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Recycling Materials in Geotechnical Applications

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ABSTRACT

Three issues on the reuse of materials in geotechnical applications in Japan are presented in this paper. First, current status of reuse of excavated soils is presented. Since natural contamination has been a concern these years, several efforts including experimental studies to evaluate the environmental suitability of these materials have been conducted. Second, traceability in environmental geotechnics has been becoming an important consideration. One joint project, in which the excavated soils generated from shield tunnel excavation are utilized as a soil material for reclamation, utilizes the electronic toll collection (ETC) system to track the soil materials. Third, utilization of disaster wastes caused by the 2011 East Japan earthquake and tsunami is required. Challenges include the proper treatment to separate soils from waste mixture and to utilize these soils in geotechnical applications.

Keywords. excavated soils, natural contamination, ICT, 2011 East Japan earthquake

INTRODUCTION

Due to the limitation of available natural recourses and land space for landfills, reuse of materials has been promoted in Japan. In particular, the reuse of materials in construction works has attracted a great attention because of the large capacity of application. Among the materials generated and/or reused in construction works, excavated soils counted the largest quantity, and several attempts have been conducted not only to promote the utilization but also to consider the prevention of contamination. After the establishment of Soil Contamination Countermeasures Law in 2002, natural contamination which may be contained in such excavated soils has been a concern, while proper method to evaluate the environmental suitability assessment is still under discussion. In addition, track and record of the information of generation, treatment, and utilization of recyclable materials such as excavated soils have been becoming an important consideration. The 2011 East Japan Earthquake and Tsunami which occurred on March 11 generated a large quantity of disaster waste and tsunami deposits which requires proper treatment and utilization. In this paper, three issues regarding the reuse of materials in geotechnical applications are presented; (1) evaluation of natural contamination from excavated soils, (2) application of ICT (information and communication technology) to reuse of excavated soils, and (3) utilization of the materials obtained through the treatment of disaster waste generated from 2011 East Japan Earthquake and Tsunami.

EXCAVATED SOILS AND NATURAL CONTAMINATION

Surplus soils have been generated through excavation processes in construction works. These soils are not categorized as waste in the Japanese legal system, while require a proper management. In 2008, a large amount of the soil (140 million m^3) was generated from construction sites, and 42 million m^3 of it were reused at construction sites. New soil materials (32 million m^3) were collected from mountains or river beds, which should be reduced due to the environmental impact. Further utilization of these soils is required.

Several institutions including governments have been aware of the natural contaminations when the excavated soils are reused in some geotechnical applications these years. There are several reasons why these natural contaminations have started to be discussed. In 2002, "Soil Contamination Countermeasures Law (SCCL)" was established. Originally, this law was set only to be applied to the soils contaminated due to human activities but not to the soils naturally containing heavy metals. However, if soils with natural contamination are excavated and transported to other places, proper treatment is necessary. Therefore, when excavation works are conducted at such a site, the possibility should be taken into account that these soils may contain heavy metals and sometimes leaching of these metals may exceed the environmental standards. Even if they exceed environmental standards, their leaching level is not high compared to artificial contamination. Since the volume of the excavation is usually large, cost effective measures should be considered based on the nature of these soils.

Heavy metals are naturally present in the geologic strata in many places all over the world. These metals are present as result of several processes such as physical, thermal, chemical and bio-chemical phenomena. Hydrothermal action is an important phenomenon in forming the minerals containing the metals. Accumulation of metals in a mineral spring is another mechanism. In sea water, dissolved metals may be accumulated in the sea bed deposits. In Japan, arsenic (As) and lead (Pb) exist with a higher concentration compared to the global average. One of the reasons is that the islands of Japan are located in the area where the Eurasian and Pacific Plates connect and geological activities, including volcanic action, have been active. Under these environments, some trace elements such as As and Pb may be accumulated. There are several forms of metals present in the geologic strata: (1) metals existing in the minerals as their main components, (2) metals existing in the minerals as their sub (particle) components, (3) metals adsorbed onto the particles contained in the rocks, such as mud stone, (4) metals existing in marine deposits, and (5) metals existing as a complex with organics. The leaching mechanism may vary from form to form.

