Needs for the decommissioning geotechnical engineering for Fukushima daiichi nuclear power plant

Les besoins de l'ingénierie géotechnique pour le déclassement de la centrale nucléaire de Fukushima Daiichi

Shigeru Goto, Hideo Komine, Yuma Saito, Ema Yoshikawa
Faculty of Science and Engineering, Waseda University, Japan, s.goto4@kurenai.waseda.jp

Makoto Suzuki
Faculty of Creative Engineering, Chiba Institute of Technology, Japan

Yasutaka Watanabe
Central Research Institute of Electric Power Industry, Japan

ABSTRACT: Fukushima Daiichi nuclear power plant was damaged by huge tsunami in the 2011 Great East Japan Earthquake. Decommissioning of the nuclear plant was presented as an urgent issue, but many difficulties persist in relation to the decommissioning process. Geotechnical engineering methods, e.g. a cutoff wall for decreasing the inflow of ground water into the plant and cover material of low radiation waste have already been applied to the site. Furthermore, we believe there are many more geotechnical engineering methods and materials that are useful for decommissioning the post-accident nuclear plant. A group of Japan Geotechnical Society researchers started to study an education system emphasizing the application of geotechnical engineering for post-accident nuclear plants under the Ministry of Education, Culture, Sports, Science and Technology, Japan. This education system is based on the new concept of 'Decommissioning Geotechnical Engineering'. This paper presents the concept of "The Decommissioning Geotechnical Engineering" and examples of Decommissioning Geotechnical Engineering technologies.

RÉSUMÉ: Fukushima Daiichi centrale nucléaire a été endommagé par le tsunami énorme dans le Grand Est du Japon tremblement de terre de 2011. Le déclassement de la centrale nucléaire a été présentée comme une question urgente, mais de nombreuses difficultés persistent en ce qui concerne le processus de déclassement. méthodes d'ingénierie géotechnique, par exemple un mur de coupure pour diminuer l'afflux des eaux souterraines dans le matériel végétal et la couverture des déchets de faible rayonnement ont déjà été appliquées sur le site. En outre, nous croyons qu'il ya beaucoup plus de méthodes et de matériaux d'ingénierie géotechnique qui sont utiles pour le démantèlement de la centrale nucléaire post-accident. Un groupe de chercheurs japonais Géotechnique Société a commencé à étudier un système d'éducation mettant l'accent sur l'application du génie géotechnique pour les centrales nucléaires après l'accident dans le cadre du ministère de l'Education, Culture, Sports, Science et Technologie, Japon. Ce système d'éducation est basé sur le nouveau concept de «désaffectation Géotechnique». Cet article présente le concept de "Déclassement Géotechnique" et des exemples de technologies de déclassement Géotechnique.

KEYWORDS: Nuclear power plant, Decommissioning, Geotechnical engineering

1 INTRODUCTION

The Fukushima Daiichi nuclear power plant sustained unprecedented damage from the tsunami of the Great East Japan earthquake of March 11, 2011. The nuclear reactor itself produced damage by dissolution of some nuclear fuel. And areas surrounding the plant was radioactive contaminated. The plant remains in a difficult state of reconstruction and repair. Therefore, the plant was decided on decommission. However, technical issues that are preventing diffusion of radioactive contaminants, nuclear fuel debris removal, demolition of the nuclear reactors and etc., must be solved in decommissioning. These technical problems must be resolved not only for safety (prevention of effects of environmental pollution on human life), but also recovery of the prestige of Japanese technology. However, some geotechnical technologies have been applied to processing of the post-accident nuclear power plant already. For example, for mitigating ground water contamination and radioactive rubble storage sites, geotechnical technologies have been extremely effective for processing of post-accident nuclear power plants. Geotechnical engineering has many technologies that can be used effectively for future decommissioning processes. Knowledge of both nuclear engineering and geotechnical engineering is required on effective utilization of geotechnical engineering technology for nuclear power plant decommissioning. Nevertheless, recognition of geotechnical engineering in the nuclear engineering field is not high. Moreover, knowledge of nuclear power plant engineering is insufficient in the geotechnical engineering field.

