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The proceedings address current issues of sustainable and decarbonized road construction, the use of new materials and technologies, as well as modern approaches to road maintenance and lifecycle management of road infrastructure. Special attention is given to international experience, innovative solutions, and strategies for reducing the carbon footprint in the transport sector.

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PROSPECTS FOR 21ST-CENTURY NANOTECHNOLOGY FOR CREATING CLIMATE-RESISTANT AND ENVIRONMENTALLY FRIENDLY TRANSPORT INFRASTRUCTURE

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Abstract. This article presents the results of fundamental laser research, experimental work, and long-term monitoring of roads constructed using belite-based road cements. Belite cements, containing predominantly dicalcium silicates (C_2S – 50-80%), provide road concrete with a service life of up to 50 years without the need for repairs. Laser studies revealed the structure of belite cement stone, formed by nanoscale formations known as colloidal calcium hydrosilicates (CSH), which facilitate the almost complete hydration of cement grains. In Kazakhstan, scientific research has proven the feasibility and development of highly wear-resistant asphalt concrete road surfaces. The reliability of fundamental and experimental research is confirmed by effective 21st-century nanotechnology in road construction and the results of long-term road monitoring, including testing of concrete samples and cores subjected to various temperatures under laboratory conditions, extracted from nanostructured concrete and asphalt concrete roads operated for more than 35-46 years and 12-19 years without repair.

Key words: Highways, fundamental research, colloidal structure, cement belite concrete, asphalt belite concrete, ecology.

The development of belite cements based on industrial man-made mineral waste (IMW) that has undergone heat treatment during primary production and possesses latent hydraulic activity is an urgent problem for research.

Recent research in the field of asphalt concrete has focused on identifying and using various polymers and bitumen additives to improve the quality of asphalt concrete [1]. However, it is well known that the binder in asphalt concrete is not pure bitumen, but rather an asphalt binder consisting of bitumen and mineral powder [1]. Finely dispersed mineral powder with a specific surface area of up to 3000 cm^2/g, combined with bitumen, forms a colloidal solution [1], which facilitates thixotropic colloidal strengthening of asphalt concrete. The strength of purely bitumen bonds is tens of times lower than bonds formed through combined interaction with mineral powder.

It is known that the colloidal system of strengthening mineral binders [2-4] has the properties of long-term preservation of thixotropy - reversible self-healing after destruction and rheopexy - strengthening under the action of loads.

Fundamental laser and experimental studies demonstrate that the colloidal structures formed during the hydration of belite cements possess unique properties, such as long-term thixotropy (self-healing after destruction) and long-term rheopexy (strengthening under the influence of traffic loads and seasonal temperature changes), exclusively under long-term road operation conditions. The advantages of using belite cements in road construction include their high technological effectiveness, enabling year-round road construction and long-term operation for up to 50 years in Kazakhstan's harsh continental climate. Monitoring of concrete roads using belite cements confirms long-term concrete strengthening over 35-46 years of road operation (within the experimental limits).

The novelty of the authors' development is confirmed by a number of patents, which may reveal the secrets to the durability of ancient Roman concrete. A comparison of traditional, long-term global road construction experience in Kazakhstan and abroad has revealed that cement-based concrete road surfaces based on rapidly hardening Portland cements (C_3S - alite, up to 65%) with a crystalline strengthening structure have a limited service life of up to 25-30 years between repairs. This is due to the laws of physicochemical strengthening processes, primarily the rapidly hardening main mineral of Portland cement – tri-calcium silicate (C_3S - alite), which is destined to deteriorate within 20-25 years. For the first time in global road construction practice, Kazakhstan has established that road concretes based on belite cements, with a colloidal structure that provides long-term strengthening, are more effective during long-term road operation, preventing the possibility of premature deformation in the concrete. It was established that the durability of belite cement structures is ensured by nanosized colloidal calcium hydrosilicates CSH, due to the complete hydration of cement grains. This contrasts with the crystalline structure of alite Portland cements, where the hydration of tricalcium silicate C_3S is limited to 60%, leading to the formation of more than 40% "Young's microconcrete"— the unhydrated interior of the cement grains. Based on these studies, the following conclusions were proposed:

The uniqueness of belite cements, characterized by the formation of a colloidal structure with nanosized calcium hydrosilicates CSH, ensures almost complete hydration of cement grains, due to which the colloidal structures have the properties of long-term thixotropy (self-healing upon destruction) and long-term rheopexy (strengthening under the influence of transport loads and seasonal temperature changes), which ensures the elimination of premature destruction in concrete, exclusively under the conditions of long-term operation of concrete roads.

