

Road System Maintenance in Winter

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Abstract: In order to eliminate the difficulties caused by the presence of snow and ice on the road surface and to create a safe, constant and convenient movement with their design speeds and loads, companies and organizations should apply a set of roads winter maintenance activities. Drifted snow on the roads is determined by a group of factors, which in most cases depend on each other and occur in different combinations. The main factors are: the climate conditions, the specific features of the area, the geometric and constructive elements of the road.

Key words: Forest roads, winter maintenance, drifted snow, snow-ups.

1. Introduction

Modern forest and agricultural roads must equally satisfy the needs of car movements throughout the seasons of the year. During the winter, drivers are forced to work in specific conditions: in snowfall, icy road surfaces, in low visibility (in snow blizzards), at low air temperatures, etc.. All this makes it difficult to maintain roadways in conditions suitable for normal use; leads to a reduction in the speed and danger of road accidents.

As a result of snowdrifts on the roads, the speed of car traffic can be reduced to several kilometers per hour, or even driving stop for a while. Due to the low speed of traffic, the cost of transport increases and economic losses are caused. The economic feasibility of winter road maintenance is determined by the inequality $C < T$, where C is the value of the road winter maintenance; T is the losses caused by the increased cost of transport in winter or the complete traffic disruption when the road is not maintained.

The losses caused by the increased cost of transport in the winter when the road is not maintained and the losses caused by the increase in the cost of transport as a result of road traffic speed lowering during snowdrifts are determined by the equation:

$$T = W_a(S_2 - S_1)$$

where W_a is the volume of road carriage during the snowdrift period, t/km; S_1 —the cost of t/km in good road conditions, S_2 —the cost of t/km on a snow-drifted road.

The profitability of winter maintenance is conditioned by the reduction of the transport time of the material resources transported on the roads, which is connected with working capital savings in the economy. Winter maintenance of roads has not only great economic significance but is also essential to traffic safety. Significant slopes of forest roads and the often heavy terrain conditions in forests create a risk of accidents. It is known that the stopping distance on a snowy or ice-covered surface increases up to twice to the braking distance on a normal dry surface. This is due to the sharp reduction in the adhesion ratio. Hence, the intensity of traffic decreases, while reducing the driving conditions comfort and increasing the accident prerequisites.

2. Materials and Methods

2.1 Factors Underlying Snow-Drifts on Roads

Snow-drifts on roads are determined by a group of factors, which in most cases depend on each other and occur in different combinations. The main factors are the climatic conditions, the specific features of the area, the geometric and constructive elements of the road (Fig. 1).

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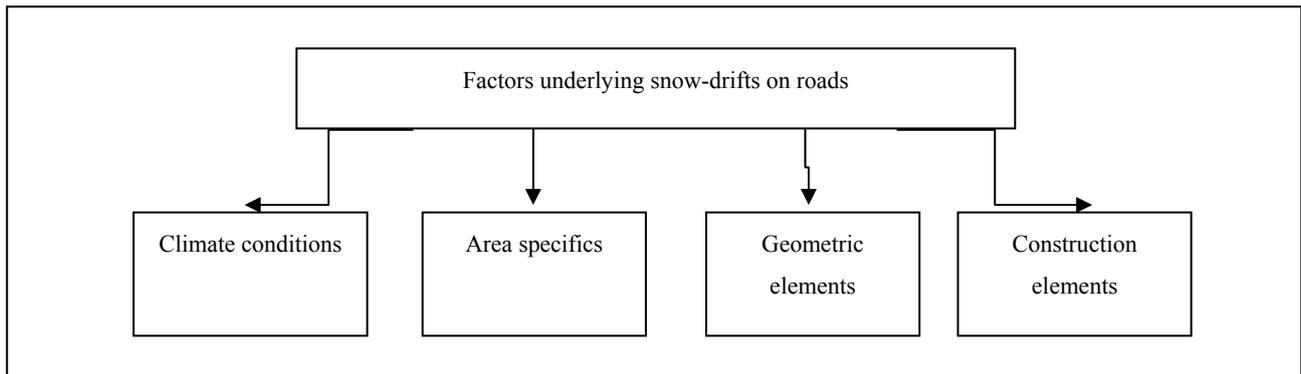


Fig. 1 Classification of factors underlying the snow-drift on road lanes.