A proposal from the Japanese Geotechnical Society was accepted for 'Human Resource Development and Research Program for Decommissioning of Fukushima Daiichi Nuclear Power Station (NPS)' by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. This proposal was aimed at establishing "Decommissioning Geotechnical Engineering," which is expected to be effective at promoting geotechnical engineering application education for the decommissioning of the Fukushima Daiichi nuclear plant. Actually, "Decommissioning Geotechnical Engineering" is expected to be a basis of education and training of young engineers because it can produce an academic field in which geotechnical engineers and nuclear engineers can collaborate.

This paper describes the basic concepts of Decommissioning Geotechnical Engineering and classification of engineering technology for nuclear plant decommissioning processes, along with examples of geotechnical technology application to decommissioning.

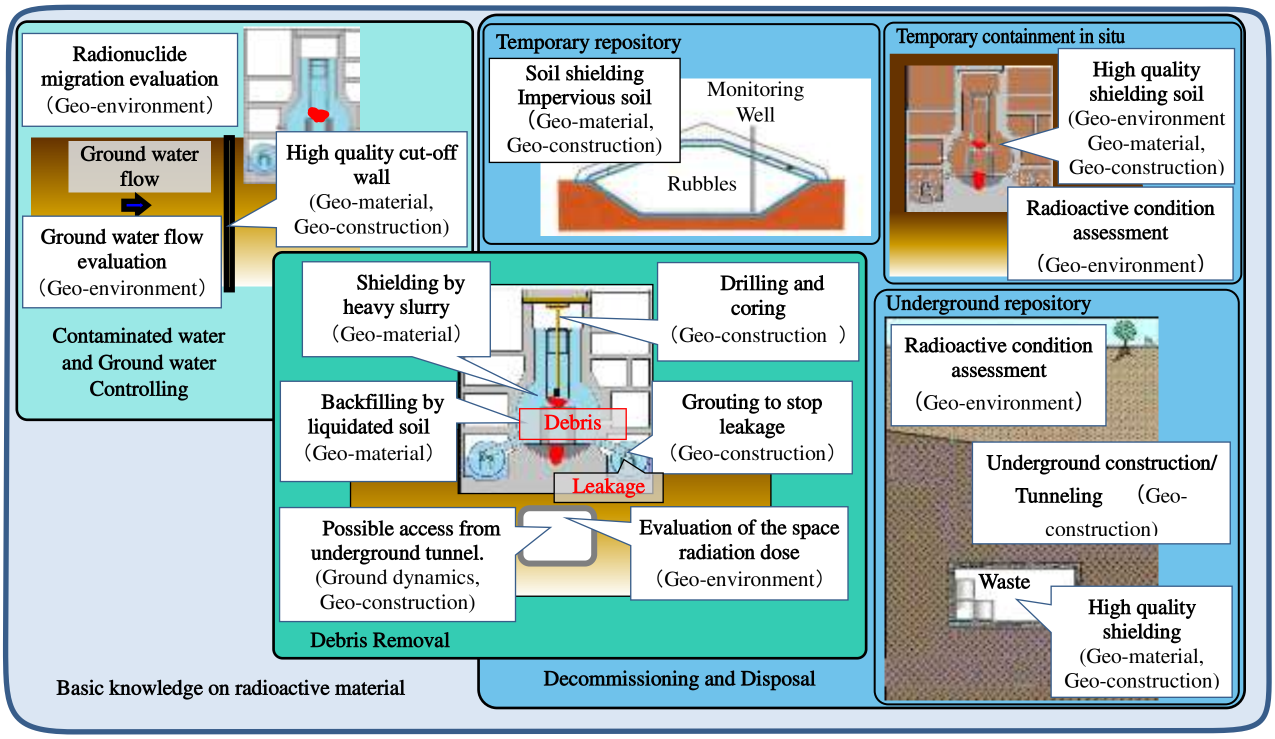

Figure 1. Schematic drawing of technologies in Decommissioning Geotechnical Engineering. Technologies are grouped in three phases that are ground water controlling, debris removal and decommissioning.

2 WHAT IS DECOMMISSIONING GEOTECHNICAL ENGINEERING?

2.1 *Purpose of the Decommissioning Geotechnical Engineering*

One purpose of establishing Decommissioning Geotechnical Engineering is to clarify guidelines for utilization of geotechnical technology on decommissioning process. On Decommissioning Geotechnical Engineering, decommissioning processes are classified in these three phases: (A) Radionuclide-contaminated water and Ground water control, (B) Removal of radiative fuel debris, and (C) Disposal of radioactive waste and nuclear reactor decommissioning. Then, geotechnical technologies, which are expected to show effective performance for decommissioning, are classified in these three phases. This technology classification might be effective to clarify performance requirements. The classification might also be effective to ascertain whether technology performance is sufficient, or not, while evaluating the substitutability and collaboration among geotechnical technologies.

