Snow as building material for construction of technological along-the-route roads of main pipelines

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Abstract. The article deals with the process of compacting snow in a closed volume with the use of vacuum processing for the construction of technological along-the-route roads of main pipelines. The relevance of the chosen study is substantiated; methods and designs for snow compaction are considered. The publication activity and defenses of doctoral and candidate dissertations on the research subject are analyzed. Patent analysis of existing methods and equipment for snow compaction with indication of their disadvantages is carried out. A design calculation was carried out using computer programs in which a strength calculation was performed to identify the most stressed places in the construction of a vibrating hydraulic tyre-type roller. A 3D model of the experimental setup was developed.

1. Introduction

During the construction and operation of main pipelines, it is necessary to provide transportation along the pipeline, as well as access to the nearest ports, motor roads and technological bases. The construction of capital roads is associated with significant financial costs and as a rule temporary roads are being built.

In regions with stable negative temperatures, temporary snow-ice roads are the most rational. The main road building materials for the construction of this type of roads are snow and ice. Snow is prepared before laying in the road bed, and ice is used in a crushed form as a solid filler or directly as a base.

Snow-ice roads must ensure uninterrupted traffic of the technological transport with the specified design loads and speeds, be built at a rapid pace with the maximum use of means of mechanization, as well as be strong and stable during the design life [1].

The undoubted advantage of temporary winter roads is their versatility, cheapness and the possibility of laying practically on any terrain, including waterways, swamps, etc.

With a small road traffic intensity, a simple construction of compacted snow is enough, but with high traffic intensities or high design loads, it is necessary to build a roadbed from pre-prepared snow with a given density and humidity.

To determine the optimum parameters of snow and to develop the working elements of snow-compacting and snow-wetting machines, the authors have been conducting theoretical and experimental studies for many years.

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Purpose of the study is the process of compacting snow in a closed volume with the use of vacuum processing for the construction of technological along-the-route roads of main pipelines.

Objectives of the study:

- to analyze the publication activity and defenses of dissertations on the research topic;
- to develop and justify the design of an experimental installation for compaction of snow with the use of the vacuum processing;
- to study the effect of vacuum parameters and compaction regimes on the intensity of the snow compaction process;
- to develop a generalized mathematical model "Vacuum compaction- snow".

2. Materials and methods

This problem has actively been studied by the authors. Egorov A.L. in his thesis presented a specialized machine with a snow-compacting element. The main idea was introduction of the process of snow compaction during its loading into vehicles. To carry out experimental studies, an installation was developed and constructed that makes it possible to obtain dependencies of the applied load on the change in the final density, for different sizes of dies. On the basis of the proposed mathematical model, a formula is derived for finding the necessary force in working member F to create a block of required density p and size S.

In addition, in the course of the study, regularities in the variation of snow density were revealed, and also rational geometric and physical parameters of snow blocks were established.

The research was continued by Sharukha A.V. In his work by the example of the construction of snow-ice roads, he proposed supplementing the technology by introducing vibration into the snow-briquetting process. In the course of the study, the necessary load parameters were found to produce briquettes of the required density. A mathematical tool for calculating the parameters of the working element of the snow-removing machine was also developed. In the thesis, the processes occurring in the vibro-compaction of snow in a closed volume are considered [2,3].

To carry out the experiments, the authors used an installation based on a vibration platform and shown in Fig. 1.

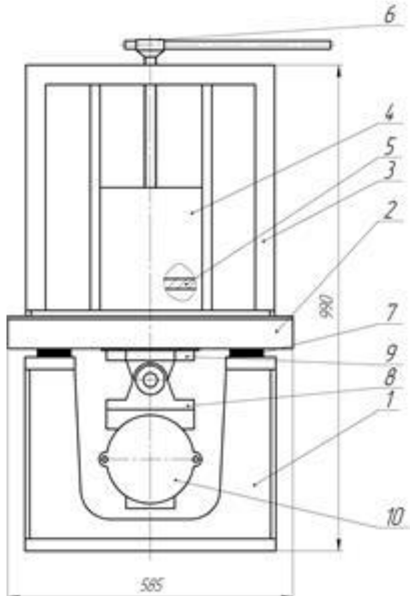

Figure 1. Installation for vibro-compaction of snow
where, 1–stand, 2–platform, 3–frame, 4–shape, 5– positive die, 6 – screw with handle, 7– elastic element (spring), 8 – lower support, 9– upper support, 10 – vibro-exciter.

