Proceedings of the 9ICEG
9th International Congress on Environmental Geotechnics 25-28 June, 2023 | Chania, Greece

https://doi.org/10.53243/ICEG2023-69

Pilot-scale and laboratory tests for efficient separation and recovery of soil-waste mixtures

A. Takai[1], Y. Shimizu[2], T. Kato[3], and T. Katsumi[4]

[1]*Associate Professor, Kyoto University, Kyoto, Japan, email: takai.atsushi.2s@kyoto-u.ac.jp*

[2]*Engineer, Okumura Corporation, Osaka, Japan, email: yuya.shimizu@okumuragumi.jp*

[3]*Assistant Professor, Kyoto University, Kyoto, Japan, email: kato.tomohiro.6u@kyoto-u.ac.jp*

[4]*Professor, Kyoto University, Kyoto, Japan, email: katsumi.takeshi.6v@kyoto-u.ac.jp*

ABSTRACT

Enormous amounts of disaster waste have been generated by several disasters which occurred in recent years. Also, for waste management including landfill mining and rehabilitation of improper dumping, soil-waste mixtures are often encountered. For further utilization of soils recovered from such mixed wastes as geomaterials, effective separation techniques need to be developed. In this study, separability of soil-wood chips mixtures is investigated by pilot-scale and laboratory tests with a special emphasis on water and fine contents of soil fractions in the mixtures. The separability of the mixtures is worsened due to aggregation of soil-wood chips mixtures, which notably occurs near the plastic limit of soil fractions. Rotary screens can attribute to a better separability, compared to vibratory screens, probably because of better agitation and beating of materials. It was also found that drying of soil-waste mixtures is essential for efficient separation. Based on the results obtained, proper selection of screens according to the type of disaster is also suggested.

Keywords: soil-waste mixtures, disaster waste, recovered soil, sieving, rotary screen, vibrating screen

1 INTRODUCTION

Japan is subject to frequent natural disasters because of tectonic, geographical, topographical and meteorological conditions, compared to other countries (Cabinet Office, 2021). Especially in recent years, earthquakes and heavy rainfall disasters have been occurring more frequently due to climate change. These disasters generate substantial volumes of waste, which prevents the reconstruction process. Approximately 213 million tons of disaster waste will be generated by the Nankai Trough Earthquake that is expected to occur in the near future, according to the latest estimates (Ministry of the Environment, 2022).

In disasters such as tsunamis and floods, a large proportion of disaster waste is a mixture of soil and other materials, which impedes the effective recycling of disaster waste. For example, in the Great East Japan earthquake and tsunami, as shown in Figure 1, soil-waste mixtures account for 1/3 of all disaster wastes by weight in Iwate and Miyagi prefectures (Katsumi et al., 2016). In such huge disasters, only rough separation using heavy machines is conducted first at temporary storage sites, followed by advanced mechanical separation at secondary storage and treatment sites using various equipment and machineries. The separation systems mostly consisted of several processes of “crushing” and “separating” (Katsumi et al., 2014). However, the systems installed in each site was designed on a site-by-site basis, and, therefore, the quality and the purity of recovered materials also differed (Katsumi et al., 2017). Despite the demands for the active utilization of recovered materials, there has yet to be a quantitative study on the accuracy of sieving.

Given such background, this study aims at clarifying technical factors affecting the quantity and quality of soil recovered from mixed wastes. Pilot-scale and laboratory tests were performed on soil-wood chips mixtures to elucidate the effects of water content and fines content on the separation efficiency of mixed wastes. Rotary and vibrating screens were used for sieving. Although the actual separation systems mostly consisted of crushing and separating processes, this study focused on the separating process, that is sieving process, because it greatly affects the quantity and quality of soil recovery.

