UDC 625.768.5

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SNOW ACCUMULATION DYNAMICS ON SLOPES AND DITCHES FOR UNSOLVED GROOVE

Statement of the problem. The problems of estimating a residual snow load capacity for unopen grooves and predicting the beginning of snow accumulation on the driveway have been discussed.
Results. The mathematical model for the calculation of snow accumulation on slopes and in ditches of grooves is presented which takes into account snowfall accumulations. The balance equation for the calculation of snow accumulations in an unopen groove is suggested. The calculation formula of snow container for a typical unopen groove, which takes into account its depth is presented. The dates of full filling of unopen grooves, slopes and ditches have been predicted. The calculations are performed for typical cross-section profiles of hollow of over 1.0 m in depth.
Conclusions. It has been concluded that a knowledge about snow accumulations is necessary in the calculation and predicting the beginning of snow accumulation on the driveway. The problem of a further research addressing the choice of a proper snow removal technique based on the results of engineering monitoring has been discussed.

Keywords: winter road maintenance, snow accumulation, snow container of slopes and ditches, unsolved hollow.

Introduction

Modern regulations and government guidelines make stronger provisions for the level of highway maintenance and traffic safety.

In order to improve highway performance, the effects of snowfalls and storms have to be dealt with in a short space of time. In order to meet ever-growing requirements, there should be a precipitation forecast, travelling conditions on roads should be assessed with the warnings on the dangerous driving conditions on roads following a snow fall. This information is crucial to the decisions made as snow plowing efforts get underway. Predicting snow loads on highways following a storm or a snowfall allows one to determine the amount and frequency of the maintenance works to be carried out and do so in a regulated space of time.

According to the classification set out in the regulations, areas of highways in unopen grooves are deemed to be at high risk of skidding [1]. These areas require extra maintenance efforts over the winter period as they are most probable to show greatest snow deposits on roads.

The complexity of snow transfer and accumulation and a variety of factors contributing to this process hinder the experimental research to define the amount of snow deposits on roads. Therefore in order to tackle the quantitative estimation of snow deposits in unopened grooves, the mathematical modeling methods were employed.

In order to calculate snow deposits on the carriageways of the highway areas of the groove, the authors have come up with mathematical models that make allowance for a flux of wind-blown snow flowing through different longitudinal profiles of the highway subbase depending on the geometrical elements comprising them [2], as well as the calculation algorithm and its implementation program [3].

The suggested models enable one to define the amount of snow deposits over the winter period based on the calculation of the total snow transfer to a certain highway area, however they do not account for the snow deposits dynamics over the winter period, i. e.

- change of geometrical parameters of longitudinal profiles of grooves due to increasing snow accumulations on slopes and ditches;
- snow accumulations following snowfalls;
- snow pushed off the road by maintenance fleets;
- decreasing snow accumulations over the period between storms and snowfalls owing to the contribution of climatic factors.

The results of the evaluation of snow accumulation dynamics enable the determination of the amount of snow accumulations on the highway driveway at any point of the time and can be used to define areas of highways that can be potentially at high risk of skidding based on special road weather forecasts.

1. Snow accumulation balance on slopes and ditches of an unopen groove

In order to account for the snow accumulation dynamics we suggest a set of models that describe the snow accumulation balance in unopen grooves.

According to how fluxes of wind-blown snow flow through unopen grooves as shown in Fig. 1., storm snow deposits in the following way: first, the snow deposits on a down-wind slope going down the slope as it increases gradually filling the ditch, driveway, wind-ward slope, i. e. the entire groove [4].

According to the physical compliance with the physical processes a snow accumulation zone can routinely be divided into two parts — the lower and the upper one (Fig. 1). In the lower part of the groove that is geometrically confined by the polygon ABCDEFK there is a vortex motion of the flux with a reverse rotation (vortex) and in the upper part (AKG) there is a vortex-free motion of the surface. As a blizzard moves on, it is the zone of the vortex motion of the flux that is originally filled. Snow deposits on slopes and ditches of the groove thus causing the snow accumulation surface to incline towards the highway (AK) 1:5. If snow brought is sufficient, the upper zone of the groove AKG is filled due to snow precipitation caused by a decreasing rate of the flux of wind-blown snow. According to A. P. Vasilyev, the upper zone of the deposits AG has a slope of 1:8 [5].

