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RESEARCH ARTICLE

ANALYSIS OF THE SNOWSTORM FLOW AROUND A SNOW PROTECTION FENCE MODEL BASED ON WIND TUNNEL TESTS

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Abstract. *The article is devoted to the study of the effectiveness of multifunctional snow and noise protection structures designed to improve road safety and protect roadside areas in conditions of intense snow transfer and increased noise load. The relevance of the work is due to the need to develop engineering solutions that simultaneously reduce traffic noise and prevent the formation of snowdrifts on highways and in the urban environment. An analysis of existing research has revealed three main areas: numerical CFD modeling of snow protection, experimental tests in wind tunnels, and the study of turbulent two-phase flows. At the same time, a comprehensive assessment of the effectiveness of screens based on the integration of aerodynamic modeling, PIV visualization and route visibility analysis remain insufficiently investigated. The purpose of the study is to determine the optimal parameters for the placement and design of road screens based on an analysis of the aerodynamic characteristics of air and snow flows and visibility conditions. The scientific novelty consists in obtaining new data by the PIV method on the distribution of velocity fields and the structure of turbulent zones near various types of snow protection structures. For the first time, a quantitative assessment of the influence of geometric parameters of screens on snow retention processes and roadway visibility has been performed. Experimental studies were carried out in an open-type wind tunnel using a snow model based on activated clay. Four schemes for the placement of fences with a height of 3-5 m are considered. The method of optical anemometry based on particle images was used to analyze the air flow. It was found that traditional structures with a height of 5 m contribute to the flight of the stream and the accumulation of snow masses on the right side of the road, impairing visibility. The most effective fence is 4 m high, located at a distance of 1.5 m from the curb. This design reduces turbulence, prevents snow accumulation on the roadway and ensures adequate visibility conditions. The results obtained can be used in the design and modernization of highway engineering protection systems.*

Keywords: *wind tunnel, aerodynamic tests, snow protection fences, effects of reducing snowdrifts and visibility on the road.*

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ҒЫЛЫМИ МАҚАЛА

ЖЕЛ ТУННЕЛІНДЕГІ СЫНАҚТАРҒА НЕГІЗДЕЛГЕН ҚАРДАН ҚОРҒАЙТЫН ҚОРШАУ МОДЕЛІНІҢ АЙНАЛАСЫНДАҒЫ БОРАН АҒЫНЫН ТАЛДАУ

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Аңдатпа. *Мақала қардың көп тасымалдануы және Шу жүктемесінің жоғарылауы жағдайында жол қозғалысы қауіпсіздігін арттыруға және жол бойындағы аумақтарды қорғауға арналған көпфункционалды қар мен шудан қорғау құрылыстарының тиімділігін зерттеуге арналған. Жұмыстың өзектілігі көлік шуының деңгейін төмендетуге және автомобиль жолдары мен қалалық ортада қардың пайда болуына жол бермейтін инженерлік шешімдерді әзірлеу қажеттілігіне байланысты. Қолданыстағы зерттеулерді талдау үш негізгі бағытты анықтады: қардан қорғаудың сандық CFD модельдеуі, жел туннельдеріндегі эксперименттік сынақтар және турбулентті екі фазалы ағындарды зерттеу. Сонымен қатар, аэродинамикалық модельдеу, PIV-визуализация және жолдың көрінуін талдау интеграциясы негізінде экрандардың тиімділігін кешенді бағалау жеткілікті зерттелмеген күйінде қалып отыр. Зерттеудің мақсаты-ауа-қар ағындарының аэродинамикалық сипаттамаларын және көріну жағдайларын талдау негізінде жол экрандарының орналасуы мен дизайнының оңтайлы параметрлерін анықтау. Ғылыми жаңалық-PIV әдісімен жылдамдық өрістерінің таралуы және қардан қорғайтын құрылымдардың әртүрлі түрлеріне жақын турбулентті аймақтардың құрылымы туралы жаңа мәліметтер алу. Алғаш рет экрандардың геометриялық параметрлерінің қар ұстау процестеріне және жол төсемінің көрінуіне әсерін сандық бағалау жүргізілді. Эксперименттік зерттеулер белсендірілген сазға негізделген қар моделін қолдана отырып, ашық типтегі жел туннелінде жүргізілді. Биіктігі 3-5 м қоршауларды орналастырудың төрт схемасы қарастырылған. Ауа ағынын талдау үшін бөлшектердің суреттерінен оптикалық анемометрия әдісі қолданылды. Биіктігі 5 м болатын дәстүрлі құрылымдар ағынның ұшуына және жолдың оң жағында қардың жиналуына ықпал етіп, көрінуді нашарлататыны анықталды. Ең тиімдісі-жол жиегінен 1,5 м қашықтықта орналасқан биіктігі 4 м қоршау. Бұл дизайн турбуленттілікті азайтады, жол бойында қардың жиналуын болдырмайды және көрінудің нормативтік жағдайларын қамтамасыз етеді. Алынған нәтижелер автомобиль жолдарын инженерлік қорғау жүйелерін жобалау және жаңарту кезінде пайдаланылуы мүмкін.*

Түйін сөздер: *жел туннелі, жел туннелі, қардан қорғайтын қоршаулар, қарды азайту және жолдағы көріну әсерлері.*