Proper assessment should be conducted to evaluate whether excavation would cause the leaching of heavy metals and the consequent environmental impacts, when construction works are conducted at sites where these soils and rocks are present. If these soils and rocks are planned to be reused as soil materials such as embankments, assessment should be done to evaluate whether any adverse environmental impact will be expected at the site of reuse, and whether the necessary measures should be taken to prevent the environmental impact.

Figure 1 summarizes the factors and their influences on the leaching behavior of heavy metals of natural soils and rocks when they are excavated. The leaching behavior will depend on the type of construction works, such as cut, deep excavation, tunneling, embankment, etc. When the rocks are crushed through excavation works, the surface area and the consequent leaching potential will be increased. If these excavated materials are compacted at the site of utilization well enough to prevent the water and air infiltration from the surface, the decrease in exposure to water will decrease the leaching potential, as well as preventing oxidization causing further leaching. Proper compaction therefore are considered an effective measure against heavy metal leaching. Similar effects can be expected for the cover layer which may also minimize the water and air infiltration, and limit the oxidization. Groundwater level may affect the degree of saturation and the redox potential, and the consequent leaching potential: if the materials are placed beneath the groundwater, the redox potential will remain low.

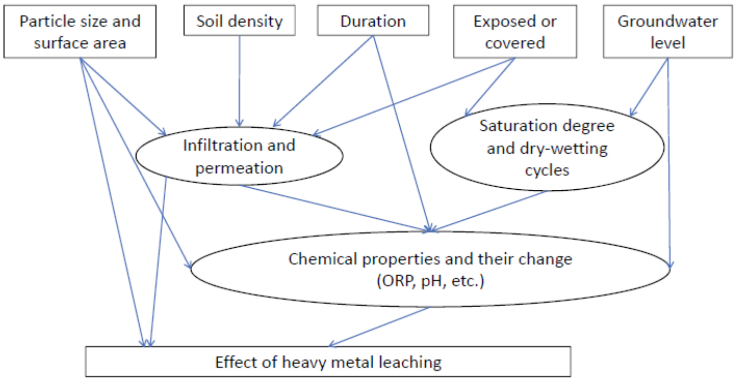

Figure 1. Factors affecting the heavy metal leaching naturally contained in soils and rocks (Katsumi et al. 2010)

