Conditions of occurrence of ice formations and dense snow on the road surface

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Abstract. The article presents the types of possible snow and ice deposits on the road surface, the conditions of their occurrence, physical and mechanical properties and the duration of their formation. The conditions of snow transfer and possible conditions for the occurrence of snowfall and the process of its formation are analyzed. Information about the frequency distribution of snow in Russia is provided and the analysis of the dependence of the number of snowfalls on air temperature is performed. Data analysis was performed on the thickness of a possible compacted snow layer on the road surface, on the number of cases of ground icing on road and airfield surfaces depending on temperature and air humidity.

1. Introduction
Snow falls on the road in two ways: as a result of snowfalls and wind snow transfer. At the same time, the volume and speed of snow on the road can vary within a very wide range. So in the Nizhny Novgorod region for the year on average about 500 mm of rainfall, of which 30% falls on the cold period. It should be noted that in winter there is a maximum of days with rainfall of more than 0.1 mm (equivalent to snow thickness of more than 1 mm), but only 10% of rainfall falls more than 5 mm per day (50 mm of snow cover height). The daily maximum rainfall is 15...20 mm (150...200 mm height of snow cover per day).

The duration of snowfall per day on average 8...9 hours, sometimes 60...70 h, and the absolute maximum is the value recorded in December 1971, when the duration of the snowfall amounted to 125 hours. Average duration of rainfall is about 200 h per month, but in November – December, this value could reach 280...370 h [1].

2. Research methodology and results
All types of snow–ice formations formed on the road surface, according to external signs are divided into loose snow, dense snow, glassy ice. The snow accumulation on the road surface occurs as a result of rainfall and wind snow transfer arising due to road surface unevenness and minor obstacles also affected the slope of the surface relative to the direction of the snowstorm [2].
Loose snow is deposited on the road surface in the form of an even layer in thickness. Deposits are formed during snowfall in windless weather. The density of newly–fallen snow can vary from 60 to 200 kg/m$^3$. Depending on the moisture content of the snow can be dry, humidity and wet. In the presence of a layer of loose snow on the road surface, the coefficient of adhesion of tires with the coating is reduced to 0.2 [3], [4].

Wind speed determines the amount of snow carried, and the direction–areas of accumulation. The minimum wind speed at which the transfer of dry newly–fallen snow begins is 3.5–4.5 m/s and is determined by the snow characteristics [5].

In a calm snowfall or blizzard (wind speed up to 3 m/s), a uniform snow cover with a thickness of 0.01–0.3 m, a density of 80–150 kg/m$^3$ is formed. Denser snow deposits are formed during a snowstorm (at wind speeds of more than 10 m/s density reaches 250 – 350 kg/m$^3$), when snow particles are transferred above the snow cover. The density of such snow formations depends on the wind speed. It is customary to evaluate roads in 5 categories, depending on the accumulation of snow as a result of snow transfer (table 1.) [5].

| Accumulation of snow as a result of snow transfer | Class accumulation of snow as a result of snow transfer | The value of the indicators | The average volume of snow transfer on the road $q_{av}$ (thous. m$^3$/km) | The maximum amount of snow transfer on the road $q_{cm}$ (thous. m$^3$/km) |
|--------------------------------------------------|-------------------------------------------------------|----------------------------|-------------------------------------------------|-------------------------------------------------|
| Very strong                                      | 1                                                     | >0.80                      | >35                                             | >100                                            |
| Strong                                           | 2                                                     | 0.51–0.80                  | 21–35                                           | 61–100                                          |
| Average                                          | 3                                                     | 0.26–0.50                  | 11–20                                           | 36–60                                           |
| Weak                                             | 4                                                     | 0.11–0.25                  | 6–20                                            | 16–35                                           |
| Small                                            | 5                                                     | <0.10                      | <5                                              | <15                                             |

