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Satbayev University

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ИЗВЕСТИЯ

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METHOD OF CALCULATION AND FORECAST OF THE DEGREE OF SNOW CAPACITY OF CHANNELS

Abstract. The article substantiates the regularities of the formation of snowdrifts in the channel excavation based on field, laboratory and computational-theoretical studies, since the process of snow-bearing channels is insufficiently studied. During the operation of the Irtysh-Karaganda canal, the experience of studying and solving issues of determining optimal methods of combating these processes has been determined. The substantiation of the influence of the direction of the impact of the blizzard wind and the parameters of the channel excavation on the degree of its susceptibility to snowdrifts given. In addition, based on the assessment and forecast of the possible consequences of drifts, methods proposed to combat winter difficulties on the canals in the form of congestion and congestion phenomena, which leads to a decrease in the channel capacity up to the complete cessation of water supply. In this case, the wandering of the stream causes the re-formation of the channel. The water retention formed above the jamming zone contributes to its exit to the shores or the breakthrough of the accumulated snow and ice mass down the channel, below this section there is a subsidence of snow and ice cover to the bottom and shores. Such difficulties can paralyze the functioning of the water supply tract, causing the termination of water supply to consumers for a long time.

Based on theoretical layouts, the transfer of snow particles at different angles of attack and wind speeds affecting the formation of the channel recess slope is justified. The dynamics of changes in the conjugate values of the wind angle of attack and the slope coefficient of the snow - bearing profile at different values determined. Various schemes of snowdrift in trapezoidal and polygonal channels have calculated. The assessment of the state of snow-carrying capacity of the trapezoidal cross-section channel in various cases of the snow transfer process has carried out.

Key words: canal, snowdrift, canal slope, coefficient of natural slope of snowdrift, prevailing direction of blizzard wind, jam-jam phenomena, snow-free profile.

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АРНАЛАРДАҒЫ ҚАР ҮЙІНДІЛЕРІНІҢ ЕСЕПТЕУ ЖӘНЕ БОЛЖАУ ӘДІСІ

Аннотация. Мақалада табиғи жағдайда, зертханалық және теориялық- есептеу зерттеулері негізінде канал қазбаларындағы қардың пайда болу заңдылықтарының негіздемесі келтірілген, себебі каналдардың қардан тазарту процесі әлі жеткілікті деңгейде зерттелмеген. Ертіс-Қарағанды каналын пайдалану кезінде осы аталған процестермен күресудің оңтайлы тәсілдерін анықтау мәселелерін зерттеу және шешу тәжірибесі айқындалды. Боранды желдің және арнаны қазу параметрлерінің қар үйінділеріне әсер ету дәрежесіне әсері туралы негіздеме берілген. Сондай-ақ, сырғанаудың ықтимал салдарын бағалау және болжау негізінде каналдардағы қысқы қиындықтардың алдын-алу үшін, су беру толығымен тоқтатылғанға дейін каналдың өткізу қабілеттілігінің төмендеуіне әкелетін құбылыстардың кептелісі түрінде күресу әдістері ұсынылған. Бұл жағдайда, ағынның адасуы арнаның қайта құрылуына әкеледі. Су тіреуішінің қысымды-кептеліс аймағынан жоғары қалыптасқан жағалауға шығуына немесе жинақталған қар-мұз массасының арна бойымен төмен қарай сырылуына ықпал етеді және осы аймақтан төменгі ағын бойында қар-мұз жамылғысының түбіне және жағалауына шөгуі байқалады. Мұндай қиындықтар су құбыры жұмысын тоқтатып, тұтынушыларға ұзақ уақыт бойы су беруді тоқтатуына алып келеді.

Теориялық орналасулар негізінде қар бөлшектерінің әр түрлі жел есу бұрышы мен желдің жылдамдығымен тасымалдануына негізделеді және ол канал қазындысы беткейінің қалыптасуына әсер етеді. Желдің есу бұрышының коэффициенті мәндерінің және әр түрлі мәндердегі қарлы ппішінінің еңіс коэффициентінің өзгеру динамикасы анықталды. Есептеулер арқылы трапеция және полиогональды каналдардағы қардың әр түрлі сызбалары анықталды. Қар тасымалдау процесінің әр түрлі жағдайларында каналдардың трапециодальды қимасына қар жинақталу және жылжу жағдайына бағалау жүргізілген.