The group of climatic factors refers to the amount and intensity of snowfall, the snow cover thickness, the frequency and duration of blizzards, the temperature regime and the duration of winter, the amount of snow masses transferred, the dominant winds speed and direction, etc..

The snow on the road, fallen as snow or carried in a blizzard, makes it difficult to maintain the road in winter. There are difficulties in selecting the type and size of the snow-protection facilities. At snowfall, snow is usually amassed with approximately the same thickness, and in such cases it is not very dangerous for our roads, as the thickness of the snow layer is about 10 cm and is thicker only in extreme cases.

The volume of snow fallen during snowfall can be determined from the meteorological station data from the equation:

$$\Delta q_c = \frac{Q}{f} = 20Q$$

where Δq_c is the volume of snow fallen during the snowfall per road surface unit, kg/m^2 , Q —the mass of snow in the rainfall measuring vessel, kg; F —the rainfall measuring vessel cross section which is 0.05 m^2 .

Meteorological stations, however, do not measure the volume of snow carried in blizzards. These observations are made by road services, which indirectly determine the volume of snow transferred to the road in a single blizzard from the equation:

$$\Delta q_b = \frac{100(\omega_2 - \omega_1)\rho_3}{\varphi_3 \sin \alpha p}$$

Where Δq_b is the volume of snow transported in a blizzard for 1 m width from an area perpendicular to the wind direction, kg.

φ_3 —the snow-retention rate of the snow-protection facility;

$\omega_2 - \omega_1$ —the cross section of the snow bank in the snow-protection facility before and after the blizzard, m^2 ;

ρ_3 —the average density of the snow on the snow protection facility, kg/cm^3 ; αp —the angle between the measuring device plane and the wind direction.

Snow protection fences are sized based on the total volume of snow transferred during blizzards in winter.

The volume of snow accumulated on the road and on the snow protection facilities is a function of the intensity of snow and blizzards.

The frequency and duration of snowfalls and blizzards influence the snow clearance volume and duration and the operation of snow protection facilities.

The temperature regime also influences winter maintenance. At low temperatures, the productivity of the workforce decreases, and the machines capacity is not fully used [1, 5].

The speed and direction of dominant winter winds is a factor, on which the roads winter maintenance manner is largely dependent. At higher wind speeds, a greater volume of snow is transported on the road and snow protection facilities. These facilities are sometimes considerably loaded and, under certain conditions, may be ruptured, tilted, or plucked. With

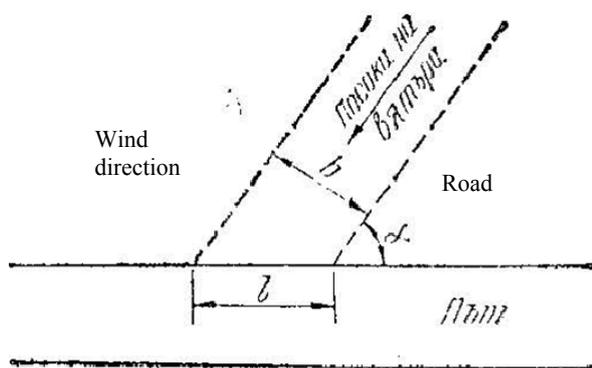


Fig. 2 Influence of angle α on the road's snow coverage.

the increase of the angle α , between the wind direction and the road axis, snow-drifts also increase (Fig. 2).

The total volume of snow transported in a blizzard blowing at an angle α relative to the road section l , is:

$$Q_b = \Delta q_b \cdot b = \Delta q_b \sin \alpha$$

The equation demonstrates that if Δq_b and l are constant values, then Q_b increases with the angle α increase.

Hence, the most intense snow drifts are formed by winds blowing perpendicular to the road.

