# Estimation amount of snow deposits on the road

Olga V. Gladysheva

Voronezh State University of Architecture and Civil Engineering, Russia
Email: gladov@box.vsi.ru

## ABSTRACT

The article under consideration gives the results of the research on quantitative estimation of snow deposits on different parts of roads during blizzards. The methods of mathematical modeling were used to solve the problem.
There suggested a mathematical model giving a general description of processes of snow accumulation on roads. This model considers the basic weather and road factors, which are necessarily, have to be taken into account. Their list is given in the article.
In article the mathematical models describing snow transfer and snowbring to a site of a road. The models take into account the type of cross-section of road.
Data provided by automatic road meteorological stations can serve as initial data for calculations.
The realization of the models in the form of computer program is considered. The example of calculation for the certain road section is presented.
**Keywords:** road, mathematical modeling, snow transfer, snowbring, amount of snow deposit.

## 1. INTRODUCTION

For the purpose of providing road safety in winter the road service team carries out a complex of activities. The standards in force for winter service presuppose timely removal of ice sediments and clearing of the road surface from snow.

The main type of winter slipperiness on most of the territory of Russia is snow coasting. One of the ways of its prevention is a well-timed clearing the roads from snow. The technology of work presupposes repeated passing of snow-removal machines. The interval between passages of machines is determined by the intensity of snowfall and the requirements of the winter service standards.

The intensity of the snow blockades depends on large number of factors, both weather and road. The quantitative estimation of those factors is an important problem, which has not got its solution yet.

## 2. THE CALCULATION OF THE SNOW TRANSFER AND THE SNOWBRIHG ON THE ROAD

The amount of snow deposit on the road depends on the volume of snowbring. The method of summarized transfer suggested by N.E. Dolgov and D.M. Melnik is used to calculate the volume of the snowbring [1], [2]. The method takes into consideration the intensity of snow transfer, which depends on the wind speed and the time during the snow transfer occurs with particular intensity.

The volume of snow transfer in winter period ($W_t$) is calculated to the formula:

$$W_t = \frac{t}{m} \sum_{i=1,(V>5)}^{m} C \cdot V_i^3 = I_c \cdot t, \tag{1}$$

where $t$ is the summary duration of snowstorms for winter period, hour; $m$ is the number of measurements of the wind speed during snowstorms (at speeds over 5 m/sec); $C$ is an empiric factor, equal to 0,00046 for density of snow 0,17 m$^3$/m; $V_i$ is the wind speed during snowstorms, m/sec; $I_c$ is the average intensity of snowstorms during the winter period, m$^3$/m hour.

Collecting the data provided by meteorological stations the winds with the speed less than 5 m/sec are not taken into consideration, because their energy is not sufficient to transfer falling and fallen snow.

The dependency between the average intensity of horizontal snow transfer and the wind speed at the weathercock height is expressed by the following formula:

$$I = C \cdot V^3, \tag{2}$$

where $I$ is the intensity of horizontal snow transfer, m$^3$/m h; $C$ is the factor to proportionality which depends on density the snow; $V$ is the wind speed at the weathercock height, m/sec.

The volume of the snowbring to a highway at the end of the winter period from one direction ($W_{sb}$) is calculated according to the formula:

$$W_{sb} = W_t \cdot \sin(\alpha_r - \alpha_i), \tag{3}$$

where $\alpha_r$ is the direction of the highway, degree ; $\alpha_i$ is the direction of the wind, degree.

The volume of the snowbring to one side of the highway within the winter ($W_b$ ) is calculated according to the formula:

$$W_b = \sum_{i=1}^{7} W_{sb,i} \cdot \sin(\alpha_{\partial} - \alpha_i), \tag{4}$$

where $W_b$ is the amount of snow brought to one side of the road, m$^3$/m; $W_{sb,i}$ is the amount of snow transfer by one compass point, m$^3$/m; $\alpha_i$ is the azimuth of compass points, degree; $\alpha_r$ is road azimuth, degree.

For each direction of the road the number of compass point from which snow transfer is calculated equals 7. Counting the amount of snow transfer winds blowing at an angle less than 30° are not taken into consideration. Figure 1 gives the scheme of calculating of directions from which snow is brought to one side of the road, directed northward. The zone of each direction (at 16 compass points) is calculated by sector with the arc of 22,5°.