The studies of G. V. Belobgeskogo [6] developed zoning of the USSR territory according to the complexity of snow control on the seven distinctive zones. The light areas of snow control are areas where snowfall is 5 – 15 over the winter, snow depth is 0.1–0.2 m, and the volume of snow transfer 25–30 m/m$^3$. Areas of difficult snow removal include tundra and steppe areas with a significant amount of snowfall. So in this area includes both the Arkhangelsk and Murmansk oblast, and Altai Krai, Orenburg and Samara region, where a minor amount of snow the size of his snow transfer can reach 1000 m/m$^3$. To areas particularly challenging snow control is the territory of Chukotka, the Northern part of Yakutia and the Kamchatka region, where snowfall in winter exceeds 60, the snow depth can reach 2 m, and the volume of snow transfer 1000 m/m$^3$. The remaining parts of the Russian Federation belong to the areas with medium and difficult complexity, they include the Krasnoyarsk territory [5].

Snow cover in some regions of the Russian Federation is up to 11.5 months a year and, in fact, does not have time to completely melt, as for the complete melting of snow requires 20–25 days [7].

Rainfall forming snow deposits on the earth's surface is characterized by zonal distribution. In different climatic regions there is a significant difference in average air temperatures (table. 2) at which snow falls [8].

| City   | Average temperature during snowfall, °C, by month |
|--------|--------------------------------------------------|
|        | November | December | January | February | March    |
| Bratsk | –11.6    | –17.5    | –18.1   | –20.7    | –14.8    |
Table 2 shows that the most frequent snow falls in the central regions of the European part of Russia at temperatures up to –10°C in Siberia up to –20°C.

Formation of dense snow (Figure 1) occurs in the presence of wet snow on the road surface under the influence of vehicles and certain meteorological conditions. It has a thickness – from a few millimeters to several tens – and a density of 300 to 600 kg/m³.

The greatest probability of formation of dense snow occurs under the following weather conditions:

- snowfall at air temperature from –0 °C to –6 °C;
- at air temperature from –6 °C to –10 °C and humidity above 90 %;
- at positive temperatures and high intensity of snowfall (more than 0.6 mm/h), (snow does not have time to melt on the surface and is compacted by tires of vehicles) [3].

Figure 1. Examples of roads with different amounts of snow on the roadway: a – with fully cleared the snow from the roadway; b – partially cleaned the snow from the roadway; c – the road with its usual dense snow.

Snow has the property of changing its physical characteristics (density, strength) under the influence of vehicle tires. The process of forming a dense snow includes three stages:

- mechanical compaction of snow (formed dense snow density 350–500 kg/m3). In this case, the coefficient of adhesion can reach 0.20–0.25;
- the gradual formation of ice on its surface as a result of periodic freezing and thawing (from the friction of tires of vehicles) of the upper layer of the dense snow. The density of such deposits is 600–650 kg / m3;
- further compaction and freezing of the dense snow until it turns into solid ice with a density of 900 kg/m3. The coefficient of adhesion is reduced to 0.1–0.15.

The process of formation of this type of icing affects the air temperature (formed faster at 0 °C, slows down at below –10 °C). Water film on the snow or ice surface is formed during thaws, when the coating occurs dense snow or ice. In this case, the coefficient of adhesion reaches the minimum values 0.03–0.15 [9].

The thickness of the dense snow depends on the amount of rainfall, the frequency of rainfall and their nature. The intense increase in the thickness of the dense snow is observed in the period from November to January, as this period accounts for more than half of all rainfall in winter. Comparison of rainfall and thickness of dense snow shows that in November 40% of snow fell turned into dense snow, in December 35% and January 30% [10], [11]. The decrease in the amount of snow turned into dense snow formations is explained by a decrease in air temperature and a decrease in the intensity of
snowfalls.

Map–diagram of the potential power of dense snow density of 500 kg/m$^3$ for the South of Eastern Siberia developed A. A. Mayevsky (1987), which is based on data on snow cover [12]. On the hilly plains of the South of Eastern Siberia, the thickness of the dense snow reaches 200 mm, and in the mountains of the Sayano–Baikal region exceeds 500 mm.