Түйінді сөздер: канал, қар үйіндісі, арна еңісі, қардың табиғи жылжу еңіс коэффициенті, қарлы боранның бағыты, кептеліс құбылыстары, қарсыз профиль.

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МЕТОДИКА РАСЧЕТА И ПРОГНОЗ СТЕПЕНИ СНЕГОЗАНОСИМОСТИ КАНАЛОВ

Аннотация. В статье на основании натурных, лабораторных и расчетно-теоретических исследований дается обоснование закономерностей формирования снежных заносов в выемке канала, так как процесс снегозаносимости каналов недостаточно изучен. При эксплуатации канала Иртыш-Караганда определен опыт изучения и решения вопросов определения оптимальных приемов борьбы с этими процессами. Дается обоснование влияния направления воздействия метелевого ветра и параметров выемки канала на степень подверженности ее снежным заносам. А также на основании оценки и прогноза возможных последствий заносов предлагаются способы борьбы по предупреждению зимних затруднений на каналах в виде заторно-зажорных явлений, которые приводят к уменьшению пропускной способности канала вплоть до полного прекращения подачи воды. При этом блуждание потока вызывает переформирование русла. Образованная выше зажорно-заторная зона подпора воды способствует ее выходу на берега или прорыву накопленной снежно-ледовой массы вниз по каналу, ниже этого участка наблюдается оседание снежно-ледового покрова на дно и берега. Такие затруднения могут парализовать функционирование работы водопроводящего тракта, вызывая прекращение водоподачи потребителям на длительное время.

На основе теоретических раскладок обоснован перенос снежных частиц при различном угле атаки и скорости ветра влияющих на формирование откоса выемки канала. Определена динамика изменения сопряженных значений угла атаки ветра и коэффициента откоса снегозаносимого профиля при различных значениях. Расчетным путем определены различные схемы снежного заноса в трапециадальных и полигональных каналах. Произведена оценка состояния снегозаносимости канала трапециодального сечения при различных случаях процесса снегопереноса.

Ключевые слова: канал, снегозаносимость, заложение откоса канала, коэффициент естественного откоса снежного заноса, преобладающее направление метелевого ветра, заторно-зажорные явления, снегонезаносимый профиль.

Introduction. In areas with strong snowstorms during the winter operation of canals, sections that run in a deep recess and are located perpendicular to the prevailing winds are of particular danger. Under the influence of snow masses of considerable thickness, the ice cover pressed through with the formation of jamming phenomena, which leads to a decrease in the throughput of the channel up to a complete cessation of water supply. In this case, the wandering of the stream causes the reformation of the channel (Brethouwer, 2021). The water backwater formed above the jamming zone contributes to its outflow to the banks or the breakthrough of the accumulated snow-ice mass down the channel, and below this section, the snow-ice cover settles to the bottom and banks (Dyunin, 1990).

The snow-carrying capacity of canals currently studied extremely insufficiently. There are no proven methods for calculating this phenomenon, which are necessary in the design. Some experience in the study of these issues has been accumulated in recent years in connection with the operation of the Irtysh-Karaganda canal (Trofimova et al, 2010). In addition, we have an attempt to generalize the long-term material available in relation to railways and roads, as well as to develop methods for combating this phenomenon.

Patterns of formation of drifts in channels. With a natural slope of a snow drift, the air flow, meeting on the way of advancement with the channel, flows around it according to the laws of aerodynamics. The embankment (cavalier) of the canal causes its narrowing along the vertical, leads to an increase in the speed in the lower layers, which excludes the possibility of snow drift within the windward slope and embankment bed. In contrast, the excavation of the channel causes the flow to expand vertically, as a result, the speed in the lower layers decreases, which creates conditions conducive to snowfall in the form of a skid.

Materials and basic methods. Theoretical and experimental studies (Ibrayev et al, 2022) established that the area of displacement of a turbulent jet flowing down from a certain threshold is limited by straight lines (Brethouwer, 2021). The upper boundary of spreading, which corresponds to the condition of maintaining the initial longitudinal velocity, has an angle of inclination to the horizon of the order of 5°, and the lower one, equal to zero longitudinal velocity, is about 10°. Hence it follows that for an irrotational flow around a recess, its opening angle should not exceed 10°, or the slope coefficient (m) should not be less than 6. However, this does not mean that the natural slope of a snow drift that forms in the channel channel under prolonged exposure to a certain wind force (velocity) must coincide with the line of zero longitudinal velocities, as some researchers admit (Trofimova et al, 2010).