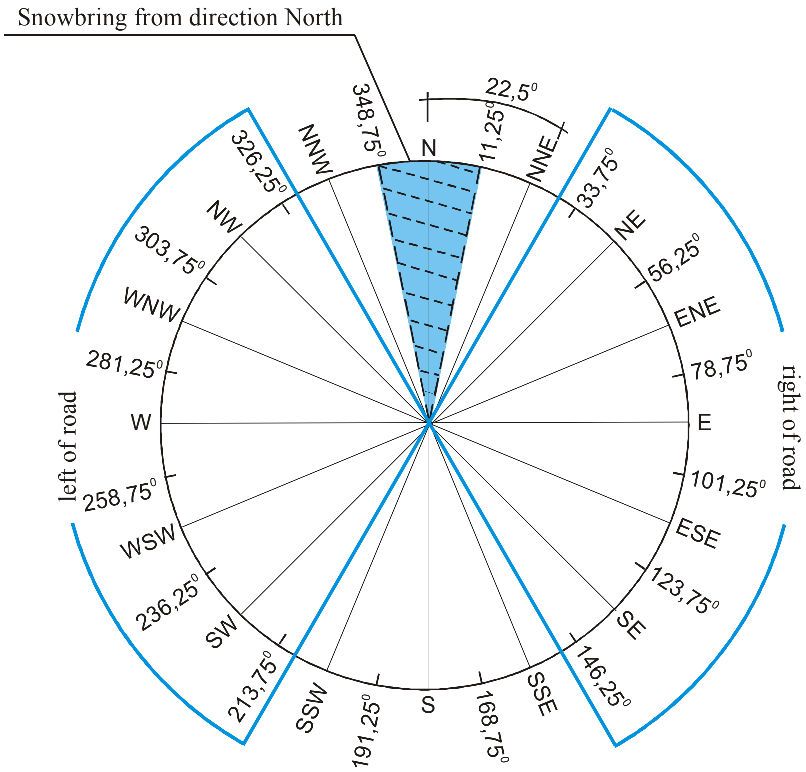



Fig. 1. Scheme of calculation of snowbring to the road directed on northward.

## 3. MODEL OF CALCULATING THE AMOUNT OF SNOW, DEPOSITED ON THE ROAD AFTER SNOWSTORM

There is a mode of calculating the amount of snow deposited on the road surface after snowstorm. There are chosen parameters influencing accumulation of snow on the road surface.

The general model of quantitative evaluation of snow dependence of roads at the next snowstorm or snowfall is the following:

$$W_{r,i} = f(h(t), a(t), t) + W_d(t) \tag{5}$$

where $W_{r,i}$ is a quantity of snow deposit on the road surface; $h(t)$ is parameters of outer factors (meteorological factors) are in the Table 1; $a(t)$ is road parameters are in the Table 2; $t$ is a time, $W_d(t)$ is the quantity of snow deposits accumulated by the moment of the next snowstorm or snowfall.

| *Components of the vector of weather factors* | *Name of parameter* | *Symbol of parameter* | *Unit* |
|---|---|---|---|
| $h_1(t)$ | atmospheric phenomenon (type of precipitation ) | | |
| $h_2(t)$ | time of beginning of the phenomenon | $t_n$ | hour |
| $h_3(t)$ | time of finishing of the phenomenon | $t_k$ | hour |
| $h_4(t)$ | wind speed | $V$ | m/sec |
| $h_5(t)$ | wind direction | $\alpha_в$ | compass point |
| $h_6(t)$ | temperature of air | $T$ | $^0C$ |
| $h_7(t)$ | duration of the phenomenon | $t$ | hour |
| $h_8(t)$ | intensity | $I$ | $m^3$/sec |
| $h_9(t)$ | density of snow deposit | $\delta$ | $t/m^3$ |

Table. 1. Meteorological factors.

| *Components of the vector of road factors* | *Name of parameter* | *Unit* |
|---|---|---|
| $a_1(t)$ | road direction | compass point |
| $a_2(t)$ | working mark (height of embankment, depth of ditch) | $H$ |
| | geometrical parameters of cross-section of road | |
| $a_3(t)$ | slopes ramp of ditch | $m_1$ |
| $a_4(t)$ | slopes ramp of embankment (ditch) | $m_2$ |
| $a_5(t)$ | slopes ramp of cuvette of ditch | $m_3$ |
| $a_6(t)$ | width of cuvette | $l_1$ |
| $a_7(t)$ | width of ditch shelf | $l_2$ |
| $a_8(t)$ | depth of cuvette | $h$ |
| $a_9(t)$ | width of road shoulder | $a$ |
| $a_{10}(t)$ | width of carriageway | $b$ |
| $a_{11}(t)$ | width of road surface | $B$ |
| $a_{12}(t)$ | cross-section slope of carriageway | $i_1$ |
| $a_{13}(t)$ | cross-section slope of road shoulder | $i_2$ |
| $a_{14}(t)$ | availability and type of snow protection | - |

Table. 2. Road factors.

