SNOWDRIFT MODELLING IN THE WIND TUNNEL FOR ROADS

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Abstract: *The paper presents an experiment on a simulated snow drift due to wind action upon a segment of road. The study was developed in the Atmospheric Boundary Layer Wind Tunnel SECO2 belonging to the Faculty of Construction and Building Services in Iasi, Romania and was motivated by the increased interest in the security of transport on the existent national roads that will be modernized and the future high-ways that will be designed all over the country and expected to be affected by strong winds and severe snow falls during winter, reason why being taken into account. The physical model studied included the shape of the snow deposit both sides from the road and the efficiency of the protection barriers placed at different distances from the road was analyzed. The model of the segment of the road was scaled to 1/50 and the material used to simulate the snow is obtained from glass balls. The barriers for protection against snow storm accumulations have a porosity of 50%.*

KEYWORDS: SNOW TRANSPORT IN TURBULENT AIR, SNOWFRIFT IN WIND TUNNEL, PHYSICAL EXPERIMENTS IN WIND TUNNELS

1. Introduction

Modelling the redistribution of the snow deposit under wind drift action had become a major problem for the exploitation in normal conditions of the communation roads and transportation in general. The modern technical and economical evolution of the European countries depends in a the most important degree on insuring a constant trading traffic between them, for all over the year and thus, keeping a functional infrastructure is vital in this process.

In most snowy regions, the combination of wind and snowfall often leads to unwanted snow depositions in lees created by obstacles or other places where wind reduces its transport capacity. Snow transport is mainly driven by this interaction between wind, topography and vegetation, but also interaction between moving snow particles, humidity, temperature etc. affects the overall transport. In all cases wind is the primary snow drift parameter.

As knowledge and technical development increased, men became more and more dependent on transportation and an infrastructure which had to be kept open all year long and this is why, this domain is one of the first where snow control was systematically applied. In an early written description G. D. B. Johnson (1852) analyzed the effect and consequences of snow drift around roads and railroads in Norway, by giving a remarkable description of snow drift around fences, buildings, and road cuts. He even studied the effect of snow fences used in combination and his work is probably one of the first written scientific studies within the field of snow engineering.

Physical experiments in wind tunnels, water flumes and in full scale are still used for prediction of snow drifts. Unfortunately, these kinds of experiments are time consuming, expensive and not easily available for the common engineer, so the need for a more commonly available tool for predicting possible snow drift formations is certainly present.

2. Snow Transport in turbulent air conditions

A natural mixture of snow consists of particles of a wide range of sizes. In most situations particle transport is due to the presence of all of the three previously mentioned transport modes (fig. 1):

i) *Creeping* happens at the ground level when particles are agitated by impacting other particles; during creeping the moving particles do not loose contact with the fixed particles at the surface, forming its solid contour. This process does not directly depend on wind speed but on the impact among particles and can therefore be seen as part of the saltation process.

ii) When the shear stress at the ground is high enough, particles can be drawn out from the surface. They take off and follow ballistic trajectories before they bounce back on the ground; this hopping of particles is called *saltation.* When impacting on the ground they can entrain other particles into creeping or saltation, or bounce themselves back up again.

iii) Small and light particles can even reach higher elevations where wind field grains influence on the trajectories. This is referred to as *suspension* or suspended transport. The trajectories are then no longer dominated by gravity, but are dictated by the arbitrariness of the wind speed. The drag forces exerted by the turbulent air flow make them follow paths through the air that are close to random walks. The intermediate state between saltation and suspension is referred to as modified saltation, where the particles show characteristics of both, saltating and suspended transport /10/.

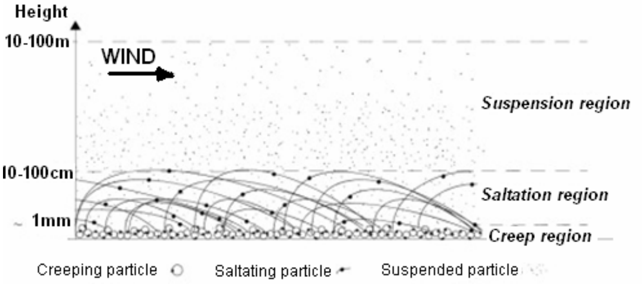


Fig. 1 *Illustration of the transport regions above a horizontal snow surface (Sundsbø, 1997).*

The heights of the different transport regions in the figure above are only meant as guiding values, since the transport processes are very much connected and no sharp borders exist.

