Environmental geotechnics and education initiatives for recovery from the Fukushima I Nuclear Power Plant accident

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ABSTRACT

Japan was severely impacted by the 2011 off the Pacific coast of Tohoku earthquake, and radiation from the subsequent accident at the nuclear power plant in Fukushima continues to pose problems for the region. This paper describes efforts that are underway to remediate the area based on civil engineering and environmental geotechnic principles. Specifically, this paper describes recommendations from a special task force that was organized by the Japanese Geotechnical Society (JGS) in response to the accident. The task force has identified several areas where new environmental geotechnic technologies are needed and has put forth ideas for educational initiatives that will be necessary to train future engineers to work on the project. Research efforts on behalf of the authors and collaborators to develop new radiation shielding geo-materials are also presented. Preliminary data show that heavy bentonite based slurry has exceptional shielding properties, and this geo-material may be useful for radiation shielding near and inside of the nuclear reactors. Lastly, some ideas regarding the design of intermediary repositories for contaminated soil are presented. Such repositories will be used to store contaminated soil for a period of 30 years.

Keywords: accident of nuclear power plant, radioactive waste disposal technology, radioactive contaminated soils, environmental geotechnics, civil engineering

1 INTRODUCTION

The entire country of Japan, but especially the eastern region, was adversely impacted by the 2011 off the Pacific coast of Tohoku earthquake, and the subsequent severe accident at the nuclear power plant in Fukushima has been particularly problematic. Presently, all regional engineers including the authors must do their best to reduce the risks associated radioactive waste and minimize the contamination.

The first author has been researching and developing technology to dispose of radioactive waste from nuclear power plants since 1987. Specifically, this technology involves the geological disposal of high-level radioactive waste (HLW), which will be a substantial portion of the waste starting disposal until 2030 to 2040. Moreover, the first author has been researching and developing technology for other types of radioactive waste such as low-level radioactive waste (LLW) and the trans-uranium nuclide waste (TRU) etc. It is hoped that such research and technology can help to facilitate the cleanup of radioactive waste and contaminated soils that were produced following the nuclear accident triggered by the Tohoku earthquake on March 11, 2011.

This paper describes the damaged nuclear power plant at Fukushima and presents options for using new technology to remediate the land based on civil engineering and environmental geotechnic principles. A project of the Japanese Geotechnical Society (JGS) that is being supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is described along with insights from discussions at JGS through January 2015. These discussions have culminated into medium- and long-term plans for addressing the damaged nuclear power plant (see Fig. 1). The authors also present their point of view for how soils contaminated with radiation should be stored. Finally, the authors outline an engineering policy for acting on this project according to the Japanese Government Policy on Nuclear Power that was developed in 2005.

2 RECOVERY FROM THE DAMAGED NUCLEAR POWER PLANT AT FUKUSHIMA BASED ON CIVIL AND GEOTECHNICAL ENGINEERING PRINCIPLES

This section describes what is known about the damaged nuclear power plant at Fukushima and introduces a project of the JGS that was initiated to help the area recover from the disaster; the project is being supported by MEXT. Factual details regarding the situation at the
Fukushima I Nuclear Power Plant, which was damaged badly during the Tohoku earthquake in 2011, are still not clear because the high levels of radiation around the site are preventing ground-based investigations. Regardless, all engineers in Japan are doing their best to collect accurate information at the site. Currently, plans are being made to send in robotic samplers that can communicate electronically, and many nuclear, mechanical, and electronic engineers are now working on the development of such technologies.

We, the geotechnical and civil engineers, are also developing new technologies to assist in the recovery efforts for the disaster site. To help coordinate such activities, the JGS has established a special task force. Members of the special task force are listed in Table 1.

This task force has spent some time discussing the need for new environmental geotechnic technologies that can be used in all aspects of recovery and remediation from the nuclear power plant accident. As a result of the discussions that have taken place up until January 2015, medium- and long-term plans have been devised that focus on the following subjects.