Snow accumulated in ditches and at slops changes the geometrical parameters of cross-section of road. For its calculation the parameter of quantity of snow deposit $W_d(t)$ accumulated on road side is introduced. Value of the parameter depends on meteorological and road factors and calculated at precipitations, snow compression at melting and transportation of snow by road machines at snow cleaning from carriageway. The model takes into account the type of cross-section of road. There are models for low embankments, open and closed ditches due to the difference of their streamlining by windsnow flow.

**3.1 Model of quantitative evaluation of snow deposits on embankments**

For quantitative evaluation of snow deposits on embankments there is solution of the task of streamlining of the wedge by the flow of tough uncompressible liquid [3].

The scheme of calculating takes into account availability of ditches and have seven rated sections (Fig. 2).

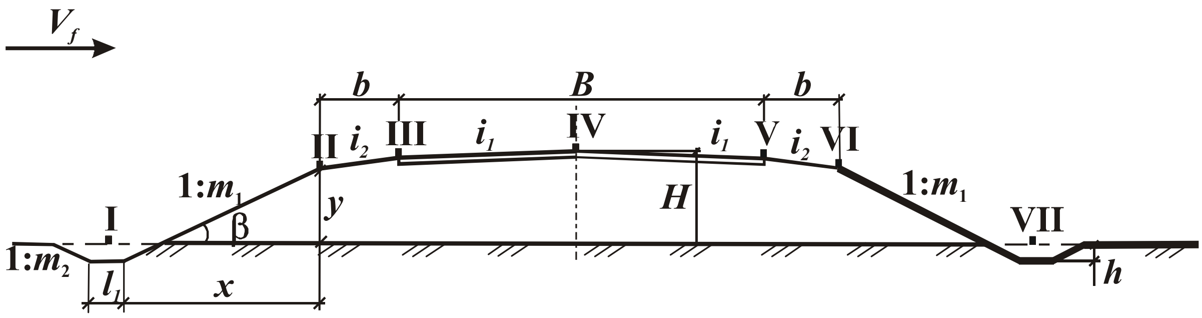



Fig. 2. Scheme of quantitative estimation of snow deposit on the embankments

At embankments snow accumulates in windward side of the ditch of first. Calculation of snow deposit at section I is based on geometrical parameters of the ditch. Maximum quantity of deposit in the windward ditch:

$$Q^I_{d.\max} = \frac{1}{2} h\left(2l_1 + h\left(m_1 + m_2\right)\right), \tag{6}$$

where $h$ is a depth of the ditch, m; $l_1$ is a width of the ditch, m; $m_1$, $m_2$ are a slope ramp of ditch.

If snow capacity of the windward ditch is more than the quantity of brought snow ($Q^I_{d.\max} > W_b$), than the quantity of snow deposit at section I equal the volume snowbring ($Q^I_{d.\max} = W_b$). If the condition is not observed than the quantity of snow deposit equals snow capacity of the ditch ($Q^I_d = Q^I_{d.\max}$), and then snow carried ($W_{b1}$) farther is calculated according to the formula:

$$W_{b1} = W_b - Q^I_d . \tag{7}$$

At sections II - IV calculations of snow deposit are done through snow loss ($\Pi$) caused by change of speed of windsnow flow:

$$\Pi = 1 - \left(\frac{V}{V_f}\right)^3 , \tag{8}$$

where $V_f$ is field wind speed, m/sec; $V = V(x, y)$ is the speed of windsnow flow in the point with coordinates $x$ and $y$ over embankment , m/sec.

Changes of speed of windsnow flow are calculated according to the formula:

$$\frac{V}{V_f} = x^m . \tag{9}$$

Factor considering the wedge angle is calculated according to the formula:

$$m = \frac{\beta}{2-\beta}, \tag{10}$$

where $\beta$ is the angle of wedge opening.