A natural mixture of snow consists of particles of a wide range of sizes. In most situations particle transport is due to the presence of all of the three previously mentioned transport modes. The large particles will either become immobile or be transported by creeping on the surface. Intermediate particles will basically remain in the saltation layer while small light particles will go into suspension. The amount of transport in each mode depends on wind speed, snow properties and distribution of particle size and shape.

The heights of the different transport regions in the figure above are only guiding values, since the transport processes are very much connected and no sharp borders exist.

The presence of heavy particles in the air modifies the wind profile. As a matter of fact, particles are accelerated by drag force which means that there is a momentum exchange between wind molecules and the denser ice molecules. Thus wind velocity is reduced when snow particles are present in the air. Higher above the ground, the influence of particle on the wind profile becomes very small, therefore can then be neglected /14/.

This important assumption supports the idea of separating the domain into two layers with different physical proprieties: in the first layer momentum exchange is considered, and in the second layer neglected. We therefore consider a suspension layer above and a saltation layer below a certain height, as show in figure 2.

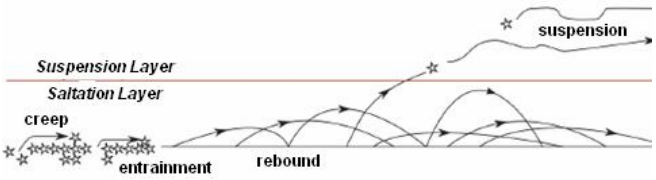


Fig. 2 The transport modes of the snow over a surface considering the two defined layers /10/

Regarding the transport rate we may observe that at moderate wind speeds the major part of the transport occurs in the first few centimetres near the surface. With increasing wind speed, the relative contribution of suspension increases (fig. 3).

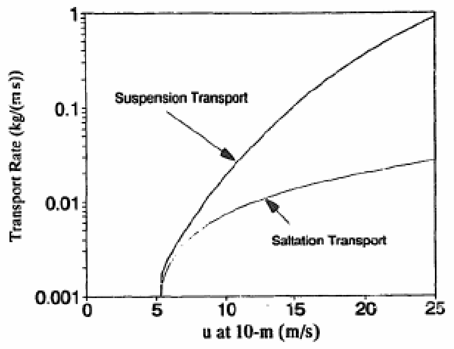


Fig. 3 Transport rate with increasing wind speed

Gauer (1999) mentions a probably more realistic rate of up to 40% depending on the wind speed (table 1).

***Table 1.** Mass transport contribution of the different transport modes /15/*

Transport modes	Rate mass transport
Creeping	5-25%
Saltation	50-75%
Suspension	4-40%

Snow particles in wind transport are usually fragments of the origin snow crystals**.** Snow particles tend to fall into smaller pieces if they are affected by winds during, or soon after snowfall. Drifting particles gradually become smaller and more rounded due to abrasion and evaporation. The different classes of particles will appear with rather mono-dispersed size distribution in the respective transport layers (fig. 4).

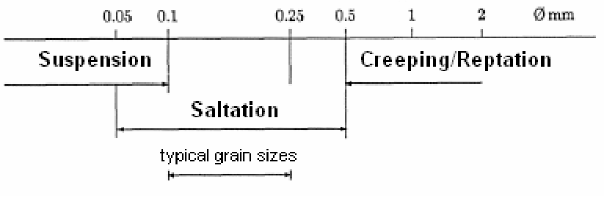


***Fig. 4** Range of typical particle sizes per transport mode/15/*

3. Snowdrift modelling

Wind driven transport of snow particles is taking place in three principal modes: creep, saltation and suspension. Saltation is the dominating mode for the first few meters above a snow surface and the saltation mode needed to be modelled in the wind tunnel.

Complex similarity criteria are not independent from each other and it is basically impossible to satisfy all of them simultaneously.