Figure 1. *Piled disaster waste generated by the 2011 Great East Japan earthquake and tsunami.*

2 MATERIALS AND METHODOLOGIES

2.1 Materials used

Decomposed granite (DG) soil and Tochi clay were used in this study. DG soil, which is widely distributed in Japan and forms the subsurface ground, was bought from a local market in Kyoto. Tochi clay is one of the commercially available industrial clays and selected because of its ease of handling. Table 1 shows their basic physical properties. DG soil is mainly composed of gravel and sand fractions with the maximum diameter of 19 mm. The soils were mixed to prepare composite soils having fines content, *Fc*, of 15 and 40%. These values were determined based on data of actual recovered soils generated in the Great East Japan earthquake and tsunami (Katsumi et al., 2017).

Wood chips passing through a 19 mm screen with their short side facing up against the screens were used. The wood chips were selected considering actual disaster waste contains fine wood chips, which was a main reason preventing their use in construction projects. By reducing such wood chips can be

Table 1. *Physical properties of soils*

	Particle size			G_s (-)	w_L (%)	w_P (%)
	Gravel	Sand	Fines			
Decomposed granite (DG) soil	42.8	51.2	6.0	2.59	NP	NP
Tochi clay	0.0	2.8	97.2	2.73	34.0	17.6
DG soil + Tochi clay (F_c = 15%)	-	-	-	-	33.6	23.0
DG soil + Tochi clay (F_c = 40%)	-	-	-	-	36.3	19.2

Decomposed granite (DG) soil   Tochi clay   Wood chips

Figure 2. *Photos of materials used in this study.*

reduced, further utilization of the recovered soil can be expected. therefore, such fine wood chips were used as a target waste in this study. The wood chips were obtained from a recycled board manufacturing plant with a longitudinal length of larger than 19 mm. Figure 2 shows the appearance of the soils and wood chips used in this study.

2.2 Preparation of simulated soil-waste mixtures

Wood chips with a longitudinal length of larger than 19 mm and with a short width of smaller than 19 mm were randomly selected and mixed thoroughly by hand to ensure homogeneity. After oven drying, simulated mixed wastes were prepared by mixing the composite soils and wood chips at a ratio of 9:1 by dry weight. This ratio was determined based on actual data from the Great East Japan Earthquake (Okumura Corporation 2014). The water content, *w*, was varied with six standards from 10 to 36% in the pilot-scale and laboratory tests. These values were also determined considering realistic conditions in actual sites. Table 2 summarizes the mixing conditions for the pilot-scale and laboratory tests.

Table 2. *Mixing conditions for pilot-scale and laboratory tests*

Name	Fine content of soil, *F*c (%)	Water content of soil, *w* (%)	Name	Fine content of soil, *F*c (%)	Water content of soil, *w* (%)
Fc15w10	15	10	Fc40w10	40	10
Fc15w15		15	Fc40w15		15
Fc15w20		20	Fc40w20		20
Fc15w23		23	Fc40w25		25
Fc15w28		28	Fc40w30		30
Fc15w34		34	Fc40w36		36

2.3 Methodologies

As introduced in the introduction, the separation systems, installed as part of advanced mechanical separation at secondary storage and treatment sites, mostly consisted of several processes of “crushing” and “separating” (Katsumi et al., 2014). Because a main role of the mechanical crushing is not to segregate soil from waste but to shred soil-waste mixtures to smaller fractions, the final quality of recovered soil is affected mainly by separation process. Therefore, this study focused only on the separation process.

2.3.1 Pilot-scale test

Pilot-scale tests were conducted using a rotary screen (5800Tr, TrommALL) and a vibrating screen (BM545S, Komatsu), as shown in Figure 3. Both machines are portable and have been used for actual disaster waste treatment on site. The rotary screen has a diameter of 1.5 m and a length of 3.7 m, tilted 3.8°, and rotated at 17 rpm. The vibrating screen has an area of 3.7 m^2, tilted 10°, and vibrated in the vertical direction. The mesh size was 20 mm for both screens. All the materials including water were thoroughly mixed in a steel vessel using a backhoe, as shown in Figure 4. To minimize changes in the water content of the materials, the mixed materials were transferred via a conveyor belt to the screens immediately after the mixing step. After sieving, the passed materials and the residual materials were separately collected in 1 t flexible container bags and the mass of each fraction was measured using a hanging scale. A panoramic view of the pilot-scale test is also shown as Figure 4.