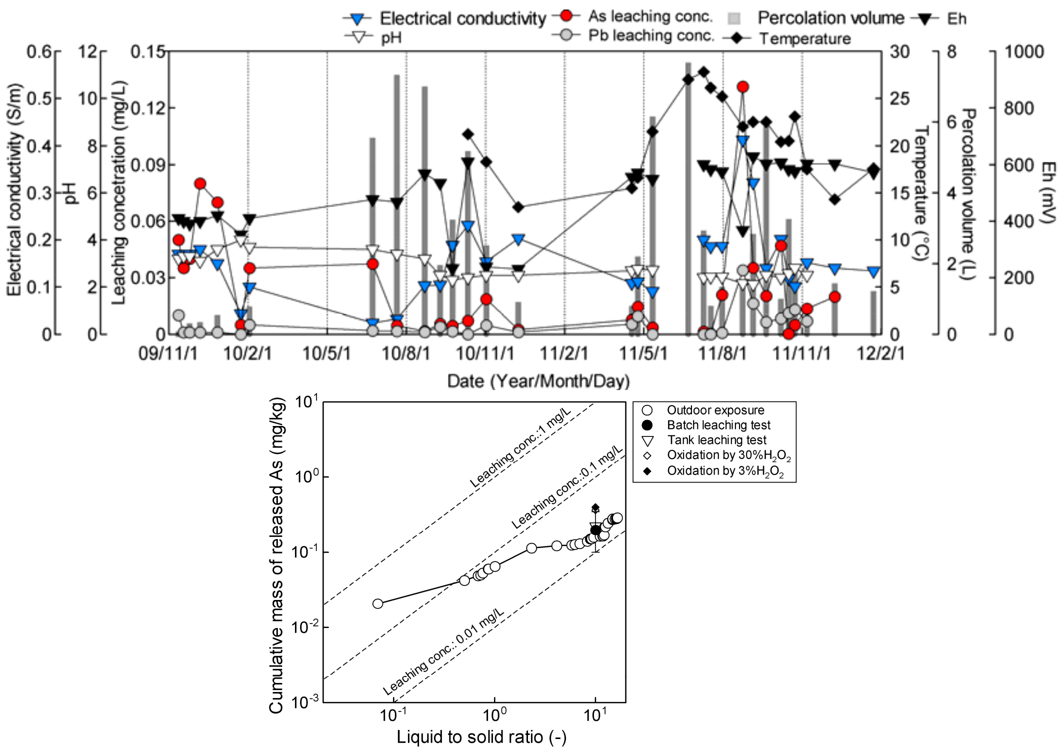

Figure 2. Rainwater infiltration tests on excavated rocks (top) and comparison with the results of other leaching tests (bottom) (Inui et al. 2012a)

Evaluation of soil contamination is conducted based on the regulatory methods which may not be scientifically reasonable to be applied to the excavated rocks since they have been established for artificial contamination. Long-term assessment is important for rocks because some exhibit acidification once they are exposed to the air and water due to excavation. Several researchers conducted the long-term leaching tests under the condition of rainwater infiltration, as well as laboratory leaching tests including accelerated conditions. Figure 2 is an example of the data presented by Inui et al. (2012a), indicating that accelerated oxidization test using 3% H_2O_2 solution or Japanese regulatory batch leaching test may be comparable to the rainwater infiltration test which was continued for 3 years. These results are expected to be systematically organized to understand properly the leaching behaviour and achieve cost effective measures.

TRACING TECHNOLOGY

Traceability is an important consideration in the geotechnical application of recyclable materials. There have been several attempts to develop the system to track these recyclable materials along the processes of generation, treatment, utilization, etc.

A joint project has been conducted to utilize the excavated soils discharged from shield tunnel excavations at a highway construction work, as earthen materials at a land reclamation site. The locations of these sites are shown in Figure 3. Information and communication technology (ICT) utilizing the existing electronic toll collection (ETC) system is applied to manage the soils, since two projects such as tunnel excavation and reclamation are operated by the different bodies and are tied together into this joint project. A brief summary is presented below in this chapter based on Yamaguchi et al. (2012).

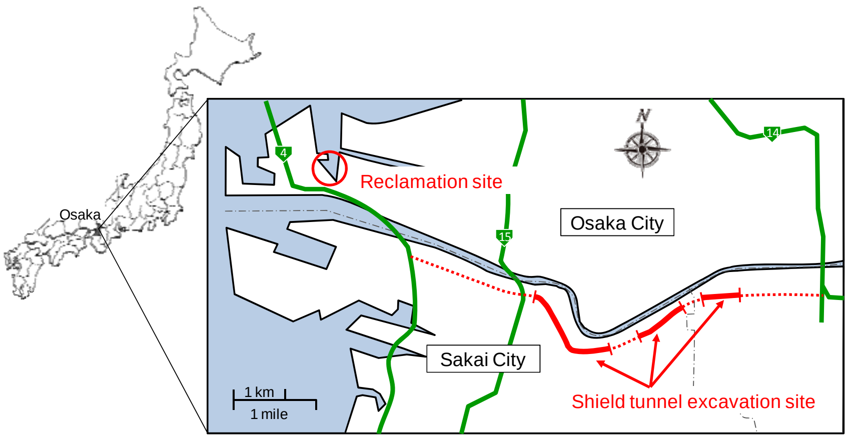

Figure 3. Locations of the project sites (Yamaguchi et al. 2012)

