A NUMERICAL CURVED FLUME TEST FOR DEBRIS FLOW VELOCITY ESTIMATION: JUSTIFICATION OF USING SUPER-ELEVATION

Yokohama National University Student Member ○ Md Aftabur Rahman
Yokohama National University Fellow Kazuo Konagai

1. INTRODUCTION

Debris flow velocity estimation is of paramount importance for debris hazard mitigation strategy. There is no straight-forward procedure to estimate the debris flow velocity because of its rapid onset and high uncertainty. In most of the cases, velocities were estimated from post-event field investigations of super-elevation along curved paths. However, a post - event field investigation identifies only the circumstantial evidences of flow velocities. Hereafter, this paper describes anomalies of mud-marks-based velocity estimation procedure, numerical simulation of 3D flume test to discuss how the procedure can be improved, and implementation of numerical findings in analyzing real field data.

2. PROBLEMS IN REALITY

A debris mass leaves mud marks along its flow path, and when it travels through a curved channel, the height difference Δh between mud marks on inner and outer walls, referred to as super-elevation, appears. Commonly, velocities are estimated from the observed super-elevation using the Forced Vortex equation given by Equation (1)

$$v = \sqrt{\frac{g \times R \times \Delta h}{k \times b} \cos \alpha} \tag{1}$$

where, R = radius of curvature of bend, Δh= super-elevation, b= width of channel section, g= gravitational acceleration, α=channel inclination, k=correction factor for viscosity. Post-event field survey requires to measure the bend radius and super-elevation at a certain section of flow trace. The critical issue that arises in the field is that only the highest flow-marks are left after the event which can misread the actual velocities (Fig.1). Moreover, splashes and hydraulic jumps sometimes leads in erroneous measurement of super-elevation. In fact, a large flume test conducted by USGS revealed that velocity using super-elevation underestimate the actual velocity by 30%.

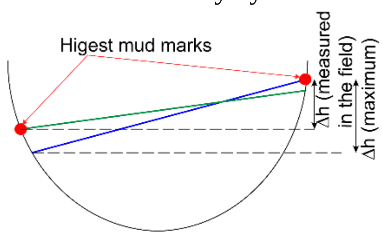

Fig.1 Problems in reality of estimating flow velocity

Finding a realistic approach to rationally estimate flow velocities is thus important for practical engineers. Though a flume tests can be very pertinent to spur your thinking, a real scale debris flow test is often cumbersome. Moreover, achieving complete similarity (geometrical, kinetic & dynamic) in experiment is close to impossible. In light of limitation of the experimental investigation, these large scale problems are now-a-days modeled numerically and can provide better agreement with the real situation. Thus, keeping all the issues in mind, this research takes a numerical approach for debris flow velocity estimation and afterward results are compared with one of the well documented debris flow event in Japan.

3. NUMERICAL MODELING

Numerical modeling of debris flow has been done by many researchers over the last decades. Most of the numerical simulations are based on Eulerian description. However, large deformation of debris flow restricted the use of conventional mesh-based tools. Meanwhile, in recent years, mesh-free particle methods are widely used in numerical analysis of flow materials. Smoothed Particle Hydrodynamics, commonly known as SPH is one of the mesh-free particle method based on Lagrangian description. It was initially developed for the astrophysical problems (Lucy 1977) and later extended into the diverse field including hydrodynamic problems. SPH can track the motion of each particle, accurately predict the velocity and naturally handle the free surface flow. Complex geometrical shape can also modeled easily in SPH. Thus, SPH is a plausible approach for this study and used in the proposed numerical modeling. Detail features and formulations of SPH are available in Liu and Liu 2003.

4. MODELING OF CURVED FLUME

A 3D curved flume was modeled using the SPH numerical scheme. From the upstream to the lower stream ends, the flume has a reservoir at the upstream end, a length-changeable straight section, an upper curved portion, the second straight channel and a lower curve (Fig.2). The Bingham constitutive law was used for modeling the debris materials. Lagrangian parameters of particles were set at appropriate values considering the geometric, kinetic and dynamic similarities.

Keywords: Debris flow, SPH, Velocity, Numerical modeling, Shiraito river
Contact address: 79-5,Tokiwadai, Hodogaya-ku, Yokohama, 240-8501, Japan.

