Optimal Values of Friction Parameters from Snow Chute Experimental Study and Simulation of Runout distances

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Abstract*— The characteristic properties of a snowpack that are important to assess potential to produce an avalanche are density, temperature and crystal type. The prediction of snow avalanche runout distance from dynamic equations require estimate of internal and external friction terms. Experimental study of avalanche flow in chute are increasing to study various processes involved in it for the improvement in the understanding of avalanche dynamics. The velocity and runout distance of avalanche events are essential inputs in the planing and design avalanche control scheme. The values of these flow variables depend upon the coulomb friction and turbulent friction, and it is not always possible to get the values of these parameters for known initial and boundary conditions from fields. In this paper, results of snow chute experiments carried out at Dhundhi, Manali, India are presented to study the snow avalanche flow behavior and to determine the optimum values of friction parameters. A number of experiments were carried out in the snow chute for various avalanche flows using natural snow of density between 350 kg/m^3 to 600 kg/m^3. The geometry of the fractured snow mass at the motion of avalanche event was considered to have constant width, 2.0 m length varies from 2.0 m to 5.0 m and fracture depth from 0.3 m to 1.0. The snow chute experiments were carried out using wet snow under a temperature between -4º to 4º C. The avalanche flow was viewed and recorded by the CCD cameras connected to a digital video recorder. The data collected has been used for the estimation of friction parameters, namely dynamic friction and turbulent friction. To arrive at the optimum values of frictional parameters, μ and ξ, computational runs were taken to simulate runout distance using analytical solutions given by Keshari et al. model. The runout distance for various values of μ between 0.15 to 0.30 at an interval of 0.05 and for ξ values ranging from 600 to 1200 at an interval of 100. The computed results were compared with the experimentally measured values. Results reveal that the optimum value of μ and ξ 0.25 and 800, respectively, to simulate runout distance. The runout distance is strongly sensitive to μ and less influenced by the other model parameters namely ξ and h.

***Keywords*— Avalanche Dynamics, Numerical Model, Runout Distance, Snow**

I. INTRODUCTION

Dynamics of an avalanche is a complex phenomenon. Its understanding is an important part in predicting the reach and destructive force of snow avalanches. Estimation of avalanche runout distance is important, because the runout distance has an effect on the design and placement of control structures that may be in the path of flowing snow. Avalanche dynamics models are tools to predict avalanche flow parameters and impact pressure on structures in a complex mountain terrain. Model results are used to prepare hazard maps in snow bound mountain region and also to determine the layout & dimensions of the avalanche control structures in an avalanche area. A number of mathematical models have been developed by various researchers worldwide to describe the motion of snow avalanches (Dent and Lang 1983, Norem et al. 1987, 1989, Nohguchi 1989, Savage and Hutter 1989, Salm 1993, McClung and Mears 1995, Bartelt et al. 1999, McElwaine and Tifenbancher 2003, Naaim et al. 2004, Platzer et al. 2007, Keshari et al 2010). These models have shown significant improvement from the first used Voellmy fluid model for understanding the avalanche dynamics. However, these models are primarily based on Saint-Venant equation or its modified form using active-passive pressure coefficient proposed by Savage and Hutter to include the granular media concept. Presently, avalanche flow parameters and run-out distances are determined by numerical models based on hydrodynamic theory considering Voellmy fluid, which requires careful selection of friction parameters. In these models, the friction parameters are dependent on the quantity of released snow mass, fracture depth, moisture content, temperature, channel roughness and geometry etc. The influence of surface roughness and channel geometry is observed by simply changing the value of flow friction parameters without considering the effect of the complex granular motion of a flowing avalanche. For avalanche hazard zoning and avalanche protection measures understanding of friction parameters and effect of retarding and diversionary structures on the avalanche flow is very important. To solve this problem computer simulation of avalanche flow is a useful approach, but this technique requires understanding and investigation of some physical parameters. Since natural avalanche is a stochastic process its observation for similar initial and boundary conditions is very difficult. Therefore, to carry out repeated experiments for similar initial and boundary conditions a snow chute has been designed and constructed in snow bound area. The results of the experiments conducted in the snow chute are used to verify the existing avalanche flow models, friction laws and also to study friction laws and to study the energy dissipation due to different types of diversionary and retarding structures. It is also observed that these experiments help to distinguish the effect of coulombs friction and turbulent friction by measuring the run out distances for varying run out zone slopes.