“Yamatogawa Route,” the 9.7 km long highway newly constructed along the south bank of the Yamato River, includes three tunnel sections with a total length of 3.9 km excavated using shield tunnelling excavation method. Geological strata consist of Pleistocene laminated layers of sand and clay. Shield excavation has started in early 2011 and will be continued until later of 2013. Since the soils exhibit a muddy state due to their high water content, the excavated soils discharged are classified as sludge, and must be treated as waste under the Japanese legal system. Soil improvement should be conducted prior to the effective utilization as earthen material. It is estimated that a volume of 760,000 m^3 of soils will be excavated, the total number of 10-t truck transportation will be 158,000, corresponding to 500 vehicle trucks per day.

The site where the excavated soils are reclaimed is an old lumber yard called “No. 6 Lumber Yard,” having an area of 83,000 m^2 in the Port of Osaka. The site has not been used as a lumber yard any more, and creating land space due to reclamation work is expected to contribute to the effective use of this space. It has been decided that this site would accept the excavated soils discharged from shield tunnel excavation works at Yamatogawa Route. The land reclamation project is comprised of seawall construction and reclamation. There are multiple institutions to contribute to this joint project: Hanshin Expressway Co., Ltd., Osaka Prefecture, and Sakai City for tunnel excavation, Osaka City for governmentally responsible for reclamation, and Hanshin Expressway Engineering Co., Ltd. for reclamation work, and soil improvement.

This project has the several requirements. First, it is necessary to apply a waste management system using “manifest” according to the law, because the excavated soils discharged from the site are categorized as industrial waste. Second, a centralized and efficient management system is required because a large quantity of soils are excavated, transported, treated, and utilized, and also because multiple numbers of companies and institutions are engaged in transportation of the soils. Third, adverse influences of soil transportation on the local traffic including congestion should be minimized.

The waste generators have a duty to track whether the wastes are properly managed using a manifest system. An electronic manifest system has been established by Japan Waste Network, in which web and mobile phones are used to manage the necessary data regarding waste generation, transportation, treatment, and disposal. In this project, since large amounts of the excavated soils are generated resulting in a large number of transport vehicles to be engaged, an existing electronic toll collection (ETC) system has been incorporated with a conventional electronic manifest system so as to manage the soils. ETC is a system to pay toll fees without stopping the vehicle by a wireless communication between a vehicle-mounted device and a roadside antenna that has been installed in the toll gate of the toll road; it is based on Dedicated Short Range Communications (DSRC) in which the 5.8 GHz frequency band is used for short-distance wireless communication based on the international standards, and has been allowed to other applications as well as highway toll collection for these years in Japan. Main equipments and devices are listed in Table 1. The vehicle-mounted ETC device is not a special one, but one that has been used in conventional toll gate systems in highways nationwide.

Table 1. Equipments facilitated for ETC system (Yamaguchi et al. 2012)

Place and subject	Main equipments facilitated	Processes conducted
Vehicles transporting the excavated soils	Vehicle-mounted ETC device	Install the vehicle data prior to the work
Sites generating the excavated soils	ETC gates, mobile computer, communication equipments	Issue the manifest
Site accepting, treating, and reclaiming the excavated soils	ETC gates (both for entrance and exit), computer	Report transportation and disposal
Data center	Server computer, communication equipments	Certificate the vehicle data, cooperate with JWNET

There are several steps using ETC manifest system.

1. Prior to the application, information of all the vehicles (vehicle number and weight, ID number of vehicle-mounted ETC device, driver, etc.) has been registered in advance.

2. At the occasion when the vehicle loaded with the excavated soils is weighed at the exit of a shield tunnel excavation site, an electronic certification is conducted by ETC gate facilitated at the same place. Based on this certification, a manifest with the record of soil weight is electronically issued. ("Departure from shield tunneling site" in Figure 4)

3. During the soil transportation between the shield tunnel and the reclamation sites, the position of each vehicle can be monitored by global positioning system (GPS), so that we can check whether the vehicles are properly driven on the designated route or not and whether traffic congestion occurs by these transportations.