The angle of wedge opening is calculated through geometrical position of rated section:

$$\sin\beta = \frac{y}{\sqrt{x^2+y^2}}. \tag{11}$$

Formulas of calculation of snow quantity deposited on embankments and of snow quantity carried farther for sections II – VI are given in Table 3.

| ***Section number*** | ***Calculation formulae*** | | | |
|---|---|---|---|---|
| | ***of distance between the point of rise of streams and rated section*** | ***of height of rated section*** | ***of quantity of snow deposit at rated section*** | ***of quantity of snow carried past*** |
| II | $x = m_1 \cdot y$ | $y = H–(0{,}5B{\cdot}i_1+b{\cdot}i_2)$ | $Q^{II}_d = W_{b1} \cdot \Pi$ | $W_{b2} = W_{b1} - Q^{II}_d$ |
| III | $x = b$ | $y = b \cdot i_2$ | $Q^{III}_d = W_{b2} \cdot \Pi$ | $W_{b3} = W_{b2} - Q^{III}_d$ |
| IV | $x = 0{,}5B$ | $y = 0{,}5B \cdot i_1$ | $Q^{IV}_d = W_{b3} \cdot \Pi$ | $W_{b4} = W_{b3} - Q^{IV}_d$ |
| V | $x = 0{,}5B$ | $y = -\,0{,}5B \cdot i_1$ | $Q^{V}_d = W_{b4} \cdot \Pi$ | $W_{b5} = W_{b4} - Q^{V}_d$ |
| VI | $x = b$ | $y = -\,b \cdot i_2$ | $Q^{VI}_d = W_{b5} \cdot \Pi$ | $W_{b6} = W_{b5} - Q^{VI}_d$ |

Table. 3. Formulas of calculation of snow quantity deposited on the road surface.

At section VII on leeward side slope and in ditch quantity of snow deposit is calculated according to their geometrical parameters, total snow capacity of the slope and the ditch is calculated. Total snow capacity of slope is limited by location of snow surface 1:8 and can be calculated according to the formula:

$$Q^{VII}_{d.\max} = \frac{1}{2}h\left(2l_1 + h\left(m_1 + m_2\right)\right) + H^2\left(4 - \frac{1}{2}m_1\right). \tag{12}$$

Analysis of snow blockades of leeward side ditch is done similarly to wind ward ditch, and the quantity of snow carried farther ($W_{b7}$) is calculated according to the formula:

$$W_{b7} = W_{b6} - Q^{VII}_d. \tag{13}$$

Quantity of snow deposit on the road surface of embankments ($Q_d$) is calculated according to the formula:

$$Q_d = Q^{III}_d + Q^{IV}_d + Q^{V}_d + Q^{VI}_d. \tag{14}$$

**3.2 Model of the quantitative evaluation of snow deposit in open ditches**

At snowstorms into slopes of open ditches there are deposits of snow due to change of speed of windsnow flow. In calculation scheme (Fig.3) there are six characteristic sections at which change speed correlation ($V/V_f$) occurs.

To calculate dependence of share of snow fallen from windsnow flow (n) on slopes ramp (m) formula of A.K. Djunin is used [4]:

$$\frac{V}{V_f} = \sqrt{1 - \frac{1}{2}\left[erf\,\frac{h_n + y}{2ax} + erf\,\frac{h_n - y}{2ax}\right]}, \tag{15}$$

where $h_n$ is depth of lowering of surface of slope, m; $a$ is factor of turbulence (at natural conditions accepted a = 0,06); $x$ is abscissa counted from the top point of the threshold , m; $y$ is height of the point under consideration, m; erf ($h_n \pm y$) is error integral of Gauss.

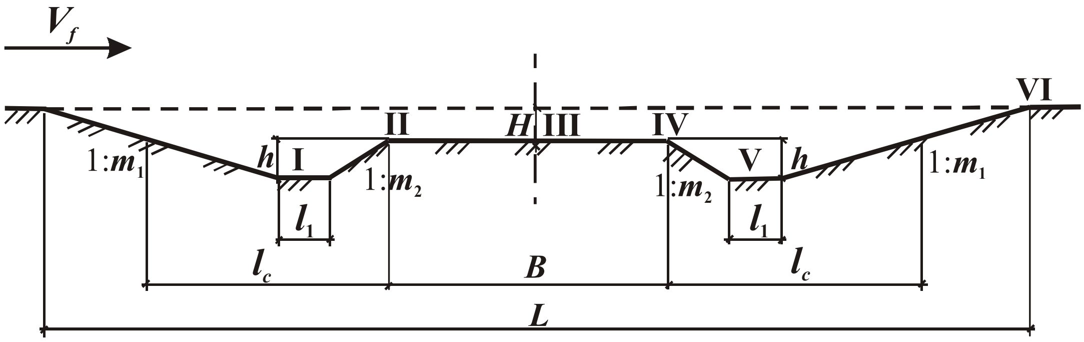



Fig. 3. Calculating scheme of quantitative evaluation of snow drifting of open ditches.