The physics of flowing snow is poorly understood, and thus accurate estimation of model parameters is difficult with reference to present experimental data. Generally empirical calibration and operational experience are used. The suggested values can be found in "Swiss Guidelines" for model implementation written by Salm et al. (1990). However, these guidelines were written for the traditional versions of the Voellmy model and may not be applicable to hydraulic-continuum implementation. Another major problem with these traditional approaches is that no account is taken of flow regime transitions and mass change. This may be the main reason why the optimum parameters vary significantly from one avalanche to another. Model predictions are often quite sensitive to the parameters values (Nishimura and Maeno 1987,1989 Barbolini et al. 2000, Tibert et al. 2015).

The experiments have been conducted in the snow chute using natural snow. In this paper we have presented the observations & results of these experiments. The steel surface has been used in present study. In the future experiments we intend to use modified surfaces having greater co-efficient of friction.

II. SNOW CHUTE EXPERIMENTATION

II.1 *Avalanche chute experimental setup*

The experimental setup consists of the following components (Figure 1)-

(a) Loading platform- It is used to collect natural snow from slopping ground to provide the snow to feeding platform.

(b) Snow Feeding platform (Hopper)- It is trapezoidal in shape, 6.0m long, 2.0m wide at lower end and 4.0m wide at upper end and 1.0m deep. It is supported with hinge at lower end and by a pair of hydraulic jacks at its upper end. The snow is collected on feeding platform and released into snow chute channel by tilting the feeding platform.

(c) Hydraulic jacks- Two sets of hydraulic jacks have been installed in snow chute. One set is used to tilt the feeding platform to release snow into snow chute channel and other set is used for adjustment of slope of testing platform.

(d) Snow chute channel with walkway-The snow released from snow feeding platform slides through snow chute channel of 30m length, 2m width and 1.0-m deep. The sides of channel are made of transparent Polycarbonate sheet of 4mm thickness to visualize the moving snow from sides. There is 0.90m wide walkway along both sides of the channel to serve as inspection path and access to the chute channel. The snow chute channel has two segments of 22m with 30° and 8m with 12° slope. A maximum of 18 m^3 volume of snow and other granular materials can be made to slide down like an avalanche.

(e) Testing platform- The snow chute channel terminates at the test-bed, which is 12m long and 4m wide. It is used for the model study of avalanche control structures in the middle and run-out zones. This platform also has a provision of slope adjustment up to -15° by operating the hydraulic jacks to study the run-out distance for the reverse slope.

