

In the Kesennuma treatment area, the tsunami-related sediments of 890,000 tons were treated in about one year and were consequently recycled as geomaterials of 1,110,000 tons. The grain size contributions and compaction properties of the geomaterials were improved, blending with the coarse-grained materials such as recycled crashed stones from concrete wastes. According to the results of geotechnical and geoenvironmental tests, it was confirmed that the recycled geomaterials were applicable to embankments and fillings. The mechanical stabilization with the coarse-grained materials increased the recycling rate and reduced the amount of final disposal in the Kesennuma treatment area.

In utilizing the recycled geomaterials, it is important that the attention be paid to intended use, design criteria and geotechnical conditions. It is also required that risk managements be carried out without fail. In the Kesennuma treatment area, leachate concentrations of heavy metals higher than the environmental criteria for soil were observed in some tsunami-related sediments. In such cases, the treatment of immobilization was conducted as risk reduction measures against diffusion of contaminants into soil and groundwater. It is considered that the utilization of recycled geomaterials containing the immobilized soils should be promoted with continual risk estimates and risk managements (e.g. monitoring, soil covering, etc.) which are suitable for geoenvironmental conditions of the sites and the surrounding areas.

Finally, the utilization situation of the recycled geomaterials is summarized as follows.

Within the work period of the disaster waste management project by the Miyagi prefectural government, the recycled geomaterials were utilized in the repair works of roads, shore protections and external elements of buildings. The amount of utilization was only 15% of the whole recycled geomaterials. The full-scale utilization began in April, 2014. They are planned to be applied to land readjustment projects and other reconstruction works (Photo 3).

Photo 3. Recycled geomaterials (about 30,000 m³)

REFERENCES