The value of the coefficient of natural slope of a snow drift depends on the wind speed during a blizzard and the initial speed of snow transfer. With an increase in wind speed, the natural slope becomes steeper, and the coefficient decreases to 6, and with a decrease, it flattens.

According to a number of authors (Imanaliyev et al, 2022), the wind speed at which the transfer of snow particles on a horizontal terrain begins, ranges from 3 to 4 m/s, depending on the roughness of the underlying surface, the physical and mechanical properties of snow particles, and others. factors. It is quite obvious that in the presence of a slope, this value will be different (Trofimova et al, 2010). From the equilibrium condition of a snow particle on such a surface, it is easy to determine the initial transfer velocity:

$$V_{\text{н}}^{\varphi} = V_{\text{н}}\sqrt{cos\varphi \pm \frac{sin\varphi}{f_{\text{тр}}}}, \tag{1}$$

or the horizontal component:

$$U_{\text{н}}^{\varphi} = V_{\text{н}} \cos\varphi \sqrt{\cos\varphi \pm \frac{\sin\varphi}{f_{\text{тр}}}}, \tag{2}$$

where $V_{\text{н}}$ - initial snow transfer rate on sloping terrain;

φ - angle of inclination of the underlying surface;

$f_{\text{тр}}$ – coefficient of friction of snow particles on the underlying surface.

In formulas (1) and (2), the plus sign in the radical expression corresponds to the rise, the minus sign - to the descent of the underlying surface in the direction of the wind.

Verification calculations show that at an angle of inclination of the underlying surface = 10°, corresponding to the lee slope of the channel excavation, the value can be taken equal to, the correction factor in this case is 0.92–0.96 (Hunt and et all, 1988).

Based on the analysis of the change in the epora of the longitudinal velocities of the turbulent jet in the spreading zone. The values of the slope angle of the underlying surface of the slope coefficient were obtained, corresponding to the initial snow transfer velocity of 3 m/s: at wind speeds of 10, 15, 20 and 30 m/s, respectively - 3°40’ and 15 .7; 4°50’ and 11.8; 5°30’ and 10.3; 6°30’ and 8.9.

The values and characterize the natural slope of the snowdrift in the channel excavation at = 3 m/sec. As can be seen, their values do not correspond to the line of zero longitudinal velocities. Calculations of parameters of snow drift in channels.

We considered the influence of the angle of attack of the wind on the formation of a snowdrift (Hunt and et all, 1988). Its maximum parameters in the channel observed at perpendicular winds. The lower boundary of the maximum drift in normal wind direction is at a distance from the windward edge of the channel (Fig. 1, section 1-1). The cross-sectional area in this case is

$$F = \frac{1}{2}h^2(m_0 - m), \tag{3}$$

Where h - excavation depth subject to snow drift;

m - channel slope factor.

With oblique winds, the area of maximum drift in their direction (section 2-2) is found as

$$F = \frac{1}{2}h^2\left(m_0 - \frac{m}{sin\alpha}\right), \tag{4}$$

Where α - angle of influence of the wind to the axis of the channel.

The projection of this section onto the normal direction (section 3-3) is determined by the expression

$$F = \frac{1}{2}h^2\,(m_0 sin\alpha - m), \qquad (5)$$

We introduce the notation $K_m = \frac{m}{m_0 sin\alpha}$, then under the influence of wind of any direction, formula (5) will look like:

$$F = \frac{1}{2}m_0 h^2\, sin\alpha(1 - K_m), \qquad (6)$$

As the angle of attack α decreases, the lower boundary of the limiting snowdrift approaches the lee edge. At some ratio of the values of α and m, the equality can be realized, which means that the surface of the maximum drift coincides with the slope plane of the channel. This is the non-loadable profile that meets the condition (Karnovich and et al, 1986).

For all values $\alpha \le \frac{\arcsin m}{m_0}$, there will be no snowdrifts in the channel bed (Karnovich et al, 1986). The conjugate values of α and m here for the particular case m_0= 6 ... 12 are given in Table. 1. With a slope coefficient m≤2,5 and an angle of attack of the wind not higher than 15°, drifts are not observed.

