APPLICABILITY OF CFD PREDICTION TO THREE-DIMENSIONAL SNOWDRIFT AROUND A CUBIC BUILDING MODEL
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Abstract

This paper presents the results of CFD prediction of snowdrift around a cubic building model, in which a new snowdrift model developed by the present authors is examined. Numerical results using this new model are compared with results obtained by the previous model and field measurements. It is confirmed that the predicted snowdrift patterns, i.e., erosion around the upwind corners and deposition in front of and behind the model obtained from the new CFD method, correspond well with those of the field measurements.

Key words: CFD, Snowdrift, Turbulent flow

1. INTRODUCTION

Snowdrift formation around buildings is a major problem in snowy regions. Wind and water tunnels using modeled snow particles have often been used to predict it. However, these apparatuses are not easily adaptable to snowdrift and have limitations with regard to similarity law. Therefore, CFD (Computational Fluid Dynamics) methods have been investigated as design tools for snowdrift around buildings in snowy regions.

This paper presents the results of CFD prediction of snowdrift around a cubic building model using a new snowdrift model based on experimental and numerical studies by the authors. This model includes the effect of buoyancy due to local difference in drifting snow densities and turbulence dissipation due to snow particles. The numerical results are compared with data obtained from detailed field measurements taken to validate the accuracy of the snowdrift modeling.

2. OUTLINES OF COMPUTATIONS

2.1. Flowfield Analyzed

Snowdrift around a surface mounted cubic model employed in detailed field measurements carried out by Oikawa et al. (1999) in Sapporo, Hokkaido was adopted as the analyzed flowfield. The model was 1.0 [m] high, which corresponds to the actual size of the cube used in the field measurement.

2.2. Outline of snowdrift model

The governing equations of the new snowdrift model proposed in this study are shown in Table 1. The modified k-ε model proposed by Durbin (1996) is used as the turbulence model. The underlined terms are added to take into account the effects of snow on the flowfield. The underlined terms with ‘A’ and ‘B’ express the buoyancy effects of local difference in drifting snow densities and the effects of snow particles on the turbulence property, respectively.

Here, CS3=0.25, CS4=1.6

Snowfall velocity \( \langle \Phi_p \rangle \) [m/s] is defined as the value on the snow surface (except when wind velocity equals zero). Therefore, \( \langle \Phi_p \rangle \) corresponds to snow deposition flux on the surface. Here, \( \langle \Phi_p \rangle \) is the drift density at the first grid adjacent to the snow surface in the CFD calculation selected as the CV. Subscript \( p \) means a CV value. The deposition rate \( M_{dep} \) [kg/s] on the horizontal surface of the CV is given by:

\[
\frac{\partial \langle \Phi \rangle}{\partial t} + \frac{\partial \langle \Phi \rangle}{\partial x_j} = \frac{\partial}{\partial x_j} \left( -u_j \langle \Phi \rangle \right) + \frac{\partial}{\partial x_j} \left( -u_j \langle \Phi \rangle \right) - \left( \langle \Phi \rangle \right) \frac{\partial}{\partial x_j} \left[ -\langle u_j \rangle \langle \Phi \rangle \right]
\]
where, $\Delta x \Delta y \ [m^2]$ is the horizontal area of the CV.

The erosion rate $M_{ero} \ [kg/s]$ due to the shear stress on the horizontal surface of the CV is given by:

\[
M_{ero} = \rho_f \frac{\Delta x \Delta y}{\sigma_x} \left( \frac{d}{d \xi} \left( \frac{\partial (\bar{u}_x \bar{u}_x)}{\partial \xi} \right) + \frac{\partial}{\partial \eta} \left( \frac{\partial (\bar{u}_x \bar{u}_x)}{\partial \eta} \right) \right)
\]

(19)

where, $\rho_f$ is the density of fluid.

The net deposition rate $M_{total} \ [kg/s]$ on the horizontal surface of the CV is given by:

\[
M_{total} = M_{dep} + M_{ero}
\]

(20)

where, $M_{dep}$ is the net deposition rate due to the shear stress on the horizontal surface of the CV.

Variation of snow depth per unit time $\Delta z \ [m/s]$ is obtained from $M_{total}$ divided by accumulated snow density $\rho_s \ [kg/m^3]$ and $\Delta x \Delta y$.

\[
\Delta z = \frac{M_{total}}{\rho_s \Delta x \Delta y}
\]

(21)

In addition, when erosion occurs ($u^*_x > u^*_x$), the surface boundary condition for the transport equation of $<\Phi>$ is given by:

\[
\frac{-v_x (\bar{u}_x \bar{u}_x)}{\sigma_x} \left( \frac{d}{d \xi} \left( \frac{\partial (\bar{u}_x \bar{u}_x)}{\partial \xi} \right) + \frac{\partial}{\partial \eta} \left( \frac{\partial (\bar{u}_x \bar{u}_x)}{\partial \eta} \right) \right) = \frac{M_{ero}}{\Delta x \Delta y}
\]

(22)

### 2.3. Computational cases

The computational cases conducted here are summarized in Table 2. The drift density $<\Phi>$ at the inflow boundary and the threshold friction velocity are changed as parameters. The profile of drift density $<\Phi>$ at inflow for Case-3 is illustrated in Fig. 1. It should be noted that the inflow density of drifting snow should be set as constant with height as long as the influence of saltation is not considered in the transport equation of $<\Phi>$, as was done in the previous study (Tominaga et al., 2006). The parameters relating to the physical properties of snow are given by the preliminary study for boundary layer flow by the authors (Okaze et al., 2008) as shown in Table 3.
Accumulated snow density $\rho_S$ is set to correspond to the value observed in the field measurement (Oikawa et al., 1999).

