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EFFECTS OF CURVATURE IN AVALANCHE DEFLECTING DAMS

Arne Moe*, Fridtjov Irgens*, Ulrik Domaas** and Carl Bonnevie Harbitz**
*Norwegian University of Science and Technology, Department of Structural Engineering, Richard Birkelands veg 1a, N-7491 Trondheim, Norway
**Norwegian Geotechnical Institute, P. O. Box 3930 Ullevål Stadion, N-0806 Oslo, Norway

Summary Three different models have been applied to evaluate the centrifugal effects in curved avalanche paths. The objective of this work is to achieve better understanding of how curvature influences avalanche flow. This knowledge is useful for design of deflecting dams; potentially effective and relatively cheap protection measures for changing the course of a slide.

INTRODUCTION

Avalanches and other types of slides represent significant danger to people and property in large parts of the world. Deflecting dams, i.e. dams that change the courses of avalanches to prevent impact upon houses or roads, are used as protection from this hazard. A curved deflecting dam can catch the avalanche at a gentle angle of impact. The flow direction is continuously and gently altered along the whole length of the dam, hence avoiding the more abrupt deflection of a straight dam. As will be shown in the article, spreading the deflection over longer time and distance results in significantly lower run-up heights on the deflecting structure or terrain. A direct consequence of this is that curved deflecting dams may be built lower than straight ones—with less impact to the local environment and at lower cost.

The purpose of the present study is to achieve quantitative knowledge about the effect of curvature on run-up heights. We compare observed behavior to computational results for naturally curved avalanche tracks, applying three models that are described below.

Similar studies have been presented by Irgens, Harbitz and others [5], [2]. The present study, however, involves the improved NIS simulation procedure, as well as the quasi-static run-up model for curved deflecting dams that have not been previously published.

THE APPLIED COMPUTATIONAL MODELS

The quasi-static curved channel model

This model is based on a set of geometrical and kinetic relations, that have been implemented in a spread sheet [6]. An open channel is described by the curvature radii in the horizontal and vertical planes and inclination of the centre line, and by the shape of its cross section. The channel cross section is defined by its inner and outer wall slopes and the width of the channel floor. In addition, the area of the flow cross section is derived either from the volume flux or from the initial flow height, i.e. the flow height without centrifugal displacement of the surface. If the path is in fact a wide area restricted only on one side, the width of the channel is chosen very large, and the cross section area must be given through the volume flux rather than through the initial flow height.

A stationary flow through a fixed cross section is studied. The flow is considered to be inviscid, hence the free surface assumes an inclination perpendicular to the effective body force, consisting of the gravity and the centrifugal forces. These are calculated from the velocity and the shape of the centre line of the channel. Given the orientation of the free surface, we can compute the run-up height on the channel wall.

Though very simplified, this model provides us with information on which properties are most influential given certain conditions: Numerical derivatives of the run-up height with respect to each individual input parameter shows the significance of each of these.

The Schieldrop leading edge model

This model does not, in contrast to the other two, compute run-up on a curved deflecting dam. Instead, the trajectory of the centre of mass of avalanching material arbitrarily hitting a plane deflecting dam wall is computed. This gives us information about which angles of incident that can be handled by a given deflecting dam without the dam being overstepped.

The terrain is described as an inclined plane, with a straight deflecting dam oriented at an oblique angle to the avalanche flow. The inclination, the wall slope and the angle of incidence are the geometrical parameters considered in the computations.

The deflecting dam model is based on the Voellmy-Perla equations, comprising a dynamic drag coefficient and a Coulomb friction. The equations are solved numerically with a fourth order Runge-Kutta procedure.

The Norwegian Geotechnical Institute (NGI) presently use this model as a tool in dam design, and the PCM [8] model is usually applied to provide velocity input and to calibrate material parameters. In this study, however, we have used velocity input from the NIS model, in order to make the comparisons more valid. Domaas and Harbitz [1] showed that the model systematically predicted lower run-up heights than what was observed, and established a best fit relationship between predictions and observations.

The Norem, Irgens and Schieldrop (NIS) model

The NIS model is based on a constitutive model of granular materials and a simplified simulation procedure for the flow. The constitutive model was proposed by Norem et al. [7]. The material properties of the model are specified by a coefficient of Coulomb friction, a shear viscosity, two viscoelasticities, representing the effect of normal stress differences, and a cohesion parameter. The simulation procedure was proposed by Irgens [3] and later improved by Irgens et al. [5] and Irgens [4]. A further improvement is presented in this paper.

The flowing material is assumed to be confined to a channel-like portion of the terrain. The avalanche is approximated by a set of volume elements with varying heights and varying widths, compensating for converging and diverging effects in a real terrain. Horizontal centrifugal effects, due to curvature of the horizontal projection of the flow path, are taken into account. These effects result in an inclination θ of the free surface and a corresponding displacement of the centre line. The centerline of the avalanche is a space curve, which is determined by the terrain and the dynamics of the flowing material.

The cross-sections of the flowing material are approximated by circular segments defined by their radii. The equation of motion in the stream-wise direction and the continuity equation are integrated over the cross-section of the flow. These equations and the geometrical relation between the flow height and the flow width, due to the circular segment approximation, provide three equations for the three unknown: the average flow velocity, the maximum flow height, and the flow width, as functions of time and position. The partial differential equations are solved by a finite difference scheme, with second order central differences in the stream-wise direction and by a fourth order Runge-Kutta procedure with respect to time. The finite difference scheme is Eulerian, requiring a special procedure to make the avalanche progress along the path. Initially the snow is assumed to fill a finite number of volume elements and is at rest. The volume of material passing through the front section fills the downstream volume element ahead of the front. When the accumulated volume exceeds the current value of the volume of that element, partly determined by the current flow height at the front, it is assumed that the avalanche front has advanced one subsegment. A similar procedure is applied to the tail of the avalanche.

In the applied simulation procedure, a new procedure for displacing the centre line is implemented. A differential equation for acceleration perpendicular to the initial path is introduced, giving the displacement a certain inertia. The displacement differential equation is solved for the *centrifugal angle* θ with a second order Runge-Kutta procedure. The following procedure is used for the displacement of the centre line:

1. The velocities of the first run are basis for the initial displacements, but the simulation uses the initial centre line throughout the simulation.
2. The next simulation runs with a centre line that is displaced according to the centrifugal effects of the previous run.
3. The θ values of the two runs are compared.
4. This procedure is repeated until the computed displacement of two subsequent runs are satisfactorily similar.

This improved handling of the centrifugal displacement procedure results in realistic run-up heights, and allows effects of rapidly changing curvature radius to be taken into account.

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