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CFD Simulation of Snow Fences

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Abstract: Snow fences play a significant role in transporting snow away from roads, buildings and recreational areas. Although some guidelines for fence design exist these are mostly empirical in nature and are potentially difficult to apply in complex terrain and for multiple fences scenarios. Numerical modelling of the wind flow and snow transportation using Computational Fluid Dynamics (CFD) has the potential to allow site-specific topographies to be considered with multiple fence designs for optimisation. Manipulation of the snowfield to emulate climate change effects in New Zealand for a long term ecology monitoring project involved two angled porous fences set up with no knowledge of the interactions of the fences with each other or the topography. Due to site remoteness there is no opportunity to monitor the fence design effectiveness in the field. Numerous factors contribute to a successful fence design for this situation such as porosity, slat arrangement and angle to flow. Previous work studied varying fence porosity with a wind flow perpendicular to the fence. It was found that porosity is an important parameter of fence design and that slat arrangement may have some effect that needed to be quantified. This work extends the initial simulations and examines the effect the angle and orientation of the snow fence to the incoming wind has with different fence porosities and slat arrangements. The angling of snow fences is found to have the potential to allow manipulation of snow accumulation patterns although the relationship between fence design and positioning is complex. Numerical modelling has been shown to be effective as a tool for exploring fence design possibilities. It is recommended that simulations are undertaken in the design and planning stages for new fences to ascertain a more optimum combination of fence design and positioning for the prevalent wind direction.

Keywords: Snow fences; Computational Fluid Dynamics; multiphase flow; fence porosity.

1 INTRODUCTION

Environmental fluid modelling is an established tool for understanding the mechanisms of wind flow in other situations such sediment transportation over dune systems ([Pattanapol, W. et al., 2007; Wakes, S.J. et al., 2010b]. Such numerical modelling allows for multiple situations to be modelled, results to be obtained across the entire domain and easy comparisons to be made (Bezerra, C. et al., 2005; Wakes, S.J. et al., 2010a; Wakes, S.J. et al., 2010b). It is recognised that simulations are often an idealised version of reality but allow changes in parameters to be quantified in a controlled situation. Environmental fluid dynamics modelling is a useful tool for fence design comparisons with some basic parameters for the simulations established in previous work (Wakes, S., 2014). Modelling can aid in final design and placement of a snow fence through the understanding of the impact fence parameters have on snow accumulation.

Barriers are used generally to control the deposition of snow around buildings, roads and other infrastructure in countries and for storage of water such as Norway, Canada and Russia. There are empirical guidelines to aid with the design of these depending on whether the barrier is a fence, tree line or hedge (Tabler, R.D., 1968; Tabler, R.D., 1986). It is common to design such barriers using existing knowledge and standard guidelines with little ability for adaptation to local topography and prevalent wind direction. Less common is to use a barrier to deliberately deposit or clear snow from a specific area. In New Zealand snow fences have been used to simulate climate change effects on flora (Smith, B. et al., 1995). These snow barriers are usually placed in challenging environments and any monitoring of their effectiveness becomes very difficult. Terrain is also variable and usually little is know about the variability of wind direction and strength. As these fences can be in place for years it
is important to optimise their design and positioning as much as possible. It is crucial to understand the purpose of the fence in order to get a more optimum combination of design and placement.

Work has been done on understanding the relationship between barrier design and effectiveness in idealised experimental conditions (Anno, Y., 1984; Anno, Y. et al., 1981). Although this has led to some important conclusions these studies are often limited by scale and duration. Previous work undertook numerical modelling of snow fences using Environmental Fluid Mechanics. This work determined important modelling parameters such as the effect of the turbulence model used. The porosity of the fence to the wind was also found to influence the effectiveness of a snow barrier (Wakes, S., 2014). This work was limited to fences perpendicular to the incident wind direction over a flat surface and demonstrated the viability of using such a tool in fence design. It was recognised that there were many aspects of fence design that should be explored to build a more complete picture of the mechanisms involved such as angle and orientation of fence (fence positioning) as well as porosity, slat arrangement and dimensions (fence design). To progress the understanding of fence design the interaction between the orientation of the fence to incident wind direction and parameters such as porosity and arrangement of fence slats will be explored.

2 METHODOLOGY

Computational Fluid Dynamics (CFD) software, ANSYS Fluent, was used for the simulations. The method follows closely that in Wakes (2014) with the two-equation Realisable k-ε turbulence model used and the standard law-of-the-wall used at solid surfaces. The simulations were modelled as steady state with fine grid resolution. It was recognised that this may result in lower predictions of snow accumulation but as this was a comparative study it was not considered a significant issue. The Euler-Euler (mixture) model was used to model the two-phase snow-air transportation with a spherical particle of density 350kg/m and a diameter of 100µm. The sides and top of the domain has symmetry boundary conditions with the far end as a pressure outlet. The left boundary denotes the centreline of the two fence situation. Wall boundaries (floor and fence) had a roughness height of 10⁻⁴m. The wind velocity profile followed a power law. The snow mass inlet is 20% snow volume fraction (1400 kgs⁻¹) and 80% air volume fraction (20kgs⁻¹) (Wakes, S., 2014).