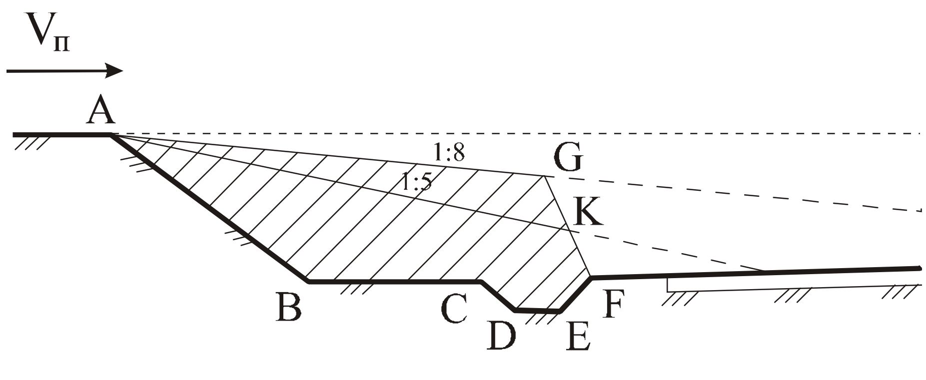

Fig. 1. Schematic of snow deposits in the unopened groove

According to the regulations set out in the guidelines, the driveway and the shoulder should be kept clear of snow at any time [1], therefore deposits on slopes and ditches of the groove towards the driveway and shoulders (GF) can be restrained by a natural slope 1:0.5. The maximum amount of snow that slopes and ditches of the groove can hold corresponds to its snow capacity.

Snow capacity in the unopen groove experiences constant changes over the winter period. As blizzards and snowfalls hit, snow accumulations increase due to freshly fallen snow. Road crews carry out re-distribution of snow by pushing it off the driveway and shoulder on both sides off to the slopes and ditches. In between the stormy weather there is a decline in the amount of previously fallen snow under the impact of a range of climatic factors [6].

Snow deposits on the slopes and ditches of the unopened groove at any point of time can be specified by the equilibrium equation:

$$Q_{отл} = Q_{сн} + Q_{мет} + Q_{уб} - Q_{пот}, \quad (1)$$

where $Q_{сн}$ is the amount of snow during a snowfall, m^3/m; $Q_{мет}$ is the amount of snow brought to the groove during storms, m^3/m; $Q_{уб}$ is the amount of snow pushed onto the slopes and ditches of the groove by the winter service vehicles, m^3/m; $Q_{пот}$ is the amount of snow loss affected by a range of climatic factors, m^3/m.

This paper sums up the outcome of the research of the accumulation of snow deposits on slopes and ditches of unopen grooves following snowfalls and storms.

The amount of snow that the slopes and ditches of the unopened groove can hold is crucial to predicting risks of skidding, i. e. the residual snow capacity is

$$Q_{ост} = Q_{НВ} - Q_{отл}, \quad (2)$$

where $Q_{НВ}$ is the initial snow capacity of the slope and ditches of the groove considering the geometrical parameters of the longitudinal profile of the road, m^3/m; $Q_{отл}$ is the amount of snow on the slopes and ditches of the unopened groove as for the period of the precipitation forecast.

In order to be informed on the amount of snow deposits on the slopes and ditches of the unopened groove and the likelihood of snow accumulating on the highway carriageway during the forecast snowfalls and storms, it is necessary to follow the dynamics of all of the above.

2. Physical parameters of the snowpack

Weather observers measure the amount of precipitation using the equivalent amount of water in a unit of snow which is collected and melted into water. In order to calculate the amount of snow using the weather station data it is essential that the snow density parameter is used. The density of fallen snow depends on a number of exterior conditions with the temperature of the environment and wind speed during the precipitation being central [7].