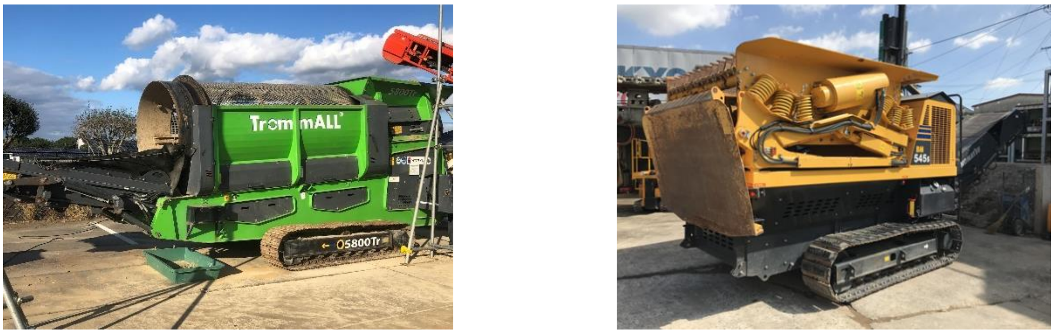

Figure 3. *Rotary screen (left) and vibrating screen (right) used in the pilot-scale tests*

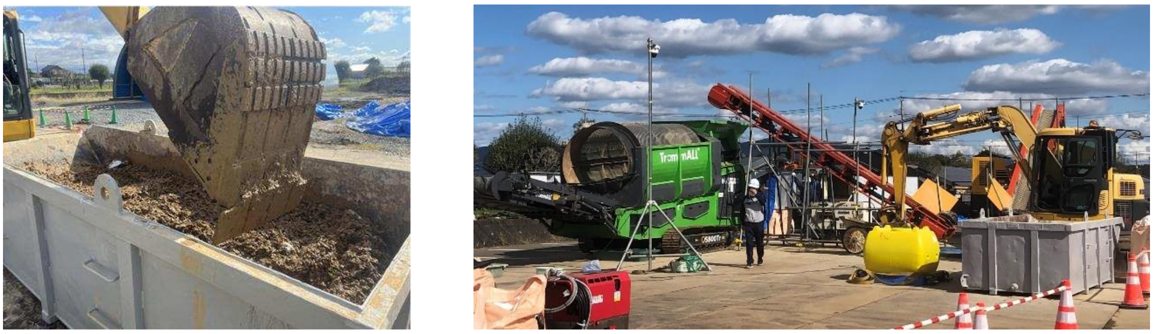

Figure 4. *Mixing of materials (left) and panoramic view of pilot-scale test (right)*

2.3.2 Laboratory test

Pilot-scale tests are costly and time-consuming, and they require a great deal of effort to obtain the results. Therefore, if the laboratory test could reproduce the pilot-scale test, it would be better to assess the results on a smaller scale and at a lower cost. Laboratory tests were conducted using a rotary screen (SC-1, Minoru Sangyo) and a vibrating screen (MIC-110-01, MARUI) shown in Figure 5. The mesh size was 20 mm for both screens. The tests were conducted using simulated mixed waste samples prepared for the pilot-scale tests. Approximately 2 kg of each sample was subjected to sieving. The rotary screen allows the samples to be fed by pushing them through a screw. The rotational speed was adjusted to the same speeds as the pilot-scale tests. When testing with the vibrating screen, the sample was placed directly onto the screens and vibrated horizontally at 185 rpm for 60 seconds.

