Simulation of process of sand mass transfer over road

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Abstract. This article presents the results of theoretical studies to substantiate the optimal parameters of sand-proof structures and their influence on the amount of retained sand; to establish the nature of the distribution of air-sand flow when flowing around the roadbed of highways and the speed zone of this flow; the shapes and installation dimensions of sand-proof structures, as well as the nature of the drift of individual parts of the highway with sand. For clarity, the results are presented in the form of illustrations.

1 Introduction

In sandy deserts, the movement of sand from one place to another under the influence of wind is a natural process that creates certain difficulties in the design, construction, and operation of infrastructure facilities in various sectors of the national economy. Periodic drifting of objects, including transport facilities, by moving sands adversely affects their uninterrupted and safe operation. First of all, this applies to roads and railways, the drift of which with sand disrupts their rhythmic operation, worsens the conditions for the movement of all types of vehicles and trains, as well as the operation of roads, and significantly increases the costs of their current maintenance.

Since the development of desert zones and the construction of railways and roads there, sand-fixing and sand-protecting work has been done to reduce the negative impact of mobile (transported) sands on them. Methods, types, methods, constructive and technological solutions used to secure mobile sands and protect against them have been constantly improved for over a hundred years. However, currently used technological solutions do not protect highways and roads fully from the impact of moving sands.

Therefore, the development and implementation in practice of new (or improved) effective, resource-saving methods and design solutions based on 100 years of world experience in protecting roads from moving sands, as well as on modern innovative technologies and taking into account local conditions, is an urgent task [1, 2].

Sand mobility can be viewed as a function of many factors, i.e., internal and external. In this case, external factors include wind, humidity, temperature, and relief; to the internal granulometric and mineralogical composition, salinity, particle shape, and other physical and mechanical properties of sand.

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The study of the nature of the wind, and the air flows it creates, is of great interest from the point of view of engineering work on modeling the process of sand transfer and reducing their negative impact on transport facilities. The formation and impact of air sand mass on several civil structures and infrastructure in sandy deserts have been studied by many scientists in various parts of the world.

In particular, N.J.Middleton [3] described the danger of sand-and-dust storms on civil objects in his works; on urban infrastructure C.L.Zhang et al. [5]; on agricultural infrastructure X.M.Wang, C.X.Zhang, E.Hasi, Z.B.Dong [6]; highways J.H. Redding, J.A. Lord [7], railways L. Bruno, D. L. Fransos, A. Giudice, L. Raffaele [8].

The air-sand flow interacts with any type of obstacle on the ground surface, which in turn causes erosion, movement, and sinking of the sand around them to the surface after the wind dies down, i.e., the speed gradually decreases or becomes equal to zero. Digital simulation of the movement of sand flying with the wind; study of wind and sand flow aerodynamics; eolian processes, i.e., erosion, transport, sedimentation, and, as a result, drift are studied using the Euler-Lagrange model or the full Euler model [9].

The processes related to the aerodynamics of the air-sand flow have been carried out at research facilities and aerodynamic facilities. Recommendations have been made based on the local conditions of the research facilities' area [10].

Wind energy can cause severe damage to buildings and vegetation, erode exposed soils, and carry soil particles to dangerous downwind locations. Windbreaks can be used to reduce the harmful effects of wind on plants and soil [11]. Windbreaks are important artificial windbreaks that are always produced with non-zero porosity and are classified as vertical, horizontal, lattice, perforated boards, and windbreaks; the type of barrier used depends on the materials available. Vertical windbreaks, usually constructed from readily available, inexpensive, and simple building materials such as live or dead plant branches, are widely used to prevent sand drift [12]. It has been shown that porous barriers are more effective than solid barriers [13].