The volume of snow transferred during blizzards throughout the winter on the left and right side of the road over 1 m of its length can be determined by D. M. Melnik's empirical formula, after it is converted from mass into volumes:

$$W = \frac{0.774 \cdot 10^{-4}}{\rho_s} \sum_{i=1}^n \sum_{k=1}^m v_f^3 \sin \alpha \cdot t_k$$

where ρ_s is the density of the depressed snow, kg/m^2 ; V_f —the wind speed determined by the meteorological station, m/s ; t —the snow blizzards duration, h ; α —the angle between the wind direction and the road axis, $^\circ$; m —the number of cases with different velocities of the snow blizzards ($\kappa = 1 - m$); n —the number of cases with different angles between the wind direction and the road axis ($i = 1 \dots n$).

Winds at speeds of less than 6 m/s , winds blowing aslant (with respect to the road) at an angle α of less than 30° and winds blowing at positive temperatures are not taken into account in the above formula.

A longer winter period adversely affects the operation of the road as it is associated with a larger volume of work. That is why the machines wear out faster and the snow protection facilities have a shorter operation life [3].

The peculiarities of the area around the road, such as relief, vegetation, altitude, are essential for the road's snow-coverage.

The snow cover in mountainous and hilly area is very uneven. Highly hilly and intersected areas are characterized by natural areas of blowing out and calm. In these areas, snow is blown out from the heights, as the airflow rate there is higher, so it is deposited in the lower places. In other words, the snow is accumulated by the lower relief and the small quantities of snow masses carried on the roads are safe.

In a flat area, the snow cover is more uniform, but in blizzards significant amounts of snow are sometimes transported to a single place because its source is practically unlimited. A lot of effort and resources are required for the winter maintenance of routes traced in such areas.

Forest areas impede the transfer of snow by the wind. Low bushes prevent snow-drifting only until the snow is over piled, and then the area is free of greenery.

Depending on the altitude, roads are harder or easier for winter maintenance. For example, in high mountain roads, longer winter maintenance in harsh climatic conditions is typical compared to roads in the same geographical area but at a lower altitude. The snowing degree of a particular road in the same area, under the same conditions, is entirely determined by the nature of the trajectory, the geometric and constructive elements of the road and its connection to the surrounding terrain [5].

The factors influencing the degree of snowfall on the roads are: the route layout in view of the relief features, its orientation towards the dominant winds direction, the longitudinal and transverse road profiles, the number of curves in it and their radii [1]. While

climate factors can be hardly influenced, those can be influenced by designers, starting from the track research—its geometric elements, onto its constructive spatial solution. The cross sections have the greatest influence on snowing: roads with shallow trenches but with small width of the road lane have the highest snowing. Roads with a broader lane are snowing slower. Road sections with curves are snowing faster than the straight ones. There, the productivity of slow-moving machines is reduced.

3. Results and Discussion

3.1 Types of Snow-Coverage

Road snow-coverage can be two types: ubiquitous and in the form of snow-drifts (partial).

The ubiquitous snow-coverage is the result of heavy snowfall in quiet weather. Such snow-coverage is characteristic of forest areas and places preserved from strong winds. In this type of snow-coverage, the snow accumulates with approximately the same thickness on the ground, including roads. However, it does not pose a danger to our roads, as in a single snow-fall in our country the snow cover reaches merely 10 cm of thickness.

The snow-drifting of the track is the result of blowing out, transfer and deposition of snow particles under the influence of the wind. This kind of snow coverage is called snow blizzards. Depending on the speed at which the snow particles are transported, we distinguish snow blizzards at wind velocity $v < 20$ m/s and snow blizzards at wind velocity $v > 20$ m/s.

According to the climatic features of our country, snow blizzards, which are subdivided into three types: high blizzards, ground blizzards, mixed blizzards have significant importance.

High blizzards are observed in windy snowfall. In this type of blizzards, only snow-fall flakes which have not yet reached the ground are transported.

Ground blizzards are not accompanied by snowfall—with them, the wind blows away and transfers snow from the snow cover.

Mixed blizzards carry both snowflakes in the snowfall and snow masses blown away from the existing snow cover.