Figure 5. *Rotary screen (left) and vibrating screen (right) used in the laboratory tests*

2.3.3 Evaluation of separation efficiency

After the separation in the pilot-scale and laboratory tests, the passed and residual mass was separately measured. In this study, the percentage passing was defined as the proportion of the wet mass of the passed materials to the total mass. Figure 6 shows how soil-waste mixtures were separated by the screens and the definition of the residual and passed materials. Following this step, gravimetric separation of each sample was conducted to evaluate their purity. Figure 7 shows a photo of the gravimetric separation. Here, the samples of 300 to 2000 g were put into water. Because soil stuck on

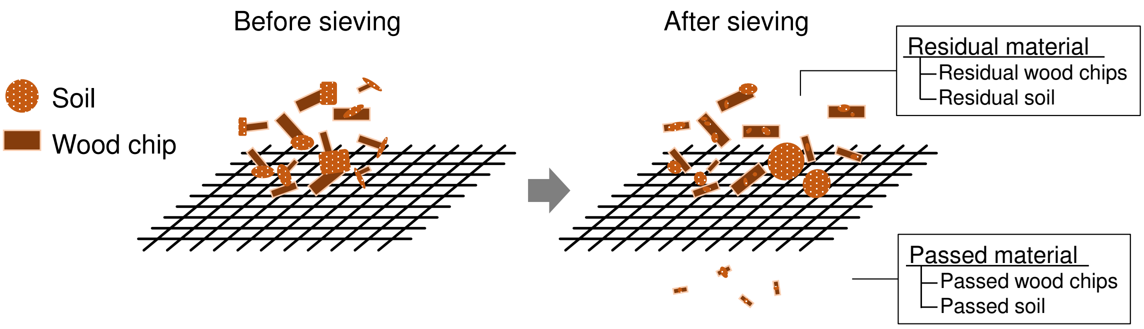

Figure 6. *Conceptual diagram of tests and definition of material names*

Figure 7. *Gravimetric separation of soil and wood chips*

the wood chips cannot be separated only by the immersion in water, such soil was scraped off by hand in water until the wood chips got visually clean.

3 RESULTS AND DISCUSSION

3.1 Separability

Figure 8 shows the results of the pilot-scale and the laboratory tests in terms of percentage passing, the wet ratio of passed material to total material. The left and right figures are of the rotary screens and the vibrating screens, respectively. In the pilot-scale and the laboratory tests, the percentage passing with *Fc* = 40% decreased when *w* < 25%, while it increased when *w* > 25%. Despite the differences in the scale, this trend is similar for both tests. However, different percentage passing was obtained in the two tests. This difference may be caused by variations in the potential energy. The height which the sample was lifted by the rotary screen in pilot-scale tests was higher than that in laboratory tests. A consistent qualitative trend in the percentage passing was observed for mixtures with *Fc* = 15%. The percentage passing decreased at *w* < 28% while increased at *w* > 28%. The percentage passing for the higher fine fraction content was smaller in both the pilot-scale tests and laboratory tests. This is because a high fine fraction results in a high suction because of the high water retention capacity, which made soil particles and wood chips adhere to each other. Since the soil particles became clumped together, the soil-waste mixture was easier to remain on the screen.

As for the vibrating screens, in the pilot-scale tests and laboratory tests, the percentage passing with *Fc* = 40% decreased when *w* < 25%, while it increased when *w* > 25%. The percentage passing with *Fc* = 15% was the smallest at *w* = 23% in the pilot scale tests and at *w* = 28% in the laboratory tests. The similar results of *w* = 23% and 28% in laboratory tests imply that the amount of the passed material might get smaller at around *w* = 25%, which led to the lowest percentage passing also for *Fc* = 40%. Both in pilot-scale tests and in laboratory tests, the higher the fine fraction content, the smaller the percentage passing.