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НАУЧНАЯ СТАТЬЯ

АНАЛИЗ ТЕЧЕНИЯ МЕТЕЛИ ВОКРУГ МОДЕЛИ СНЕГОЗАЩИТНОГО ЗАБОРА НА ОСНОВЕ ИСПЫТАНИЙ В АЭРОДИНАМИЧЕСКОЙ ТРУБЕ

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Аннотация. *Статья посвящена исследованию эффективности многофункциональных снего- и шумозащитных сооружений, предназначенных для повышения безопасности дорожного движения и защиты придорожных территорий в условиях интенсивного снегопереноса и повышенной шумовой нагрузки. Актуальность работы обусловлена необходимостью разработки инженерных решений, позволяющих одновременно снижать уровень транспортного шума и предотвращать образование снежных заносов на автомобильных дорогах и в городской среде. Анализ существующих исследований выявил три основных направления: численное CFD-моделирование снегозащиты, экспериментальные испытания в аэродинамических трубах и изучение турбулентных двухфазных потоков. Вместе с тем недостаточно исследованной остается комплексная оценка эффективности экранов на основе интеграции аэродинамического моделирования, PIV-визуализации и анализа видимости трассы. Цель исследования заключается в определении оптимальных параметров размещения и конструкции дорожных экранов на основе анализа аэродинамических характеристик воздушно-снежных потоков и условий видимости. Научная новизна состоит в получении методом PIV новых данных о распределении полей скоростей и структуре турбулентных зон вблизи различных типов снегозащитных сооружений. Впервые выполнена количественная оценка влияния геометрических параметров экранов на процессы снегозадержания и видимость дорожного полотна. Экспериментальные исследования проведены в аэродинамической трубе незамкнутого типа с использованием модели снега на основе активированной глины. Рассмотрены четыре схемы размещения ограждений высотой 3–5 м. Для анализа воздушного потока использован метод оптической анемометрии по изображениям частиц. Установлено, что традиционные конструкции высотой 5 м способствуют перелету потока и накоплению снежных масс на правой стороне дороги, ухудшая видимость. Наиболее эффективным является забор высотой 4 м, расположенный на расстоянии 1,5 м от обочины. Такая конструкция снижает турбулентность, предотвращает накопление снега на проезжей части и обеспечивает нормативные условия видимости. Полученные результаты могут быть использованы при проектировании и модернизации систем инженерной защиты автомобильных дорог.*

Ключевые слова: *аэродинамическая труба, аэродинамические испытания, снегозащитные заборы, эффекты уменьшения сугробов и видимости на дороге.*

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1 INTRODUCTION

We can say that roads are the most important line of life, occupying a prominent place in our everyday life. Snow-proof fences protect roads from damage caused by severe snows and winds [1]. Improving the effectiveness of snow protection of highways is a priority task [2; 3]. Created on the basis of the application of careful research and scientific developments, important data from aerodynamic and field tests, snow protection fences are the fruits of technologies that protect our lives [4].

The use of snow and noise shields in road transport infrastructure. Current trends in urbanization and expansion of transport networks require the introduction of effective engineering solutions to minimize the anthropogenic impact on the environment and ensure road safety. One of the key elements of roadside construction is snow and noise protection screens. These structures are specialized acoustic and wind damping structures installed along highways, railway tracks and along the perimeter of industrial zones.

The main function of noise shields is to reduce the sound pressure level penetrating from traffic flows into adjacent residential and recreational areas. Their principle of operation is based on the processes of reflection, absorption or diffraction of sound waves. The effectiveness of properly designed and installed acoustic barriers reduces the level of urban noise by 15-25 dB. This ensures the achievement of regulatory sanitary and hygienic indicators in residential areas, significantly improving the quality of life of the population and reducing the risks of diseases associated with constant acoustic stress.

In parallel with acoustic protection in regions with difficult climatic conditions, snow protection structures play a critical role. Their integration into the roadside infrastructure is aimed at changing the aerodynamic profile of the air flow. By reducing the wind speed in the surface layer, the screens contribute to the controlled deposition of blizzard snow on the approaches to the ground. This prevents the formation of snowdrifts and snow drifts directly on the roadway, which radically increases traffic safety, preserves the required highway capacity and minimizes the economic costs of winter road maintenance.

Thus, snow and noise protection screens are a comprehensive tool for engineering protection. Their design requires strict consideration of the route geometry, landscape features, climatic factors and acoustic parameters of the traffic flow, which makes them an indispensable component of the sustainable development of modern transport infrastructure.

Snow barriers are also installed in urban environments, where there is a large wind component in the foothill area. In such megacities, it is necessary to consider these fences as architectural structures that carry not only design and futuristic objects, forming the landscape and spatial organization of memorial parks in terms of their psycho-emotional perception, but also protective functions [5; 6].

Let's take the example of Riken Kogyo Co., Ltd., where the development of snow protection technologies took place in Japan. Riken Kogyo Co., Ltd., having achieved success in developing the first steel snow fences 50 years ago, contributed to improving traffic safety in winter and supporting the economy of Hokkaido, as well as the Tohoku and Hokuriku regions through snow protection measures for roads from snowstorms and snow drifts [7].

From 1989 to 2013, the following developments were underway: a fully folding snow protection fence, created taking into account the surrounding landscapes; a rising and falling snow protection fence; a multifunctional snow protection fence to protect against headwinds; a multifunctional noise protection fence and methods for automatic vertical folding of already built snow protection fences in the NETIS information system for new technologies [7].

In the research laboratory of snow and ice technologies, in order to study and investigate measures to protect against snow damage, an installation (camera) reproducing the conditions of a snowstorm for aerodynamic tests has been created (Fig. 1) [7].