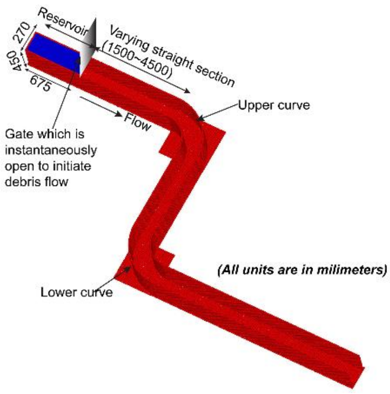

Fig.2 Modeling of curved flume

5. RESULTS & DISCUSSION

Super-elevations were seen along the curved channel of the flume. To compare with real mud marks left on river walls, only the highest flow marks at different sections of the curved flume was extracted and used to estimate the velocity which is defined as $V_{mud.}$ Actual velocities (V_{obs}) on these cross-sections from numerical simulation were also recorded and compared with velocities estimated from mud marks. This ratio is plotted against normalized distance (normalized with initial source length) and is depicted in Fig.3. Mud-marks underestimate the actual velocities close to the source region, whereas mud-marks-based velocities converged on the actual velocities as the distance from the source increases. Based on the nature of the scatter plot shown in Fig.3 (a), an exponential relationship was established. This generalized form can be used to adjust the mud-marks-based velocities observed in situ. Therefore, a verifiable example is needed prior to use it for practical purposes.

A massive debris avalanche near the rim of Hakone crater, Kanagawa prefecture, Japan was occurred immediately after the Great Kanto Earthquake of 1923.The detached mass ran down the valley of Shiraito River in a thick cloud of dust and rushed into the Nebukawa town with thunderous roar breaking and burying houses along the flow path. Precise drawing of flow marks on the left and right banks of Shiraito River by Mr. Kazumasa Uchida exists in the Kanagawa Prefecture Archives. These flow marks were used to estimate the velocities, which were then adjusted with the numerically obtained exponential fitting line and plotted in Fig.3 (b). Adjusted velocities were further compared with Kobayashi's (Kobayashi 1985) result which is based on Saint-Venant hypothesis for a one-dimensional non-Newtonian flow with the inclusion of an additional friction slope term. Adjusted velocities exhibit quite good agreement with Kobayashi's results and were consistent with the scenario estimated from verbal evidences.

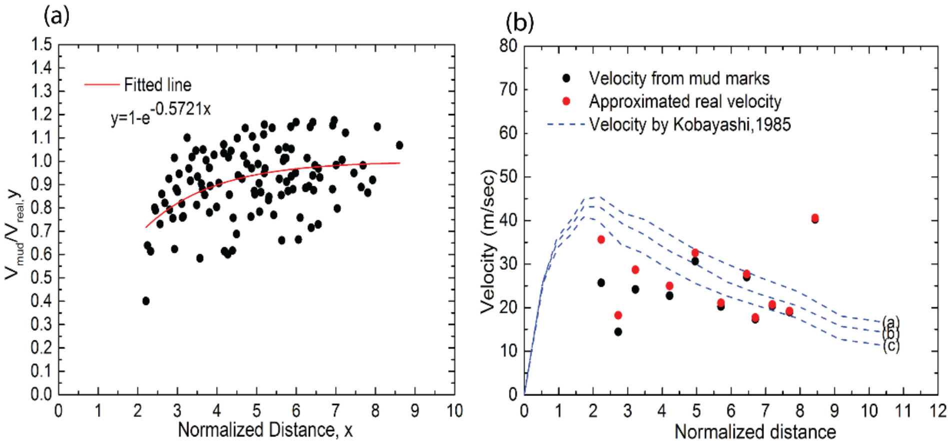

Fig.3 (a) Normalized distance and velocity of debris flow, (b) Velocity adjustment of Shiraito river debris flow

6. CONCLUSION

The proposed simplified method to adjust mud-marks-based debris flow velocities yielded a consistent result with the scenarios for a real debris flow disaster estimated from both verbal evidences and Saint-Venant hypothesis for a one-dimensional non-Newtonian flow. However, this simulation is based upon simplified channel configuration and further development may refine the outcomes. Yet, proposed numerical modeling realistically simulates the debris flow velocities despite the several shortcomings of the model.

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