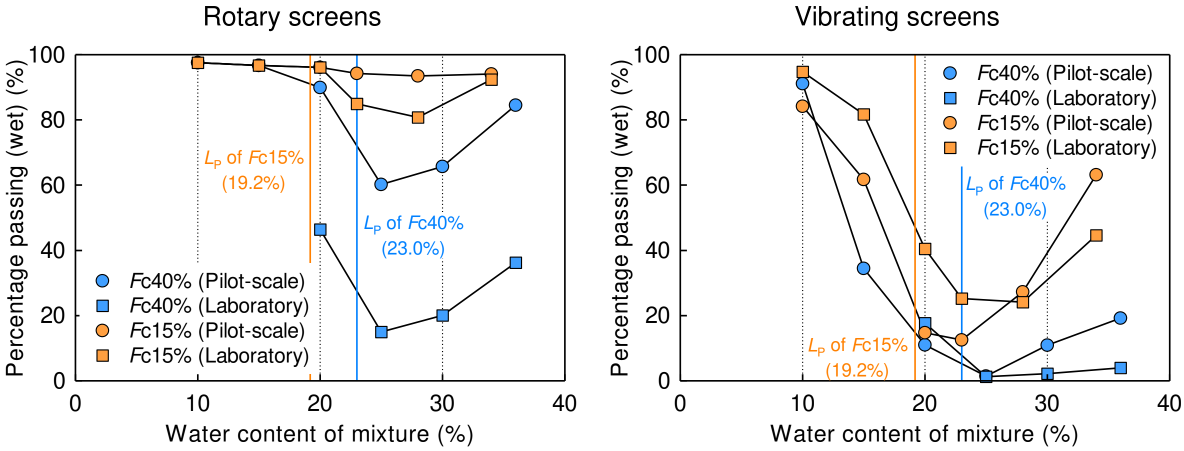

Figure 8. *Results of pilot-scale and laboratory tests*

Figure 9. *Appearance of residual materials generated from pilot-scale tests (Fc15%, w23%)*

From these results, it was found that the separation of the mixtures was worsened due to aggregation of soil-wood chips mixtures, which notably occurred with high water and fine contents. It was also implied that the separation efficiency of the mixture becomes worst near the plastic limit of soil fractions in the mixtures. However, because the water contents of the lowest percentage passing is not completely consistent with their plastic limit, detailed investigation needs to be done to clarify mechanisms.

The percentage passing using rotary screens was higher than that using vibrating screens for the same fines content. Two possible reasons could explain this result. The rotary screens agitate and shake samples evenly as they rotate. Vibrating screens, however, shake samples as they slide across the screen, resulting in clogging and uneven separation. Secondly, the samples in rotary screens are struck and sorted from a height of about 1.5 m, but in the vibrating screens, the samples are almost never lifted. They are only sorted through slight vertical vibrations and the dynamic impact acting on the mixtures is limited compared to the rotary screens. Although not being lifted to the top of the rotary screens, the samples are lifted by the screens and beaten to the bottom of the screens, which helps separation. Figure 9 shows the appearance of the residual materials for *F*c = 15% and *w* = 23%, generated from the pilot-scale tests. It is also obvious that the residual materials obtained through the vibrating screen are aggregated.

3.2 Quality of the passed material as soil

The final goal of this research is to recover soil fractions mixed in the wastes as geomaterials. Therefore, the purity of such recovered soil is also an important parameter. If wood chips are remained in recovered soil, because the durability and usability of the material would be lowered, the recovered soil would not be actively recycled. Therefore, the purity of the passed material, which is considered for recovery as soil in practice, based on the percentage of wood chips contained in the passed materials by dry mass basis. Figure 10 shows the percentage of wood chips of the passed materials obtained from the pilot-scale test. It was found that the percentage of wood chips repeatedly moved up and down with the changes in the water content, and any trend could not be found. However, when comparing