The formation of vitreous ice on the road surface is the most dangerous phenomenon. It appears on the coating as a smooth glassy film with a thickness of 1 to 3 mm (density 700–900 kg/m$^3$, adhesion coefficient from 0.08 to 0.15) and occasionally as a matte white rough crust (density 500–700 kg/m$^3$) with a thickness of 10 mm or more [3].

The formation of winter slippery (varies from 5 to 50 cases per year) on roads depends on meteorological conditions and thermal properties of road surfaces. The most common case is the formation of ice on the coating as a result of freezing raindrops, drizzle, fog directly on the coating or in the surface layer of air; ice crust is formed in winter at air temperatures from +4 to −20 °C: 55% of cases fall on the period 0...−5 °C; 80% for a period of +2...−6 °C; 90% for a period of +2...−15 °C. Relative humidity has an important influence on the formation of ice conditions [9].

For practical purposes, it is essential to identify the relationship of winter slippery road surfaces with meteorological conditions. In tables 3 and 4 data on the formation of ground icing on road and airfield surfaces at different temperatures and humidity are presented [13].

**Table 3.** Number of cases of ground icing on road and airfield surfaces at different air temperatures.

| Air temperature | Number of cases of ground icing | % of the total number of cases |
|-----------------|---------------------------------|------------------------------|
| от +4 до 0      | 116                             | 15                           |
| от 0 до −5      | 464                             | 54                           |
| от −5 до −10    | 212                             | 26                           |
| от −10 до −15   | 34                              | 4                            |
| от −1 до −20    | 7                               | 1                            |
| Итого           | 803                             | 100                          |

**Table 4.** Number of cases of formation of ground icing on road and airfield surfaces at different humidity.

| Relative humidity % | Number of cases of ground icing | % of the total number of cases |
|---------------------|---------------------------------|------------------------------|
| 90 – 100            | 70                              | 41                           |
| 80 – 90             | 25                              | 15                           |
| 70 – 80             | 55                              | 32                           |
| 60 – 70             | 10                              | 6                            |
| 50 – 60             | 1                               | 0,5                          |
| 40 – 50             | 1                               | 0,5                          |
| Менее 40           | 8                               | 5                            |
| Итого               | 170                             | 100                          |

After analyzing the data table, 4 and 5 it can be seen that 95% of icing occurs at temperatures from +4 °C to −10 °C and 88% of cases at a relative humidity of 70–100%.

There are several classifications of icy–frosty phenomena and various types of winter slipperiness of road and airfield pavements, which are based on certain concepts: processes of formation, structure of sediments, physical properties, technology liquidation, etc.. They can be grouped into three groups:

- classification of ground icing species used in meteorology [12] – [15];
- classification of types of icing of road surfaces and runways of airfields [16] – [21];
- the simplest classification of types of winter slippery appearance or technology works for maintenance of roads and airfields [3], [22] – [26];

Types of winter slippery artificial coatings, depending on the conditions of formation are divided into five groups. The first group includes those types of winter slippery, which leads to the formation of freezing moisture available on the coating, which occurs from a sudden decrease in air temperature to 0 °C and below. Rainfall may be absent. This type of icing forecasters called ice [9].

Another way of icing is the fall of sleet or rain at a positive air temperature and further freezing when the temperature drops to negative. The area of ice formation depends on the thickness of the water film, negative air temperature, wind speed, thermal resistance of the road structure.

The rate of ice formation depends on the thermal properties of the roadway. The thickness of the ice layer can be from 1 mm to 2–3 cm and depends on the micro–roughness and evenness of the coatings and the water layer. This type of ice is characterized by a very low coefficient of adhesion (about 0,08–0,15), the homogeneity of the vitreous ice, the homogeneity of the structure throughout the thickness of the ice layer. The ice density reaches 900 kg/m³.