Moreover, these geotechnical technologies are grouped into four academic classifications, i.e. Ground dynamics, Ground environmental engineering, Geo-material engineering, and Geo-construction management engineering. Details of each academic classification will be mentioned later. This systematization of geotechnical technologies is expected to advance technological development and the creation of new technologies. This systematization of geotechnical technologies, with classification of the technologies both according to decommissioning phases and academic fields, forms the bases of education of actual decommissioning technologies for the education of young engineers.

2.2 *Subject of Decommissioning Geotechnical Engineering*

Although future subjects of Decommissioning Geotechnical Engineering include normal decommissioning processes of nuclear plants, an immediate subject is the Fukushima Daiichi Nuclear Power Plant which sustained tsunami damage. Decommissioning of this plant presents several urgent issues. The subject of the engineering is expected to be the nuclear plant environment and surrounding facilities. Radioactive waste from the nuclear plant accident and scrapping of facilities during the decommissioning process are also anticipated as engineering subjects.

2.3 *Technical evaluation criteria of Decommissioning Geotechnical Engineering technologies*

For Decommissioning Geotechnical Engineering, practical uses of geotechnical engineering technologies for environmental improvement in decommissioning work are mainly considered. Therefore, the evaluation axis of developing technologies shows Area radiation reduction performance and Radioactive contamination diffusion prevention performance. Moreover, support for other decommissioning technologies must be regarded as important performance. However, the usual technology qualities which are quality stability, ease of handling and etc. are also important.

3 DETAILS OF ACADEMIC CLASSIFICATIONS FOR DECOMMISSIONING GEOTECHNICAL ENGINEERING

3.1 *Ground dynamics*

Ground dynamics is technology that is expected to be used to verify the stability of the nuclear plant structure and surrounding ground of the structure, the shapes of which would change during the decommissioning process. Ground dynamics technology can also be used to examine construction methods for maintaining the stability of the power plant buildings structure and the surrounding ground. Nuclear plant buildings are important targets of stability examination. Furthermore, the soil structure and tunnel space that can be prepared for the decommissioning work are also important targets of the stability examination. Examination of these stabilities is important on both the static state and seismic states.

Table 1. Geotechnical Decommissioning Engineering technical map. Technologies are grouped in the three phase and classified in to four academic classifications.

		Decommissioning phase		
		(A) Radioactive contaminated water and Ground water controlling	(B) Removal of radiative fuel debris	(C) Disposal of radioactive waste and Decommissioning of the nuclear reactor
Academic classification	Ground dynamics	Contaminated water vessel stability. etc.	Underground space stabilty. etc.	Decommissionig phase building stublity change. etc.
	Ground environment engineering	Wide area ground water flow estimation. etc.	Radioactive assesment of the underground space etc.	Groundwater flow estimation on underground repository. etc.
	Geo-material engineering	High performance cut-off wall material. etc.	High quality radioactive sheilding liquid. etc.	High performance sheilding material. etc.
	Geo-construction management engineering	High performance cut-off wall construction. etc.	Contaminated water leaking stopping etc.	High performance temporary repository construction. etc.

Educational lessons for ground dynamics consist of the following: traditional soil dynamics lectures, static and seismic ground model tests, and numerical coupling analysis of structures and the ground.

3 .2 *Ground environmental engineering*

Ground environmental engineering includes prediction and monitoring technologies for radioactive problems related to the ground and/or underground water. Ground environmental engineering technologies are used for examination of the diffusion of radioactive materials that would be caused by ground water flow that might be changed by decommissioning processes. Radioactive conditions in underground space by tunneling that would be prepared for the decommissioning work are also a target of the environmental technologies examination.

Educational lessons for Ground environmental engineering are expected to consist of the following: lectures related to underground water flow, practice of monitoring, prediction and evaluation on underground water flow, and evaluation tests for radioactive shielding performance of soil materials.

3 .3 *Geo-material engineering*

Geo-material engineering consists with technologies of dealing geo-materials that are slurry of stabilizing liquid of boring holes, bentonite mixed soil of waste covering materials, etc. These technologies are effective to improve the geo-material performance for underground water flow stoppage and for radioactive contamination shielding.