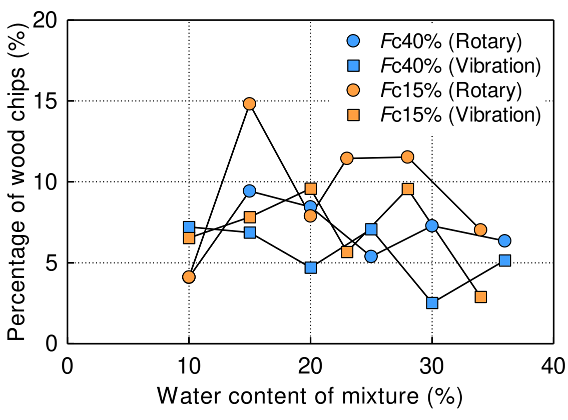

Figure 10. *Percentage of wood chips in passed material obtained from pilot-scale tests*

*F*c = 15% and 40% for both the rotary and vibrating screens, the percentage of wood chips tended to be 1 to 6% lower when *F*c = 40%. This is probably due to the fact that the higher fine content tends to adhere the wood chips, and thus, the wood chips are trapped in the residual materials over the screen size.

3.3 Preferable conditions for soil recovery

From the viewpoint of geotechnical engineers, a better separation should recover more soil, and the soil should be of high purity (quality) to promote utilization as geomaterials. In this study, to judge the efficiency of separation, two indices were used.

- Soil recovery rate (%): A quantitative index defined as the dry mass ratio of passed soil to total soil used. Because at least half of the total soil should be recovered, the criterion was set at 60% or more in this study.
- Percentage of wood chips (%): A qualitative index defined as the dry mass ratio of passed wood chips to passed materials (passed wood chips + passed soil), introduced in the previous section. Considering the previous research which evaluated strength of soil-wood chips mixture (Tsuji and Nakamura, 2019), the criterion was set at 10% or less.

Figure 11 shows the relationship between the soil recovery rate and the percentage of wood chips obtained from the pilot-scale tests. Considering the definition of the indices, the yellow-hatched right bottom zone can be categorized as preferable conditions of separation for soil recovery because the percentage of wood chips in the passed materials is small (< 10%), that means high quality, and the soil recovery rate is high. Especially, the two plots overlapping around the circle in the figure, *F*c15*w*40 and *F*c40*w*10, can be regarded as the best conditions for the present study. Regardless of fine content of soil, the water content of 10% resulted in the most efficient separation process as the percentage of wood chips in the passed materials was ~5% and the soil recovery rate was ~100%. This result implies that drying of soil-waste mixtures is essential for efficient separation. Therefore, piled soil-waste mixtures should not be separated immediately after rainfall events, and prevention of rainfall infiltration into those piles by placing sheets is effective.

Another finding is that, overall, the performance of the rotary screen is much better than that of the vibrating screen. However, for *F*c = 15%, the quality of recovered soils was relatively low probably due to large impact against low suction, which cannot encapsulate wood chips in soil aggregates over the screen. Therefore, rotary screens would be more effective for the treatment of clay-rich disaster wastes, generated by tsunami, while the vibrating screens could be also an option for the treatment of sand-rich disaster wastes, generated by river flooding, etc.

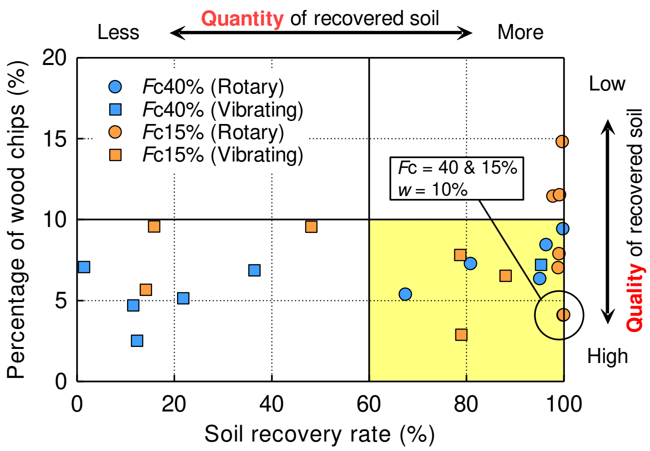

Figure 11. *Quantity and quality of recovered soil obtained from pilot-scale tests*

