Rainfall-Induced Erosion for Unsaturated Soils and Preventive Measures

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（降雨による不飽和土の侵食特性と適応策に関する研究）

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論 文 内 容 の 要 旨

Rainfall-induced soil erosion is a natural hazard and potential risk associated with land degradation, sedimentation, shallow landslide, flood, embankment failure and environmental pollution. Recently, rate of soil erosion is expected to vary due to the change of amount and magnitude of rainfall caused by global warming. Soil erosion is a dynamic and complex physical process. It is common that assessment of soil erosion has been conducted through empirical methods. Attempt to understand the mechanism of soil erosion through physical process has not been satisfied.

In order to mitigate soil erosion problems, it is important to better understand the mechanism of soil erosion under heavy rainfall. To achieve this, it is important that the mechanism needs to consider physical properties of influencing factors. Subsequently, preventive measure needs to be identifying not only application of hard infrastructure, but also the application of sustainable materials (e.g. recycling organic waste). In this study, characteristics of rainfall-induced soil erosion are studied based on objectives of (1) development of new measuring device for dynamic properties of rainfall and (2) measuring soil erosion associated with the use of geotechnical engineering principles. The contents of this thesis are organized into seven chapters as follows:

In Chapter 1, research background, problems and necessity of soil erosion under the global warming-induced climate change were introduced. Research necessity, objectives, scope and limitation, a case study and outline structure of the thesis were described.

In Chapter 2, two main influencing factors for rainfall-induced soil erosion were reviewed. The two factors are rainfall erosivity and soil erodibility. These two factors are commonly prerequisite parameters for many soil erosion models (e.g. the Universal Soil Loss Equation and Water Erosion Prediction Project). Current determination methods of the two factors are summarized according to climate and geographical locations. Furthermore, soil erodibility indexes and effect of soil erodibility on soil erosion were also reviewed.

In Chapter 3, quantification method for rainfall erosivity was proposed through the development and verification of a measuring instrument. Strain gauge-based sensors equipped miniature cantilever strip were developed for measuring terminal velocity, kinetic energy, mass, size, and impact force of raindrops. These parameters were calibrated and correlated with the

output of the sensors. It was found that the newly developed instrument was capable of measuring the parameters in automatic and continuous manner. Moreover, with the aid of a dynamic and portable data logger, the instrument was able to capture the sampling and recording output data with high accuracy up to 200 kHz of frequency and 5 μs. Using the instrument, results of falling velocity test using a waterdrop of 4.00 mm in diameter falling from varying heights up to 20 m were in close agreement with results from literature data. An equation was therefore derived and proposed to estimate the rainfall terminal velocity, kinetic energy, size, mass and impact force as a function of the output of the strain-gauge sensors.

In Chapter 4, application of the principles of geotechnical engineering was employed to study soil erosion. One of the most important principles was the use of the hydro-mechanical properties of soils. Soil-water retention curve and permeability function of an unsaturated Masa soil from Fukuoka prefecture were investigated through experimental setup. Rainfall experiment was conducted to investigate the responses of the soil-water retention curve and permeability function. Heavy rainfall of varying intensities was applied to study the soil erosion under wetting-drying soil conditions. Hydrological characteristics, soil loss, and response of soil suction and moisture were described according to results obtained. It was found that changes of soil-moisture and soil suction (described by soil-water retention curve) offered significant information on characteristics of soil erosion under heavy rainfall intensities of 30, 60 and 90 mm/h.

In Chapter 5, soil erosion characteristics in terms of sizes of eroded sediments subjected to 1D and 2D rainfall experiments were conducted. The experiments took into account the effect of initial soil conditions on soil erosion such as soil moisture and soil suction. It was found that in 1D rainfall experiment, the initially saturated specimen produced the lowest soil loss compared to initially unsaturated condition with soil suction up to 400 kPa. This was due to protective film or layer of water on soil surface under heavy rainfall intensity of 70 mm/h. In addition, median sizes (D50) of suspended sediment and eroded soil from the experiments were found to be within range of 0.01-0.05 mm in diameter.

In Chapter 6, mitigation method for reducing soil erosion was investigated. Compost and biochar wastes were mixed with a red soil from Okinawa prefecture to improve the nutrient or water holding capacity and permeability. Rainfall experiment was conducted under rainfall intensity of 30, 60, 90, and 120 mm/h. Results showed soil-water retention curves could be employed as criteria to link to soil erosion characteristic. This was because the water retention curve of the original soil could be improved by the addition of the organic wastes. Results showed that mixing organic waste to the soil did not effectively reduce soil loss in a short-term experiment. However, it is recommended that different arrangement of materials or combined with other techniques could offer protection of soil erosion against heavy rainfall in long term.

In Chapter 7, summaries, conclusions and recommendations for future study were presented.