After the production of snow briquettes, the values of their mass and geometric dimensions were recorded.

As a result of processing experimental data, numerical coefficients of mathematical models were obtained.

The result of these studies is the proof of the hypothesis of the rational use of vibration in the process of snow compaction, and it is also proved that when using vibration in a closed volume, an effect can be obtained in the form of saving costs for compaction.

Bykov V.Yu., a researcher from MADI (Moscow Automobile and Road Construction State Technical University), also carried out studies in this field. A feature of his scientific works is an increase in the efficiency of the process of pressing snow due to its vacuum processing. It was found that snow has such physical properties as porosity and the resulting air permeability of snow. It is noted that the nature of the interrelation between air permeability and porosity depends most strongly on the structure of snow and, in particular, on the grain sizes [4].

The experimental stand (Fig. 2) makes it possible to carry out a complex of studies of the snow compaction process under various conditions, including vacuum processing. The stand is equipped with automated systems for recording and processing a wide range of experimental data.

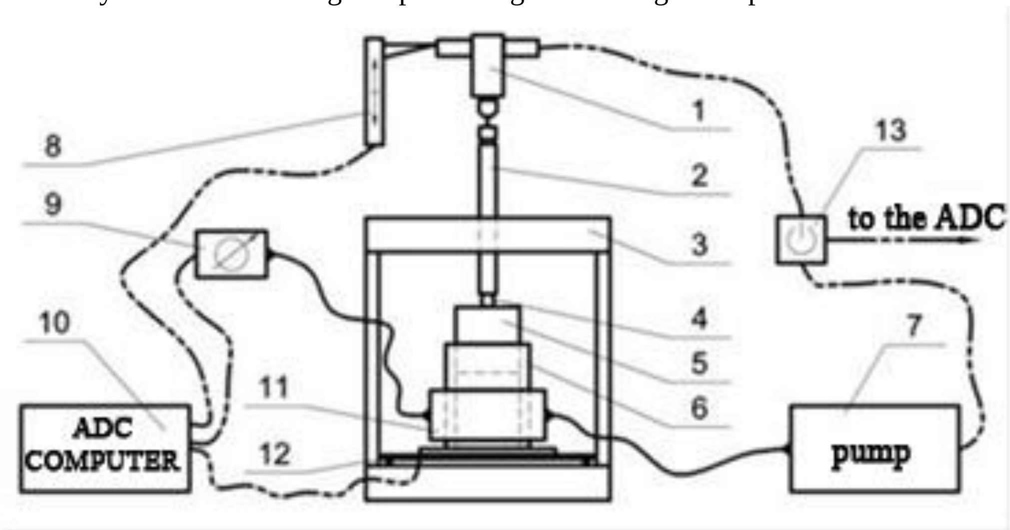

Figure 2. A scheme of the experimental stand
where, 1 – electric motor; 2 – screw; 3 – channel frame; 4 – ball end; 5 – piston; 6 – press chamber; 7 – vacuum pump; 8 – piston stroke gauge; 9 – pressure gauge; 10 – analog-to-digital converter connected to a PC; 11 – vacuum bandage of the press chamber; 12 – strain-gauge balance; 13 – start/end sensor.

Thus, the dependence of energy costs on snow pressing and its simultaneous vacuum processing was theoretically established and experimentally confirmed. Due to vacuum processing, it was possible to reduce the volume of compacted snow. The workflow was optimized, which made the compaction process more efficient. Energy consumption costs were also optimized and a methodology was developed for calculating the parameters of the vacuum snow-pressing equipment. It is proved that, depending on the intensity of gas tapping, it is possible to compress snow with the required characteristics.