Educational lessons related to Geo-material engineering are expected to include the following: soil chemistry and soil physics lectures, geo-material blending tests, evaluation technical training of material performance and construction experiment with geo-materials. The lessons are expected to include experiments related to the radiation shielding performance of geo-materials.

3 .4 *Geo-construction management engineering*

Geo-construction management engineering aims to grow up construction management ability of geo-construction engineer. Here, construction management includes choosing optimal geo-materials and geo-construction methods according to the states of construction sites. The geo-construction methods are expected to include ground excavation and backfilling, constructing structure foundations, grouting geo-chemical materials, underground space constructing, etc.

Selection of the optimum materials and construction methods in accordance with the site state is usually carried out during construction planning in the general construction project. Because construction planning is work that specifically determines the order of construction works based on the specified dimensions, the geo-construction management engineering can be interpreted as academic technologies that foster capabilities for creating high-concreteness scenarios.

Educational lessons for geo-construction management engineering would include lectures of numerical planning theory and civil engineering system theory. Project schedule management and quality management are included on civil engineering system theory. Training of the virtual simulation technology for construction planning and experience of working on actual construction site are also included in the lesson. Training at actual sites must be held in collaboration with construction companies.

Moreover, because basic knowledge of radioactive material is necessary for geotechnical engineers, decommissioning engineering education would include lectures that are the properties of radiations, the characteristic, the half-life of a radioactive material, the concept of a radiation shield, etc.

4 GEOTECHNICAL TECHNOLOGIES FOR POST-ACCIDENT DECOMMISSIONING OF NUCLEAR PLANTS

Figure 1 shows a schematic drawing of technologies that are consist with Decommissioning Geotechnical Engineering. Many geotechnical technologies have been classified into three phases of decommissioning: (A) Radioactive contaminated water and Ground water control, (B) Removal of radioactive fuel debris, and (C) Disposal of radioactive waste and Decommissioning of the nuclear reactor. Technologies of these three phases are also based on basic knowledge related to nuclear engineering. Table 1 presents an example of Geotechnical Decommissioning Engineering technical map. In this map, geo-technical technologies that are expected to be effective for decommissioning processes are classified both on three decommissioning phases and four academic classifications. Although the table shows only a few technologies, because space is limited in narrow areas, 87 actual technologies have already been located in the map. Some examples of developing technologies will be presented below.

4 .1 *Soil electrical resistivity measuring for monitoring ground freezing conditions*

This technology is located on the decommissioning phase of '(A) Radioactive contaminated water and Ground water controlling', and on the academic classification of 'Geo-construction management engineering'.

This technology is effective for ground freezing wall construction that is necessary to cut-off of underground water flow because it can evaluate the impermeability of frozen ground instantly. Frozen soil walls have been applied to the Fukushima Daiichi nuclear power plant to reduce groundwater inflow to the building because frozen ground is quite impermeable.

Temperature monitoring is used for controlling of the artificial ground freezing method generally. However, freezing points of soils are not the same as those of usual water freezing point of 0°C under some conditions. Then, even if ground temperatures are lower than the 0°C of the usual water freezing point, the ground might possibly remain unfrozen. However, the water electrical resistibility will be altered dramatically with the phase change to ice because the electrical resistibility of ice is quite different from that of water. Figure 2 shows the electrical resistivity of water, ice, frozen soil specimens, and unfrozen soil specimens. Although small differences remain between frozen sand and frozen clay, frozen soil electrical resistivity is markedly greater than that of unfrozen soils. That fact is clear evidence that the phase change of void water can influence the electrical resistivity of soils directly. Soil electrical resistivity measuring techniques are expected to improve the quality control technology of artificial freezing ground walls in the future.

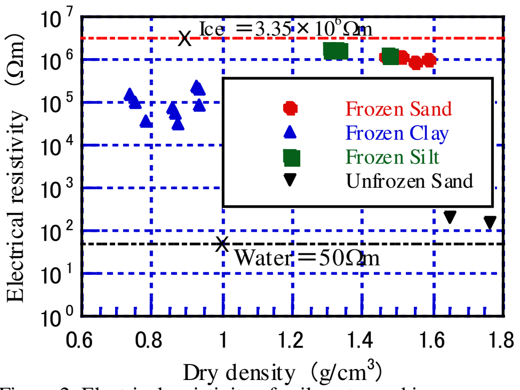

Figure 2. Electrical resistivity of soil, water and ice.