Firstly, the steady flowfield was calculated without drifting snow, and then the unsteady computation was conducted considering drifting snow.

### Table 2: Computational cases

<table>
<thead>
<tr>
<th></th>
<th>(&lt;\Phi&gt;) at inflow boundary [kg/m³]</th>
<th>Threshold friction velocity (&lt;u^*&gt;) [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1</td>
<td>0.05</td>
<td>0.21</td>
</tr>
<tr>
<td>Case-2</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>Case-3</td>
<td>cf. Fig.1 (0.05 at upper boundary)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

![Fig. 1 Inflow profiles of the drift density (Case-3)](image)

### Table 3: Parameters relating to physical properties of snow

<table>
<thead>
<tr>
<th></th>
<th>Snowfall velocity (&lt;w_f&gt;) [m/s]</th>
<th>Accumulated snow density (\rho_s) [kg/m³]</th>
<th>Diameter of snow particle (D_s) [m]</th>
<th>Height at snow surface (z_s) [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
<td>150</td>
<td>1.5x10^{-4}</td>
<td>3.0x10^{-5}</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

3.1. Influence of boundary condition on snow depth

The horizontal distributions of snow depth at $t^*=100$ for all cases using the new snowdrift model are shown in Fig. 2. Here, $t^*$ is non-dimensional time defined by $H$ and $<u^*>$. The deep-colored part in the figure indicates large snow coverage. The snow depths are normalized by the value at the reference point. Only for Case-2, the ideal snow depth, obtained by the boundary condition $<w_f><\Phi>\rho_s$, is made dimensionless because no snow accumulation occurs far from the building. In Case-1 (Fig. 2(1)), there are small undulations of snow over the whole domain, although small erosion regions are formed near the upwind corners of the building. This is because excess shear stress occurs only at the separation regions around the building due to the large threshold friction velocity in this case (cf. Table 2). However, in Case-2, the snow is eroded over a wide region, except for the area in front of and behind the building, due to the small $<u^*>$ value. Where $<u^*>$ at inflow is smaller than $<u^*>$, the vertical profile of $<\Phi>$ at inflow can be set as constant with height because saltation does not occur. However, where $<u^*>$ at inflow is larger than $<u^*>$, such as for Case-2, the large value of $<\Phi>$ due to saltation near the snow surface at inflow must be considered. For this reason, Case-2 underestimates the snow deposition over the whole domain due to this underestimation of incoming drift density.

In Case 3, which has large drift density near snow surface at inflow due to saltation (cf. Fig. 1), the depositions in front of the building and outside the separation regions become large. As a result, two large erosion regions are clearly observed near the upwind corners of the building.

![Fig. 2 Horizontal distribution of normalized snow depth](image)
3.2. Comparison of snow depth distribution with field measurement results

Fig. 3 compares the snow depth distributions obtained from the previous CFD model (Tominaga et al., 2008) and the present model with those obtained from the field measurement. Snow depth is normalized by the value at the reference point, which was not affected by the building. The erosion regions near the upwind corners of the building in the present CFD result are much larger than the previous results. Furthermore, the large peaks of snow accumulation outside the separation regions near the building, which were observed in the previous model, are not seen in the field measurement. This over-prediction of snow deposition is mainly caused by the fact that the Pomeroy’s model overestimates the transport rate in a non-equilibrium saltation layer such as flow around a building. The result of the snowdrift patterns, i.e., erosion around the upwind corners and deposition in front of and behind the building, obtained by the present CFD shows good correspondence with the field measurements. Fig. 4 compares the horizontal distributions along a lateral line crossing the building. The results of the previous CFD have too large peaks around the building, which are not observed in the present CFD results and the field measurement.

![Fig. 3 Comparison of horizontal distribution of normalized snow depth](image)

![Fig. 4 Comparison between normalized snow depths obtained from CFD and field measurements along lateral line (x/H=0.1)](image)

4. CONCLUSIONS

The accuracy of the CFD method for predicting snowdrift around a cubic building model using the new snowdrift model proposed by the authors was examined by comparing its results with those from the previous CFD model and field measurements. The snowdrift patterns, i.e., erosion around the upwind corners and deposition in front of and behind the building obtained by the present CFD shows better correspondence with those obtained from the field measurement and the wind tunnel experiment than the previous CFD results.

References