All the works stated that the task of pressing snow is, first of all, the task of reducing the porosity of snow. Intensifying the gas tapping contained in the pores of snow makes it possible to achieve an increase in the degree of its compaction, while reducing the effort required for this. On the basis of experimental studies, the effect of the applied load on the change in the final density of snow was determined for static briquetting in a closed volume, with vibration and vacuum processing.

Researchers have developed and proposed options for attachments to road-building machines for snow compaction, for freezing snow and for making snow briquettes and ice blocks [4,12,15].

3. Overview of the methods of snow compaction

1. Static compaction.

Static compaction is provided by rolling. The compacting action of rollers depends on the maximum contact pressures, the distribution of pressures over the contact area, the contact surface dimensions, the rolling speed and the number of passes. The maximum contact pressures have a major influence on the strength of the material. An increase in the minimum size of the contact spot leads to an increase in the thickness of the compacted layer.

Increasing the length of the contact of the working element with the material and reducing the speed of movement lead to an increase in the loading time of the material being compacted. This positively affects the quality of compaction of materials, especially with viscous properties.

Among the various types of static rollers, rollers on pneumatic tires have proved to be the most universal and effective, so it makes sense to consider the rolling process exactly by these rollers.

When soils are compacted by vibrating, the vibrator mass is introduced into the state of oscillatory motions due to the energy brought to the exciter. After the vibro-exciter, due the kinetic energy of the latter, particles of soil are also introduced into the state of oscillatory motions. In the absence of shock pulses from the vibrator side, soil particles are only affected by inertial forces. The latter are proportional to the masses of these particles. In view of the fact that the masses of these particles are not the same, the arising inertial forces are also different. As a result of the difference in inertial forces, shear stresses arise at the contact points of the particles. Up to certain limits, these stresses are balanced by adhesion forces or the strength of the water-colloidal adhesive binders. After exceeding these limits, mutual displacements of these particles occur. Shear stresses are proportional to inertial forces; therefore, they are determined not only by the difference in the masses of the neighboring particles, but also by the accelerations that develop during vibrational motions.

The largest displacements of particles relative to each other are observed in disconnected soils, in which only frictional forces act. In cohesive materials, adhesion forces are added to frictional forces, which can not, to a large extent, be overcome by inertial forces during vibration; therefore, in cohesive materials, vibration causes a greater degree of elastic deformation.

The main parameters of particle oscillations are amplitude, frequency, velocity, acceleration.

3. Tamping.

For compaction by tamping, dropping plates on excavators and ramming machines are used.

Tamping is based on successive impacts of the plate on the material. Compaction happens due to the kinetic energy of the dropped weight, which is expended on the irreversible movement of the material particles and squeezing of the liquid phase films from the contact zones between the mineral particles, as well as the elastic compression of the material.

Compaction is most affected by the impulse of force, the time of impact, the speed of the dropped weight.

Specific impulse is the main characteristic of the tamping process.

Tamping is characterized by a short duration of stresses and a significant depth of propagation of the stress-strain state. Tamping machines are able to compact snow as layers of large thicknesses. Therefore, plates are used, as a rule, when due to the large thickness of the layer other machines are unsuitable.

4. Vacuum processing

Vacuum compaction can significantly reduce or eliminate the need for a loading embankment and ensure that strict requirements for subsidence sizes are met. Due to the lack of embankment and associated issues of soil stability under embankment, this technology is perfectly suitable for snow consolidation [5, 7, 8].

The main advantages of vacuum compaction technology are:

- significant reduction in the consolidation period compared to the static compaction time;

- reduction in the risk of shear deformations of snow.

4. Experimental

After the patent analysis, advantages and disadvantages of the methods used in devices and machines for snow compaction were taken into account, which allowed designing a laboratory installation for vibro-vacuum compaction of snow.

The experimental installation for the vibro-vacuum compaction (Fig. 3) is a camera mounted on a stand of a vibration platform, on which is a field vibrator of the type IV-98E. In the compacting chamber, a pneumatic cylinder is installed to create pressure of the output element on the compacted snow.