The density of a freshly fallen snowpack formed in no-wind conditions can be defined using the formula suggested by R. G. Coulter who assumed the snow density to exponentially grow as so does the temperature:

$$\delta = 16,018 \exp(1,907 + 0,0835T), \tag{3}$$

where T is the air temperature, ^{0}C.

In no-wind conditions a snowpack takes the form of a flat layer of snow and therefore the amount of new snow deposits following a snowfall can be given by

$$Q_{сн} = O_s / \delta , \tag{4}$$

where O_s is the amount of the precipitation registered by the weather station, mm of water.

A snowpack formed during snowfalls is subject to the wind effect. M. A. Bibelo established the empirical relationship of new snow deposits on the average air temperature and wind speed [7]:

$$\delta = 152 - 0,31T + 1,9\overline{V}, \tag{5}$$

where $\overline{V}$ is the average wind speed, m/sec.

The amount of snow brought to the road is dependent on the parameters of stormy spells, their duration, direction and wind speed during a storm [4]:

$$Q_{мет} = W_{сп} = W_{пер} \cdot \sin\left(\alpha_{д} - \alpha_{i}\right), \tag{6}$$

where $W_{сп}$ is snow brought to the road, m^3/m; $\alpha_д$ is the road direction, degrees; α_i is the wind direction, degrees; $W_{пер}$ is snow brought in the same bearing:

$$W_{пер} = C \cdot V^3 \cdot t = I \cdot t, \tag{7}$$

where t is the duration of a storm, h; C is the empirical coefficient of 0.00046; V is the wind speed during a storm, m/sec; I is the intensity of a storm, m^3/m·h.

Snow during storms normally accumulates on the previously fallen snow and the snow accumulations on the slope and ditch of the unopened groove at a specified period of time is

$$Q_{отл} = Q_п + Q_{св}, \tag{8}$$

where Q_n is the previously fallen, m^3/m; $Q_{св}$ is the amount of new deposits following a storm or a snowfall, m^3/m.

3. Snow capacity of the unopened groove

In order to use the suggested model in the calculation we essentially need the following initial data: geometrical parameters of the longitudinal profiles of a motorway and weather station data. All the research was confined to the areas of highways that cross the unopened grooves of over 1.0 m in depth. Less deep grooves are in the initial areas of the deep grooves and are left out of consideration in the ongoing research since they are designed to be open or to fit the subbase in order to protect these areas from skidding.

According to the calculation scheme presented in Fig.1 and typical geometrical parameters of the subbase of highways [8] the snow capacity of the slope and ditch of the unopened groove depending on its depth *H* can be calculated using the equation

$$Q_{НВ} = 0,4329H^2 + 0,8658H + 0,2129. \tag{9}$$

Equation (9) allows one to determine the snow capacity of a typical unopened groove of any depth.

4. Calculating snow deposits on the slopes and ditches of the unopened groove

The initial weather data in implementing the calculation using the suggested technique is the one brought by the state weather station network and automatic road weather station. The following piece of data needs to be selected at each observation period:

– type of precipitation;
– time of precipitation, h;
– amount of fallen precipitation, mm of water;
– air temperature, ^{0}C;
– maximum wind speed, m/sec;
– wind direction, bearings.

If there are several precipitation occurrences within the space of 24 hours, the initial information is processed individually for each of these.

The software complex *Microsoft Visual Fox Pro* was selected to automate the calculation using the suggested technique. The processed data bases were converted to the table format in *Microsoft Excel* where the graphs were designed using the results of the performed calculation. The calculation was performed to define the amount of snow accumulations on the slopes and ditches of the unopened grooves for six winter periods.

Fig. 2 shows the average value of the indices of the dynamics of snow accumulation obtained in six years of the observation on the area of the highway that crosses the unopened groove with the snow capacity that is sufficient to for the slopes and ditches to hold all the snow.