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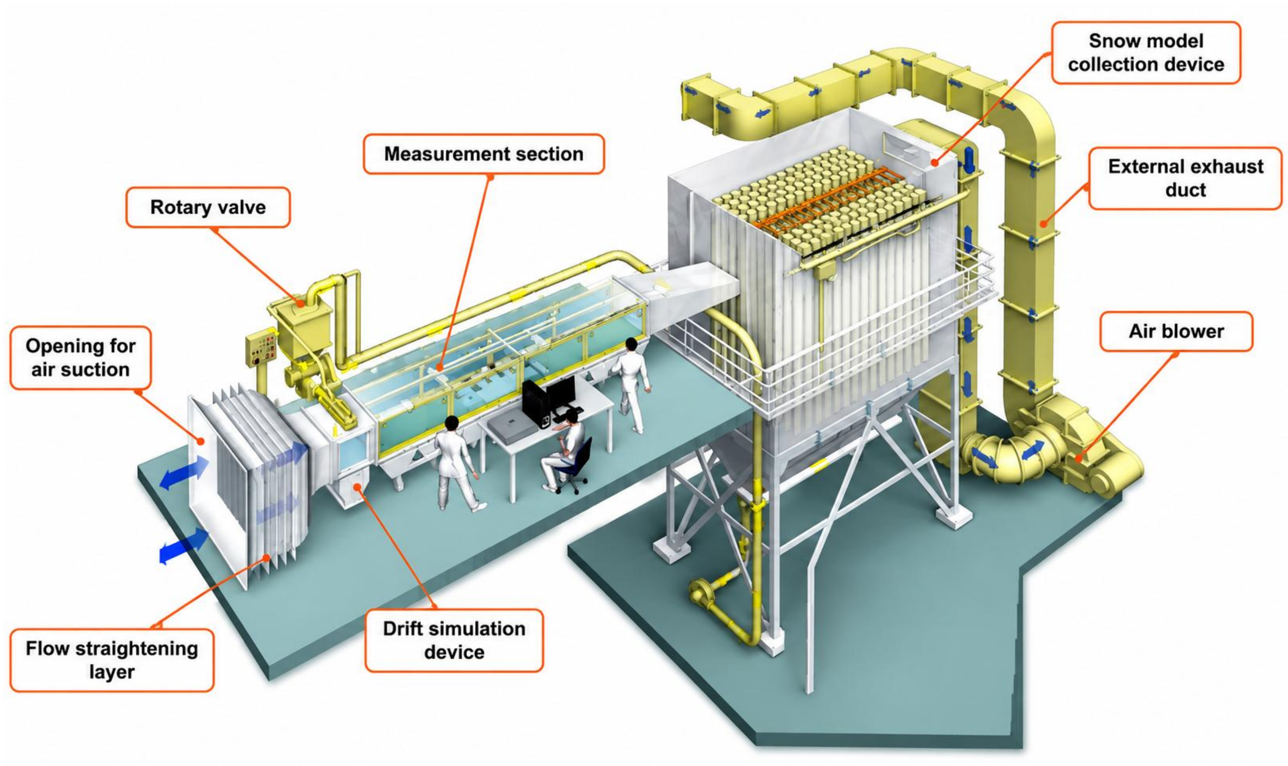

Figure 1 – Aerodynamic testing facility [7]

An analysis of modern research shows that the tasks of snow transfer and snow protection are considered using different approaches. The first group of works is devoted to engineering tasks of protecting highways from snow drifts. For example, CFD modeling is used [8-11] to evaluate snow transfer processes and justify the placement of snow protection structures. The main focus of these studies is on flow aerodynamics and the selection of optimal protective device designs.

The second group of studies is related to experimental modeling [12]. Aerodynamic tests in pipes are considered to determine the parameters of snow loads on structures. Unlike numerical methods, experimental studies allow obtaining data close to real conditions, but require significant time and resources.

The third direction is represented by fundamental research of turbulent flows and particle transport [13-16]. These works develop the mathematical apparatus for modeling two-phase flows and turbulence, but they are not directly focused on the design tasks of snow protection structures.

A significant amount of modern foreign research is devoted to regional and landscape modeling of snow transfer, redistribution and melting of snow cover [17-28]. Such models take into account the influence of terrain, climate, wind conditions, and physical properties of snow, ensuring high accuracy in predicting snow cover over large areas. However, their main purpose is related to hydrological and climate research, and not to evaluate the effectiveness of road snow protection devices.

Thus, existing studies either consider the aerodynamic processes of snow transport without a detailed analysis of the operation of specific snow protection structures, or focus on regional modeling of snow cover. The issue of a comprehensive assessment of the effectiveness of snow protection fences based on a combination of aerodynamic modeling, modern flow visualization (PIV) methods and analysis of visibility conditions on highways remains insufficiently studied. This scientific gap is the subject of this study.

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2 MATERIALS AND METHODS

Design and research: design of various snow protection and wind protection fences and snow protection structures; preliminary research and study of snow storms, snow drifts and visual range interference, verification of effectiveness through numerical modeling and wind tunnel tests; rental of equipment for meteorological observations, experimental analysis and observations.

The Riken Koke aerodynamic testing equipment allows you to reproduce the conditions of a snowstorm by creating a vortex flow of air from artificial snow in a wind tunnel.

Table 1 - Main Characteristics of the Wind Tunnel [7]

Parameter	Specification
Model	Open-Circuit Wind Tunnel
Wind Speed	0–7 m/s (inverter-controlled)
Motor Power	22 kW × 4 units
Air Flow Rate	435 m³/min
Air Pressure	125 mm H_2O
Test Section Dimensions	Height (H) 750 mm × Width (W) 1000 mm × Length (L) 5700 mm
Nozzle Dimensions	2050 × 1800 mm
Snow Drift Simulation Device	Pressure-spray type blizzard generation apparatus
Artificial Snow Material	Activated clay (particle supply rate: 1 mm/10 min; feed rate: 0.11 m³/h)
Artificial Snow Collection Method	Rear filter system (116 m² filter area)
Snow Discharge Method (Pulsating)	Air-jet diaphragm system (0–60 s pulse interval)
Rear Filter Dimensions	Height 4000 mm × Width 4700 mm × Length 2250 mm
Rotary Airlock Capacity	0.279 m³

By creating reduced models of snow protection fences and terrain, visually reproducing damage, snow drifts and conditions during a snowstorm, it is possible to identify the most effective snow protection measures. Photographs of the experimental model in a wind tunnel (snow deposition experiment) are shown in Fig. 2. The scale of the model is: snow deposition experiment: 1/100; visualization experiment: 1/50. The scale of the sedimentation experiment focused on the phenomenon of snowdrift and compared with snow particles or activated clay. Various experiments using activated clay: visualization experiments, drift experiments, measurement of wind velocity distribution, Taft experiment: 1) Reproduction of a phenomenon similar to a natural snowstorm by spraying a snow model; 2) Analysis of the places of occurrence of drifts and the mechanism of occurrence of snowdrifts; 3) Modeling the assessment of the performance characteristics of snow protection equipment.