1) Predictions for land and groundwater contamination by radionuclides from now until decommissioning (a time span of about 40 years).
2) Development of boring technology and excavation methods such as tunneling that can be used for excavation of the fuel debris remaining in the nuclear reactors.
3) Planning and development for the disposal of large amounts of radioactive waste from the accident and decommissioning of the damaged nuclear plant.

While there are many other subjects that need to be addressed for successful recovery efforts, the task force has selected the above three subjects to focus on because these are the topics that we are currently capable of promoting by ourselves given the lack of detailed information on the damaged nuclear power plant. Figure 1 shows a conceptual diagram of the targeted focus areas.

The task force has also discussed the need for educational initiatives in geotechnical and civil engineering. As of January 2015, the curriculums shown in Table 2 have been identified as necessary for educating the new generation in geotechnical and civil engineering work that will be required to recover from the nuclear power plant accident. With the implementation of these educational initiatives in universities, new engineers should be able to contribute effectively to the decommissioning of the damaged nuclear power plant.

Now, the authors would like to introduce briefly a brand-new research focus of the authors’ research group.

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**Table 1. Task force of the Japanese Geotechnical Society**

|                     | Chairman | JGS President |
|---------------------|----------|---------------|
| Prof. Ikuo Towhata  |          |               |
| Dr. Toru Sueoka     | Vice-Chairman | Former JGS President |
| Prof. Atsuo Okumura| Adviser  | Past JGS President |
| Prof. Hiroshi Komine| Moderator | Waseda University |
| Dr. Shigeru Goto    | Secretary general | Waseda University |
| Prof. Makoto Suzuki | Member   | JGS Vice-President |
| Prof. Mamoru Minami | Member   | Kyoto University |
| Prof. Takeshi Kato   | Member   | Kyoto University |

**Table 2. Necessary educational subjects**

| Subject                  | Purpose                                      | Remarks                                      |
|--------------------------|----------------------------------------------|----------------------------------------------|
| Geotechnical engineering | Stability analysis of damaged plant          | Stability analysis, site investigation       |
| Geoenvironmental engineering | Investigations of and predictions for the ground and geo-space at the site over the next 40 years | Site investigation, monitoring, numerical analyses |
| Geo-materials            | Geomaterials for shielding radiation and ground improvements to remove fuel debris | New geomaterials, heavy drilling in bentonite based slurry, shielding material |
| Geo-construction         | Construction methods for removing fuel debris and decommissioning | Tunneling, sealing off water migration in the ground, filling, boring, and decommissioning |

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**Fig. 1. Necessary technologies in environmental geotechnics for recovering and decommissioning damaged nuclear plant**
at Waseda University that is being conducted in conjunction with the Seibu Construction Co. Ltd., the Hojun Co. Ltd., and the Soil and Rock Engineering Co. Ltd. We are developing a new radiation shielding geo-material that can shield against both gamma rays and neutron beams. The heavy gravity of the geo-material enables the new technology to shield against gamma rays, and this is because of the characteristics of electromagnetic waves. Additionally, the high water content of the geo-material enables the new technology to shield against neutron beams. Therefore, the geo-material can shield against multiple environmental hazards. Inspired by the discussions mentioned above, our group has conducted fundamental experiments to examine the radiation shielding properties of optimal geo-materials such as some types of soils and heavy bentonite based slurry. Figure 2 shows the setup used for these experiments. Figures 3 and 4 show examples of the experimental results obtained to date, and they indicate that heavy bentonite based slurry has exceptional shielding properties. This geo-material can be made available for radiation shielding near and inside of the nuclear reactors by filling up the damaged reactors as shown in Fig. 5.

3 AUTHORS' POINT OF VIEW FOR HOW RADIOACTIVE CONTAMINATED SOILS SHOULD BE STORED

Huge amounts of radioactive contaminated soils were produced during the nuclear power plant accident. This section presents a description of the authors’ point of view for how those contaminated soils should be stored (Komine, 2012).