The transition to environmentally friendly, cold, nanostructured asphalt concrete in road construction, eliminating toxic gases both during construction and during long-term operation from heating of asphalt concrete road surfaces, will ensure protection from air pollution in large cities.

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DRAINAGE SYSTEM IN ROAD DESIGN – REQUIREMENTS AND COMPONENT CHARACTERISTICS

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Abstract. The article examines the main requirements for the design of drainage systems, their characteristics, and criteria for selecting components. Recommendations are also provided for choosing the optimal type of drainage system.

Keywords: highway, drainage system, roadside ditch, longitudinal slope, capacity, ecology.

The design of drainage systems for highways aims to prevent pollution and ensure the durability of pavement structures. Effective drainage helps to avoid road washouts, flooding, and other adverse impacts.

Main requirements for drainage systems. The design of road drainage systems is based on key regulatory documents: SN RK 3.03-01-2013 and SNiP 2.05.02-85. These standards regulate the selection and installation of external sewage systems for collecting and diverting surface water.

It is essential that the systems are capable of handling predicted peak discharges, which must not exceed maximum values determined from long-term data. The probability of exceeding the calculated volumes varies depending on the road category and ranges from 2–4% for different classes of highways.

Types of drainage channels and their characteristics

Surface drainage – the simplest and most cost-effective systems. They consist of gutters with grates along or across the road, allowing water to flow off naturally. These systems work effectively on sections with small slopes, where stormwater quickly disperses into the surrounding environment. Their main advantage is low construction and maintenance costs. The structure is simple and made of readily available materials.

Subsurface drainage systems **–** used in areas with high groundwater levels, such as urban or industrial zones. These systems include pipes installed beneath the pavement. A key feature is the required treatment of wastewater from petroleum products and other pollutants. Pipes are laid on a sand-gravel bed with a slope to ensure gravity drainage.

Combined systems – integrate both surface and subsurface drainage elements, which helps optimize construction and operating costs. This type of system is effective in urban and industrial areas, where water purification is necessary but it is also important to reduce excessive costs. Combined systems allow for flexible adaptation to local conditions and effectively manage different types of wastewater.

Elements of the Drainage System. Gutter trays with grates are installed along roads. Their primary function is to collect rainwater and meltwater. They represent channels that effectively divert moisture from the roadway. To prevent large debris from entering the system, these channels are equipped with grates, ensuring uninterrupted drainage performance. The trays are easy to install and provide high efficiency when the hydraulic cross-section is properly calculated.

Pipes for underground installation are intended for transporting wastewater from surface channels to remote areas or treatment facilities. They are laid beneath the roadway at a certain depth to prevent freezing and damage in the event of soil frost. Pipes can be manufactured from various materials depending on operating conditions and required strength.

Sand traps are devices installed at points where water is discharged into the urban sewage system. They serve to prevent clogging of municipal storm sewers. Their installation is a mandatory technical requirement for connection to the network.

Point storm inlets are installed at locations where water tends to accumulate on the road surface. They collect moisture and direct it into the drainage system. Installing such inlets in strategically important spots ensures effective collection and diversion of water, thereby preventing flooding and road surface damage.

Recommendations for Selecting the Optimal Type of Drainage System. When choosing the optimal type of drainage system for roads in Kazakhstan, it is necessary to consider the region's climatic conditions, type of pavement, and rainfall intensity. One of the most common drainage types is the storm sewer system, which is suitable for areas with high precipitation levels. It is also important to take into account the quality of materials used for drainage systems to ensure their durability and reliability.