Figure 2 – Models of snow protection fences in a wind tunnel [7]

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The PIV method (particle image anemometry) is an optical method for measuring a fluid, which can be used to obtain the instantaneous velocity of multiple points in a flow without contact. By taking slow-motion images of rapid processes with a high-speed camera (Fig. 3, a), due to digitization on a computer, it is possible to quickly and accurately analyze the flow of a snowstorm around a snow fence (Fig. 3, b).

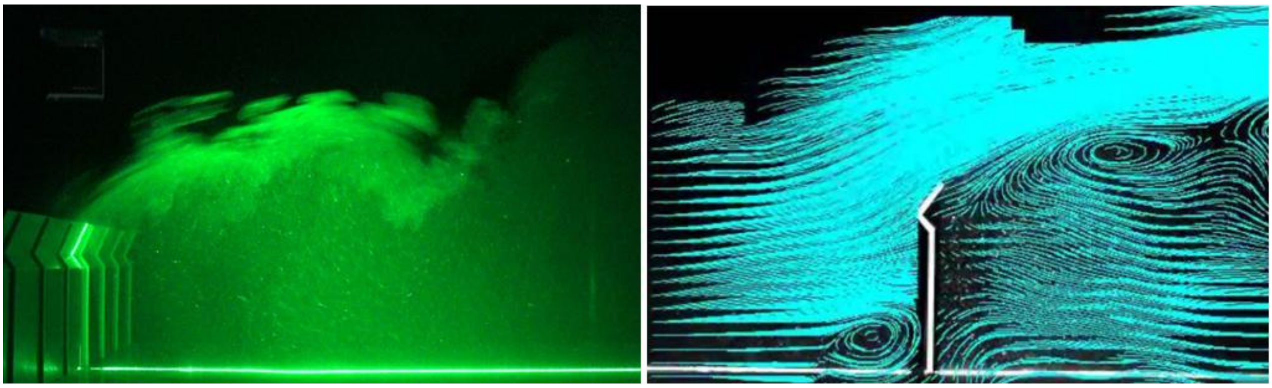

Figure 3 – Images of rapid snowstorm processes around a snow protection fence [7]

To study the structure of the air flow, the PIV (Particle Image Velocimetry, particle image anemometry) method was used, which makes it possible to determine instantaneous velocity fields in a large number of points in the study area without contact. The method is based on recording a sequence of images of tracer particles moving with the air flow, and subsequent digital processing of frames using correlation analysis. The survey was carried out with a high-speed camera, which made it possible to record fast-flowing snow transfer processes and obtain detailed information about the flow structure near snow protection structures. Image processing and calculation of velocity vector fields were performed using specialized PIV analysis software.

The experimental studies were carried out in an open-type wind tunnel equipped with a blizzard flow reproduction system. The air flow velocity was controlled by an inverter control in the range from 0 to 7 m/s. The ventilation system included four electric motors with a capacity of 22 kW each, providing an air flow rate of up to 435 m3/min at a pressure of 125 mm of water.

The working measuring section of the wind tunnel measured 1000×750×5700 mm (width × height × length), the nozzle dimensions were 2050×1800 mm. A pressure-spray type device forming an artificial snowstorm was used to simulate snow transfer. Activated clay with a feed rate of about 0.11 m3/h was used as a snow model. The model snow was collected through a 116 m2 filtration system, and the material was discharged by a pulsating air-jet device with an adjustable cycle of 0-60 s.

To analyze the structure of the air flow, the PIV (Particle Image Velocimetry) method was used, which makes it possible to determine instantaneous velocity fields from a sequence of images of particle tracers. The data obtained were used to evaluate the aerodynamic characteristics of various snow protection structures and to analyze the processes of snow drift formation in the roadside area.

In aerodynamic studies of snow transport, parameters of the following order are often found: flow velocity: 5-15 m/s; model scale: 1:20-1:100; shooting frequency: 250-1000 fps; resolution: 1024×1024 or 1920×1080 pixels; PIV correlation window: 32×32 or 64×64 pixels; velocity measurement error: 2-5%.

Experimental studies were carried out in a wind tunnel on four options for the placement of snow protection structures in order to assess their impact on the distribution of air flows, the formation of snow drifts and areas of limited visibility.:

– scheme No. 1 - traditional snow protection fence with a height of 5 m with a distance from the embankment slope of about 5 m;

– scheme No. 2 - high-performance snow protection fence with a height of 5 m, installed at a distance of up to 5 m from the curb;

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– scheme No. 3 is a high-performance snow protection fence with a height of 4 m, located at a distance of about 1.5 m from the curb;

– Scheme No. 4 is a 3 m high highly efficient snow protection fence located directly at the curb.

For each scheme, the fields of air flow velocities, the nature of vortex formation, and the conditions for the formation of snow deposits in the roadside area were analyzed.

3 RESULTS AND DISCUSSION

The results of the aerodynamic tests made it possible to compare the effectiveness of four snow protection schemes according to the criteria of snow tolerance and visibility. For conditions corresponding to the formation of a 20 mm thick snow cover in the model (equivalent to about 2 m in field conditions), there were no significant differences in the depth of snow deposits between the left and right lanes of traffic. The lowest depth of snow accumulation on the right side of the road was observed when using a highly efficient 4 m high snow fence installed at a distance of 1.5 m from the curb, as well as a 3 m high fence located directly at the curb.

The analysis showed that schemes No. 1 and No. 2 (the height of the fence is 5 m, the distance from the embankment is about 5 m) are characterized by the transfer of snow flow through the fence, followed by snow deposition on the right side of the road, which leads to the formation of snow accumulation zones near the carriageway. For the scheme with a 3 m high fence, an increased accumulation of snow near the fence was noted due to insufficient snow collection space. According to the totality of indicators, the scheme with a 4 m high fence installed at a distance of 1.5 m from the curb turned out to be the most effective.