4 CONCLUSIONS

This study investigated separability of soil-wood chips mixtures by pilot-scale and laboratory tests for utilization of soils recovered from mixed wastes. The key findings of this study are as follows:

1) The separation of the mixtures is worsened due to aggregation of soil-wood chips mixtures, which notably occurs with high water and fine contents, because a larger fine content results in a higher suction because of the higher water retention capacity, which makes soil particles and wood chips adhere to each other. It was also implied that the separation efficiency of the mixture becomes worst near the plastic limit of soil fractions in the mixtures.
2) The rotary screens can pass more samples than the vibratory screens probably because of better agitation and beating of materials regardless of fine contents and water contents.
3) The percentage of wood chips in passed materials tends to be lower with a higher fine content probably because soil with the higher fine content can adhere wood chips, and thus, the wood chips are trapped in the residual materials.
4) Regardless of fine content of soil, the water content of 10% resulted in the most efficient separation process. Therefore, drying of soil-waste mixtures is essential for efficient separation.
5) Overall, the performance of the rotary screen is much better than that of the vibrating screen. However, for F_c = 15%, the quality of recovered soils was relatively low probably due to large impact against low suction, which cannot encapsulate wood chips in soil aggregates over the screens. Therefore, rotary screens may be more effective for the treatment of clay-rich disaster wastes, generated by tsunami, while the vibrating screens could be also an option for the treatment of sand-rich disaster wastes, generated by river flooding, etc.

5 ACKNOWLEDGEMENTS

This research was financially supported by the Environment Research and Technology Development Fund (JPMEERF20201004) of the Environmental Restoration and Conservation Agency Provided by the Ministry of Environment of Japan and JSPS KAKENHI Grant Number JP21K19865. The authors wish to thank Mr. Hiroomi Habuchi and Dr. Yoshikazu Otsuka (Okumura Corporation) for their support on the pilot-scale tests. The authors would like to express their sincere gratitude to Mr. Kansei Hiraoka (formerly Kyoto University) and Mr. Michihiro Ishida (Kyoto University) for their great contributions to data analysis introduced in this manuscript.

REFERENCES

Cabinet Office (2021). Disaster management in Japan, https://www.bousai.go.jp/1info/pdf/saigaipamphlet_je.pdf, (accessed February 13, 2023).

Katsumi, T., Endo, K., Imanishi, H., Inui, T., Kazama, M., Nakashima, M., Okawara, M., Otsuka, Y., Sakamoto, H., Sakanakura, H., Suzuki, H., Takai, A., & Yasutaka, T. (2014). Environmental geotechnics for the recovery from 2011 East Japan earthquake and tsunami, In A. Bouazza, S. T. S. Yuen & B. Brown (Ed.), Seventh International Congress on Environmental Geotechnics, (pp. 170-189). Melbourne, Australia.

Katsumi, T., Takai, A., Inui, T., Okawara, M., Endo, K., & Sakanakura, H. (2016). Soils recovered from disaster debris, Japanese Geotechnical Society Special Publication, 2(54), 1888-1892.

Katsumi, T., Okawara, M., Kawashima, M., Endo, K., Sakanarakua, H., Iwashita S., Takai, A., & Inui, T. (2017). Soils recovered from disaster debris – characterization and utilization -, Journal of JSCE, 5(1), 145-156.

Ministry of the Environment (2022). Activity report of the Working Group on Techniques and Systems, Committee for Promotion of Disaster Waste Management, in Japanese.

Okumura Corporation (2014). Report on the consignment and results of disaster waste shredding and separation in Yamada district, in Japanese.

Tsuji, N., & Nakamura, Y. (2019). Mechanical Properties and their Influence on Foundation behaviors of Separated Waste Soils with Wood Chips, Bulletin of Aichi Institute of Technology, 54, 100-109, in Japanese.