The second group of icing include those types of winter slippery that occur on the dry surface of the road surface due to the crystallization of moisture from the air at a coating temperature below the dew point (radiation frost, crystalline plaque, black ice, etc.). The temperature range of frost formation is from −7 to −40 °C. Frost formation is possible at a relative humidity of 80–100% in clear windless weather, in which there is a negative heat balance. Rainfall is absent.

The third group consists of those icing types, which are formed in the freezing rain to cover with subzero temperature (solid, granular, frost).

The fourth group combined these types of slipperiness, which are formed by deposition of supercooled rainfall, these include rime ice granular.

Supercooled rain was observed at temperatures up to −5 °C, supercooled drizzle and up to −10 °C. the Rate of formation of ice high — 1 to 5 h. the Thickness of the crust of ice 1–3 mm, rarely to 5 mm, ice density of 700–900 kg/m³. This group include condensation type of glaze–clear ice generation when the coating is not deposited supercooled liquid droplets and ice crystals and drizzle with specific features: matte–white, heterogeneous, loose laminated structure of ice, low density (500–700 kg/m³), more heterogeneity thickness (3–10 mm), a higher coefficient of friction (0,15 to 0,20).

A characteristic feature of meteorological conditions for this type of ice: thaw after long frosts; weak frost weather, (t = 1...6 °C) and mists; low positive temperature (t = +4...+ 1 °C), and fogs at road surface temperature t = −1–−5 °C [9].

The fifth group consists of all types of winter slippery formed during compaction snow on the road surface (dense snow, icy and melting snow, melted snow) [9].

All types of icing artificial coatings have their own distinctive features–color, surface structure and physical properties – density, strength, adhesion to coatings. The advantage of these classifications is that in addition to the physics of icing and meteorological conditions, they take into account such a factor as the temperature of the coating. On the basis of these classifications, the authors identified weather and road factors affecting the formation of various types of winter slippery, investigated the conditions of their formation.

For practical purposes, road operators do not need to divide snow and ice deposits into a large number of species, depending on their origin. They use a simpler classification, which is based on a clear distinction between the types of winter slippery both in appearance and physical properties [3]. Snow–ice deposits formed on the surface of roads and airfields are divided according to their physical condition into the following types:

- Loose snow deposits.
- Solid snow or snow–ice formations.
- Induced ice or melted snow occurs as a result of freezing of snow and ice previously melted by gas jets.
• Vitreous ice.
• Granular ice differs from vitreous both in physical and mechanical properties and in appearance. On the road surface, deposits are formed in the form of a thick crust (10 mm or more) of a matte white color [27].
• Ice – a layer of smooth glassy ice formed on the surface of roads and runways of airfields as a result of freezing meltwater, rain or frost.

3. Conclusions
It is established that the accumulation of snow on the road surface occurs as a result of rainfall and wind snow transfer. The slope of the surface in relation to the direction of Blizzard winds and the presence of minor bumps and obstacles on the road surface have a great influence.

Wind speed determines the amount of snow carried, and the direction–areas of accumulation. The minimum wind speed at which the transfer of dry freshly fallen snow begins is 3.5–4.5 m/s and is determined by the snow characteristics. The nature of rainfall, their type, number, frequency of repetition, distribution by month, affects the temperature regime, 95 % of all cases of icing of road surfaces occurs at a temperature of 0 °C to – 10 °C. Sediments forming snow deposits on the earth's surface are characterized by zonal distribution. In different climatic regions there is a significant difference in the average temperatures at which snow falls. The formation of dense snow occurs in the presence of wet snow on the road surface under the action of compacting loads from the tires of vehicles and certain meteorological conditions.

Snow has the property of changing its physical characteristics (density, strength) under the influence of vehicle tires. The thickness of the dense snow depends on the amount of rainfall, the frequency of rainfall and their nature.

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