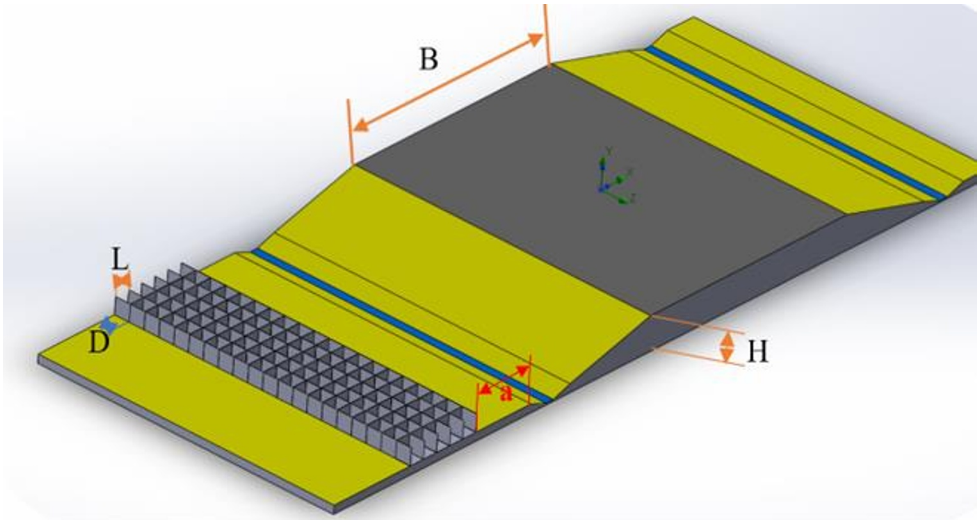
For the safe operation of highways in the desert, many scientists have used field observations [14], wind tunnel experiments [15,16], numerical simulations [17,18], and many studies of wind and highway damage and other tools. Xie [19] studied the change in wind speed and the interval of easy accumulation of sand airflow on the Liuyuan-Golmud Expressway when the sand airflow was subjected to field observation and wind tunnel testing. Based on CFD numerical simulations, Li [20] described the aeolian sand transport process, consisting of sand uplift, suspension, dispersion, deposition, and spatiotemporal concentration at the initial inflow stage. Based on these advances, Shi [21] analyzed the sand and sediment transport process when an air flow of sand passes through the subsurface using a numerical simulation method.

OBJECTS AND METHODS OF RESEARCH

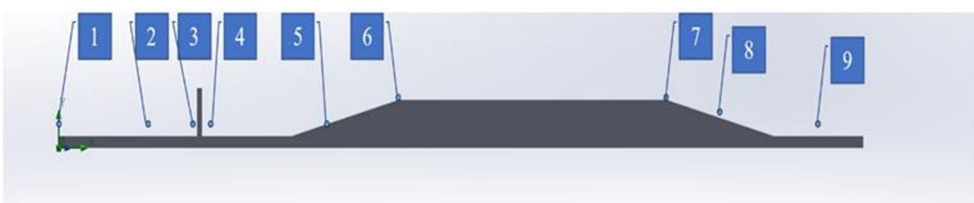
The results of previous studies have shown that the amount of sand carried largely depends on the speed, the direction of the wind, and its duration. To complement the effectiveness of previous studies, the authors set the task of investigating the nature of the propagation of the air flow and determining its speed in front of protective structures installed along the road; the flow of the roadbed by it. At the same time, it is assumed to conduct studies with various variables, i.e., varying the shape and installation dimensions of the protective structure, the initial wind speed, and characteristic points in constructing the roadbed.

Thus, it is supposed to substantiate the optimal parameters of sand-proof structures and their influence on the amount of retained sand; to establish the nature of the distribution of the air-sand flow when flowing around the roadbed and the speed zone of this flow; the shapes and installation dimensions of sand-proof structures, as well as the nature of the drift of individual sections of the highway with sand.