Table 1 - The conjugate values of the angle of attack of the wind and the slope coefficient for a snow-covered profile at various m_0

m_0	The value of α at m									
	0,5	1,0	1,5	2,0	2,5	3,0	6,0	8,0	10,0	12,0
6	4°31'	9°43'	14°25'	19°13'	24°50'	30°00'	90°00'	-	-	-
8	3°26'	7°25'	10°56'	14°25'	18°03'	22°20'	48°33'	90°00'	-	-
10	2°52'	5°44'	8°38'	11°32'	14°30'	17°28'	36°51'	53°08'	90°00'	-
12	2°14'	4°32'	7°25'	9°44'	12°07'	14°25'	30°00'	42°03'	56°01'	90°00'

Table 1 (section 3-3) shows that with oblique winds, the natural slope of the snow drift, which is usually determined along the normal to the axis of the channel (roads and railways), is equal to $m_0 sin\alpha$. Its values found in the literature range from 5 to 15 and are explained by a different combination in real conditions of the speed of the snowstorm wind, its angle of attack and the initial speed of snow transfer (Imanalyiev et al, 2022). However, they not taken into account by researchers (Hunt and et all, 1988).

In the channel, under the influence of snowstorm snow, the drift gradually formed starting from the lee edge (Karnovich et al, 1986). Moreover, in the direction of the wind, it is formed with a natural slope m_0, steeply turning down the front edge, which we take as vertical (Zhaparkulova et al, 2021).

Calculation formulas for determining the cross-sectional area of various snowdrift patterns in the trapezoidal and polygonal channels summarized in Table 2. The following designations additionally introduced (Paipai et al, 2015):

$$K_{b_6} = \frac{b_6}{m_0 h sin\alpha}, \; K_h = \frac{h_1}{h}, \; К = \frac{m_1}{m_0 sin\alpha}, \; Km = \frac{m_2}{m_0 sin\alpha}, \qquad (7)$$

Where, *x* - the length of the incomplete snow drift, counted from the lee edge;

b_6- Intermediate berm width;

h_1 - Depth of excavation below intermediate berm to ice cover;

m_I - channel slope factor below intermediate berm;

m_2 - the same, above the intermediate berm.

It should note that schemes 2.1–2.5 and the corresponding calculation formulas are also applicable for a channel with a cavalier. In hydro technical practice (Nedrigi, 1983), in order to avoid time-consuming calculations when assessing the parameters of snowdrift on channels, it recommended to use the nomograms shown for schemes 1.4 and 1.3, respectively (Table 2).

Depending on the ratio of the slope coefficient and the angle of attack of the wind, the channels can have snow-bearing and snow-bearing profiles. Formula (7) serves as a criterion for such a separation (Paipai and et all, 2015).

This process can be completed if the storage capacity of the canal bed is fully used, and incomplete - if the capacity is not used (Mukhtarov et all, 2022). A completed skid considered limiting if its lower limit remains on the ice cover (Table 2, Schemes 1.1 and 2.1) and non-limiting if it reaches the windward slope. Incomplete snowdrift accumulates within the windward slope or reaches the ice cover (Jiang Feng et all, 2020).

Forecast of the degree of snow covering of the channel bed. It is of interest to assess the degree of snowdrift in a channel of a trapezoidal section in various cases of the completeness of the snowdrift process (Karnovich et all, 1986):

1. The lower boundary goes to the windward slope with the width of the channel along the bottom equal to zero $Kb=2K_m$

$$\frac{F_c}{F_k} = \frac{1 - K_m}{1 + K_m}; \qquad (8)$$

2. Snow drift goes to the windward slope:

$$\frac{F_c}{F_k} = 1 - \frac{1}{2}\frac{K_B^2}{(K_B - K_m)(1 + K_m)}; \qquad (9)$$