Thus knowing the volume of snowbring ($W_b$) quantity of snow deposited at the considered section of ditch can be calculated according to the formula:

$$Q_d = \Pi \cdot W_b, \tag{16}$$

where $\Pi$ is snow loss caused by change of speed of windsnow flow, according to the formula Eq. (8).

And the volume of snow carried farther ($W_{bi}$) is calculated according to the formula:

$$W_{bi} = W_b - Q_d. \tag{17}$$

Formulae of calculation of quantity of snow at considered sections are the same as the formulas for embankments given in Table 3.

Quantity of snow deposit on the road surface of open ditches ($Q_d$) is calculated according to the formula:

$$Q_d = Q_d^{III} + Q_d^{IV}. \tag{18}$$

For practical calculations the model of definition of quantity of snow in the opened ditches is simplified. As snow accumulates like equal layer in the opened ditches at blizzards the relation of speeds windsnow flow can be defined only for section I under the formula Eq. (15) [5].

Quantity of snow deposited at the considered section of ditch can be calculated according to the formula Eq. (16).

Average height of snow deposited is considered under the formula:

$$h_a = \frac{Q_d^I}{L}, \tag{19}$$

where $L$ is length of a surface of slopes, cuvettes and of road surface of the opened ditches, m.

Quantity of snow deposited on the road surface of open ditches ($Q_d$) is calculated according to the formula:

$$Q_d = h_a \cdot B, \tag{20}$$

where $B$ is width of road surface.

**3.3 Model of quantitative evaluation of snow deposit in closed ditches.**

Analysis of streamlining of closed ditch by windsnow flow allows making the conclusion that quantity of snow deposited on road can be calculated basing on geometrical calculations. Two calculation schemes should be used to calculate snow drifting of closed ditches depending on correlation between volumes of snowbring and snow capacity of ditches (Fig.4). The first scheme is used to calculate of snow deposited on the road surface when volume of snowbring exceeds the snow capacity of ditches. In this case the area of snow deposit on slope and in cuvette of ditch is limited by shaded polygon in the scheme.

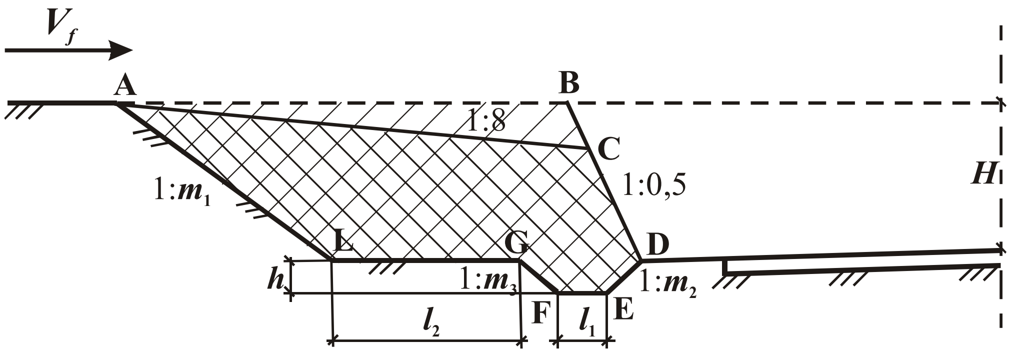



Fig. 4. Calculating scheme of quantitative evaluation of snow drifting of closed ditches.

Based on geometrical calculations maximum quantity of snow deposit on the windward slope of ditch per 1 linear meter can be calculated according to the formula:

$$Q_{sl.,cuv} = \left[ \frac{H^2 \cdot m_1}{2} + l_2 \cdot H + \frac{2l_1 + 2h(m_2 + m_3) - 0{,}5H}{2} \cdot H + \right.$$
$$\left. + \frac{2l_1 + h(m_2 + m_3)}{2} \cdot h \right] \cdot L, \tag{21}$$

The second calculation scheme is used when the quantity of snowbring does not exceed snow capacity of ditch. And the top surface of snow deposit is limited by the line AC with the base of slope towards the axis of road 1:8 [6].