In this type of snow blizzard, there are two types of snow particles movement, namely: the snow particles fall and are transported in the atmosphere or the snow particles that have already fallen on the ground are transferred. In each case, the action is triggered by the wind. The study of the two types of snowflake movements is the subject of the blizzards mechanics detailed by Soviet scientists and a theoretical basis for roadside snow protection.

3.2 Influence of the Cross Profile of the Road on Its Snow-Coverage

The road body, as a structural element of the road, causes wind speed reduction or increase, which creates conditions for deposition or blowing out of the snow masses. The different cross-sectional shapes and sizes of the road have a different snow-accumulation effect and are therefore considered separately.

3.2.1 The Embankment Road

Embankment profiles vary the wind speed depending on their height. The wind velocity is higher over the embankment, smaller—at the bottom of the wind-side slope and the smallest at the bottom of the opposite slope of the embankment. As a rule, the wind speed is higher at higher embankments (Fig. 3).

At low speeds, the transport capacity of the snow flow is reduced, and at large ones, it increases accordingly. The main part of the snow masses carried by the blizzard are deposited at the bottom of the opposite slope of the embankment (with respect to the wind direction) and the smaller part—at the bottom of the wind-side slope.

It has been found that the snow masses continue to be deposited on the embankment slopes until snow-drifts with a slope of 1:5-1:6 are piled. The roadway of the embankment is blown by the wind and, if the embankment has a sufficient height, the snow masses are not deposited on it. From here, it can be concluded

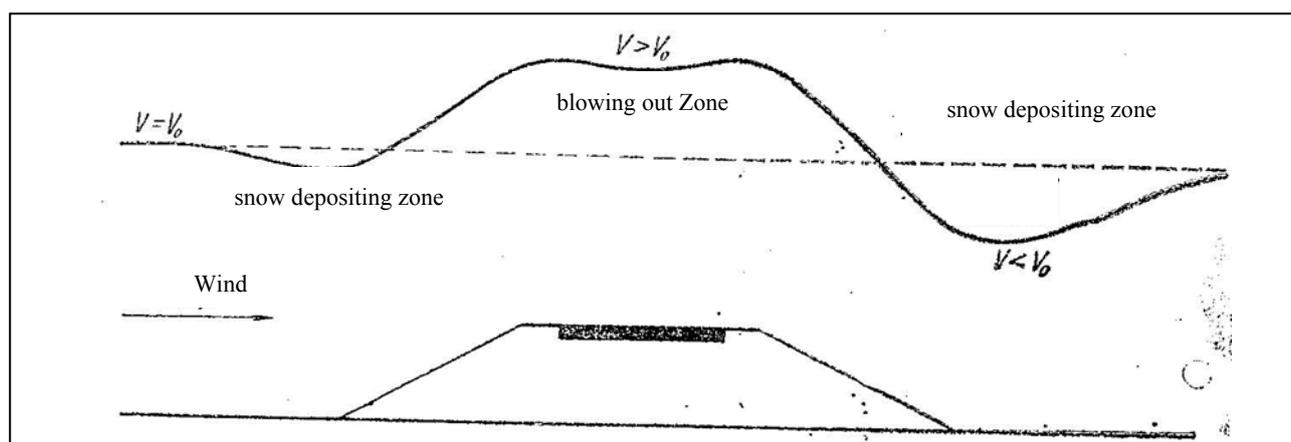


Fig. 3 Zones for snow depositing and its blowing out at the embankment.

that the high-embankment road does not accumulate snow. It should not be forgotten, however, that at the high embankments, the volume of earthworks increases, which makes road construction more expensive.

Therefore, the task is to establish the minimum embankments heights to ensure that the road does not accumulate snow.

It has been observed that, at the suitable embankment height, the snow deposits in the embankment profile area vary depending on the slopes inclination—for inclinations less than 1:6, the snow drifts are negligible or disappear completely in a smooth curvilinear shaping of the slopes' traverses.

According to the studies [2], the embankment height, which ensures the purge of the roadway, is determined by the following equation:

$$H_H = H_c + \Delta H$$

where H_H is the embankment height at which it does not accumulate snow, m;

H_c —the snow-cover thickness around the embankment, m; ΔH —the embankment elevation over the snow cover to ensure the purge of the roadway (0.5-0.8 m depending on the road class).