3. Ends on the opposite edge:

$$\frac{F_c}{F_k} = \frac{1 - K_m}{2}; \qquad (10)$$

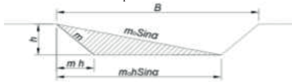
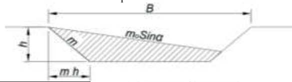
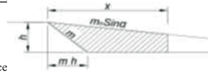
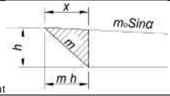
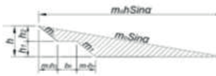
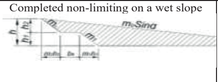
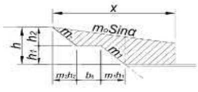
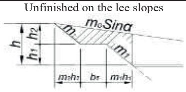
4. The lower border remains on the ice:

$$\frac{F_c}{F_k} = \frac{1}{2}\frac{1 - K_m}{K_B - K_m}, \qquad (11)$$

where: *F*- cross-sectional area of a snowdrift in a canal;

F_k- the same, channel channels above the ice cover (Kitaev et all, 2010).

Table 2. Summary table for calculating the snow carrying capacity of channels.

Schematic numbers	Snow drift patterns	Application conditions	Calculation formulas	
		1. Trapezoidal channel		
1.1	Completed Ultimate 	$K_B \ge 1 + K_m$	$F = \frac{1}{2} m_0 h^2 \sin\alpha (1 - K_m)$	(8)
1.2	Completed unlimited 		$F = \frac{1}{2} m_0 h^2 \sin\alpha \left[(1 - K_m) - \frac{(1 + K_m - K_B)^2}{1 + K_m}\right]$	(9)
1.3	 Unfinished on ice	$K_m \le K_X \le 1$	$F_X = \frac{1}{2} m_0 h^2 \sin\alpha \left[(1 - K_m) - (1 - K_X)^2\right]$	(10)
1.4	 Unfinished on the lee escarpment	$K_X = K_m$	$F_0 = \frac{1}{2} m_0 h^2 \sin\alpha K_m (1 - K_m)$	(11)
		2. Polygon channel		
2.1	Completed Ultimate 	$K_B \ge \left[1 + K_{m_1} K_{h_1} + K_{b_6} + K_{m_2}(1 - K_{h_1})\right]$	$F = \frac{1}{2} m_0 h^2 \sin\alpha \left[(1 - K_{m_1} K_{h_1}^2) - K_{m_2}(1 - K_{h_1}^2) - 2K_{h_1} K_{b_6}\right]$	(12)
2.2	Completed non-limiting on a wet slope 	$[(1+K_{m_2})(1-K_{h_1})+K(b_6)] \le K_B \le [1+K(m_1)K(h_1)+K(b_6)+K(m_2)(1-K(h_1))]$	$= \frac{1}{2} m_0 h^2 \sin\alpha \left\{[(1-K_{m_1}K_{h_1}^2)-K_{m_2}(1-K_{h_1}^2)-2K_{h_1}K_b] - \frac{[1+K_{m_1}K_{h_1}+K_{b_6}+K_{m_2}(1-K_{h_1})-K_B]^2}{1+K_m}\right\}$	(13)
2.3	Completed non-limiting on a dry slope 	$2[K(m_1)K(h_1)+K(b_6)+K(m_2)(1-K(h_1))] \le K_b \le (1+K_{m_2})(1-K_{h_1})$	$F = \frac{1}{2} m_0 h^2 \sin\alpha \left[(1-K_{m_1}K_{h_1}^2)-K_{m_2}(1-K_{h_1}^2)-4K_{h_1}K_{b_6}-\frac{(1+K_{m_2}-K_B)^2}{1+K_{m_2}}\right]$	(14)
2.4	Unfinished on ice 	$[K(m_1)K(h_1)+K(b_6)+K(m_1)(1-K(h_1))] \le K_X \le 1$	$F_X = \frac{1}{2} m_0 h^2 \sin\alpha \left[(1-K_{m_1}K_{h_1}^2)-K_{m_2}(1-K_{h_1})^2-2K_{h_1}K_{b_6}-(1-K_X)^2\right]$	(15)
2.5	Unfinished on the lee slopes 	$K_X = K(m_1)K(h_1)+K(b_6)+K(m_2)(1-K(h_1))$	$F_0 = \frac{1}{2} m_0 h^2 \sin\alpha \left\{(1-K_{m_1}K_{h_1}^2)-K_{m_2}(1-K_{h_1})^2-2K_{h_1}K_{b_6}-[1-K_{m_2}(1-K_{h_1})-K_{b_6}-K_{m_1}K_{h_1}]^2\right\}$	(16)

Results and discussions. For small values of K_B i.e. with deep recesses, the greatest snow carrying is observed. As the channel spreads or increases, it K_B decreases. The influence K_m is also not the same: it will be maximum at small K_B and minimum K_B - at large (Mokrov and et all, 2010).