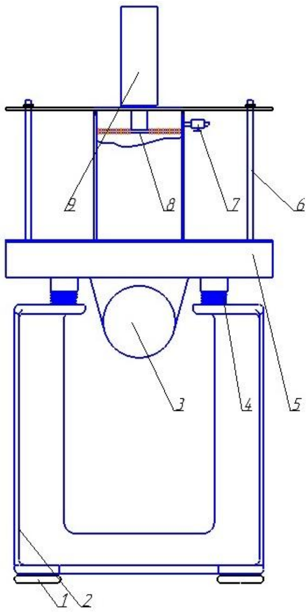

Figure 3. Experimental installation
where, 1 – anti-vibration spacers, 2 - stand, 3 – vibrator IV-98E,
4 – damping device, 5 - platform, 6 - stud, 7 – valve,
8 – compacting platform, 9 – pneumatic cylinder

A valve is installed in the chamber to connect a vacuum pump to vacuum process snow. The result of the installation operation is a compact snow briquette compressed by a combined action.

To create it, it is necessary to prepare a set of equipment, including:

1) welding inverter;
2) angle grinder;
3) drill;
4) drill kit;
5) set of keys;
6) measuring equipment (vernier calipers, tape measure, goniometer);
7) work wear

The complete set of the experimental installation includes:

1) Vibration stand, with vibration spacers.
2) Pneumatic cylinder.
3) Studs for fixing the cover top of the compaction chamber.
4) Nuts fastening to the studs of the stand, nuts fastening the studs to the compaction chamber.
5) Studs for the outside dimensions of the main structure, in our case 1m.
6) Vibrator IV-98E.
7) Bolts of fastening the vibrator to the stand.

Calculation of the experimental installation in the software Solidworks 16.

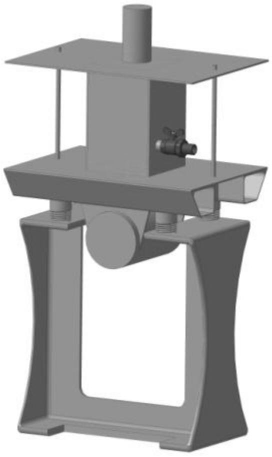

Figure 4. 3D Model in the software Compass 16

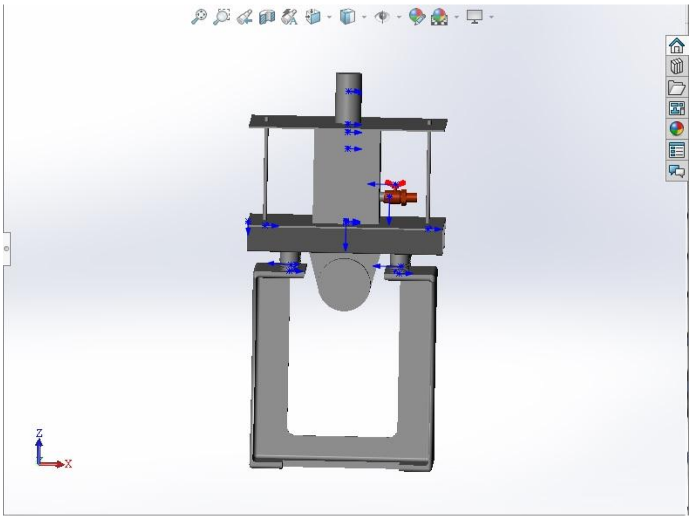

Figure 5. 3D Model in the software Solidworks 2016

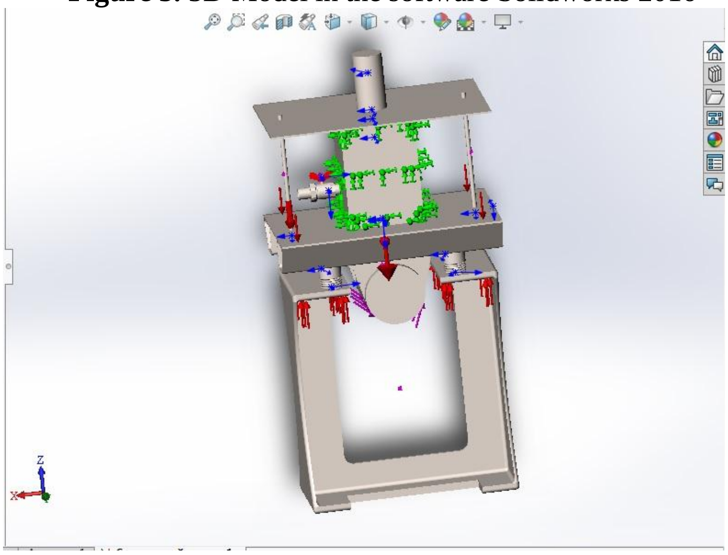

Figure 6. 3D Model with applied layers and material modulation, external factors (grid) for calculations in the software Solidworks 2016