The computational domain was 15m high, 105.5m long, 20m wide with the fence at 0° (perpendicular to the incident wind) 25m from the inlet and 2.5m from the left face of the domain. The fence was 2m high, 10m wide and 0.1m in depth. Three fence porosities were simulated (0% (solid), 25% and 50%) with a 50% porous fence having three different slat arrangements, Table 1. The 25% and 50b% fences have comparable slat depths while the 25%, 50a% and 50c% fences have the same slat spacing. The fence was rotated about the left edge of the fence either in a clockwise (towards the inlet) or anti-clockwise (away from the inlet) direction (denoted C or A respectively) and the fence angle rotated in 15° intervals up to 45°, Figure 1.

<table>
<thead>
<tr>
<th>Fence porosity</th>
<th>Slat arrangement</th>
<th>Slat depth</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>Solid no slats</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25%</td>
<td>3 slats</td>
<td>0.5m</td>
<td>0.25m</td>
</tr>
<tr>
<td>50% a</td>
<td>4 slats no slat at the bottom of fence</td>
<td>0.25m</td>
<td>0.25m</td>
</tr>
<tr>
<td>50% b</td>
<td>2 slats</td>
<td>0.5m</td>
<td>1m</td>
</tr>
<tr>
<td>50% c</td>
<td>5 slats</td>
<td>0.2m</td>
<td>0.25m</td>
</tr>
</tbody>
</table>

Table 1. Fence configurations for simulation cases.
3 RESULTS AND DISCUSSION
3.1 Orientation of Angle

Overall patterns of snow distribution are similar for fences at the same angle to the incident wind flow but orientated in different directions, Figure 2. The 25% porous fence shows only a small difference between the two orientations with the anticlockwise rotated fence showing marginally more snow volume fraction before the fence. For the 50b% case, the snow volume fraction decreases from the 25% case and there is a more marked difference between fence orientations. The clockwise orientated fence has a greater snow volume fraction. The centre of the clockwise rotated fence is slightly closer to the inlet than the anticlockwise rotated fence and therefore the snow has marginally less far to travel. The wind/snow is steered to the left by the fence and this side has the symmetry boundary closer. This could squeeze the flow and cause slowing near the fence along the front of the fence resulting in more snow deposition. The two fences at 15°C follow a similar pattern with less snow volume fraction for the 50b% case than the 25% fence at the same angle and orientation. For the 15°A orientation, an increase in fence porosity means a decrease in snow volume fraction and less of a distinct peak at the fence.
3.2 Angle of Fence

Figure 3. Snow volume fraction contours between 0.33 and 0.66 and streamlines overlaid to show wind flow pattern for 25% porous fence (a) 0°, (b) 15°, (c) 30° and (d) 45°. Wind flow left to right.

Figure 3 show the angle of orientation of the fence to the wind direction influencing the distribution of snow volume fraction around the fence. As the angle of orientation to the wind flow increases from perpendicular the snow distribution is more concentrated around the fence and there is less snow at the front of the fence. The wind is more likely to blow the snow along the fence at an angle and around the high end furthest away from the inlet (left for clockwise fences, right for anticlockwise fences). As the angle of orientation increases the fence acts as a steering mechanism for the wind flow. The recirculation in the vicinity of the fence also decreases and there is more of a difference in depth of snow before and after the fence. As the angle increases both the height and extent of the snow volume fraction before and after the fence decreases. By a 45° angle snow is concentrated around the centre before the fence and after the fence at the right end. For the left side of the fence there is very little snow distribution that decreases at higher fence angles. The wind flow is higher around the left side of the fence as the symmetry boundary is closer and therefore creates a narrower opening causing a higher wind velocity and therefore less snow volume fraction. The gap between the slats acts to speed the flow up and divert the flow from the horizontal. The vortex structure behind the
fence is complex for lower angles to the incident wind flow direction. It drives the flow down, which concentrates the snow behind the fence rather than dispersing it across the wider domain, Figure 3.

The peak of snow at the fence spreads out and becomes less distinct as the fence rotates, Figure 4. The 0° fence shows a second smaller peak after the fence which becomes less prominent as the fence becomes angled to the wind. There is more snow accumulated at a greater depth and extent at the fence at the lower angles to the incident wind. The fence centre moves away from the inlet as the angle increases. The distribution of snow becomes less prominent and concentrated at steeper angles of the fence to the wind flow.

The 0° fence shows a second smaller peak after the fence which becomes less prominent as the fence becomes angled to the wind. There is more snow accumulated at a greater depth and extent at the fence at the lower angles to the incident wind. The fence centre moves away from the inlet as the angle increases. The distribution of snow becomes less prominent and concentrated at steeper angles of the fence to the wind flow.

![Figure 4](image-url)  
*Figure 4*. Snow volume fraction with distance along domain for 25% porous fence with changing angle to incident wind direction along a line at a height 0.1m above the surface.