The thickness of the snow cover is usually accepted to be the maximum value of the average multi-annual measurements made by the meteorological station.

It has been found [2] that the purging of the embankments (their non-snow coverage) depends not

only on the absolute value of the height H_H but also on the relation:

$$\varphi_H = \frac{H_H}{B} > 0.07$$

where B is the width of the embankment at the bottom in m.

The embankments where the above ratio is observed are not snowed by blizzards, as the wind flow passes them at a rate of about 10% above the wind speed adjacent to the embankment, but at the same height above the snow cover. With increased wind speed, the transport capacity of the stream increases by about 40-50%. The snow blizzard becomes unsaturated and the snow is not deposited on the embankment. The road lanes width for most of our roads is from 8 to 12 m. To satisfy the condition for φ_H at these widths and at slope inclinations up to 1:4, it is necessary that the embankments have a minimum height of 1.20-1.50 m which corresponds to the roadway purge equation.

It is advisable to design snow-free embankments—with shallower slopes in areas with frequent snowfalls at intense blizzards. With elevated levels and embankment profiles with shallower slopes—up to 1:4, the road is given an aerodynamic form, also removing the risk of snow coverage, the roadway snow clearance is facilitated, winter maintenance becomes more economical. This must be taken into account, especially in the reconstruction of a significant part of our road network.

3.2.2 The Road in Excavation

When the wind flow passes through the trench profile, its speed is reduced depending on the trench depth. The smallest flow rate is established in the area of the wind-sweep area. Above the slope, a calm (reduced pressure) zone is formed with intense swirl motion, where the snow masses carried by the blizzard are deposited. According to the studies [4], the length of the zone with intense swirling motion of the air masses is equal to approximately 6.5 times the depth of the trench (Fig. 4). Excavations with a depth of up to 6 m begin to accumulate snow from the outer edge of the windswept slope, gradually covering the entire roadway. The snow on the specified slope is deposited in the form of a cornice (Fig. 5). Especially dangerously snow-drenched are the excavations with slopes, steeper than 1:6, with a depth of 1.5-2 m. Excavation profiles are not snow covered if conditions are created for non-swirl movement. This is achieved

by reducing the slope inclination to below 1:6 and by rounding the edges of the shallow excavation profiles slopes. In some countries it is recommended that the inclinations of the shallow excavated trenches' slopes to be from 1:8 to 1:10, thereby creating conditions to increase the wind speed and the snow purging.

In general, snow is blown on all trench profiles, but the shallow slope profiles are slower and less covered with snow. Trench profiles with depths of up to 1-1.5 m do not accumulate snow. As the trench depth increases above 1.5 m, the wind speed is significantly reduced, as a result of which the snow begins to accumulate. Moreover, the volume of earthworks and the size of the exposed areas are significant, which is uneconomic. We recommend shallow—up to 1 m—open trench profiles with and without borrow pits (for our conditions we recommend trench profiles without borrow pits) (Fig. 6).

