Geotechnical utilisation of soil generated from earthquake waste-derived wood chips

Keisuke Hamajima i), Hideto Nonoyama ii), Takeru Araki iii) and Takuma Jinno iii)

i) Master Student, Department of Civil Engineering, Nagoya University, Furo, Chikusa, Nagoya 464-8603, Japan.
ii) Assistant Professor, Department of Civil Engineering, Nagoya University, Furo, Chikusa, Nagoya 464-8603, Japan.
iii) Undergraduate student, Department of Civil Engineering, Nagoya University, Furo, Chikusa, Nagoya 464-8603, Japan.

ABSTRACT

The Great East Japan Earthquake generated a huge amount of disaster-related waste. If soil generated from wood chips derived from woody waste materials is to be effectively used as a material in soil structure, the settlement and stability characteristics of this material should be considered. In this study, a series of laboratory tests was carried out, exposing soil composed of different ratios of wood chips to varying compaction degrees. The unconfined compressive strength decreased and the stress–strain curve exhibited more ductile behaviour as the wood chip content increased, while the opposite tendency was exhibited as the compaction degree increased. Deviator stress was not influenced by the mixing rate. The cement-mixed soil exhibited the effect of curing on strength properties, with crushed stone concrete-mixed soil displaying similar tendencies.

Keywords: waste soil generated from disaster, compaction property, mechanical behavior

1 INTRODUCTION

The Great East Japan Earthquake that occurred on March 11, 2011 generated a huge amount of waste within the coastal areas affected. Soil created from waste woody materials can be reused. However, disaster-generated waste soil that contains wood chips is disposed of, because the future behaviour of this soil is unknown. Concerns regarding the settlement of the waste soil structure due to wood deterioration are growing.

The objective of this study was to clarify the mechanical behaviour of waste soil that included wood chips, and to determine whether such material is appropriate as structural geomaterials. To this end, various physical tests and compaction tests were carried out to delineate the physical properties of soils created from earthquake waste materials. Next, a series of laboratory tests was using varying compaction degrees and wood chip content that was generated from earthquake waste woody materials. The effects of both the compaction degree and the wood chip content on mechanical behaviour were studied. To clarify the effects of wood deterioration on mechanical behaviour, mechanical properties were compared between soils with various wood chip contents under constant dry density conditions. Finally, to evaluate the mechanical behaviour of crushed stone concrete-mixed or cement-mixed disaster soil, unconfined compression tests were carried out to determine the effective use of the geomaterial. The results of these tests will elucidate the potential of the waste soils for use as structural materials.

2 PHYSICAL PROPERTIES OF SOIL GENERATED FROM DISASTER-RELATED WASTE

In this study, we used soil that included earthquake-related woody material waste. Material with a grain size of less than 40 mm from a disposal site in Yamada, Iwate Prefecture, Japan, was used. Three soil samples were used for the laboratory tests outlined here. One was made by the crushing material using the rotary crushing and mixing (Twister) method (Ninomiya et al., 2002), and sieving from 40 to 9.5 mm, in consideration of the allowable maximum grain size for laboratory tests (referred to as T9.5). The other sample materials were made using wood chips crushed to T9.5 (less than 4.75 mm). These wood chips were collected from the same location, and likely originated from the remains of wooden houses, tidewater control forests, and roadside trees, all of which were destroyed by the devastating tsunami associated with the 2011 earthquake. The mixing rates of the wood chips were 2.0 and 4.0%, which are referred to as W2.0 and W4.0.

To clarify the physical and compaction properties of soil generated from earthquake-related waste, analyses of grain size (JIS A 1204), soil particle density (JIS A 1202), ignition loss of soil (JIS A 1226), and compaction via the A-a method (JIS A 1210) were carried out. Figs. 1 and 2 show the grain size
accumulation curve and the compaction curve of the waste-material based soil investigated. Table 1 lists the grain size distribution, uniformity coefficient $U_s$, coefficient of curvature $U_c'$, soil particle density $\rho_s$, and ignition loss $L_i$.

As shown in Fig. 1, no differences in behaviour were observed between the soil samples investigated. The soil samples had a wide range of grain diameters, and the geomaterials assessed in this study are classified as sandy soils (SF) for engineering purposes. The soil particle density $\rho_s$ decreased as the wood chip content increased, because wood chips are less dense than soil particles. Ignition loss ($L_i$) increased as the wood chip content increased. As shown in Fig. 2, the maximum dry density $\rho_{\text{dmax}}$ decreased and the optimum water content $w_{\text{opt}}$ increased as the wood chip content increased.