The flow visualization results (Fig. 4) showed that in Schemes No. 1 and No. 2, the airflow flies over the fence and shifts to the right side of the road. At the same time, a conventional snow barrier demonstrates lower efficiency compared to an improved design, which can lead to reduced visibility on the roadway.

Figure 4 – Visualization result using the smoke method in a wind tunnel experiment [7]

As can be seen in Fig. 5, the flow around the high-performance snow barrier has a smoother structure compared to the traditional design. This is due to the action of the guide and perforated plates, which contribute to the displacement of vortices from the edge of the fence and reduce the intensity of turbulence near the road.

According to the experimental results, the length of the visibility degradation zone for a traditional snow protection fence is about 4H, while for a highly efficient structure it reaches 7H (where H is the height of the fence). When the fence is placed at a distance of 1.5 H from the ledge of a high embankment, the point of attachment of the air flow is shifted outside the carriageway (Fig. 5).

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Schemes No. 3 and No. 4, providing for the installation of fences near the curb, demonstrated higher efficiency in reducing the snow-bearing capacity of the road compared to schemes No. 1 and No. 2. However, for scheme No. 4 (fence height 3 m), significant accumulation of snow in front of the fence was detected due to insufficient snow collection area.

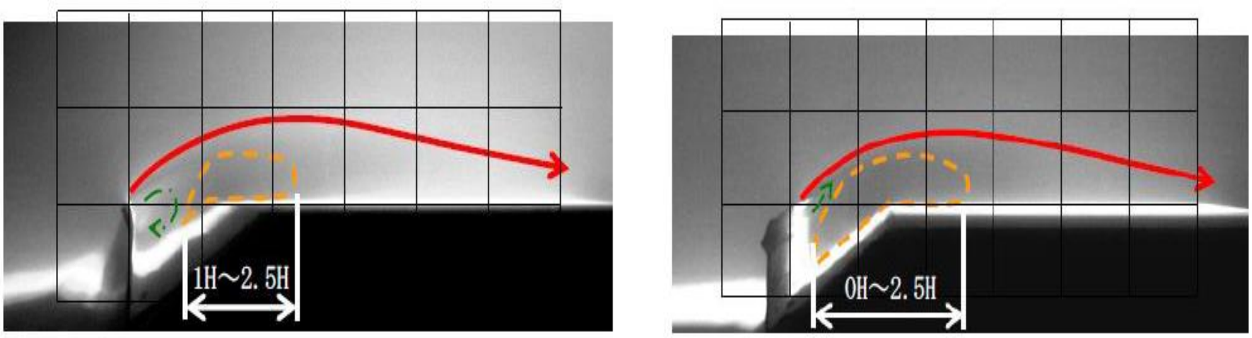

Figure 5 – Visualization result of an experiment on visualization when installing a fence at a distance of 1.5H against the wind from the ledge of a high embankment [7]

The best results were obtained for scheme No. 3, which includes a 4 m high snow protection fence located at a distance of 1.5 m from the embankment shoulder. This scheme is characterized by minimal accumulation of snow on the roadway, reduced turbulence and the most favorable visibility conditions. The results of visualization using the PIV method confirm that the effectiveness of snow protection structures is determined not only by the height of the fence, but also by its location relative to the embankment, as well as by the features of the aerodynamic structure (Fig. 5).

It was found that when the fence is moved from the slope ledge to the windward side, the area of reduced obstructed visibility decreases. For conventional and high-performance models, it is more efficient to move closer to the shoulder. In this case, it can be seen that the restricted visibility zone on the roadway is secured. The visibility reduction zone for high-performance snow intakes whose height is = 4 m → 4 × 7 = 28 m, and for fence height = 3 m → 3 × 7 = 21 m.

However, the required range for reducing visibility is: at fence height = 4m, shoulder ~ 1.5m apart: = 30m + 1.5m = 31.5m; and at fence height = 3 m. At the curb: = 30 m. Therefore, the visibility reduction zone will be insufficient.

Based on the results of experiments conducted, according to which the effect of an explosion in high bulk structures is about 2.5 hours, the visibility reduction zone is for high-performance snow intakes with a fence height of 4 m. → (4 × 7) + (4 × 2,5) = 38 m, and for fences with height = 3 m → (3 × 7) + (3 × 2,5) = 28,5 M.

Based on the above results, the improvement plan, which provides a 30 m wide visibility reduction zone, looks like this: high-performance snow intake (fence height = 4 m, slope shoulder ~ 1.5 m apart).

Table 2 - Summary of the results of the experiments [Authors' material]

No.	Snow Fence Type	Snow Deposition (Snow Drift Accumulation)	Visibility Conditions
Scheme 1	Conventional snow-control fence (fence height = 5 m; setback distance = 5 m from shoulder)	Present	Reduced visibility observed
Scheme 2	High-efficiency snow fence (fence height = 5 m; setback distance = 5 m from shoulder)	Reduced	Improved visibility
Scheme 3	High-performance snow fence (fence height = 4 m; setback distance = 1.5 m from shoulder)	Absent	Excellent visibility
Scheme 4	High-performance snow fence (fence height = 3 m; located adjacent to the shoulder)	Absent	Good visibility

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Note: All data is based on an analysis of published catalogs, official manuals, and evaluation literature by RIKEN KOGYO Inc. as of 2026, and does not represent an independent comparative analysis conducted by the authors. The main documentary sources are Japan [7].

Full-fledged engineering analysis and scientifically based dependencies:

Table 3 - Comparison of four investigated schemes of snow-retaining fences [Authors' material]

Scheme	Fence type	Height, m	Distance from shoulder	Snow deposition	Visibility	Overall assessment
1	Conventional	5	5 m	High	Poor	Low
2	High-performance	5	5 m	Moderate	Good	Medium
3	High-performance	4	1.5 m	None	Excellent	Best
4	High-performance	3	0 m	None on roadway, accumulation before fence	Good	High

Comparison of the zones of reduced visibility:

The calculated dependences are given in the article:

1) ordinary screen L = 4H;

2) high-efficiency screen L = 7H.

where H is the height of the screen; L is the length of the visibility impairment zone.