Maximum quantity of snow deposit on the windward slope of ditch per one linear meter, in this case, can be calculated according to the formula:

$$Q'_{sl.,cuv} = \left[ \frac{H^2 \cdot m_1}{2} + l_2 \cdot H + \frac{2l_1 + 2h(m_2 + m_3) - 0{,}5H}{2} \cdot H + \right.$$
$$\left. + \frac{2l_1 + h(m_2 + m_3)}{2} \cdot h - 0{,}0625\left(H \cdot m_1 + l_1 + l_2 + h(m_2 + m_3) - 0{,}5H\right)^2 \right] \cdot L, \tag{22}$$

Knowing the volume of snowbring during the winter or during a single snowstorm ($W_b$) quantity of snow deposit on the road ($Q_d$) is calculated according to the formula:

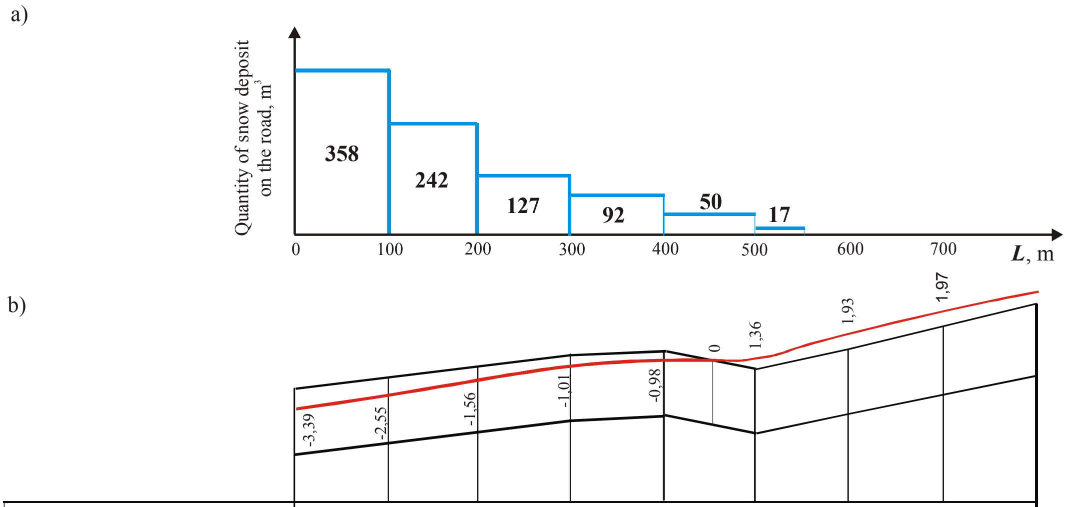
$$Q_d = W_b - Q_{sl,cuv}. \tag{23}$$

**4. APPLICATION OF MODEL OF THE QUANTITATIVE EVALUATION OF SNOW ON THE ROAD**

Models are realized in the form of the computer program.

The results of calculations are the registration of snow-bound parts and quantity of snow to be cleared after snowstorm on each snow-bound part of road, quantity of snow to be cleared after snowfall on a separate part of road and on the whole road. All coming out parameters can be calculated for any day during winter period.

The example of calculation for a site of road is presented on Figure 5.




| | | | |
|---|---|---|---|
| Volume of snowbring, m$^3$/m | 83 | | |
| Technical class of road | II | | |
| Road direction | SSE | | |
| Type of cross-section | Closed ditch | Opened ditch | Embankment |
| Stake | 1 2 3 4 5 6 7 | | |

Fig. 5. Graphic presentation of results of calculations:
a) diagram of change of quantity of snowstorm deposits on the road surface;
b) initial data for calculation quantity of snowstorm deposits on the road surface.

Calculations have been done for test parts. During experimental work adequateness of the models was tested according to the snow measurements. Data received from meteorological stations for corresponding winter periods were used to calculate the volume of snowbring.

Coincidence of calculated and actual data of quantity of snow deposits on average was 88 percent. At the experiment the volume of snow transported into ditches and onto slopes during snow-removal was not taken into consideration. Analysis of received results shows that with availability of such data coincidence will increase. Therefore the conclusion can be made about the possibility of application of the model for solution of the task of winter road maintenance.

## 5. REFERENCES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