The Ministry of the Environment in Japan issued a directive on October 29, 2011, regarding the treatment and storage of radioactive contaminated soils produced during the nuclear power plant accident. According to

![Gamma-ray source](image1)

![Heavy bentonite based slurry](image2)

![Gamma-ray detector](image3)

Fig. 2. Radiation shielding experiments for heavy bentonite based slurry (upper panel: gamma-ray shielding experiment; bottom panel: neutron-beam shielding experiment)

![Gamma-ray dose versus specific gravity](image4)

Fig. 3. Shielding experiment results showing the gamma ray dose versus the specific gravity of bentonite based slurry

![Neutron-beam source](image5)

![Heavy bentonite based slurry](image6)

![Neutron-beam detector](image7)

Fig. 4. Shielding experiment results showing the neutron beam dose versus the specific gravity of bentonite based slurry

![Specific Gravity of bentonite based slurry](image8)

Fig. 5. Concept for the utilization of heavy bentonite based slurry in damaged nuclear reactors
the directive, the excavated radioactive contaminated soils are now being stored as shown in Fig. 6, which is a temporary arrangement. The soils shown in Fig. 6 will be stored like this for three years at most; then, the contaminated soils will be moved to intermediate repositories, which are being constructed according to the schematic shown in Fig. 7. Soils at the intermediate repositories will be stored there for 30 years at the longest. The capacity (i.e., total volume) of the intermediate repositories is estimated to be 18,700,000 m³ to 28,150,000 m³, which should be sufficient to store the contaminated soils.

Engineers have been tasked with developing the technology for the storage facilities shown in Fig. 7 as soon as possible, and this work is being done in conjunction with many general contractors and construction companies. In particular, geotechnical and civil engineers have to design the specifications for the intermediate repositories according to facilities’ requirements and develop brand-new technology for constructing the facilities. The requirements for the intermediate facilities involve “containing radioactive contaminated soils” and “shielding radioactive rays.” The other important design feature will be to ensure safe and reliable operations for at least a period of 30 years.

Containing radioactive contaminated soils for 30 years means that the facilities will need to prevent the migration of radiation from the storage site. Radioactive nuclides can move to the surrounding environment via groundwater flows. Hence, water proof barriers will be an important feature of the intermediate repositories.

Shielding radioactive rays means that the geotechnical and civil engineers will need to develop clay materials and other methods that will effectively block harmful levels of radiation. Such work is already underway, as described in Section 2. While this is a new technical area for geotechnical and civil engineers, the preliminary data from experiments on radioactive rays and beams are promising.

4 CONCLUDING REMARKS

In this paper, the authors describe current efforts to address the problems stemming from the March 2011 nuclear power plant accident at Fukushima. In particular, efforts that are underway to remediate radioactive contaminated soils were reviewed.

The Japanese Government Policy on Nuclear Power from 2005 contains the following rules.

1) Fundamental rule regarding the users’ own responsibility.
2) Fundamental rule for minimizing the amount of radioactive waste.
3) Fundamental rule for treating and disposing of radioactive waste rationally.
4) Fundamental rule for treating and disposing of radioactive waste with the agreement of the nation.

The above fundamental rules were written for the disposal of radioactive waste prior to the events at Fukushima; however, these rules are applicable to the large amount of waste that was generated during the nuclear power plant accident in 2011.

The authors believe that users of nuclear energy include the entire population of Japan, so we, the Japanese, should have responsibility according to rule 1) above. The necessity of engineering issues described in this paper are based on rules 2) and 3). Furthermore, I would like to emphasize that in regards to rule 4) above, it will be very difficult for engineers to accomplish this; however, all engineers can help by making special efforts to obtain the agreement of the nation for their proposed techniques for recovery and remediation at Fukushima.

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