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EQUIPMENT FOR MONITORING, ASSESSING THE RELIABILITY AND STABILITY OF BEAM SPAN STRUCTURES OF BRIDGES

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Abstract. Many artificial structures have lost their design operating parameters - permissible transport loads have decreased and speed restrictions have been imposed. This poses a threat not only to traffic safety, but also to the overall efficiency of the transport infrastructure. To solve this problem, diagnostics and testing of transport structures are carried out using a strain gauge measuring and computing complex to measure relative deformations and stresses, as well as a measuring complex for dynamic testing.

Keywords: strain gauge, deformation and stress, vibration diagnostics, monitoring.

The process of determining the load capacity of bridges [1-3] involves comparing the classes of bridge structures with the classes of rolling stock [4], which is critical for ensuring safe operation. The use of relevant guidelines for assessing the condition of bridges and their components is already in practice, and this is an important step towards preventing possible accidents.

If defects or damage are identified, their impact on load capacity must be assessed, which may require additional testing [5]. This highlights the need for regular monitoring of the condition of bridges and timely repair work in accordance with established requirements.

Preventing such incidents requires a comprehensive approach, including monitoring the condition of infrastructure, strict requirements for the quality of repairs, and training for personnel responsible for bridge operation.

Conducting surveys and tests of artificial structures on railways and motorways, including assessment of technical condition and development of recommendations for troubleshooting, modernization of methods for high-precision measurement of deformations (stresses) and vibrations – frequencies (periods), quality control of the construction and reconstruction of artificial structures, and vibration diagnostics (monitoring) of railway tracks, motorways, and artificial structures in the road industry are the issues addressed by the Track and Artificial Structures Testing (IpiIS) research laboratory.

The Tenso intelligent deformation and force monitoring system for analyzing loads in engineering structures is capable of comprehensively assessing the condition and load of various engineering structures: an intelligent system emphasizes the presence of advanced data processing algorithms; deformation and force monitoring reflects the measurement of both deformations and stresses; analysis of structural integrity and loads is a broader formulation than simply “measurement of deformations and stresses” (Fig. 1) [6].

Figure 1. Tenso intelligent deformation and force monitoring system for analyzing loads in engineering structures

The Dynamik intelligent system is designed to conduct dynamic field tests on engineering structures such as bridges, buildings, and other structures. It allows you to measure vibrations and frequencies (periods) that occur in these objects under the influence of various loads and process the data obtained using built-in computing resources [7]. Dynamik makes it possible to comprehensively assess the strength and stability of structures, identify potential weak points, and develop the necessary measures to reinforce or modernize them. It is an important tool for ensuring the safety and reliability of artificial structures (Fig. 2).

Figure 2. Dynamic intelligent system for assessing the strength and stability of artificial structures

To ensure reliable assessment of the condition of bridge structures and establish correspondence between their design model and actual operation on motorways and railways, it is necessary to regularly monitor the stress-strain state of structures under real operating loads. Using vibration diagnostics of artificial structures, bridge engineers will be able to promptly inform operational services about the technical condition.

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OPTIMIZATION OF SPEED LIMITS ON HIGHWAYS CONSIDERING PAVEMENT CONDITIONS

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Abstract. Compliance with speed limits is significantly influenced by the transport-operational condition of roads, which in turn has a major impact on maintaining stable traffic flow speeds, as well as on road safety and driving comfort for both drivers and passengers. The appearance of potholes, cracks, and other pavement defects leads to speed reduction and increased travel time. Moreover, deteriorating pavement conditions adversely affect driver reaction times, significantly increasing the risk of traffic accidents. The key factor in enhancing road safety and maintaining stable speed regimes is the preservation of pavement quality by road maintenance services. The main objective of this thesis is to optimize speed limit regulations on highways, considering the operational condition of the road infrastructure.

Keywords: highway, travel speed, traffic accident, traction, hazardous sections

In the context of rapid development of transport infrastructure, road traffic safety remains a particularly pressing issue. Two of the key factors that have a direct impact on accident rates are vehicle speed and the operational condition of roadways. To reduce risks and improve road safety, a comprehensive analysis of these factors is essential. This includes not only regular road maintenance and repair but also the optimization of speed limits based on pavement conditions and road characteristics.

A particularly hazardous situation arises when high vehicle speeds are combined with poor road surface conditions. Even when traffic regulations are observed, accidents may occur if the road surface does not provide adequate traction or contains unexpected obstacles. The following section presents the results of field studies aimed at determining vehicle travel speeds on selected road segments. The study was conducted on sections of the Almaty – Ust-Kamenogorsk highway.