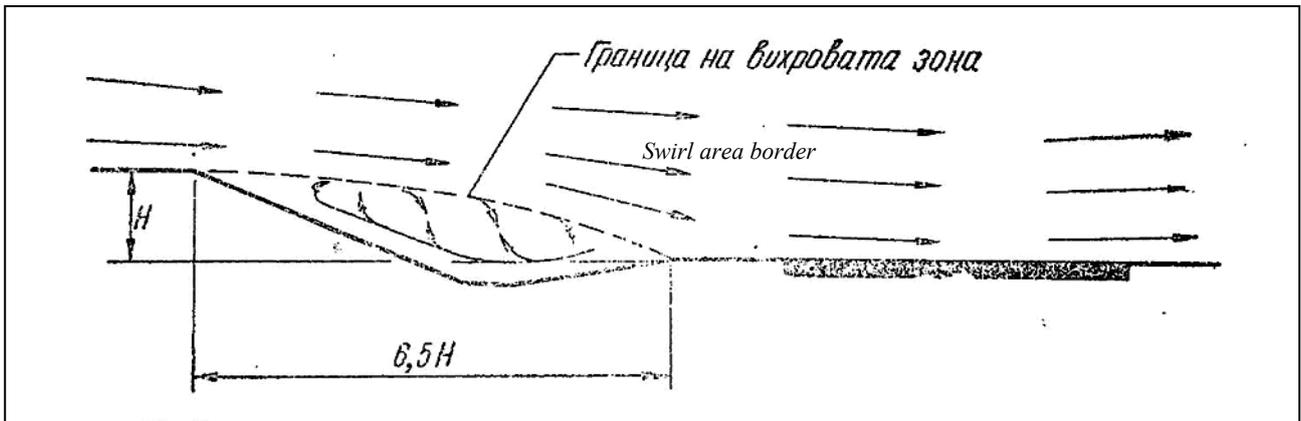


Fig. 4 Swirl area in a trench.

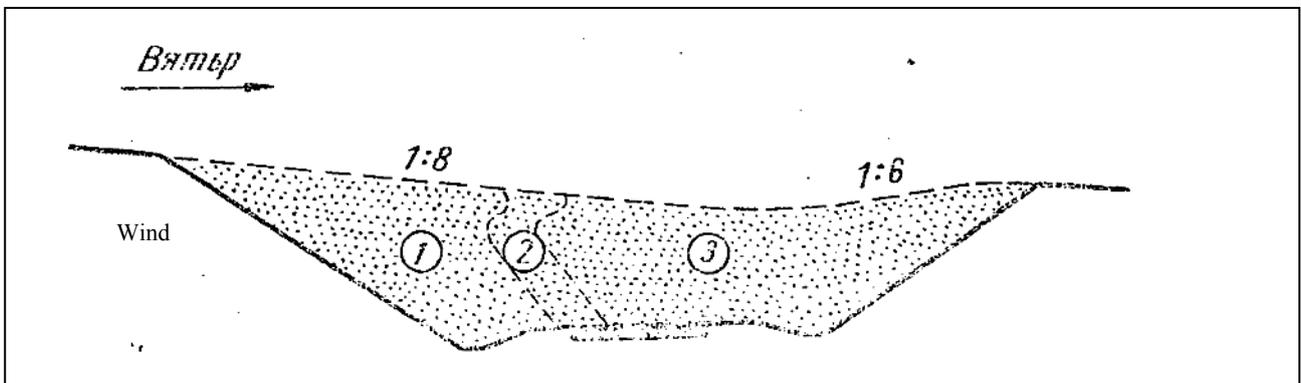


Fig. 5 Consecutive snow accumulation in a trench.

