CALCULATION OF SNOWDRIFT AROUND ROADSIDE SAFETY BARRIERS

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ABSTRACT: Snow accumulations and low visibility due to snow drifting is often a reason for temporary or seasonal closing of mountain highways. Safety devices like roadside safety barriers and snow fences, in addition to roadside snow build up, can increase these problems. This paper presents numerical simulations of snow drift over a road, with and without safety barriers on the roadside. The results from the simulations indicates that the numerical snow drift model can be used to improve the design and placement of safety barriers and to evaluate road design. The numerical snow drift model was calibrated against field measurements by Masao Takeuchi. Some details from the numerical modeling are also given.

KEYWORDS: snow, snow drifting, snow engineering

1. INTRODUCTION

In this paper we demonstrate the feasibility of using Computational Fluid Dynamics (CFD) for certain snow drift calculations. A 2.5 dimensional CAD model, figs. 2-4 is subjected to a two dimensional CFD calculation, utilising the commercial solver FLOW-3D. Application of the snow drift model makes it possible to examine visibility issues which otherwise would require a complex experimental set up, on the computer screen.

Roadside safety barriers in snow drifting areas do often act as hinder for the airflow over the road which reduces the snow carrier capability of the airflow. As a result, snow drifts will be formed on, and close to the road. Increased snow accumulations will together with increased vorticity activity lead to reduced visibility. In northern Norway there have been some experiments with different types of barriers. One which consists of wires, have shown good capabilities regarding wind and snowdrift, but unfortunately it is often destroyed by snow removing equipment. Our aim is to provide a tool, which makes it possible to simulate the effect of different road geometry, various designs and placement of conventional safety barriers, on wind and snow drift.

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2. NUMERICAL METHOD

We have used the commercially available CFD package FLOW-3D from Flow-Science Ltd. (FLOW-3D,1987), which we have customized with special numerical models for the snow drift. Airflow calculations are performed by numerical integration of the Navier-Stokes equation together with the evaluation of turbulence by a common k-e model. FLOW-3D is based on a finite-volume technique and the SOLA algorithm for solving the flow field (Hirt, 1975). Snow drift simulations are obtained by performing the following procedure for each time-step:

1. Calculation of the airflow (FLOW-3D).

2. Evaluation of snow transport based on the airflow.

3. Evaluation of the quantity of formation and erosion on the snow surface.

2.1 *Snow transport*

Wind generated snow transport is commonly divided into the three transport modes: creep, saltation and suspension (Tabler, 1994; Pomeroy and Gray, 1995). Creep and saltation near the snow surface is modeled by an empirical approach, since there is no rigorous continuum theory for this kind of multiphase flow. Also, in this work the amount of transport by creep is assumed to be small and included in the

saltation process. Above the saltation layer smaller particles are transported in suspension. The mean velocity for suspended snow particles is estimated to be close to the mean carrier wind speed. Consequently suspension of the snow fraction f is governed by a general diffusion equation (FLOW-3D,1987; Uematsu et.al.,1991; Sundsbø,1998b)

$$\frac{\partial f}{\partial t} + \frac{\partial}{\partial x}(fu) + \frac{\partial}{\partial z}(fw) =$$

$$\frac{\partial}{\partial x}(c_t v_t \frac{\partial f}{\partial x}) + \frac{\partial}{\partial z}(c_t v_t \frac{\partial f}{\partial z}) - \frac{\partial}{\partial z}(fw_{sus}) \quad (1)$$

where w_{sus} is a variable fall velocity of suspended particles; v_t is the turbulent viscosity and c_t is a diffusion constant. There are various empirical equations for transport rates of saltating or suspended snow which are based and developed from steady state conditions (Pomeroy and Gray, 1995). In most snow drift problems there are disturbances and developments and the drift profiles can seldom be considered to be in a steady state or saturated stage. The numerical snow drift model which is used in this work is able to simulate the development from zero drift to saturated conditions.