Table 1. Results of Field Measurements on Sections of the "Almaty–Ust-Kamenogorsk" Motor Road, Road Category – Ib

Section location, km	Traffic intensity, vehicles per hour	Pavement condition		
		dry	wet	loose snow
1	2	3	4	5
km 270-278	3000	134	88	93
		68	109	88
		121	111	100
		138	99	78
		121	110	69
		126	100	98
km 245-260	4000	109	103	92
		125	92	80
		115	99	79
		68	118	67
		123	103	100
		89	100	89
km 105-110	5000	104	86	59
		89	96	93
		60	103	89
		96	112	91
		121	91	105

Section location, km	Traffic intensity, vehicles per hour	Pavement condition		
		dry	wet	loose snow
km 65-75	6000	100	70	100
		85	93	89
		60	60	71
		118	113	62
km 25-35	7000	55	70	81
		112	57	77
		106	102	60
		87	71	52
		93	86	70
km 20-25	8000	64	50	80
		88	87	56
		79	60	61
		103	91	67

When establishing the correlation for calculation, field data on vehicle speeds collected on the section of the Almaty–Ust-Kamenogorsk road between kilometers 20 and 278 were used. This section is not classified as a motorway; therefore, the maximum allowed speed is 110 km/h. Consequently, in the first case, more than 60% of passenger car drivers exceeded the speed limit, indicating that on this economic stretch, the average speed increased by approximately 13 km/h.

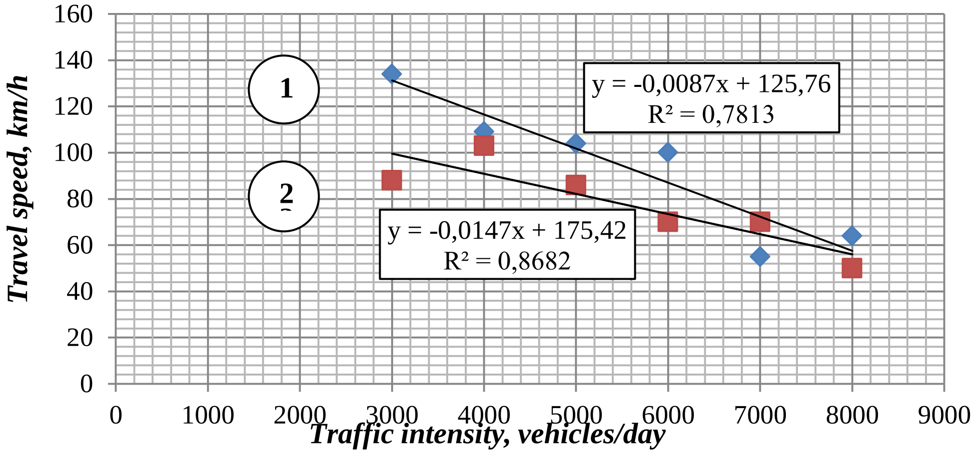

Figure 1. Correlation between traffic volume and travel speed:
1 – dry pavement; 2 – wet pavement.

By analyzing the cumulative speed curves obtained from field tests, a correlation was established between vehicle speed and traffic volume. The data were compared under dry and wet pavement conditions, where maximum speeds were observed. As shown, the differences are significant: on dry pavement, the maximum speed reached 143 km/h, while on wet pavement, it was limited to 112 km/h. A noticeable deviation was also observed with increasing traffic volume. For example, on dry pavement, with a traffic volume of 3,000 vehicles per day, the average speed of passenger cars reached approximately 123 km/h. However, under the same surface conditions, when traffic volume increased to 8,000 vehicles per day, the average speed dropped to 100 km/h.

Road traffic safety depends on a wide range of factors, but vehicle speed and the operational condition of the road surface remain among the most critical. Continuous monitoring, timely response to changes in road conditions, and the implementation of innovative solutions are key to ensuring the safe and sustainable development of the transportation system

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APPLICATION OF RECTANGULAR CULVERT PIPES IN CONSTRAINED CONDITIONS

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Abstract. To reduce the required fill depth above culvert pipes, a modification to standard culvert designs is proposed, involving the installation of an overlay slab.
Keywords: culvert pipes, standard design, fill depth, structural reinforcement, overlay slab, small bridge.