![Fig. 1. Grain size accumulation curve. Fig. 2. Compaction curve.](image)

**Table 1. Physical properties of soil generated from earthquake waste.**

| Soil samples | T9.5 | W2.0 | W4.0 |
|--------------|------|------|------|
| Gravel fraction (%) | 7.7  | 8.2  | 8.6  |
| Sand fraction (%)   | 66.2 | 67.1 | 64.0 |
| Fines fraction (%)  | 26.1 | 24.7 | 27.4 |
| $U_s$             | 28.1 | 28.3 | 23.6 |
| $U_c'$            | 1.3  | 2.3  | 1.2  |
| $\rho_s$ (g/cm$^3$) | 2.65 | 2.63 | 2.60 |
| $L_i$ (%)         | 7.1  | 8.2  | 13.6 |

### 3 SHEAR DEFORMATION AND STRENGTH PROPERTIES OF EARTHQUAKE-WASTE-BASED SOILS

To investigate soil deformation and strength properties, unconfined compression tests and CU/bar triaxial compression tests under compaction degrees $D_c$ of 90 and 100%, and confining pressures of 98.1 kPa, were performed. Test specimens (5 cm in diameter and 10 cm in height) were prepared by adjusting the compaction degree $D_c$; this involved changing the compaction energy while maintaining the optimum water content $w_{\text{opt}}$. In the triaxial compression test, the specimen was set in the triaxial compression apparatus, and saturated with de-aired water using either the double-suction or backpressure method. After this, undrained shearing tests were conducted under a constant axial strain rate of 0.0014 %/min after the isotropic consolidation process was completed.

Fig. 3 shows the relationship between compressive stress $\sigma$ and axial strain $\varepsilon_a$. In both cases, the uniaxial compressive strength $q_u$ increased with increasing compaction degree. As the wood chip content increased, the uniaxial compressive strength $q_u$ decreased and the shear behaviour became more ductile independent of the compaction degree. However, in the case of 90% compaction, the uniaxial compressive strength $q_u$ of W4.0 was the same as that of W2.0.

Fig. 4 shows the results of triaxial compression tests (i.e., the relationship between deviator stress $q$ and axial strain $\varepsilon_a$) as well as the relationship between deviator stress $q$ and effective stress $p'$ under each confining pressure. Deviator stress $q$ increased as the compaction degree increased, independent of T9.5, W2.0, or W4.0 soil sample characteristics. In terms of effective stress paths, both deviator stress $q$ and the $p'$ increased under a compaction degree of 100%. The maximum deviator stress $q_{\text{max}}$ of W4.0 was greater than that observed for the T9.5 case under the same compaction degree, which is differed from the behaviour observed for the uniaxial compressive strength $q_u$.

![Fig. 3. Unconfined compression test results.](image)

![Fig. 4. Triaxial compression test results.](image)

### 4 SHEAR DEFORMATION AND STRENGTH PROPERTIES CONSIDERING WOOD DETERIORATION OF EARTHQUAKE WASTE-BASED SOILS

If soils generated from earthquake waste are to be used as long-term structural materials, it is important to clarify the effects of wood chip deterioration. Therefore, we examined the effect of wood deterioration on the shear deformation and strength properties of the same three soils containing wood chips (W4.0, W2.0 and T9.5). Fig. 5 illustrates the process of wood deterioration.
deterioration. Sample W4.0 was assumed to have an initial structure state of 100% Dc (zero decomposition). Wood deterioration is represented here as a decrease in wood chip content within the soil, specifically from W4.0 to W2.0 and T9.5, under a constant dry density of \( \rho_d = 1.36 \text{ g/cm}^3 \). Based on the difference in maximum dry density \( \rho_{d\text{max}} \) between W2.0 and T9.5, the compaction degree Dc corresponds to 92.2 and 88.8%, respectively. The water content of all specimens was adjusted to the optimum water content \( w_{\text{opt}} \).

Fig. 6 presents the relationship between compressive stress \( \sigma \) and axial strain \( \varepsilon_a \). The uniaxial compressive strength \( q_u \) of the W4.0 sample was greater than that of W2.0 and T9.5. These results indicate that uniaxial compressive strength \( q_u \) decreases gradually as wood deterioration progresses. The results also confirm that ductile shear behaviour depends on the wood chip contents.