5. Results

The methods used in the scientific work can be divided into theoretical and experimental. The method of ascension from the abstract to the concrete, the method of idealization, the method of formalization, the method of expert assessments, and others are referred to the theoretical method of research. Experiment as a method implies the study of a phenomenon in its pure form and allows you to explore the properties of objects of research in both natural and extreme conditions. An experiment can be repeated several times to check its results [9, 10, 11].

In the course of the research, the following basic working hypothesis was formulated: increasing the efficiency of snow compaction due to the combined effect of vibro-vacuum compaction in a closed volume, for utilization of snow from adjacent areas and roads in Tyumen, with a view to reducing the cost and timing of the utilization of snow.

The object of the research is the process of compacting snow with a vibro-vacuum method in a closed volume.

Table 1. Incomplete block plan and results of expert estimate

№	Parameter	Units	Experts								Total (Ti)
			B1	B2	B3	B4	B5	B6	B7	B8	
1	Thickness of the compacted snow layer	h (m)		14		12		5		8	39
2	Natural and climatic conditions (air temperature, humidity, atmospheric pressure)	$T_{ambient}$ (^{0}C); W (%); P (mmHg);	10		10	10		7			37
4	Frequency of vibration compacting action	n (Hz), A (mm)	14		11	14	6				45
5	Vacuum action	Y mmHg			12		8	9	8		37
3	Weight (load on snow)	m (ru)	14	10					11	12	47
6	Speed of static compaction	V (m/h)		14			11		9	8	42
	Results of expert estimate (B)		38	38	33	36	25	21	28	28	247
	B^2		1444	1444	1089	1296	625	441	784	784	7907

The subject of the research is the experimental installation.

Selection and justification of factors by the incomplete block plan method (expert estimates)

Planning the experiment includes selecting and justifying the factors that affect the process of snow compaction. During selection it is necessary to analyze the materials in scientific papers of researchers. When selecting the factors, it is necessary to take into account the significance of each of them. To select and justify the factors influencing the snow compaction in the construction of temporary winter roads, a questionnaire was formed to interview experts: Karnaukhov N.N., Merdanov Sh.M., Serebrennikov A.A., Zakirzakov G.G., Sharukha A.V., Egorov A.L., Konev V.V., Yarkin A.V. Eight experts evaluated the effect of six factors on the snow compaction on a 14-point system, with each expert being able to assess the quality of three factors, and each parameter was assessed by 4 experts.

Each expert evaluated the same number of objects. Each object is checked by the same number of experts; one expert should compare each pair of objects the same number of times. All these requirements are met when using a balanced incomplete block plan with the following parameters: b=8; v=6; q=3; r=4; N=vr=bq=24.

The objective of the expert estimate was to determine the factors of the best influence on the snow compaction (a greater influence factor is estimated by a larger number of points) and to establish significant differences between different parameters [6, 13, 14]. The incomplete block plan and the results of expert estimate y_{ij} are given in Table 1.

6. Recommendations

From the analysis of literature sources and the results of previous experiments conducted by Sharukha A.V., Egorov A.L., Merdanov Sh.M., etc., the following factors are identified for further investigation: number *n* of passes of the installation, units; installation weight - m, kg; frequency of the vibrator oscillations - v, Hz.

7. Conclusion

Materials that are given in the article are prerequisites for conducting a full-scale experiment to determine the dependence of snow compaction on vibro-vacuum compaction in a closed volume. After conducting the experimental studies, it is planned to form a generalized mathematical model "Vibro-vacuum compaction - snow".

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