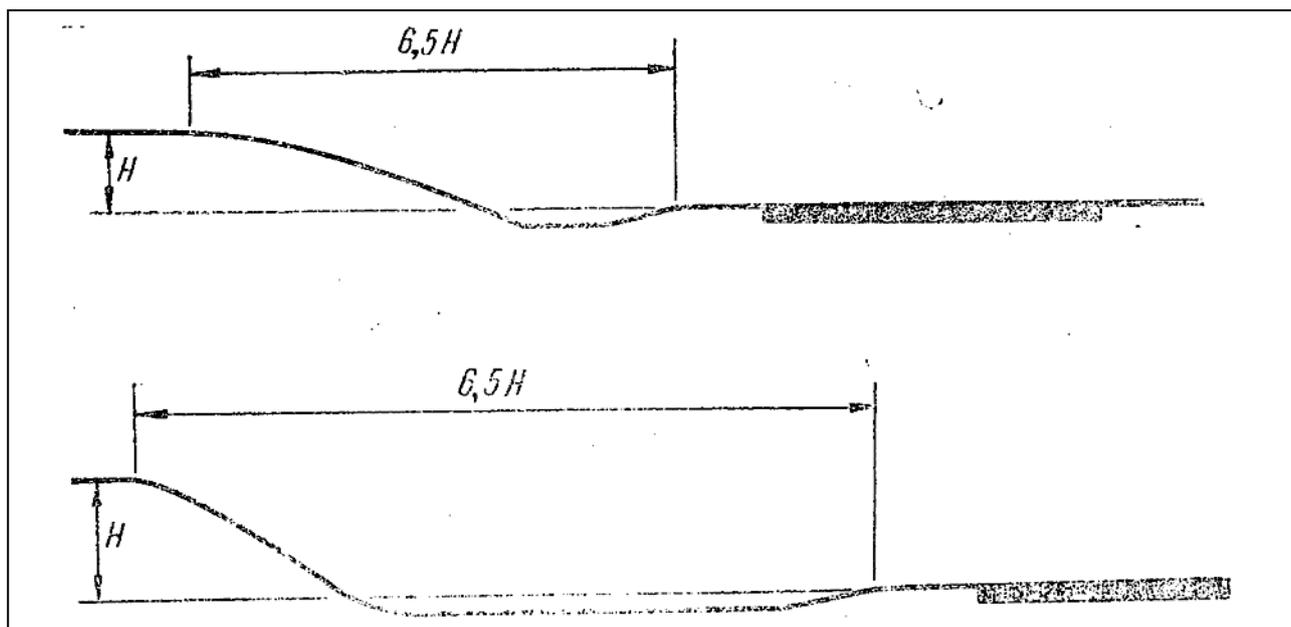


Fig. 6 Typical cross-sectional profile with a snow-deposition extension.

In snow-accumulating areas, it is economically feasible to excavate trenches with a depth of 1.5 to 5 m and 1:6-1:4 slopes.

The misconception is that steep-slope trenches of more than 6 m depth will not accumulate snow. The modern explanation is that the energy of the vortices formed in the trench is much smaller than the energy of the main stream, which is why the whirlwinds cannot blow away all the snow carried by the blizzard and deposited on the roadway. In fact, the road in the deep trenches is not snow-covered when the volume of snow transported by the blizzard in winter is less than the volume of snow that can be retained on the large slope areas. Deep trenches are not snow-covered because their slopes retain a large volume of snow.

The extent of snowdrifts in road trenches is a function of their location with regard to the dominant winds. When the axis of the road coincides with the direction of the dominant winds, then the blowing conditions are most favorable only for the open trenches but not for those with steep slopes. The road is most snow-covered when it is perpendicular to the wind direction. Snow accumulation is unavoidable in places with sudden changes in the nature of the

profiles, for example, at the boundary between the trench and the embankment. Curved road sections, especially the trench profiles, accumulate more snow than the straight parts of the road. This is explained by the greater likelihood of winds with more unfavorable direction blowing on a curved section. Therefore, it is not recommended to use trenches in a curve.

Zero places and low embankments are also snow-covered, albeit to a lesser extent than the shallow trenches. It is known from practice, that the degree of these profiles' snow accumulation depends a lot on the road surface flatness and the surrounding terrain. Snow drifts are not seen on a flat lane without tracks and humpbacks, and when there are no clusters of building materials, buildings, shrubs, trees, etc. on the road.

A significant snow accumulation factor can also be the snow-cover thickness right next to the road itself when it is higher than the road. A snow-accumulation factor is also the untimely winter maintenance. For example, the untimely cleaning of the road from the fallen snow, on which cars are passing, the cars form deep tracks and ridges, the snow-deposited of snow-removing on the waysides, etc.. All these factors help the roadway snow coverage.

4. Main Conclusions

The factors influencing the degree of snow drifting on the roads are: the layout of the route in view of the relief features, its orientation towards the dominant winds direction, the longitudinal and transverse road profiles, the number of curves in it and their radii. However, cross-sections of roads have the greatest impact on their snow drifting.

The road lane on an embankment is blown by the wind, and if the embankment has a sufficient height and shallow-slope embankment profiles—up to 1:4, the road is given an aerodynamic shape and snow masses are not deposited thereon, which also facilitates the snow-cleaning on the roadway and winter maintenance becomes more economical.

When the forest road is in a trench, shallow—up to

1 m—open trench profiles without borrow pits are recommended. When excavation depths of 1.5 to 5 m are required, it is economical to make them with 1:6-1:4 slopes.

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