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The Study of Debris Flow Activities in Granular Materials with Fine Grain

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Abstract. The purpose of this study is to observe the water-soil mixture of fine sediment particles and analyze its sediment volume concentrations at varying water supply as it flows in a channel at various slopes at the mountain district. The Finite Difference Method is utilized and incorporates both the equation for fine and course sediments and the numerical model, an equation based on mass conservation and momentum conservation. In comparing the sediment concentrations at various slopes, the inflection point of the sediment volume concentration appeared as the slope steepened. In varying water supply, fluctuation occurred as the water supply increased, and the debris flow changed to laminar flow state while the sediment changed to a suspended state.

Keywords: Debris flow, water-soil mixture, slope, sediment, fluctuation.

1 Introduction

Heavy rain is the biggest cause of debris flow and is occurring more frequently due to climate changes. Water saturated with course particle matters constitute debris flow, flowing at a fast speed at slopes, channels, and valleys [1], [2].

Using various methods, Wang et al. (2008) developed a debris flow model based on the concept of fluid mixture [3]. Wang et al. (2008)'s model utilized the following models from Newton, Bingham, Herschel-Bulkley, Dilatant, Dispersive stress, and Frictional. Meanwhile, based on the erosion and deposition model, Takahashi and Tsujimoto (1984) presented the two-dimensional finite difference model, which served as the foothold for the fluid expansion model [4]. Egashira et al. (1997) suggested the Newtonian model which addresses fluid mixture flow [5]. Based on the observation on the debris flow when it is flowed, O'Brien et. al (1993) presented the split model which describes each momentum mechanism, deposition and erosion, separately [6]. At various slope angles of the channel and variation of water supply, the water-soil mixture with fine sediment particles contributes to a downstream debris flow; the sediment volume concentration can be assessed on the canal.

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Here, c_c is the mean concentration of coarse sediment particle, c_f is the mean concentration of fine sediment particle, c_{c*} is concentration of the coarse sediment particles in deposition layers, c_{f*} is concentration of the fine sediment particles in deposition layer when the river bed is in a standstill state, and q is the water discharge of debris flow per width. With S as the erosion or deposition velocity, the following equation is proposed by Egashira et al. [5].

$$S = \nabla \cdot \phi \cdot \tan(\theta_e - \tan\theta) \quad \mathbf{(6)}$$

$$\theta_e = \arctan\left\{ \frac{(\sigma/\rho - 1)c}{(\sigma/\rho - 1)c + 1} \right\} \tan\phi \quad (7)$$

Here, ϕ is the equilibrium slope of c, and σ is the density of sediment particles. Equations (6) and (7) utilizes continuity equation and the momentum equation and shear stress, providing insight to the volume concentration of both coarse and fine sediment particles

3 Numerical Results and Analysis

3.1 The Condition of Numerical Simulation

In this study, the behavior of debris flow at the upstream and end of downstream is analyzed when the straight rectangular channel is continuously supplied with coarse and fine sediment particles. The water supply is changed to the following, 600cm^3/sec, 800cm^3/sec, 1000cm^3/sec. The following features must be set to simulate the numerical modeling. The width is 10 cm and the channel slope θ changes accordingly as 14°, 16°, 18°, and 20°. Upstream of the water-course has saturated sand, thus the paved length changes as 2 m, 3 m, and 4 m. The height from the elevation point to the upstream is 4 m. The A-A' line is the point of investigation at the downstream.

3.2 The Numerical Results for Variation of Channel Slope

Fig. 1 shows the variation of channel slope at the end of downstream when the sediment volume concentration changes based on time elapse of 30 seconds. The sediment volume concentrations for both the coarse and fine sediment particles are used. The variation of channel slope is 14°, 16°, 18°, and 20° while water supply is 600cm^3/sec and 1,000cm^3/sec. In a high-risk situation, the degree can be between 18 and 20°. Fig. 1 shows when the slope is between 14-16° the debris flow shows a peak weak in the beginning stages. After the slight peak forms in the beginning, the Fig. 1 exhibits a mild position. In contrast, the inflection point is displayed when the slope is between 18-20°; when the slope is 20°, inflection point is rapidly shown at 15 seconds. In other hands, the deeper the slope, the shorter time it takes to show the increase of debris flow.

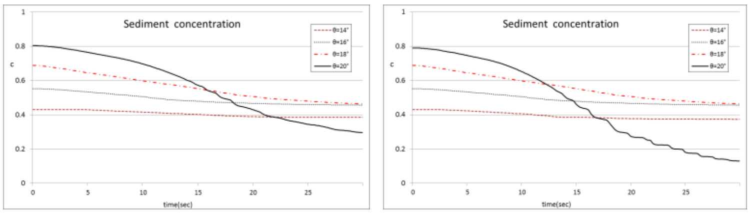

Fig. 1. Sediment concentration at the downstream end varying the angle of the channel for q=600cm^3/sec(left) and q=800cm^3/sec(right).

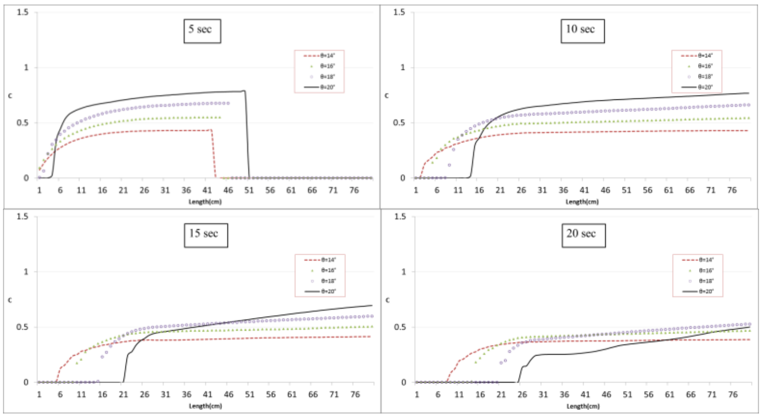

Fig. 2. Sediment concentration on the channel varying the channel slope according to time elapse for q=1,000cm^3/sec.