4.2 *Heavy bentonite-based slurry for radiation shielding*

This technology is located on the decommissioning phase of '(B) Removal of radioactive fuel debris', and on the academic classification of 'Geo-material engineering'.

Heavy bentonite-based slurry is anticipated as a geo-material developed to improve high-level radiation environments to remove the fuel debris safely. Removal method of the fuel debris with filling water of containment vessel, as a reference example of the Three Miles Island post-accident nuclear plant has been mainly considered. However, because accident containment vessels of the Fukushima Daiichi nuclear power plant have numerous damaged components, it is very difficult to do water filling of the containment vessels. Using heavy bentonite based slurry, partially filling the slurry into the vessel might be sufficient to remove fuel debris safely because the shielding performance of the slurry against both γ rays and neutron rays is high. Very-high-density of heavy bentonite slurry can effectively shield γ rays. Moreover, the water-richness of the heavy bentonite slurry is effective to shield neutron rays.

Figure 3 shows the radiation shielding performance of super-heavy slurry. The slurry has a high shielding performance against gamma radiation, and has almost equal shielding performance to that of pure water for neutron radiation.

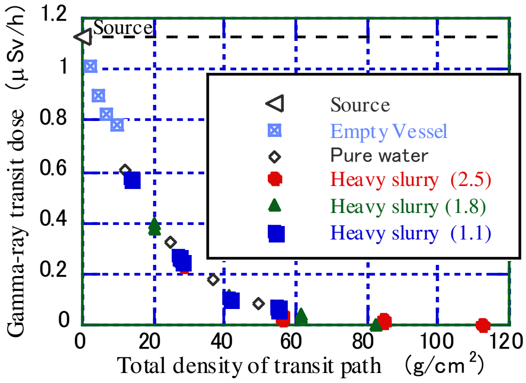

Figure 3. Quantity of gamma ray transmission through slurry.

Because super-heavy slurry is capable of adjusting the viscosity by adjusting blending, it might be useful in cases with slight water-leakage. Therefore, it is expected that the effectiveness of the super-heavy slurry would be increases by performing studies on how to use the super-heavy slurry to remove the fuel debris.

5 CONCLUDING REMARKS

Although some Geotechnical Engineering technologies were in cooperation with nuclear engineering, mutual recognition of Geotechnical Engineering and Nuclear Engineering is not high. The Fukushima Daiichi nuclear power plant requires contributions from all Japan technologies for subsequent settlement. Therefore, geotechnical engineers should also actively cooperate. The development of human resources for the next generation of nuclear power plant decommissioning is necessary for this purpose. A Japanese Geotechnical Society researcher group has proposed establishment of 'Decommissioning Geotechnical Engineering' as a field of study for next-generation geotechnical and nuclear engineers. We expect that Decommissioning Geotechnical Engineering can be effective to the subsequent settlement of Fukushima Daiichi Power Plant, and also be effective to recovery of Japanese technological prestige.

6 ACKNOWLEDGEMENTS

This study was conducted by the 'Human Resource Development and Research Program for Decommissioning of Fukushima Daiichi Nuclear Power Station (NPS)' of the Japan Ministry of Education, Culture, Sports, Science and Technology.

7 REFERENCES

Komine H., Towhata I. and Narushima S. 2015. Environmental geotechnics and education initiatives for recovery from the Fukushima I Nuclear Power Plant accident, *The 15th ARCSMGE*, TC215-05.

Saitou Y. and Komine H. 2015. Fundamental study of Electrical Resistivity Property of frozen soils for Monitoring Technique of Ground Freezing Technology, *Proc. of Geo-Environmental Engineering 2015.*

Yoshikawa E., Komine H., Saito Y., and Goto S. 2017. The evaluation for radiation shielding ability of the soil materials on the point of view of pass length in the materials and application to design for construction, *Proc. of 19th ICSMGE*.

Yoshikawa E., Komine H., Saito Y. Goto S. Narushima S., Arai Y., Mizuno M., Ujiie S., Sakoda Y., Nagae Y., Yoshimura M., and Suzuki A. 2016. Radiation shielding properties of heavy bentonite based slurry for decommissioning of the Fukushima first nuclear power plant, *Proc. Of Geo-Chicago 2016*, pp.292-297.