In highway construction, precast rectangular reinforced concrete culvert pipes—designed in accordance with standard specifications [1] - are employed to span various obstacles such as utility lines, watercourses, pedestrian walkways, and other impediments.

The design of culverts, pedestrian underpasses, and service tunnels constructed from precast rectangular concrete segments is governed by Clause 5.1.3 of SP RK 3.03-112-2013 [2], which stipulates mandatory requirements that cannot be waived. One such requirement is the minimum fill depth above the pipe-0.5 metres measured from the crown of the segment to the underside of the road pavement structure.

The thickness of the pavement structure itself varies depending on the classification of the road and typically ranges from 30 to 70 centimetres. Consequently, the minimum total height from the top of the pipe to the road surface is between 0.8 and 1.2 metres. In flat terrain, this necessitates the construction of an artificial embankment above the culvert, as illustrated in Figure 1.

The primary fill material is soil, a non-renewable resource that may only be sourced from designated borrow pits, which are often located at considerable distances from the construction site.

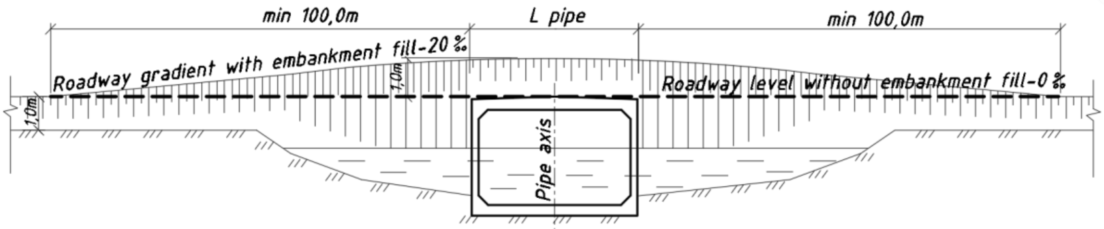

Figure 1. Design Solution in Accordance with SP RK 3.03-112-2013

Figure 1 illustrates a standard embankment arrangement for a roadway, incorporating approximately 1.0 metre of fill above the culvert pipe. Under this configuration, the raised embankment must be extended a minimum of 100 metres on either side of the culvert to ensure safe vehicular access to the engineering structure.

Such embankments are designed and constructed with a gradual and safe longitudinal gradient—typically around 40‰ under normal conditions and up to 60‰ in mountainous terrain. However, these elevated approaches significantly increase construction costs. The formation of such raised profiles above culverts results in additional expenditure related to borrow pit development, soil transportation, and embankment construction.

Under these conditions, the estimated volume of fill material required per culvert installation is as follows:

- For roads of technical category IV: approximately 2,500.0 m^3
- For category III roads: approximately 2,700.0 m^3
- For roads of technical category II: approximately 3,050.0 m^3

At present, the national road network is largely established, and new construction or reconstruction projects typically adjoin existing carriageways. Design challenges are particularly acute within urban areas, where dense development and extensive utility infrastructure constrain available space.

Under such conditions, any alteration to the horizontal or vertical alignment of roads and associated engineering structures entails considerable expense—and in many cases proves unfeasible. This necessitates the adoption of non-standard solutions, such as the installation of culvert pipes with minimal or even zero cover.

For these scenarios, the technical solution illustrated in Figure 2 is proposed: a culvert pipe structurally reinforced with a monolithic, cast-in-place, reinforced concrete overlay slab. This slab is integrally connected to the pipe body via projecting reinforcement bars, effectively merging the culvert and bridge elements into a unified structure.

This configuration results in a structural fusion of culvert and bridge elements. In Figure 2, items 1, 2, and 3 represent components typically associated with bridge construction.