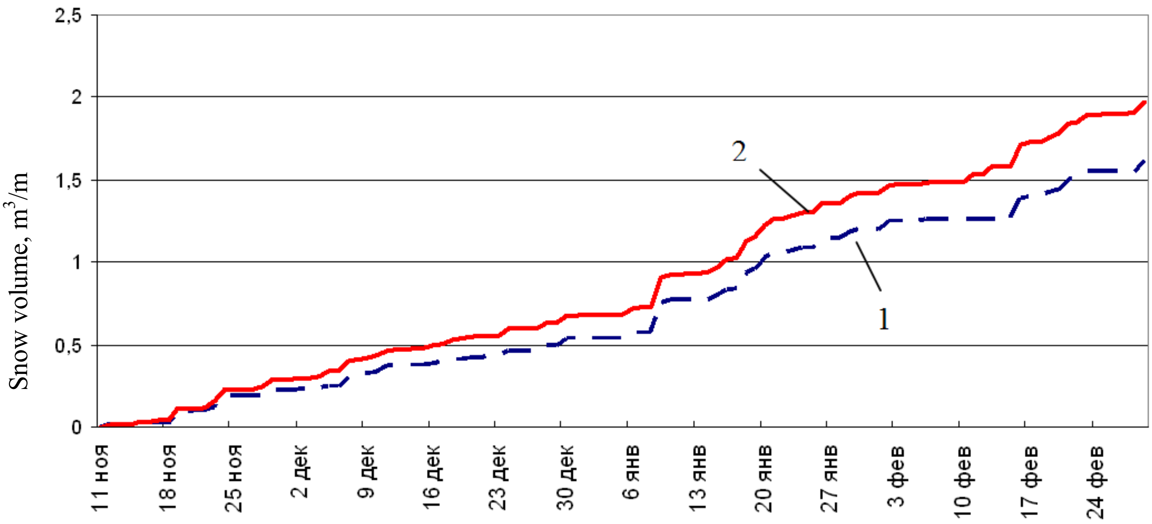

Fig. 2. Average values of snow accumulation on the slopes and ditches of the unopened groove following storms (1) and snowfalls and storms (2) in six years of observation (ноя — November; дек — December; янв — January; фев — February)

During the course of the calculation the snow density was assumed to depend on weather conditions at the time of precipitation and to remain unchanged in the long-run.

The analysis of the results suggests that snow accumulation is more intense on the slopes and ditches of the groove provided that the conjunction of storms and snowfalls is taken into consideration. The proportion of the snow during the snowfall is on a gradual increase during winter and is at its peak by the end of the season. Therefore if the amount of the snow during snowfalls is not considered, the correction error will be 20 % of the total snow accumulations.

5. Time of reaching a full snow capacity

All the unopened grooves with the snow capacity of the slopes being less than the amount of snow brought cause skidding during storms. Before the snow capacity reached its limit, snow during storms accumulated on the slopes and ditches of the unopened groove. After the slopes and ditches were filled with snow, storm snow deposits make their way onto the road surface thus causing disruptions to traffic. Snow during snowfalls is accumulated in an even layer on all the elements of the longitudinal profile of the subbase.

Snow deposits on the road surface need to be cleared by pushing it onto the slopes of the groove or taken out of its confines when there is no chance of placing the snow in the immediate vicinity of the road. Therefore the snow plowing technology has to be changed once the snow capacity of the groove reaches its limit. The calculation of the residual snow capacity of the groove and predicting the point in time at which it reaches its limit is thus of great significance.

Time of reaching the full snow capacity of the slopes and ditches for the same highway areas in different years (as identified in Table).