Fig. 2 displays the changes of sediment concentration at the channel due to the variation of channel slope. As seen in Fig. 2, the steeper the slope, the difference of elevation contributes to a highly concentrated sediment volume. As time progresses, the debris flow then reaches the downstream even faster. As the debris flow reaches the downstream the highly concentrated sediment mixes with the fluid from the high flow discharge, thereby increasing the damages.

3.3 The Numerical Results for Variation of Water Flushing

Fig. 3 shows the changes of sediment volume concentration within 30 seconds based on the variance of water supply. With the channel slope as 20° and 16°, the water supply has been changed to 600cm^3/sec, 800cm^3/sec, and 1,000cm^3/sec. As inferred by Fig. 3, as water supply increases the high flow discharge of debris flow reaches the downstream faster, and at 1,000cm^3/sec fluctuation occurred. Because the energy of debris flow is great, the debris flow changes to the laminar type; in respect to this, the bed load sediment changes to the state of suspended sediment. In other ways, as rainfall increases the liquefaction of debris flow allow the sediments to reach the downstream faster and thus increasing the hazardous levels. Fig. 3 shows the variation of sediment concentration at the upstream part of the water canal. As seen in Fig. 3, the greater the water supply at the upstream section, the traveling speed of sediment volume concentration increases. Also, at the 15 second time point, when the water supply is 1,000cm^3/sec the sediment concentration at the upstream water channel either weakens or declines. In contrast, when the water supply is 600cm^3/sec the sediment concentration at the upstream water channel is continually fixated. As the water supply increases, the debris flow passes the slope faster, and due to the flow of highly sediment concentrated mixtures, more damages can occur. Therefore, it is important to understand the influences rainfall intensity and precipitation has on slope angles to predict for debris flow-related damages.

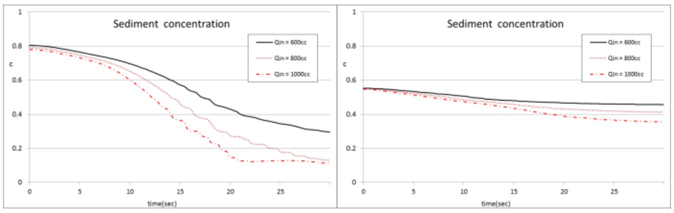

Fig. 3. Sediment concentration at the downstream end varying water supply with fine sediment fraction for θ =**20°**(left) and 16°(right).

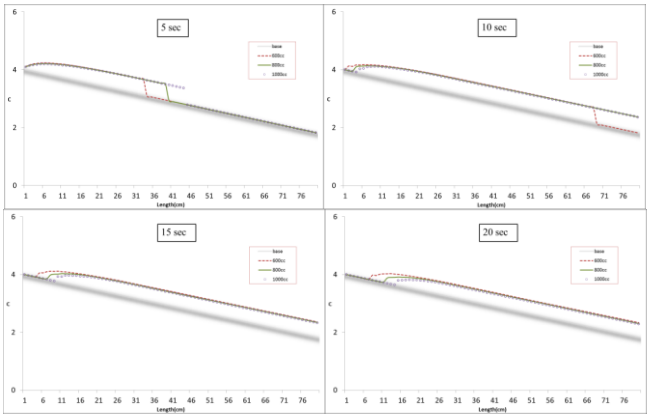

Fig. 4. Sediment concentration on the channel varying water supply with fine sediment fraction according to time elapse for θ =20°.

4 Conclusions

Recently, due to the climate changes of global warming, heavy rain has occurred more frequently in the mountainous areas, leading to debris flow-related damages to property and life. In this study, when the soil water mixture of localized heavy rain and fine sediment particles flow in the mountain regions, the downstream areas are predicted to undergo debris flow changes. When the soil water mixture repeatedly undergoes erosion and deposition in the mountainous slope face, the highly concentrated sediment volume occurs in the downstream regions. This mixes with the high flow discharged fluids, increasing energy levels and thus amplifying downstream calamities. Also, the spectroscopic factors of this study were the sediment concentration values of both coarse sediment particles and fine sediment particles.

When analyzing the sediment volume concentration based on variation of channel slope, the smaller the slope, the beginning periods of debris flow displays a weak peak. Afterwards, a gradual form develops. As the slope increases, the sediment volume concentration exhibits an inflection point. Thus, the steeper the slope this infers that the quantity of debris flow increased in a short period of time; this brings about great destruction to the lower regions of the steep-slope land. As fine-sediment mixed water supply increases, high flow discharge sediments arrive at the downstream regions faster, leading to fluctuation. As the debris flow exhibits great amount of energy, it changes to the laminar flow type; in respect to this, the bed load sediments changes to the state of suspended sediment state. As rainfall increases, the liquid form of debris flow enables the sediments to arrive at the downstream areas faster, increasing the damages. At the upstream areas of the water channel, the traveling speed of the sediment concentrations can be determined. The highly concentrated sediments combine with the fluids of high flow discharge, thus possessing the ability to bring about great destruction.

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