Table 4 - Comparison of zones of reduced visibility of snow-retaining fences [Authors' material]

Height	Conventional	High-Performance
3 m	12 m	21 m
4 m	16 m	28 m
5 m	20 m	35 m

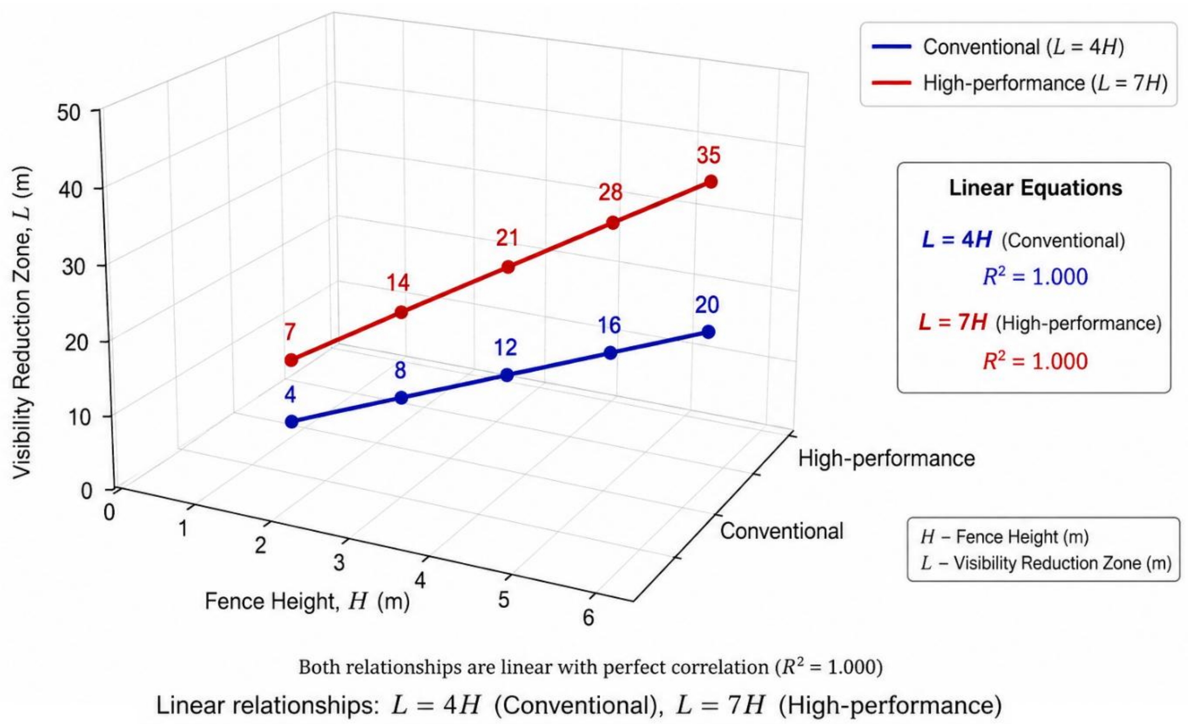

Figure 6 – Visibility reduction zone depending on the height of the fence [Authors' material]

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Performance analysis:

Increased efficiency

$$\eta = \frac{7-4}{4} \cdot 100$$

$$\eta = 75\%$$

That is, the new design increases the length of the controlled aerodynamic zone by almost 75%.

Comparison of the calculated zone:

The article shows: for a screen of 4 m → 4×7=28 m, after taking into account the additional effect of 4×2.5 =10 m, a total of 38 m.

For a 3 m → 3×7=21 m screen, the additional effect is 3×2.5=7.5 m, for a total of 8.5 m.

The resulting equation:

From the results, you can write

$$L = H(k+\alpha) \quad (1)$$

where

for the new construction k=7;

additional effect α =2.5.

then, the estimated total impact area of the structure:

$$L = 9.5H \quad (2)$$

Scientific explanation of the coefficients:

The coefficient k = 4 is typical for conventional snow shields.

Coefficient k=7 - characterizes a more efficient redistribution of the air flow due to the guide plates.

Coefficient 2.5 - takes into account the additional aerodynamic effect of the propagation of the impact zone.

Thus, equation (2) describes the total working aerodynamic area of the new design.

Table 5 - Engineering comparison of snow-retaining fences [Authors' material]

Показатель	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Snow deposition	3	2	0	1
Visibility	1	2	4	3
Aerodynamic stability	1	3	5	4
Overall efficiency	1	3	5	4

4 CONCLUSIONS

Based on the results of the conducted experimental studies, the following conclusions were formulated:

1. Aerodynamic tests have confirmed the significant influence of the design parameters of snow protection structures and their location relative to the embankment on the processes of snow transfer, snow-bearing capacity of the road and visibility conditions.

2. It has been established that traditional snow barriers are characterized by a more pronounced transfer of air flow through the upper edge of the structure, which contributes to the formation of secondary snow transfer zones and reduced visibility on the roadway.

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3. The most effective scheme considered turned out to be a high-performance snow protection fence with a height of 4 m, located at a distance of about 1.5 m from the embankment shoulder. This design ensures minimal accumulation of snow on the roadway, reduces turbulence and improves visibility conditions.

4. Additional equipment of snow protection structures with guiding lighting equipment makes it possible to increase road safety in conditions of snowstorms and limited visibility by visually marking the boundaries of the road, roadsides and sections of changing the direction of the highway.

The scientific novelty of the study lies in the experimental assessment of the aerodynamic features of various snow protection structures using the PIV method, which made it possible to identify patterns in the formation of snow transfer zones, turbulence and reduced visibility near highways.

The practical significance of the work is to substantiate the rational design and layout of a snow protection fence to reduce the snow-bearing capacity of highways and improve traffic safety. The results obtained can be used in the design and modernization of snow protection systems on highways located in areas with intense blizzard processes.