The main similarity criteria for the snowdrifting modeling are:

i) The ratio between particle drift speed U_f and the threshold friction velocity u_{*t}:

$$\frac{U_f}{u_{*t}} > 1 \qquad (1)$$

ii) The length scales must be similar:

$$\left.\frac{x}{L}\right|_{WT} = \left.\frac{x}{L}\right|_{field} \qquad (2)$$

iii) Furthermore, the increasing roughness length due to the drifting particles and the resulting increased friction loss should be considered, defining a new roughness length:

$$z_0' : \left.\frac{z_0'}{h}\right|_{WT} = \left.\frac{z_0'}{h}\right|_{field} \qquad (3)$$

with *h* denoting the height above the surface.

iv) The analysis of the particle trajectories requires the aerodynamic drag coefficients C_D to be the same in the wind tunnel and in the field /1/:

$$\left.C_D\frac{\rho L}{\rho_P D_p}\right|_{WT} = \left.C_D\frac{\rho L}{\rho_P D_P}\right|_{field} \qquad (4)$$

and

$$\left.\frac{gL^2}{u_*^2 h}\right|_{WT} = \left.\frac{gL^2}{u_*^2 h}\right|_{field} \qquad (5)$$

The index *P* denotes particle related.

Different particle materials were tested based on the theoretical considerations explained above. As expected, the best drift performance for a reasonable range of flow velocities used in the wind tunnel was found for small glass spheres with an outer diameter of 125 µm and all subsequent snow drift experiments were carried out using the glass spheres.

4. Snowdrift experiments in wind tunnel

Both the companies of administration and maintenance of the communication roads and railways and the researchers in this field are very interested in the studies on physical scaled models in Atmospheric Boundary Layer Wind Tunnels because these studies are able to model the phenomenon close to the reality and because the results may be easily compared with the observations at natural scale, on site.

The snow drifted by the strong winds cumulates in those places where the local geographical modifications or the obstacles of any nature are responsible to speeding down the blizzard.

Agglomeration of the snow in these particular areas may increase becoming drifts of huge dimensions; a constant removal with specific equipments from the route, whether it is a highway or a national road, is crucial for a normal exploitation of the lines of communication. Still, during severe winters, snow drifted areas will continue to form in couples of hours on the roads, a real danger for the auto vehicles and a constant source of accidents.

The extension of these occurs and the financial costs and loses of human lives involved are the reason for studying the phenomenon prior to design the road in order to find the places where the snow deposits on the roads and to analyze the influence of the wind action on transportation of the snow. The future shape of the road will use this information in order to avoid specific dangerous zones where the snow drift might become very important.

The study presented herein is part of an experimental program run in the Laboratory of Structural Aerodynamics the Faculty of Constructions and Building Services from Iasi, regarding the snow deposits on the roads and the efficiency of some protection measures /12/.

The wind tunnel SECO 2 has a cross section of 140x140cm and a length of about 10m (fig. 5).

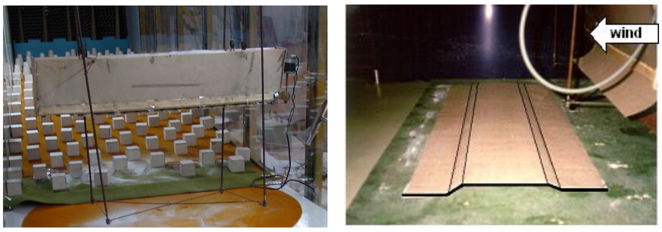
Modelling the snow drifting on communication roads implies a combination of three models: the model of a segment of road, the model of the wind in the atmospheric boundary layer and the model of the drifted snowfall.

Fig. 5 *Wind tunnel SECO 2 in the Laboratory of Structural Aerodynamics of the Faculty of Constructions and Building Services in Iaşi*

The model of the snowfall was performed with the help of a specific device, a bunker containing the glass micro balls, placed in front of the physical model and in wind from the direction of air flow in the tunnel.

The difficulties that the experiment had to surpass were determined by the necessity of reproducing the uniform rate of the snowfall for a representative period of time in parallel with matching an optimum wind speed for the experiments (a smaller or a greater speed than the appropriate may alter the pattern of the snowfall drift: too close to the device or too far, out from the experimental area). A special system of sorting was designed (fig. 6a) from which the glass micro-balls drop; the device has the possibility of moving longitudinally and vertically in the tunnel.