4. Next step using ETC is conducted at the entrance of the treatment facility which accepts the excavated soils, at which the vehicle is weighed and certified by ETC to report that the proper transportation of the wastes (excavated soils in this project) has been completed. After this step, the vehicle unloads the transported soils into the treatment facility. ("Arrival at treatment plant" in Figure 4)

5. Then, the unloaded vehicle is weighed again at the exit of the treatment facility with ETC certification, to report that the disposal is completed under the waste management manifest system. ("Unloading of soil and departure" in Figure 4)

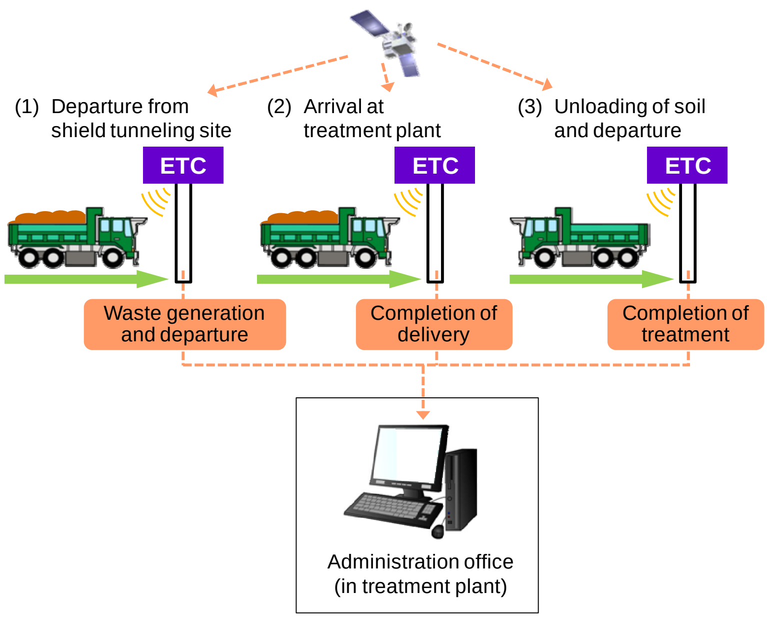

Figure 4. ETC manifest system (Yamaguchi et al. 2012)

The data collected by ETC are sequentially integrated so that the engaged companies and institutions are able to simultaneously monitor the latest status using the same updated data. The collected data are also used for the cooperation with JWNET, which manages the waste manifest system as above mentioned. Until December 2012, 67,729 of the electronic manifests were issued, which is equivalent to 350 issues per day. If we manually conduct these issues using mobile phones and/or computers, it would take approximately one minute per one issue corresponding roughly 6 hours per day in total, while ETC certification to issue the manifest requires only 0.4 to 0.9 seconds excluding the time to be weighed which is about 10 seconds. The ETC manifest system is able to automate the process and significantly reduce time, and labour works, and human errors. Not only such efficiency of management is achieved, there are other advantages such as minimizing traffic congestion, avoiding errors in data input, and preventing illegally-overloaded vehicles. Efficiency, accuracy, and safety in construction works are increased with the ETC manifest system.