### 3.3 Fence Porosity and Slat Arrangement

Fence porosity and slat depth and spacing has a significant effect on snow volume fraction, Figure 5. For example there is only significant snow at the centre of the fence when slats are introduced to make the fence porous. The wind carries the snow through the slats in the fence, which is then slowed due to the recirculation behind the slats. The snow is then more likely to deposit in the slower wind flow. Along the length of the fence the peak of snow accumulation is for the 25% porous fence although the solid (0%) fence has significant accumulation at each end. In the perpendicular incident wind case the 25% and 50% porous fences had similar snow patterns (Wakes, 2014). When the fences were angled the 50% fence cases showed more of a different snow distribution pattern from the 25% fence cases.

The solid (0%) and 50a% fences have with little or no snow around the fence. The solid fence represents a large barrier to the flow and the snow therefore is slowed around the fence and the snow is distributed evenly but at small volume fractions. With no slat at the base of the fence for case 50a% the wind flow is faster and there is virtually no snow distribution around the fence. The 25% and 50b% and 50c% fences display a similar shape along the centreline of the fence although the values of snow volume fraction are different, Figure 6.

The slat spacing can be compared with the 25% and 50b% cases having the same slat depth but different slat spacing, Figures 5 (b) and (d). The larger slat spacing for the 50b% fence appears to allow a faster flow through the fence resulting in a weaker recirculation and less drop off of wind speed behind the fence. This fence therefore accumulates less snow. The slat depth dictates the
recirculation vortex size and the slat spacing has a secondary effect in moderating the strength of the recirculation zone and its length. For snow accumulation around the fence it appears that a smaller number of larger sized slats is preferable.

The 50% porous fence cases explore the effect of slat arrangement and size on snow accumulation, Figures 5(c), (d) and (e). With no slat at the bottom of the fence, case 50a% behaves very differently to the other two slat arrangement cases. The recirculation of the wind is initiated behind the slats
because of the wind flowing through the gaps. For fences with slats at the base of the fence this recirculation creates a region of slow moving air that encourages snow deposition. With no slat at the base of the fence the wind flows unimpeded near the surface and prevents any snow accumulation. For case 50b% there is recirculation both in the vertical and horizontal direction. The larger slat depth for this case slows the flow more compared to case 50c%. This results in a higher snow volume fraction with a larger extent in the domain around the fence.

For case 50b% there is recirculation both in the vertical and horizontal direction. The larger slat depth for this case slows the flow more compared to case 50c%. This results in a higher snow volume fraction with a larger extent in the domain around the fence.

![Figure 6. Snow volume fraction through centre of fence along domain length at a line 0.1m height from surface.](image)

4 DISCUSSION

These results indicate that there are a number of factors to consider when designing a snow fence. Patterns of snow accumulation (or not) change with angle of fence, orientation, slat number and arrangement. As with any design the purpose of the fence first needs to be established to ensure appropriate application of these guidelines.

A slat at the base of the fence appears essential for the fence to have an effect. In undulating local topography this may not be easy to achieve and could sabotage the purpose of the fence by creating a venturi effect that could move snow away from the fence. A higher slat depth appears to have an effect with greater accumulation of snow before the fence and less after due to the size and shape of the recirculation zones. There is less snow accumulation around the fence when the slat spacing is larger or when the slat depth is smaller. The presence of slats results in accumulation at the centre of the fence as well as at the ends. The simulations demonstrate a complex flow with recirculation vertically and horizontally in the lee of the fence. The slat arrangement and size controls the recirculation patterns which in turn dictates the snow distribution.

The angle of fence to the wind facilitates movement of snow away from the fence. As the angle increases less snow accumulates in front of fence and more around the ends of the fence. The steeper the angle of the fence potentially the more obvious the manipulation of the snow could be. A pair of fences is useful if angled inward to the centre to funnel snow away from centre. Outward angled fences are useful to funnel snow into the centre between the fences. There appears to be little interaction between fences at the distance apart they have been modelled but this is an area for further investigation. Although the placement of a snow fence could be optimised to a prevalent wind
direction there will be a range of wind directions and strengths occurring over potentially long periods of time that the fence is in place. Information about prevalent wind directions is needed to ensure that the placement of the fence does what is required. For snow accumulation ideally the fence should be perpendicular to the wind flow for as much of the time as possible although the work has shown there is some flexibility in this requirement. When a fence is at an angle to the flow of certainly less than 30° there is also snow accumulation. If the goal is to manipulate the snow elsewhere then angled fences to the wind may be more appropriate. Ideally a fence of 25% porosity is better for greater amounts of snow accumulation when the fence is likely to be angled at least some of the time.

5 CONCLUSIONS

The numerical simulation of snow fences at angles to the incident wind direction has highlighted the complexity of the choices to be made. It can be concluded that angling the fence could enable snow to be diverted to or away from an area of interest. Also that there is an interaction between fence position (angle and orientation) and fence design (porosity, number of slats, slat depth, spacing distance) and all influence snow distribution. A larger slat depth appears to influence snow accumulation in certain areas around the fence more whilst a greater number of smaller slats results in more snow spread. There are also other aspects that still need modelling such as the distance the two fences are apart and the effect a more realistic topography may have.

REFERENCES