The area of the graph between curve 1 and straight line 3 refers to the completed non-limiting snowdrift and between straight line 3 and the axis K_m - to the completed limit. In the latter case, the maximum relative snow carrying capacity of the channel is 0.5 (Rustem and et all, 2021).

At $\frac{F_c}{F_k}$ >0.5, only complete non-limiting snowdrift is possible, and at $\frac{F_c}{F_k}$ <0.5, both limiting and unlimiting (Panpai and et all, 2015).

Skidding within the lee slope and intermediate berm does not affect the ice cover and considered safe or acceptable for canal operation. Access to the ice cover can also be safe or acceptable if the skid height does not exceed the allowable value, and vice versa (Paipai and et all, 2015).

Choosing the best way to deal with snowdrift (Hunt, 1988). We will carry out further analysis on the example of a channel with a trapezoidal section. In this case, the snow capacity of the lee slope determined by formula (11).

Denote by the depth $h_{кр}$ of the excavation at which the allowable height of snowdrift on the ice cover ensured. These values related by the relation:

$$h_{kp} = \frac{h_c^{доп}}{1-K_m} \quad (12)$$

The snow capacity of the slope with the depth $h_{кр}$ of excavation will be equal to

$$F_0^{(h_{kp})} = \frac{1}{2} m_0 h_{kp}^2 sin\alpha K_m (1 - K_m). \quad (13)$$

Then the relation $F_0 / F_0^{(h_{kp})}$ expressed as follows:

$$\frac{F_0}{F_0^{(h_{kp})}} = \left(\frac{h}{h_{kp}}\right)^2, \quad (14)$$

или

$$\frac{F_0}{F_0^{(h_{kp})}} = [[h/(h_c^{доп}) (1 - K_m)]]^2, \quad (15)$$

A graphical representation of dependence (15) shown, where the curve corresponds to the condition of equality of snow supply to the snow capacity channel of its lee slope, and the straight line parallel to the axis $F_0 / F_0^{(h_{kp})}$- the condition of equality of the depth of the excavation, the permissible height of the snow drift on the ice cover. (Grechishchev et al, 2012).

Therefore, only zone 2 needs measures against snowdrift. The nature of such works depends on the ratio between the volumes of snow brought to the channel and the snow capacity of its lee slope h, as well as between the depth $h_{кр}$ of the excavation and the critical depth. With a slight excess of the first indicator over the second, it is advisable to increase the snow capacity of the lee slope due to its location, the creation of an intermediate berm, or to provide for the simplest low-power protective devices. Analysis of formula (11) shows that the highest snow capacity of the slope is observed at K_m=0,5. Therefore, the position of slopes can be justified only up to Km=0,5 (Loitsyansky, 1973).

In cases where the depth of the excavation is slightly higher than its critical value, it is advisable to take measures to reduce the drift height on the ice cover to an acceptable value. This is achieved by cutting off some part of the canal edge with a slope factor $m_0 sin\alpha$. This method must be used for large volumes of snow.

Conclusion. The choice of the optimal method of combating snow resistance was determined on the basis of a multifactorial analysis of the relationships between the volume of snow transfer into the channel and the snow capacity of its slope, the depth of the opening and the critical depth of the trapezoidal channel.

The final choice of measures, consisting in the positioning of lee slopes, cutting the edge of the channel, the use of snow protection devices of various designs, must carried out based on technical and economic calculations for comparing options.

From the equilibrium state of snow particles on the surface, the transfer rate was determined depending on the roughness of the lower surface, the physical and mechanical properties of snow particles and other factors, which makes it possible to determine and justify the following conditions:

The natural slope m_0 of the snowdrift V_H in the channel depends on the initial speed of snow transport and the speed of the snowstorm wind V_0. For example at V_H = 3-4 m/s and V_0 = 20-25 m/s m_0 =10 obtained.

The snow profile of the channel and the criterion for its evaluation depend on the slope coefficient of the channel and the angle of attack of the blizzard line.

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