GEOTECHNICAL UTILIZATION OF DISASTER WASTES

The 2011 off the Pacific coast of Tohoku Earthquake of March 11, 2011 occurred in offshore North East Japan, and the generated tsunami attacked the coastal areas of East Japan. This natural disaster caused devastating geotechnical and geoenvironmental problems mainly in the coastal area of the Tohoku and North-Kanto Regions in Japan (Inui et al. 2012b). Through the earthquake and subsequent tsunami, approximately 20,000 Gg (20,000,000 ton) of disaster debris was generated. In addition, about 10 million m^3 of tsunami deposits transported by the tsunami requires proper treatment as well. Since it is geographically and economically unrealistic to construct new waste disposal facilities having a sufficient capacity to accept these wastes, which corresponds to several times of the annual generation of municipal solid waste in each local municipalities, utilization of these materials is required. The geotechnical utilization of the soil fraction in disaster debris and tsunami deposits has become a big challenge for geotechnical engineers since 1) clearance of debris and tsunami deposits should be urgently achieved within a few years and 2) temporal and spatial variations in the geotechnical properties of waste-mixed soils should be considered if a large amount of waste-mixed soil are used for constructing embankments and levees against tsunami in reconstruction projects. To promote the utilization of disaster debris in recovery works, the Japanese Ministry of Land, Infrastructure, Transports and Tourism (MLIT) has established two technical guidelines to construct 1) parks and green spaces as a redundancy zone against huge tsunamis in which embankments will be constructed using disaster wastes (MLIT 2012a) as shown in Figure 5 and 2) fill embankments at areas where ground subsidence due to the earthquake occurred significantly (MLIT 2012b). Green areas had a positive effect on reducing the energy of tsunami and trapping the flowing obstacles such as cars, while some trees did not have sufficient root depth, which resulted in insufficient resistance against tsunami. Therefore, embankment construction for green areas is considered advantageous.

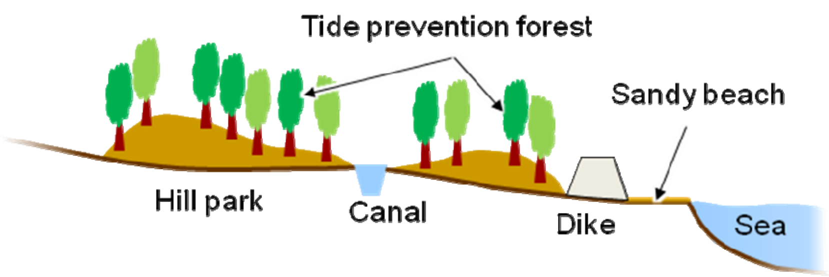

Figure 5. Green park construction for disaster recovery using waste materials (Katsumi et al. 2012)

Evaluating the engineering properties of tsunami deposits and soils separated and/or obtained from disaster waste mixture is an important issue to ensure the performance such as stability of the earthen structures if they are used. However, no experience or knowledge on the treatment and geotechnical properties of such waste mixed soil (see Figure 6) has been accumulated. Evaluation of the engineering properties of such soils obtained from the disaster wastes have therefore started to be carried out by some researchers and institutions including the JGS (Japanese Geotechnical Society) Geoenvironmnetal Technical Committee on the 2011 East Japan Earthquake and Tsunami chaired by the first author.

Figure 6. Disaster waste piled up in a temporally storage site (Inui et al. 2012b)

Typical treatment procedure of waste mixed soil implemented at the disaster waste treatment facilities is shown in Figure 7. Wastes with large sizes are removed from the mixture at a first temporary storage site (rough separation), and further separation is conducted using trommels, vibrating screens, or other machineries/equipments at a secondary storage site (secondary separation). Morita et al. (2012) sampled the soils and soil-waste mixtures from several temporary storage sites, and conducted the experiments to evaluate their basic properties such as particle density, particle size distribution, ignition loss, waste composition, compaction, and cone index. Non-separated soil (sample A-1, A-3) and roughly separated soil (A-2) were taken at a first temporary storage site in Town A, and non-separated soil (B-1, B-2) were collected at a storage site in Town B. Secondary separated soil (C-1) was taken at a secondary storage site in Town C. Roughly separated soil (D-1), which was passed through a 20-mm opening screen, was taken at a temporally storage site in Town D.