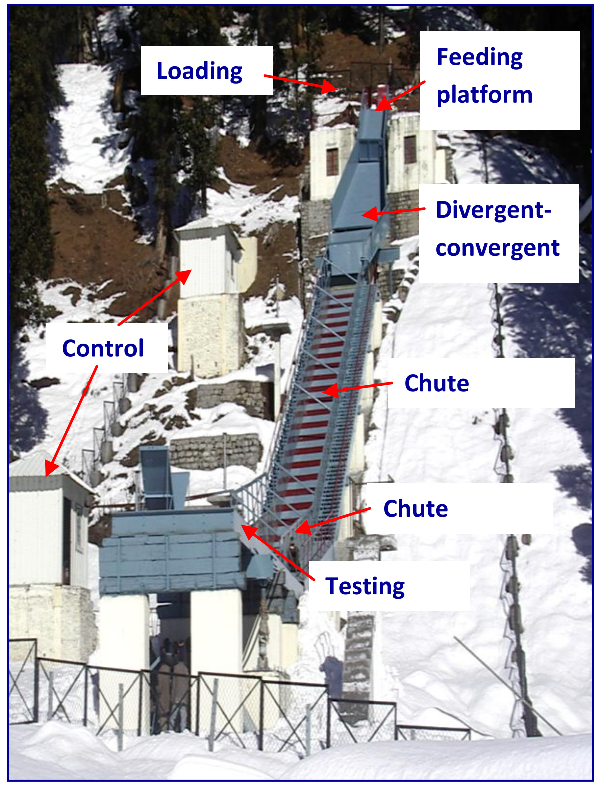


FIGURE-1: INCLINED CHUTE FACILITY AT DHUNDI

(f) Instrumentation-

To visualize and capture the motion of moving snow mass in snow chute, four number of CCD cameras are fixed along the chute channel at fixed intervals. These cameras are connected with the digital video recorder (DVR) which has facility to analyse camera picture snap by snap to study the flow parameters. The chute surface is marked at fixed intervals of 50 cm and time taken to cross these intervals is taken from DVR that is used for determination of average velocity of moving snow mass in the marked intervals. Other instruments like infrared sensors and load cells will also be used to measure velocity profile along the channel, vertical velocity profile, shear force and impact force.

II.2 Description of the study area

The snow chute on which experiments were carried out to validate the developed numerical model and understand the interaction between the avalanche and defence structure, is located in Manali. Manali is situated in Kullu district of

Himachal Pradesh state a region of northen India.It is in the foothills of the Himalayas with soaring snow capped mountains. The Beas river originating from Himalayas passes through this township. The mountainous terrain has pine and deodar trees. In this area, there are number of sites where frequent avalanches of varying in size occur during the winter period. A number of avalanche sites are observed between the Manali township and the Dhundi where snow chute has been established for carrying out avalanche flow experiments.

III. NUMERICAL MODELLING

The Keshari et al. model-

By applying conservation of mass and momentum balance law, a system of hyperbolic partial differential equations have been developed to describe the flow of the dense snow avalanche down a general path.

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x}(\rho hu)=0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho hu)+\frac{\partial}{\partial x}\left(\rho hu^2+0.5\bar{\lambda}\rho h^2\right)=\rho gh\left(\sin\theta-\mu\cos\theta+\frac{u^2}{\xi h}\right) \tag{2}$$

$$\bar{\lambda}=\begin{Bmatrix} g\cos\theta\lambda a for\ \dfrac{\partial u}{\partial x}\succ 0 \\ g\cos\theta\lambda p for\ \dfrac{\partial u}{\partial x}\leq 0 \end{Bmatrix} \tag{3}$$

$$\left.\begin{aligned}\lambda a &= \tan^2(45^0+\phi/2)\\ \lambda p &= \tan^2(45^0-\phi/2)\end{aligned}\right\} \tag{4}$$

$$\rho(h) = 350+145h-26h^2 \tag{5}$$

where x is the length along the avalanche path; t is the time; g is the acceleration due to gravity; h(x,t) is the avalanche flow height; ρ is the snow density;μ is the dry friction coefficient; ξ is the turbulent friction coefficient; λa is the internal friction parameter in active zone and λp is the internal friction parameter in passive zone.

ρ(h) is snow density at depth h (m).

IV. RESULTS AND DISCUSSION

Friction for granular materials is a complex phenomenon, which cannot be represented by a simple model and the measured values for different materials are use for practical applications. Gravity is a driving force for avalanches and sliding friction between the avalanche and the underlying snow or ground, internal dynamic shear resistance due to collisions and momentum exchange between particles and blocks of snow, turbulent friction within the snow/air suspension, shear between the avalanche and the surrounding air and fluid-dynamic drag at the front of the avalanche are factors contributes to frictional resistance within an avalanche. The prediction of snow avalanche runout distance from dynamic equations requires estimate of internal and external friction terms. Today's hazard mitigation strategies rely both on practical experiment and avalanche dynamics models that predict snow avalanche descent paths, velocity, runout distance. Depending upon size of avalanche, type of snow and the surface roughness the values of coefficient of dynamic friction μ and turbulent friction ξ varies from 0.15 to 0.30 and 600 to 1200 respectively. The value of μ and ξ can be obtained from measured run-out distance for known initial and boundary conditions for an avalanche. The fracture depth is varied between 0.3 to 1m. The observed runout distance along chute track lenghth for different fracture depths of snow pack is shown in Figure 2. It is evident from these figures that the flow height doesnot vary significantly along the chute at various sections.

