ABSTRACT

The utilization of recycled and reusable materials in the construction industry has become an alternative way to substitute natural materials. The sources of these waste materials can be different, for example, municipal waste incineration plants, residue from waste recycling or industrial processing residue, etc. Likewise, the contaminated soils might be generated from the construction works such as excavation, earthworks, and rehabilitation of contaminated sites, etc. Besides, there are areas where hazardous heavy metals and metalloids are concentrated in soil due to its geological processes. Due to the excavations or other construction works in such areas, leaching of these elements may be triggered by contact to water and air. As a result, the geogenic (naturally) contaminated soils occur. Some of the geogenic contaminated soils may be utilized in construction works in terms of mechanical properties, which may not be influenced by a state of contamination. Therefore, in this thesis, it is proposed the utilization of these soils containing naturally derived metals and metalloids in low concentration level as embankment cores for being an alternative way to substitute natural resources. Reusing these materials would reduce the use of natural resources as a construction material. This aim will prevent the deposition of slightly contaminated soils in landfills and save space in the landfills. In conclusion, that trial would be particularly beneficial in countries with limited space such as Japan.

However, national regulations might discourage to use them in construction works. With accepting this struggle, two alternative methods for the utilization of geogenic contaminated soils in embankments, which is a reusable material from the construction industry, are proposed and experimentally investigated. At the first one, the contaminated soil is considered to be placed as a core material in the embankment with a simple earthen cover, which is obtained from available in-situ soil. In the second one, the contaminated soil is also suggested to place as a core material in the embankment; however, instead of a cover layer, a drainage layer system is recommended as a countermeasure for preventing water contact to the contaminated soil. The cover layer system is proposed for the coarse-grained contaminated soil (coarser than the available in-situ soil), while the drainage layer system is for the fine-grained contaminated soils (finer-than the available in-situ soil). The efficiency of both methods is tested with a two-dimensional infiltration box test.

In the first proposed method, a capillary barrier system was designed by utilizing the coarse contaminated soil in the core of embankment under the in-situ available clean fine soil. The capillary barrier (CB) cover system is a type of cover layer which uses the hydraulic properties difference between fine and coarse-grained layers under unsaturated conditions to create water interception. The capillary barrier models were verified for the utilization of geogenic contaminated soil in the embankment. A series of laboratory experiments were conducted on the capillary barrier model with a different combination of medium sand over gravel or silica sand. In summary, it concluded that the medium sand with gravel capillary barrier models are effective for the water interception approach. However, a material combination with medium sand over silica sand did not create any capillary barrier effect, although both layers were prepared initially at fully dry conditions.

A drainage layer system is concerned with minimizing the amount of water that might contact with geogenic contaminated soil inside the embankment using a gravity flow phenomenon. This layer might prevent the existence of a potential leachate generation. The efficiency of the proposed drainage layer system is also confirmed with a laboratory infiltration box test. Three different drainage layer models were investigated using two different materials. During the experiments, all three models are tested with two different initial preparation conditions: optimum moisture content preparation case and drawdown case (free drainage after the saturation). According to experimental results, it is found that a drainage layer system with coarse-grained material at the embankment shoulder and fine-grained material (contaminated soil) in the embankment core is an alternative way for the utilization of geogenic contaminated soil in the embankment. If the contaminated soil which is placed only under the impermeable pavement layer, more than 90% of drained water flows out from the drainage layer.

Numerical studies are also included to understand the in-situ performance of the proposed methods. The analysis was solved in two stages. At first, a water balance analysis was conducted using conventional equations for the cover layer. Kyoto city, Japan, is selected as the investigation site, and its average monthly precipitation and mean temperature over the past thirty years (1985-2015) used as the primary input data. Results show that approximately 28% of precipitation percolated to the surface cover layer annually. Even if the occurrence of the maximum precipitation in summer, oppositely the maximum percolation, takes place in March. This is due to high temperatures in summer.

The evapotranspiration increases in this season. Due to the high demand for water, the summer percolation becomes less according to spring. In the second stage, a 1D contaminant transport model was used. Both seepage flow and advection/dispersion properties were considered in the model. Based on the proposed solution, the influences of time and depth from the source were investigated. The result shows that the contamination level 1.5 m from the source reaches the same input contamination level after 2190 days, although unit constant concentration and infiltration are applied during analysis.

These obtained results are represented within six chapters: the first chapter aims to clarify the objectives and to outline the contents of this research. Chapter two reviews the sources and origins of heavy metals, as well as their treatment methods, focused on the cover soils and capillary barrier system. Also, it includes literature reviews about drainage layer saturated and unsaturated water flow and contaminated transport in the soil media. Chapter three discusses the basic geotechnical experiments and unsaturated soil mechanics experiment and their results. Also, this chapter gives information about the experimental setup for the infiltration box testes, which are used for the capillary barrier system. It provides findings and discussion for the capillary barrier system experiments. Chapter four describes the experimental method for the drainage layer system. It also shows the experimental results and discussions about the drainage layer system for the utilization of the geogenic contaminated soil in the embankment. Chapter five provides a water balance analysis and a one-dimensional numerical simulation for understanding in-situ results. Chapter six summarizes the conclusion of the research, and it gives suggestions about future research direction.

From the overall results presented in this study, it can be inferred that both capillary barrier system and drainage layer system methods show encouraging experimental results. If a suitable soil combination is selected, both suggested systems might be a promising output for the utilization of naturally contaminated soil in the embankments with an appropriate design concept.

Keywords:

Geogenic contaminated soil, Cover soil, Capillary barrier, Unsaturated soil mechanics, SWCC, Drainage layer, Water interception