The segment of road was modelled at 1:50 scale, simulating the cross section through the road itself; the filling and the sides of the road may be seen in the image below (fig. 6b), the surrounding terrain being flat ground. The modelled wind speed is 5m/s, equivalent with 8m/s at the prototype scale.



a. ***b.***

Fig. 6 *Experimental conditions in wind tunnel:* ***a. -*** *the device for simulation of the snowfall; b. - model of the profile of the road with 1,00 m height (cross section)*

In the following image (fig.7) different consecutive stages of snowdrift are presented.

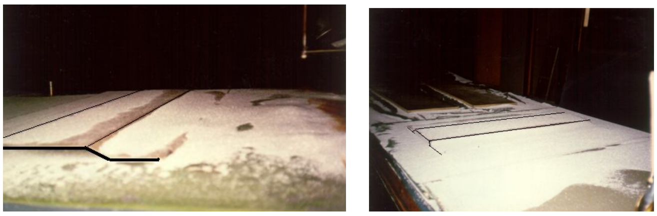


Fig.7 *Consecutive stages of snowdrift on the road*

The platform of the road was covered at the end of the experiment by a uniform layer of snow never exceeding in depth 20cm at natural scale. From the point of view of traffic, this layer might still, cause serious problems.

The thickness of the snow deposit was measured all over the segment of the road and a grid was drawn with computer aids (figure 8).

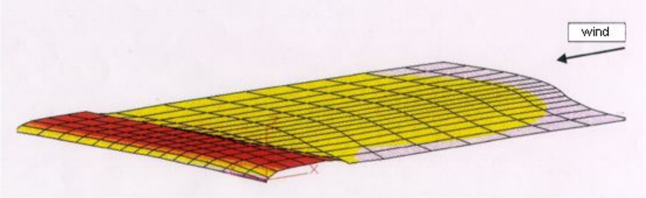


Fig. 8 *Computer aided representation of the snow deposit on the segment of the road*

5. Snow collector fences

A collector snow fence is put upstream in order to collect the incoming drifting snow before it enters the area that needs to be protected.

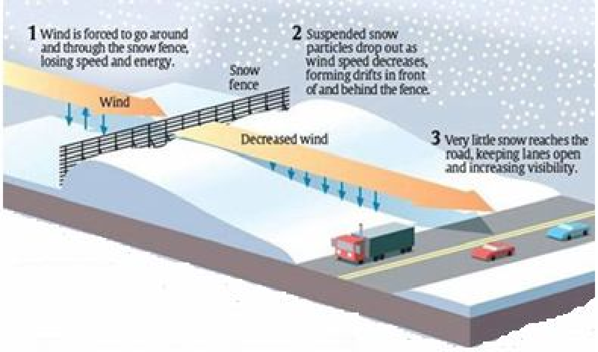


Fig. 9 *Snow fences reduce drifting, increase visibility for drivers /www.gizmodo.fr/*

The major collector mechanism is that the wind velocities are decreased behind the fence, creating drift formations in the leeward the fence (fig.10). The wind speed reduction is a function of fence porosity, orientation and shape of fence and fence openings.

Fig.10 *Drift formations leeward the snow fences*

Fences of equal porosity may have totally different shielding or collector capabilities. In general, smaller openings will result in higher wind resistance at equal porosity or open area fraction. Snow collector fences designed in a way so the wind flow passes through the fence are most effective. For larger resistance fences, the major part of the wind will pass over, rather than through the fence.

The experimental program aimed also to optimize a system of snow fences. The same segment of road was protected with a proposed system of snow fences, the distance from the platform of the road being 20 x h (40 m) from the edge of the platform (fig. 11). This distance was imposed by the necessity to avoid the possibility of snowdrift in the leeward of the snow fence.

The height of the fences is 2,00m and the porosity ratio 50%. A free circulation space of about 10% is designed for the optimization the system.