Transport by suspension is modeled so that suspension approaches asymptotically

a saturated transport rate given by:

$$q_{sup\,ension} = \frac{u(10)^{4.13}}{853119} \quad (2)$$

where $u(10)$ is the air velocity at the height of 10m (Tabler et al.,1990). Eq. 2 is a modified some to fit calibration data. Transport by saltation is analogue with suspension modeled to approach asymptotically a saturated saltation transport rate given by Pomeroy and Gray (1990):

$$q_{saltation} = \frac{0.68 \rho u_{*_t}}{u_* g}(u_*^2 - u_{*_t}^2) \quad (3)$$

2.2 *Calibration of the snow drift model*

The snow drift model which includes both transport by saltation and by suspension was calibrated against measurements by Masao Takeuchi, fig. 1. Takeuchi (1980) measured the development in horizontal distribution of drift-snow transport from a boundary from which there were no drifting snow to saturation. In this experiment the friction velocity was 0.44 m/s and the threshold friction velocity was 0.29 m/s. The total saturated transport rate was 20 g/ms, which in our model is divided into 6 g/ms drift by saltation and 14 g/ms by suspension, given by eq. 3 and eq. 2 respectively. Details from the numerical model is found in Sundsbø (1998b)
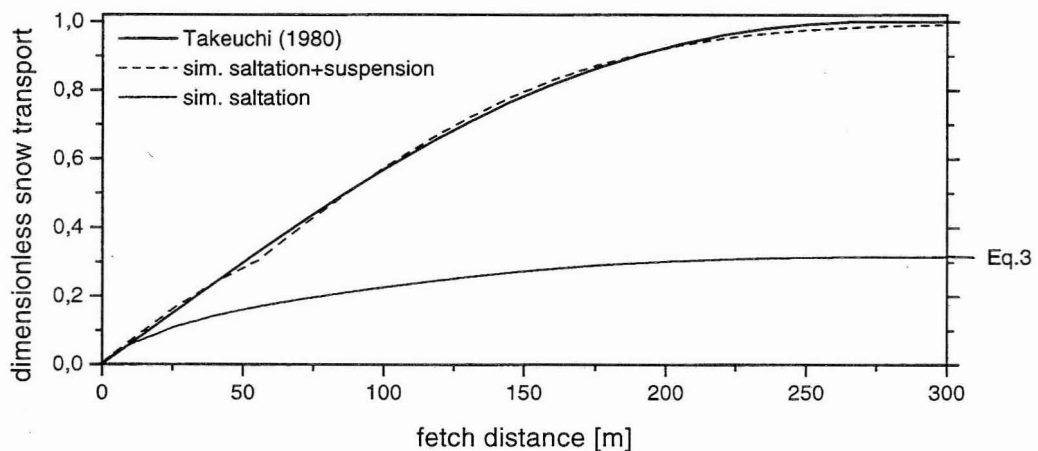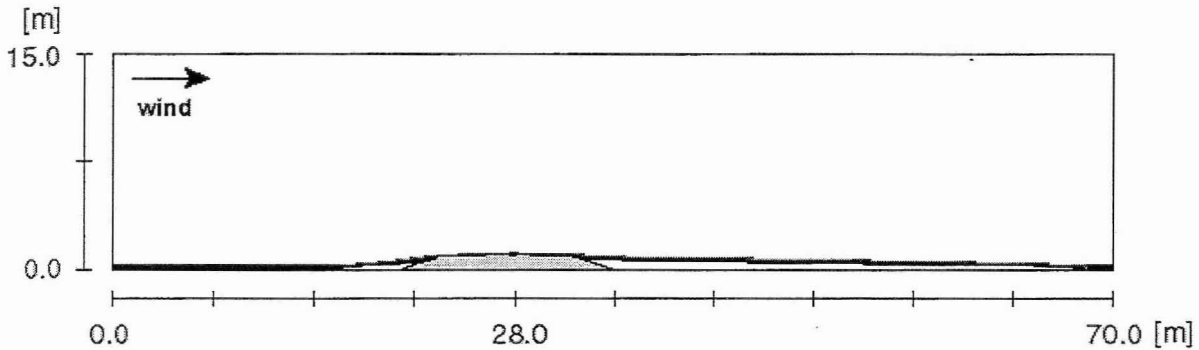

Figure 1. Numerical simulation of the development in horizontal snow transport rate from a zero drift boundary to saturated conditions are reached.