REFERENCES

1. **Bondar I.S., Nugumanov N.S., Suleimenov M.Kh., Abdurakhmanov A.A.** (2024). Snow protection fences of modular design with adjustable snow retention volume / International Journal of Advanced Logistics, Transport and. Vol. 9, 1, 9-21. https://doi.org/10.52167/2790-5829-2024-9-9-21
2. **Bondar I.S., Aldekeyeva D.T., Zhuandyk A.M.** (2021). Effective measures to protect from snow drifts automobile roads of Kazakhstan / Bulletin of KazATK, 1(116), 10-17. https://doi.org/10.52167/1609-1817-2021-116-1-10-17 [2. **Bondar', I.S., Aldekeeva, D.T., Zhuandyk, A.M.** (2021). Effektivnye mery po zashchite ot snezhnykh zanosov avtomobil'nykh dorog Kazakhstana. Vestnik KazATK, 1(116), 10–17. https://doi.org/10.52167/1609-1817-2021-116-1-10-17]
3. **Bondar I.S., Suleimenov M.H., Əbirzhan A.S.** (2023). Methods of snow removal on automobile roads of the Republic of Kazakhstan. VESTNIK Kazakh Automobile and Road Institute. 4, 41-53. [3. **Bondar', I.S., Suleimenov, M.Kh., Abirzhan, A.S.** (2023). Metody uborki snega na avtomobil'nykh dorogakh Respubliki Kazakhstan. Vestnik Kazakhskogo avtomobil'no-dorozhnogo instituta, 4, 41–53.]
4. **Bondar I.S., Ibraimov A.K., Nurakhova A.K., Zhandauletov A.** (2020). Snow protection afforestation along the roads of the Republic of Kazakhstan. Kazakhstan // Collection of materials of XVIII interuniversity scientific-practical conference of undergraduates and students. Conference of undergraduates and students, held in the framework of the realization of the New Economic Policy of Kazakhstan “Нұ”. Economic Policy of Kazakhstan “Nurly Zhol - the way to the future” Almaty: KazADI, 11-17. [4. **Bondar', I.S., Ibraimov, A.K., Nurakhova, A.K., Zhandauletov, A.** (2020). Lesonasazhdeniya dlya zashchity ot snega vdol' avtomobil'nykh dorog Respubliki Kazakhstan. In: Sbornik materialov XVIII mezhvuzovskoi nauchno-prakticheskoi konferentsii magistrantov i studentov. Konferentsiya magistrantov i studentov, provodimaya v ramkakh realizatsii Novoi ekonomicheskoi politiki Kazakhstana “Nurly Zhol – Put' v budushchee”. Almaty: KazADI, 11–17.]
5. **Onufriv, Ya. O., & Lemaikina, K.** (2020). Формування психоемоційного впливу на відвідувачів меморіальних парків засобами ландшафтної архітектури. Сучасні проблеми Архітектури та Містобудування, (57), 62–73. https://doi.org/10.32347/2077-3455.2020.57.62-73 [5. **Onufriv, Yu., Lemaikina, K.** (2020). Formirovanie psikhoemotsional'nogo vozdeistviya na posetitelei memorial'nykh parkov sredstvami landshaftnoi arkhitektury. Sovremennye problemy arkhitektury i gradostroitel'stva, (57), 62–73. https://doi.org/10.32347/2077-3455.2020.57.62-73.]

https://doi.org/10.51488/1680-080X/2026.2-20

6. **Onufriv, Ya. O.** (2015). Theoretical bases and research methods in visual quality of the landscape within the context of landscape and spatial organization of ski resorts. Space & Form: scientific journal. Vol. 24, 1. 137-148. URL: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-4a74ec55-92d7-48b0-8270-6cc71837a7b1
7. **RIKEN KOGYO** Inc. (2026). High-performance Snow/Wind Fence Technology.
8. **Sannikov D.N., Servatinskii V.V.** (2024). Simulation of snow fences for road protection from drifted snow. Vestnik Tomskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta – Journal of Construction and Architecture. Vol. 26 (3), 233−241. (In Russian). https://doi.org/10.31675/1607-1859-2024-26-3-233-241 [8. **Sannikov, D.N., Servatinskii, V.V.** (2024). Modelirovanie snezhnykh ograzhdenii dlya zashchity dorog ot zanosov. Vestnik Tomskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta – Journal of Construction and Architecture, Vol. 26(3), 233–241. (In Russian). https://doi.org/10.31675/1607-1859-2024-26-3-233-241]
9. **Filimonov, S. A., Litvintsev, K. Yu., Dekterev, A. A., Minakov, A. V., Meshkova, V. D., Sharafutdinov, R. A., & Zaharinskiy, Yu. N.** (2022). Application of computer modeling methods in the design of snow protection systems. Architecture, Construction, Transport, 3(101), 46-55. (In Russian). https://doi.org/10.31660/2782-232X-2022-3-46-55
10. **Filimonov S.A., Dekterev A.A., Gavrilov A.A. [et al.].** (2021). The influence of landscape and urban development on modeling of transport of pollutants in Krasnoyarsk city / Journal of Physics: Conference Series. Sevastopol, 012134. https://doi.org/10.1088/1742-6596/2057/1/012134
11. **Lebedeva I.V., Maslov A.V., Berezina M.M.** (2020). Experimental studies to establish the design parameters of snow loads / Bulletin of the Scientific Research Center "Construction", 2(25), 66-76. https://doi.org/10.37538/2224-9494-2020-2(25)-66-76 [11. **Lebedeva, I.V., Maslov, A.V., Berezina, M.M.** (2020). Eksperimental'nye issledovaniya po ustanovleniyu raschetnykh parametrov snegovykh nagruzok. Vestnik Nauchno-issledovatel'skogo tsentra "Stroitel'stvo", 2(25), 66–76. https://doi.org/10.37538/2224-9494-2020-2(25)-66-76]
12. **Menter, F.** (1993). Zonal two equation k-ω turbulence models for aerodynamic flows / 24th Fluid Dynamics Conference. – Orlando, Florida: American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.1993-2906
13. **Zaichik L.I., Drobyshevsky N.I., Filippov A.S. [et al.].** (2010). A diffusion-inertia model for predicting dispersion and deposition of low-inertia particles in turbulent flows / International Journal of Heat and Mass Transfer. Vol. 53, 1–3, 154–162. https://doi.org/10.1016/j.ijheatmasstransfer.2009.09.044
14. **Gavrilov A.A., Shebelev A.V.** (2018). Single-fluid mixture model for laminar flows of highly concentrated suspensions / Bulletin of the Russian Academy of Sciences. Fluid and Gas Mechanics. 2, 84–98. https://doi.org/10.7868/S0568528118020081 [14. **Gavrilov, A.A., Shebelev, A.V.** (2018). Model' odnozhidkostnoi smesi dlya laminarnykh techenii vysokokontsentrirovannykh suspenzii. Izvestiya Rossiiskoi akademii nauk. Mekhanika zhidkosti i gaza, 2, 84–98. https://doi.org/10.7868/S0568528118020081]
15. **Suiazova V.I., Debolskiy A.V., Mortikov E.V.** (2024). Study of surface layer characteristics in the presence of suspended snow particles using observational data and Large-Eddy Simulation / Izvestiâ Akademii nauk SSSR. Fizika atmosfery i okeana, 60, 2. https://doi.org/10.31857/S0002351524020057
16. **Marsh C.B., Pomeroy J.W., Wheater H. S., Spiteri R.J.** (2020). A finite volume blowing snow model for use with variable resolution meshes / Water Resources Research. Vol. 56, 2. https://doi.org/10.1029/2019WR025307
17. **Christopher B. Marsh, Zhibang Lv, Vincent Vionnet, Phillip Harder, Raymond J. Spiteri, John W. Pomeroy**. (2024). Snowdrift-Permitting Simulations of Seasonal Snowpack Processes Over Large Mountain Extents / Water Resources Research, 60, 8. https://doi.org/10.1029/2023WR036948