For this purpose, a simulation model of a section of the road was developed with the following parameters: width B (15.0 m), embankment height H (1.5 m), sand-protective structures in row type with cells D (m) x L (m) are installed at a distance a (5.0 m) from the edge of the cuvettes (Fig. 1., a,b).



a)



b)

Fig. 1. Fragment of a section of a motor road and a sand-protective structure: a) (H=1.5 m; B=15.0 m; L(m) x D(m); a=5.0 m); b) (H=1.5 m; B=15.0 m; L=2.0 m; a=5.0 m)

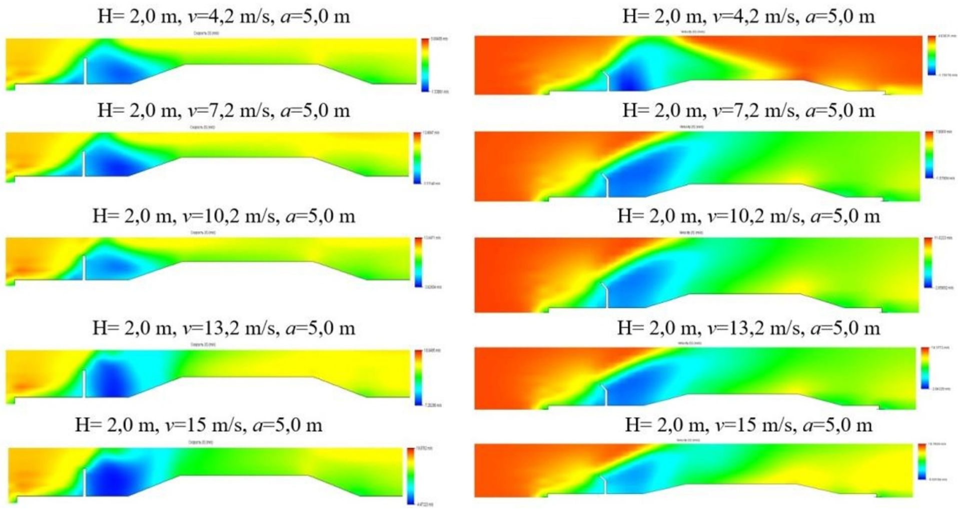
Simulation of the process of air-sand mixture transfer over the road was carried out using the standard SOLIDWORKS Flow Simulation software package, with periodic changes in the above-mentioned parameters of the road and protective structures. To improve the accuracy of calculations and the reliability of the results, the number of iterations for each change in the initial data was 100 or more times. At the same time, it was assumed that the direction of the wind, and hence the air-sand flow, is perpendicular to the axis of the road.

2 Results and discussion

On a simulation model of an embankment with a height of 1.5 m, corresponding to a motor road of the 2nd category, using a software product, multiple modeling of the process of formation of an air-sand mass and its distribution was carried out at various initial wind speeds, cell sizes of protective structures. As a result of the calculations, curves (isolines)

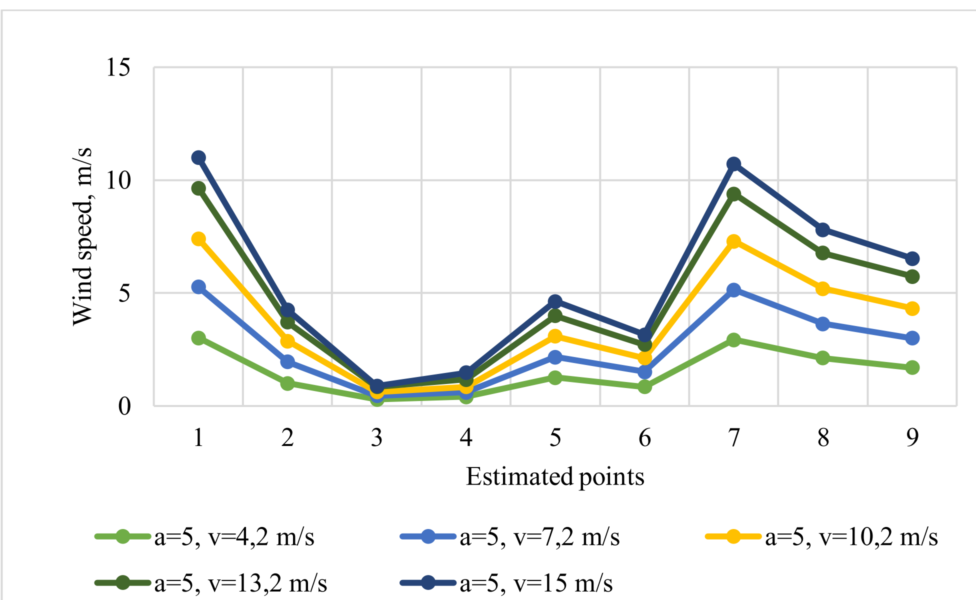
https://doi.org/10.1051/e3sconf/202340102043