Table

Time of reaching a full snow capacity of the slope and ditches of the unopened groove

Depth of the groove, m	Accumulation conditions	Time of reaching the full snow capacity in different years of observation					
1.0	Storms	**15/11**	09/01	**18/01**	**30/12**	22/12	**07/12**
	Storms and snowfalls	**15/11**	18/12	**18/01**	**30/12**	10/12	**07/12**
2.0	Storms	15/01	**09/01**	20/01	21/01	19/01	06/12
	Storms and snowfalls	11/01	**09/01**	18/01	19/01	19/12	12/12
3.0	Storms	нд*	**09/01**	21/02	**26/01**	16/12	16/02
	Storms and snowfalls	17/02	**09/01**	20/01	**26/01**	10/01	06/01
4.0	Storms	nr	**09/01**	nr	**29/01**	nr	**16/02**
	Storms and snowfalls	nr	**09/01**	21/02	**29/01**	24/01	**16/02**
5.0	Storms	nr	02/02	nr	**01/03**	nr	**16/02**
	Storms and snowfalls	nr	17/01	21/02	**01/03**	20/02	**16/02**

End of Table

Depth of the groove, m	Accumulation conditions	Time of reaching the full snow capacity in different years of observation					
6.0	Storms	nr	19/02	nr	06/03	nr	nr
	Storms and snowfalls	nr	02/02	nr	01/03	nr	20/02
7.0	Storms	nr	23/02	nr	nr	nr	nr
	Storms and snowfalls	nr	11/02	nr	22/03	nr	nr
8.0	Storms	nr	nr	nr	nr	nr	nr
	Storms and snowfalls	nr	13/02	nr	nr	nr	nr
9.0	Storms	nr	nr	nr	nr	nr	nr
	Storms and snowfalls	nr	22/02	nr	nr	nr	nr
10.0	Storms	nr	nr	nr	nr	nr	nr
	Storms and snowfalls	nr	nr	nr	nr	nr	nr

Note: nr — full snow capacity is not reached.

Time of reaching the full snow capacity of the slope and ditch of unopen grooves depending on their depth was calculated using two methods (considering and not considering snowfalls occurring). The analysis if the calculation results suggests that the time coincides only in 34 %. In 40 % considering the snow accumulations only following storms the full snow capacity is reached later than when snow deposits following snowfalls is taken into account as well. The difference between the time is from a couple of days to a couple of weeks. So, for the sixth year of the observation considering snow deposits only following snowfalls in the groove of 3.0 m the amount of snow reached the full snow capacity on February 16th and as early as on January 6th with snow deposits following storms and snowfalls considered. In 26 % snow accumulations following snowfalls does not reach the full snow capacity of the groove while considering the amount of snow following snowfalls the residual snow capacity of the same groove will be off.

Time of reaching the full snow capacity for a number of years varies largely. Grooves of different depths located in the identical climatic conditions and having the identical full snow capacity will be registered at different points in time with the less deep groove being registered earlier in time. So, during the first year of observation the snow capacity of the unopened grooves of 1.0 m in depth was off on November 15th and on February 17th for those of

3.0 m in depth with the deeper grooves (4.0 m and over) remained unchanged. The same thing happened during the winter periods to follow. Snow capacity was off in all of the unopened groves of up to 9.0 m in depth in the most snowy second year.

Fig. 3 shows the graphs that indicate the average values of the dynamics of the snow accumulation on the slopes and ditches of the unopened grooves of different depths.