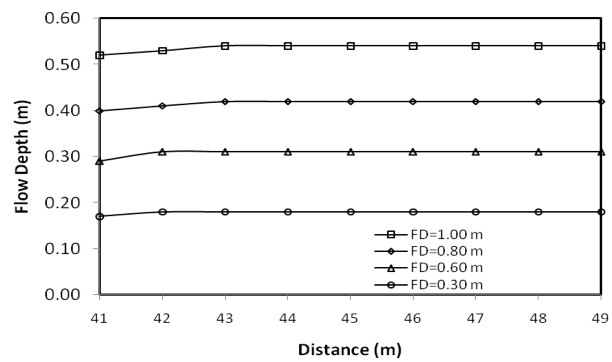
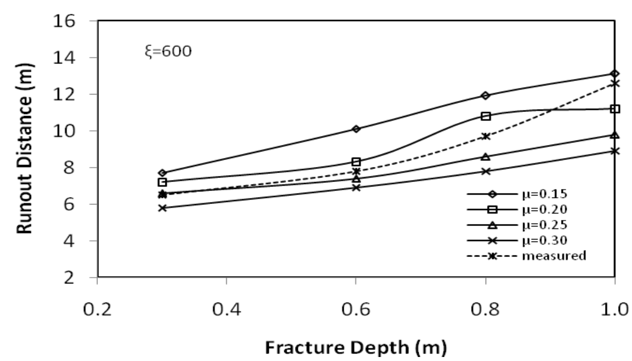
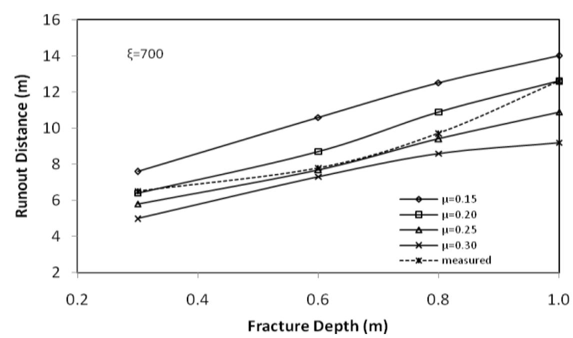


FIGURE 2 VARIATION OF FLOW DEPTH ALONG CHUTE IN RUNOUT ZONE FOR DIFFERENT FRACTURE DEPTHS



(A)



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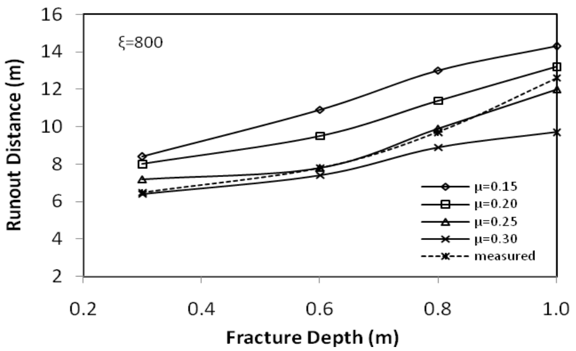
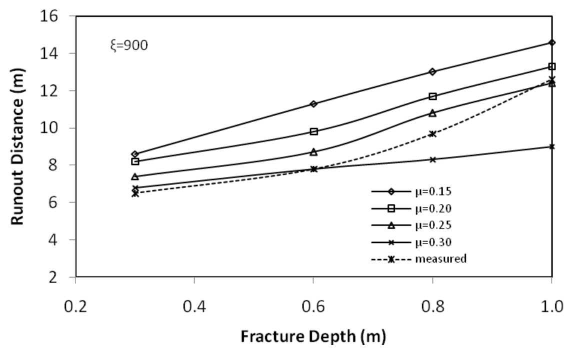


(C)



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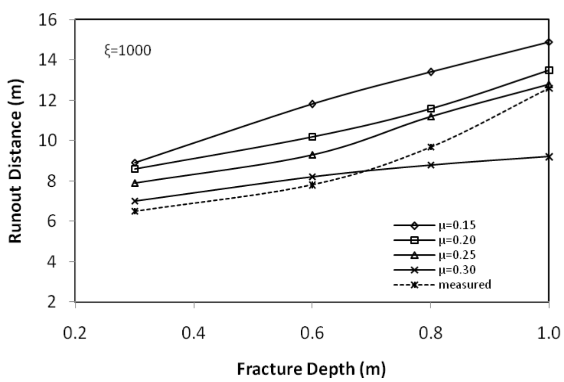