were obtained that characterize the distribution of the velocity zone (Fig. 2) of the air-sand flow and variation of different wind speeds at calculated points (Fig. 3), streamlined subgrade, with various sizes of a protective structure of a square shape of various sizes.



a) straight fence *b)* g-shaped fence

Fig. 2. The ability to trap sand in two different types of barriers:



a)

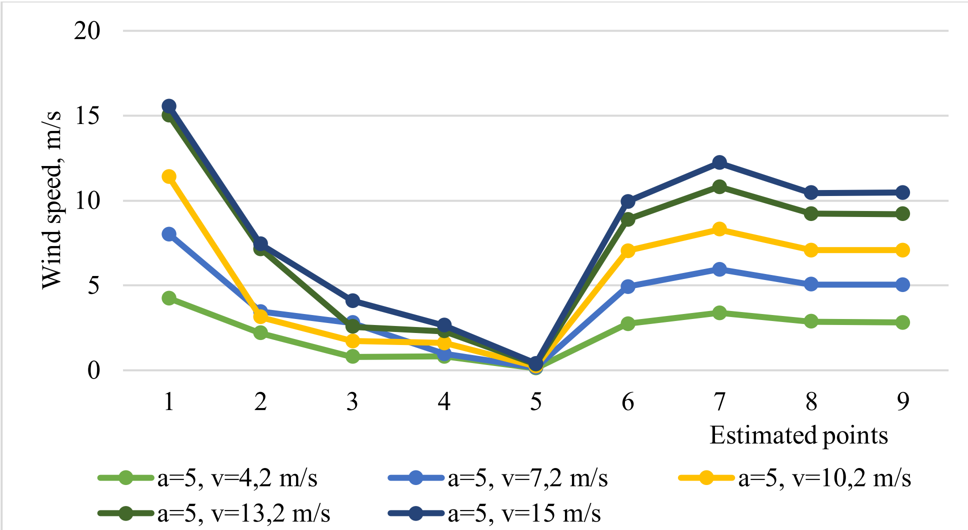


Fig. 3. Variation of different wind speeds at calculated points.

Analysis of the obtained curves (isolines) of the distribution of the air-sand flow velocity zone shows that:

- the distribution of the velocity zone of the air-sand flow, the streamlined subgrade depends on the size of the protective structure;
- with an increase in the size of the protective structure, the speed of the air-sand flow on the edge of the subgrade increases from 0.063 m/s to 6.566 m/s;
- the speed of the air-sand flow on the road surface increases with an increase in the size of the protective structure from 0.878 m/s to 7.241 m/s;
- therefore, it was found that the possibility of sand blocking depends on the height of the barrier and its construction;
- only one of its disadvantages is the large number of types of work performed when using this type of high barrier.

3 Conclusion

As a result of many years of research, various methods and methods for protecting transport facilities from sand drifts in deserts have been developed and proposed. Despite the variety of protection methods that these methods have been studied enough, and their results are widely used in practice, an effective way to protect transport infrastructure facilities and structures from drifts in sandy deserts has not been developed.

The results of calculations carried out using modern applied software products generalization of the above conclusions allow us to draw the following conclusions:

- the mechanical method of protecting roads from sand drifts has not exhausted its capabilities;
- the dimensions of the protective structure have a significant impact on the speed of the secondary air-sand flow streamlined by the protective structure;
- the amount of sand deposited on the road surface increases with a decrease in the size of the protective structure;
- the nature of the trajectory of the air-sand flow does not depend on the size of the protective structure.

- Developing efficient and resource-saving technologies based on local raw materials, considering local features to ensure the safe operation of transport infrastructure facilities and structures.

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