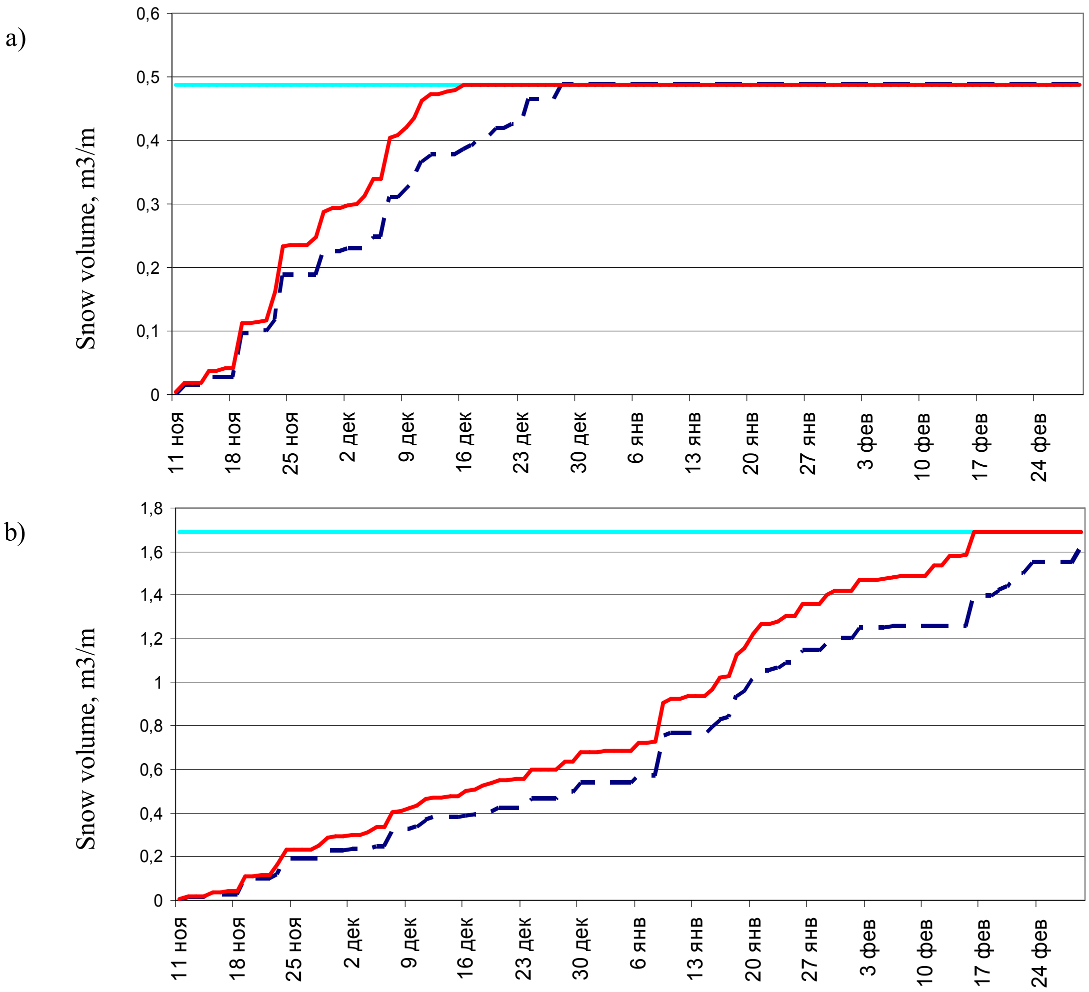

Fig. 3. Snow accumulation dynamics on the slopes of the unopened groove:
a) of 1.0 m n depth, b) of 5 m in depth: is snow accumulations following snowfalls and storms, m^3/m;
is snow accumulations following storms, m^3/m;
is the full snow capacity of the slope and ditch of the groove, m^3/m
(ноя — November; дек — December; янв — January; фев — February)

The calculation results suggest that in order to analyze the residual snow capacity of the unopened grooves over the winter period it is necessary that there is an engineering monitoring of this parameter considering the dynamics of snowfalls and storms taking place. The results of engineering monitoring help to make a viable choice of snow plowing efforts on the areas of highways that cross the unopened grooves.

Conclusions

1. We have suggested the method for calculating the residual snow capacity of the unopened groove which is the first to account for snow deposits following snowfalls and to reveal the information on the time of snow deposits starting to occur on the carriageway of highways.
2. The model developed during the course of the study can be made use of in the engineering monitoring of road skidding which assists the timely choice of a set of snow plowing efforts to be undertaken.
3. The research results can be further supplemented with the view to account for the amount of snow pushed off the motorway by winter service vehicles and decreasing snow accumulations in between snowfalls and storms under the impact of climatic factors.

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