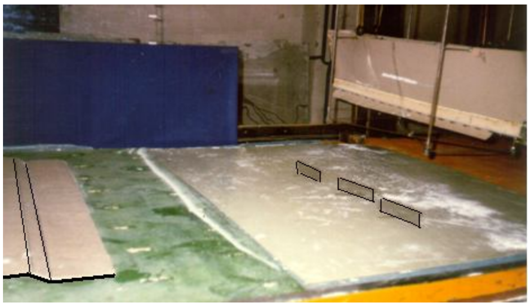


***Fig. 11** Model of the road with a protection barrier of snow fences*

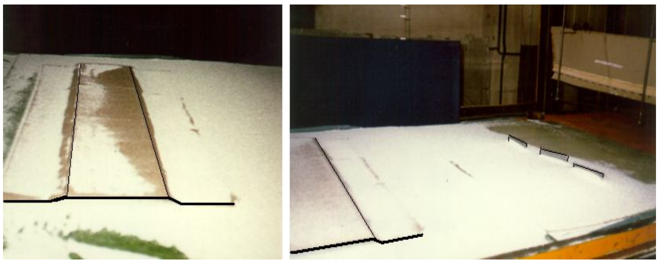


***Fig. 12** Intermediar stages during the drifting of the road and the snow deposit in the snow fences area*

The snow layer is almost inexistent on the platform of the road when is is protected by the barrier. In open space the thickness of the snow deposit reaches 60-70 cm height and in the fences area the maximum thickness is 180 cm (fig. 13).

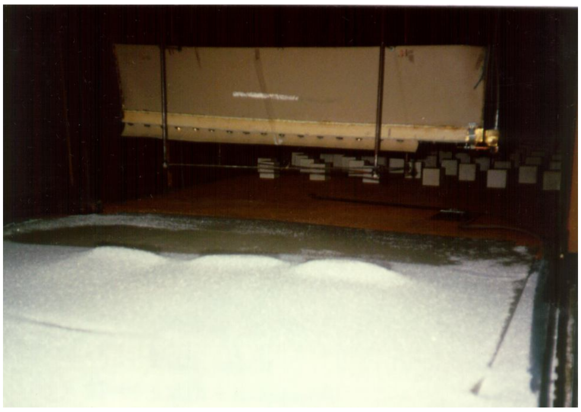


***Fig. 13** Snow deposits determined by the presence of barriers*

It is important to mention that tests did not reveal a typical shape of snow deposit behind the fences. Only about 10% frow reaches on the model comparing with the observed quantity of 40% in the case of un-protected road. Even when the fences are covered by snow, the effect of „protection" is maintained (fig.13).

The mean heights of the snow deposits were predicted using the Student's „t" distribution with a reliability level of 95% (fig. 14)

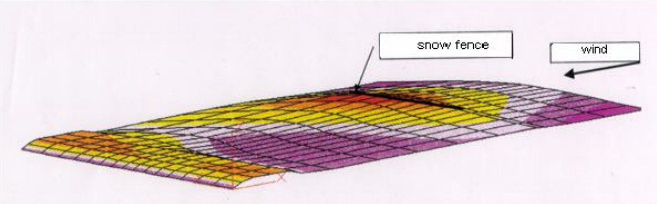


***Fig. 14** Computer aided representation of the snow deposit in the presence of the snow fences*

6. Conclusions

The complexity of the phenomenon of snow agglomeration due to wind action makes studies in wind tunnel to be difficult but in the same time relevant. Developing continuously the modelling techniques in laboratory may increase the accuracy of the simulation making possible to study different methods of either protection or optimization of various design solutions for roads.

Snow particles transported in the air move by rolling on the ground and hopping at heights of about 10cm; higher in the air the movement becomes turbulent. Although the snow may be entrained higher, iti is only on the first 5m from the ground that theis phenomenon is interesting for study.

Snow deposits will always form in quiet areas where the wind speed is reduced considerably. The role of protection barriers is to create these spaces along the road in order to improve the traffic security. In this respect, researches and studies on natural scale and on models try to anticipate the worst scenarios of snow drifted deposits on lines of communication with as much accuracy as the science is able to apply. For that, both rigorous modelling laws and keen observation methods must be seriously developed.

The studies in the wind tunnels are very useful from this point of view mainly considering that nowadays, the design of highways is a major necessity in the economic development of a country.

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