https://doi.org/10.51488/1680-080X/2026.2-20

18. **Louis Quéno, Rebecca Mott, Paul Morin, Bertrand Cluzet, Giulia Mazzotti, Tobias Jonas.** (2024). Snow redistribution in an intermediate-complexity snow hydrology modelling framework / The Cryosphere, 18, 8. 3533-3557. https://doi.org/10.5194/tc-18-3533-2024
19. **Matthieu Baron, Ange Haddjeri, Matthieu Lafaysse, Louis Le Toumelin, Vincent Vionnet, Mathieu Fructus.** (2024). SnowPappus v1.0, a blowing-snow model for large-scale applications of the Crocus snow scheme / Geoscientific Model Development, 17, 3. https://doi.org/10.5194/gmd-17-1297-2024
20. **Rebecca Mott, Adam Winstral, Bertrand Cluzet, Nora Helbig, Jan Magnusson, Giulia Mazzotti, Louis Quéno, Michael Schirmer, Clare Webster, Tobias Jonas.** (2023). Operational snow-hydrological modeling for Switzerland / Frontiers in Earth Science, 11. https://doi.org/10.3389/feart.2023.1228158
21. **Meshkova V.D., Dekterev A.A., Gavrilov A.A., Litvintsev K.Yu.** (2020). SigmaFlow CFD code as a tool for predicting the wind environment around a group of buildings / Journal of Physics: Conference Series. – Yalta, Crimea. 012119. https://doi.org/10.1088/1742-6596/1675/1/012119
22. **Yuanyuan Li, Huamei Mo, Guolong Zhang, Qingwen Zhang, Florence Naaim-Bouvet, Hervé Bellot, Feng Fan.** (2025). Estimation of region-varying snow drifting intensity over China considering local climatic conditions / Journal of Building Engineering, 111, 113557. https://doi.org/10.1016/j.jobe.2025.113557
23. **Theodore B. Barnhart, Annie L. Putman, Aaron J. Heldmyer, David M. Rey, John C. Hammond, Jessica M. Driscoll, Graham A. Sexstone.** (2024). Evaluating Distributed Snow Model Resolution and Meteorology Parameterizations Against Streamflow Observations: Finer Is Not Always Better / Water Resources Research, 60, 7. https://doi.org/10.1029/2023WR035982
24. **Manuel Saigger, Tobias Sauter, Christina Schmid, Emily Collier, Brigitta Goger, Georg Kaser, Rainer Prinz, Annelies Voordendag, Thomas Mölg.** (2024). A Drifting and Blowing Snow Scheme in the Weather Research and Forecasting Model / Journal of Advances in Modeling Earth Systems, 16, 6. https://doi.org/10.1029/2023MS004007
25. **Ross Mower, Ethan D. Gutmann, Glen E. Liston, Jessica Lundquist, Soren Rasmussen.** (2024). Parallel SnowModel (v1.0): a parallel implementation of a distributed snow-evolution modeling system (SnowModel), Geoscientific Model Development, 17, 10. 4135-4154. https://doi.org/10.5194/gmd-17-4135-2024
26. **Annelies Voordendag, Brigitta Goger, Rainer Prinz, Tobias Sauter, Thomas Mölg, Manuel Saigger, Georg Kaser.** (2024). A novel framework to investigate wind-driven snow redistribution over an Alpine glacier: combination of high-resolution terrestrial laser scans and large-eddy simulations / The Cryosphere, 18, 2. https://doi.org/10.5194/tc-18-849-2024
27. **Alicia F. Pouw, Homa Kheyrollah Pour, Alex MacLean.** (2023). Mapping snow depth on Canadian sub-arctic lakes using ground-penetrating radar /The Cryosphere, 17, 6. 2367-2385. https://doi.org/10.5194/tc-17-2367-2023
28. **Edoardo Raparelli, Paolo Tuccella, Valentina Colaiuda, Frank S. Marzano.** (2023). Snow cover prediction in the Italian central Apennines using weather forecast and land surface numerical models / The Cryosphere, 17, 2. 519-538. https://doi.org/10.5194/tc-17-519-2023

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