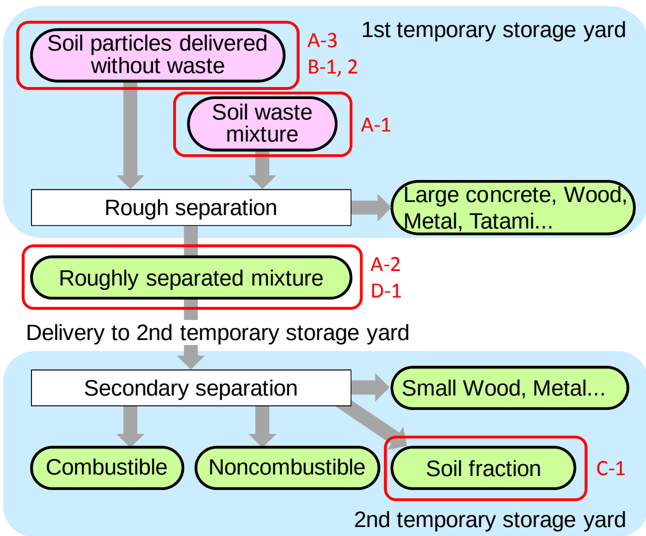

Figure 7. Typical treatment procedure of waste mixed soil (Morita et al. 2012)

One of the important considerations is the effect of combustible substances on the engineering properties, since these combustibles may be deteriorated, resulting in the emission of gas and leachate and ground settlement. Ignition loss test conducted on the sample sieved by a 2 mm opening screen according to JIS A 1226 does not consider all the organic matters in the soil-waste mixture mainly consisting of combustible wastes such as wood chips, paper scraps or plastic, etc. Because most of these combustible materials exist with particle sizes larger than 2 mm. Therefore, Morita et al. (2012) conducted manual separation test in which the fraction over 2 mm was separated into combustible, noncombustible, and soil particles.

Compaction characteristics of each sample are shown in Figure 8. The numbers listed in left side of each compaction curve represent the percentage of the combustible content larger than 2 mm of each sample. From this result, the samples of high combustible content such as A-1 and D-1 exhibited a high optimum water content for obtaining the maximum dry density. Besides, the maximum dry density values of such samples are low (1.1 to 1.4 g/cm^3) compared to other samples (1.7 to 2.0 g/cm^3). This is because the samples which contain large amounts of combustible substances cannot be properly compacted, and the densities of combustible substances are low. The samples which contain smaller volumes of combustible substances exhibited lower optimum water contents and higher maximum dry densities, and have clear peaks of compaction curves. Therefore, it is expected that such samples can be used as geo-materials with their strength values greatly improved by the compaction. Further investigation is required to evaluate how the waste and combustible matters will affect the engineering properties for a long term by their decomposition if the waste mixed soil be recycled in geotechnical applications.

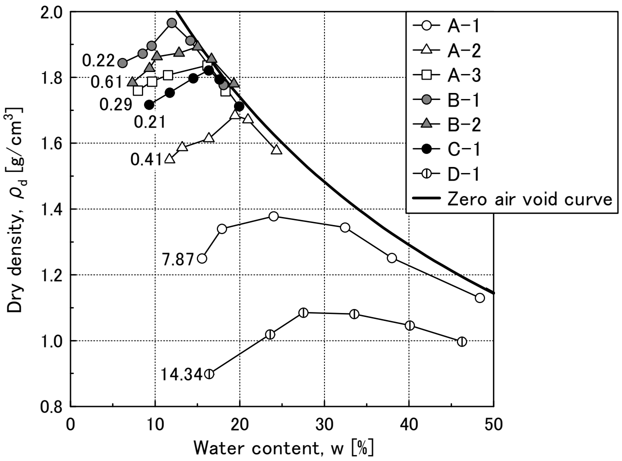

Figure 8. Compaction curves of the soils obtained from disaster waste (Numbers next to each curve represent percentage of the content of combustible materials.) (Morita et al. 2012)

CONCLUDING REMARKS

Japanese status on the reuse of materials in geotechnical applications are presented in this paper, with three topics such as reuse of excavated soils, application of ICT, and utilization of disaster wastes. The topics presented in this paper include utilization of the knowledge and technology which had previously been accumulated in the area of geotechnical and geoenvironmental engineering. They also require challenges utilizing the innovative technology beyond the traditional geoenvironmental engineering, such as application of ETC system and evaluation of soil-waste mixture. Further developments based on such contributions are expected for the utilization of materials in geotechnical applications.

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