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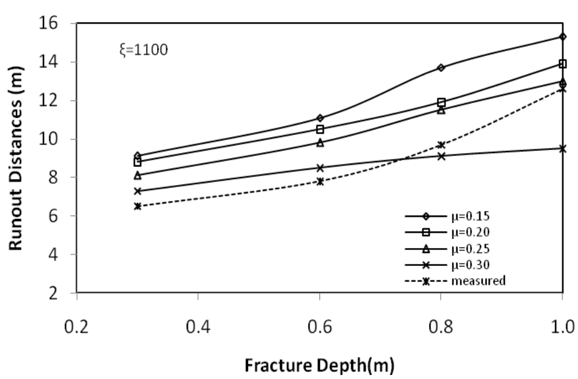
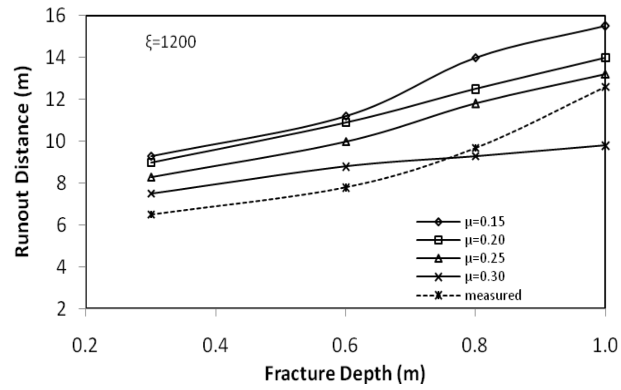


(F)



(G)

FIGURE 2 (A)-(G) COMPARISON OF MEASURED AND SIMULATED RUNOUT DISTACE

For the Keshari et al. model we have taken the density as a function of fracture depth. The comparison of measured and simulated runout distances for different models is shown in Figure 3 (A) to (G). Results show that runout distance is strongly sensitive to μ and less influenced by ξ. As the fracture depth increases the runout distance also increases. The most suitable values of μ and ξ for the Developed Model are 0.25 and 800 respectively to satisfy runout distance.

V. CONCUSIONS

An experimental setup for large-scale experiments on dense snow flows has been presented. The snow mass having initial depth of 0.3 m to 1 m was released from chute hopper stops in deposition zone. The snow flows generated on the chute have a structure similar to that of real dense snow avalanches. The flow attains maximum velocity at the lower part of 30º chute channel. The runout distnce along chute channel is measured by the installed digital video camera. The Dhundhi chute introduced as an important tool for the investigation of avalanche flow parameters.

The friction were estimated for Keshari et al model and program NMA from comparison of measured and simulated run-out distance. The Keshari et al. model gives good estimates of runout distance with the proper selection of friction coefficients for various snow conditions in the chute flows. The range of coefficient of friction μ and a ratio of avalanche mass-to-drag, M/D are estimated for natural snow. The varying values of coefficients are taken in different segments of the chute. The program NMA gives spatial and temporal variation of runout distance and flow depth. The results shows that measured runout distance matches well with simulated values obtained from Keshari et al. model.

The output of the models is critically depends on input friction coefficients. The unique solution of these models is not possible so the range of friction coefficients is obtained. These coefficients are seen as fit parameters used to fit the model behaviour to observed avalanche events and using the fitted values to compute runout distance of avalanches under similar conditions.

The extension of study for natural avalanche terrain will have more practical applications. To develop a proper physical model for avalanche flows, it is necessary to distinguish between coulomb friction at the sliding surface and internal friction within the flow body that will leads to better understanding behavior of flowing snow. The measurement of flow normal velocity profiles and basal friction forces will lead to a deeper understanding of internal frictional processes. Further the instrumentation will be developed to measure the shear forces and vertical velocity profile of flowing snow to study the constitutive behavior of flowing avalanche snow.

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