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FLOW-3D ®      t-200.0  y-5.000E-01  (ix-2 to 161  kz-2 to 31)
00:20:44  22-SEP-98 qopk        hydr3d:    version  7.0.1      hp  1996
Road-sim
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Figure 2. Numerical simulation of snow drift around a road cross section
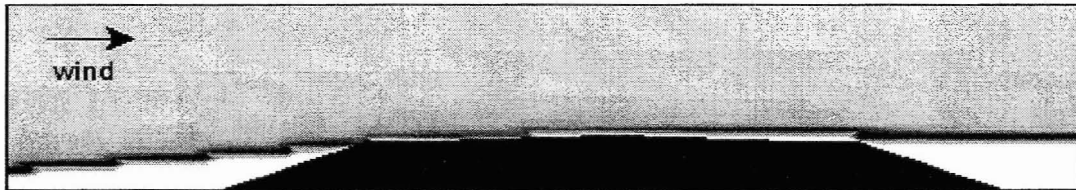with side gradients at 1:2, showing accumulation surface near the road.

Figure 3. Detail from numerical simulation of snow drift with the setup from fig.2. Snow accumulations
around the road is shown as a white region and drifting snow on the surface is shown as a dark "fog".
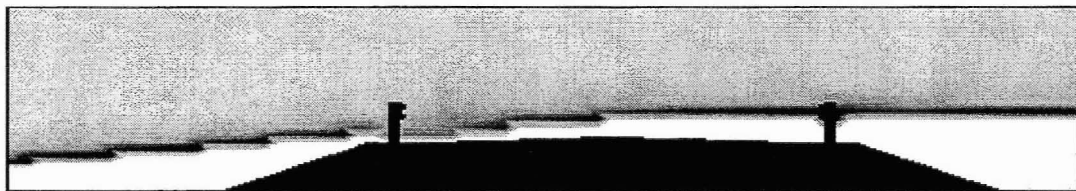

Figure 4 . Same simulation as in fig.3. showing the effect of roadside safety barriers on snow drift.

2.3 *Boundary and initial conditions*

Inlet air velocities are given by the specified logarithmic velocity profile:

$$u(z) = \frac{u_*}{\kappa}\ln(\frac{z}{z_0}) \wedge z_0 = 0.12\frac{u_*^2}{2g} \quad (4)$$

Where the surface roughness length z_0 is given for snow covered grain fields (Pomeroy and Gray, 1990). This velocity profile is also used as an initial condition to the flow field.

Takeuchi's saturated snow drift profile given by the sum of eq. 2 and eq. 3 is used as inlet snow transport conditions. It is also assumed that the snow surface is a complete and erodable except for the road cross section which is initially free from snow. The friction velocity on the snow surface boundary is calculated from eq. 4. Other boundary and initial conditions is found in Sundsbø (1998b).

3. NUMERICAL SIMULATIONS

Figure 2-4 shows numerical simulations of snow drift around a road cross section which has a road width of 7.5 m, a height of 1.5 m and side gradients equal to 1:2. The cross section is placed in a flat terrain and inlet friction velocity, threshold friction velocity and inlet snow drift profile was set according to the described calibration setup from Takeuchi's measurements. Numerical simulations was performed with and without 0.9 m high safety barriers on the roadside.

The simulation with no barriers (fig.2-3) showed as expected, minimal snow accumulation on the road. The simulation with safety barriers on the roadside showed larger snow deposits (fig.4) on and around the cross section.

4. CONCLUDING REMARKS

It has been demonstrated by numerical simulations how roadside safety barriers can lead to larger snow deposits on, and close to the road section. Thus, computational fluid dynamics can be a efficient tool in investigating different road and safety barrier designs. Future work should extend snow drift simulations to also include visibility analyses. However, numerical methods for simulating snow drifts based on the friction velocity are limited to relatively flat terrain and simple geometry.

More about numerical modeling and simulation of snow drift can be found in Uematsu et al. (1991); Sundsbø (1997); Gauer (1998); Liston and Sturm (1998); Naaim et al. (1998).

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NOMENCLATURE

Roman letters

c_t	diffusion constant
f	snow phase volume fraction
g	gravity
q	snow transport rate [kg/ms]
t	time
u, w	velocities
u_*	friction velocity, $= (\tau_0/\rho)^{1/2}$
u_{*t}	threshold friction velocity
w_{sus}	terminal velocity for suspension
x, z	coordinates
z_0	roughness height

Greek letters

κ	von Kármáns constant (~ 0.4)
ρ	air density
ν_t	turbulent kinematic viscosity