Fig. 7 shows the triaxial compression test results (i.e., the relationships between deviator stress \( q \) and axial strain \( \varepsilon_a \), and between deviator stress \( q \) and mean effective stress \( p' \)). The W4.0 sample had the greatest maximum deviator stress \( q_{\text{max}} \). This \( q_{\text{max}} \) decreased as the wood chip content decreased; this is the same tendency as that observed in the unconfined compression test. Based on the effective stress path (the \( q - p' \) curve), sample W4.0 can be regarded as a heavily overconsolidated soil. Sample W2.0 can be considered an overconsolidated soil, in which the initial OCR was less than that of W4.0. Finally, the T9.5 sample can be considered a normally consolidated soil (Asaoka et al., 2002). These findings suggest that wood deterioration decreases the initial OCR, thereby decreasing the maximum deviator stress \( q_{\text{max}} \).

For the curing effect, as the cement content increased, the value increased further with increasing cement content. For the curing effect, as the cement content increased,
peak strength increased and the axial strain of the peak strength was reduced in the cement-mixed soil. The sample D20 revealed solidification due to curing, similar to that demonstrated for cement-mixed soil. Also, brittle destruction was not observed in the case of sample D20.

Table 2. Test results.

| soil samples | test method for cone index unconfined compression test | Curing period (day) | Cone index (kPa) | w (%) | ρ(t) (g/cm³) | Curing period (day) |
|--------------|--------------------------------------------------------|---------------------|-----------------|-------|---------------|---------------------|
| B9.5         |                                                        | 2,124               | 26.8            | 1.63  |               | 0                   |
| D20          |                                                        | 5,698               | 24.0            | 1.75  | 7             | 28                  |
| C03          |                                                        | 4,500               | 26.3            | 1.74  | 7             | 28                  |
| C05          |                                                        | 4,694               | 23.2            | 1.78  | 7             | 28                  |
| C10          |                                                        | 4,751               | 22.8            | 1.66  | 7             | 28                  |

Fig. 8. Unconfined compression test results.

Fig. 9. Relationship between uniaxial compressive strength and curing period.

6 CONCLUSIONS

In this study, a series of laboratory tests was carried out using soils generated from earthquake-related waste to determine their physical properties under various degree of compaction, wood chip contents, and when mixed crushed concrete or cement. To clarify how wood deterioration affects mechanical properties, these characteristics were compared between soils with various wood chip contents under dry density conditions. Also, to evaluate the mechanical behaviour of disaster soil mixed with crushed concrete or cement, unconfined compression tests were carried out. Our findings can be summarised as follows:

1) As the wood chip content increased, soil particle density $\rho_s$ and maximum dry density $\rho_{dmax}$ decreased, and optimum water content $w_{opt}$ and ignition loss $L_i$ increased. Soil samples varied minimally in terms of grain size distribution, so all soil samples were classified as sandy soils (SF).

2) Uniaxial compressive strength $q_u$ increased with the compaction degree. As the wood chip contents increased, the unconfined compressive strength $q_u$ decreased, initial stiffness decreased, and shear behaviour became more ductile independent of the compaction degree.

3) The triaxial compression test revealed that the deviator stress $q$ increased as the compaction degree increased, independent of the soil content. Soils with a higher wood chip content exhibited higher maximum deviator stress $q_{max}$ under the same compaction degree; this was not the same tendency as unconfined compressive strength $q_u$ due to the confining pressure. If the wood chip content is optimised, soils have the potential for use as a reconstructive material that can withstand a certain level of settlement, if adequate compaction is used to set the material initially.

4) Wood deterioration decreases the wood chip content over time under a constant dry density. As this occurred, soil samples exhibited higher maximum deviator stress $q_{max}$ and seemed to be more heavily overconsolidated.

5) In comparison with sample B9.5, sample D20 had the high strength value, demonstrating an unconfined compressive strength $q_u$ that exceeded 100 kPa after curing for 7 days. In addition, it was confirmed that sample D20 showed solidification due to the curing, similar to that observed in cement-mixed disaster soil.

ACKNOWLEDGEMENTS

This work was supported by Grant-in-Aid for Challenging Exploratory Research numbered 25630199 of JSPS.

REFERENCES

1) Ninomiya, K., Akagami, M., Oyama, T. and Miyamoto, M. (2002): Example in use of an industrial method for pre-mixing of soils using a rotary crushing and mixing procedure. JSCE, Proc. of 1st Symposium for Civil Engineering Construction Technology, 225-232 (in Japanese).

2) Asaoka, A., Noda, T., Tamada, E., Kaneda, K. and Nakano, M. (2002): An elasto-plastic description of two distinct volume change mechanisms of soils, Soils and Foundations, 42(5): 47-57.