# RHEOLOGICAL FLOW MODELLING OF SNOW AVALANCHES

**By**

**Amod Kumar**

**DEPARTMENT OF CIVIL ENGINEERING**

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AMOD KUMAR

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Dedicated

to

my parents

Shri Vishwanath Singh

and

Smt Sharmista

# CERTIFICATE

This is to certify that the thesis entitled **"Rheological Flow Modelling of Snow Avalanches"** being submitted by Amod Kumar to the Indian Institute of Technology, Delhi for the degree of Doctor of Philosophy is a bonafide record of research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard, fulfilling the requirements of the said degree. The results contained in the thesis have not been submitted, in part or full, to any other university or Institute for the award of any degree or diploma.

Dr. A. K. Keshari
Professor
Dept. of Civil Engineering
I.I.T. Delhi
Hauz Khas, New Delhi, India

Dr. H. S. Gupta
Senior Scientific Officer
Dept. of Civil Engineering
I.I.T. Delhi
Hauz Khas, New Delhi, India

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Amod Kumar

# ABSTRACT

The snow avalanche is one of natural hazards in snow bound mountainous regions which is drawing significant attentions by worldwide researchers. In India, Jammu and Kashmir (Higher reaches of Kashmir and Gurez valleys, Kargil and Ladakh), Himachal Pradesh (Chamba, Kullu- Spiti and Kinnaur) and Uttrakhand (Tehri, Garhwal and Chamoli) have snow bound avalanche prone regions. The people living in these areas are directly or indirectly affected by snow and avalanche problems and they remain cut off from the rest part of the world as highways in these regions remain closed during winter due to snow and avalanche problem. Many infrastructural projects, namely highway, railways, transmission lines, hydel powers and winter tourism are coming in avalanche prone regions which need better understanding of avalanche dynamics and interaction between avalanches and protecting structures. This helps significantly in hazard assessment and designing control structures. The avalanche flow depends on terrain parameters, quantity of released and entrained snow mass from the formation zone and the middle zone, respectively, and the snow rheology. The granular and rheological properties of moving snow are dependent on terrain roughness, channel geometry and mechanical properties of snow including density variation.

The currently used avalanche dynamics models lack in the actual description of rheological properties of moving snow mass. In this study, an improved one dimensional avalanche dynamics model is presented by incorporating rheological properties of moving snow mass. The developed model consists of a set of partial differential equations describing mass and momentum conservation, and are obtained by making use of Criminale-Ericksen-Filbey-Fluid (CEFF) and granular mass theories for the snow rheology. The model incorporates the density variation, velocity distribution and pressure distributions, which facilitates to account variation in the snow and flow properties during the initiation of

avalanche occurrence as well as during its movement along the flow path, because of associated physical processes. The rheological behaviour of moving snow mass is introduced in the density varying model by incorporating mass flux distribution factor and momentum distribution factor. These factors depend on slip velocity, fluidization layer thickness, channel shape and density gradient in avalanche mass. The granular effect is incorporated by introducing the term active earth pressure coefficient in acceleration phase and passive earth pressure in deceleration phase. The solution is obtained numerically using McCormack Finite Difference Method. The experiments were also carried out in a snow chute at Dhundhi, Manali to validate the developed numerical model and to understand the effect of channel transition on the avalanche flow with different contraction and divergence angles.

Analytical solution is also obtained for the studying the interaction between avalanche flow and diversionary protecting structures. The processes involved in dissipating energy at supercritical flow transition is studied. The results obtained from the numerical model are in good agreement with the experimental observations and also with the published results in literature for some cases.

A number of computational run were taken to investigate the variation of velocity and flow depth along the avalanche path. The sensitivity analysis is carried out to investigate the sensitivity of various model parameters consisting of friction and pressure coefficients and distribution factors on results in term of velocity, flow depth, runout distance. Results were also obtained to estimate the run up heights of oblique jump for different deflection angle of supercritical flow transition resulting from the presence of protecting structure in avalanche path.

The developed model has been also applied to real avalanche site, MSP-7, called Phindri Nallah near Manali, India.

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