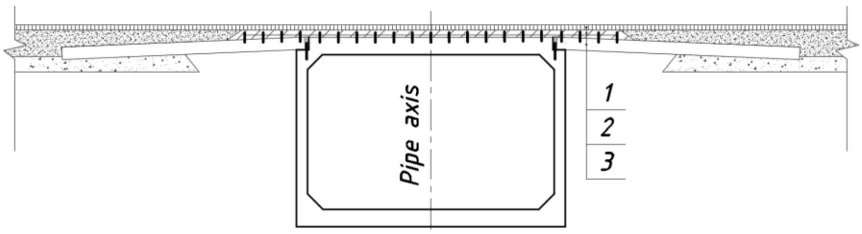

Figure 2. Culvert Reinforced with a Monolithic Overlay Slab**:** 1 – Roadway surfacing; 2 – Monolithic overlay slab integrally connected to the culvert body via projecting reinforcement; 3 – Transition slab bearing on a crushed stone bedding

In addition to the overlay slab, the culvert structure incorporates several elements typical of small bridge design:

- Safety barriers along the carriageway
- Pedestrian walkways with parapet railings, particularly suited for urban environments
- Transition slabs for structural integration

The proposed design is optimally suited for prefabrication at precast concrete manufacturing facilities and offers several advantages over bespoke monolithic construction, including:

- Reduced material consumption compared to cast-in-place alternatives
- Certified products verified by technical quality control departments
- Efficient use of electrical energy during factory production
- Simplified assembly of precast components, leading to accelerated construction timelines

The primary drawback lies in the logistical challenge of transporting precast elements from the manufacturing plant to the construction site.

To enable widespread adoption of this design, it is necessary to revise the existing standard project documentation [1] and modernise the production process for culvert segments [3].

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SEEPAGE AND STABILITY OF ROAD EMBANKMENTS: A NUMERICAL - PROBABILISTIC APPROACH

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Abstract. Under changing climate conditions and increasing extreme precipitation, the stability of earthen structures becomes a critical issue. This article combines two modern approaches to assessing the stability of road embankments: computational fluid dynamics (CFD) modeling of seepage processes and probabilistic analysis using the Monte Carlo method and finite difference method. CFD modeling allows a detailed representation of pressure and velocity fields, while probabilistic methods quantify the uncertainty of soil parameters and estimate the probability of failure. The comparison highlights the importance of integrating both approaches for more reliable risk assessment.

Keyword: seepage; road embankment; slope stability; probabilistic analysis.

The stability of embankments is a critical factor in the design, construction, and operation of transport infrastructure, dams, levees, and other civil engineering facilities. Failure of an embankment may result in severe economic losses, environmental disasters, and even human casualties. Contemporary climatic changes, manifested through increasingly frequent extreme precipitation events, fluctuations in groundwater levels, and soil saturation, exert a significant impact on the performance of earth structures. Slopes and the embankment body become particularly vulnerable under conditions of seepage, where they are exposed to internal erosion, strength reduction, and progressive deformations.

Recent studies confirm that the quality of soil compaction during embankment reconstruction is a decisive condition for long-term stability (Bondar, Abdirzhan, & Begejanova, 2025), while spatial modeling of structural systems has become an essential tool for predicting the behavior of complex engineering facilities (Bondar, Aldekeyeva, & Ospanova, 2024). At the same time, experimental evidence on the dynamic properties of soils (Bondar et al., 2025) provides not only a refinement of calculation parameters but also the basis for developing new protective strategies against extreme external actions.

To investigate seepage flow and the resistance of the embankment to erosion, a two-dimensional model was developed. The computational environment was based on the ANSYS Fluent software, which is capable of solving three-dimensional fluid flow problems in porous media (ANSYS Inc., 2023). A typical road embankment was selected, with a height of 4.0 m, a crest width of 3.0 m, and side slopes of 1:1.5. The total length of the modeled section along the road was 10 m. The embankment was assumed to rest on a weak foundation with a groundwater table located 0.5 m below its base. Precipitation was simulated as surface infiltration with an intensity equivalent to daily rainfall of 50 mm/day.

The embankment soil was assumed to be medium-density sandy loam with a filtration coefficient of $1\times10^{-5}\ \frac{m}{s}$, in accordance with the guidelines provided by Gorev (1982). At the base of the embankment, a sand drainage layer with a thickness of 0.5 m and a filtration coefficient of $5\times10^{-4}\frac{m}{s}$ was incorporated. The schematic representation of the model is shown in Figure 1.

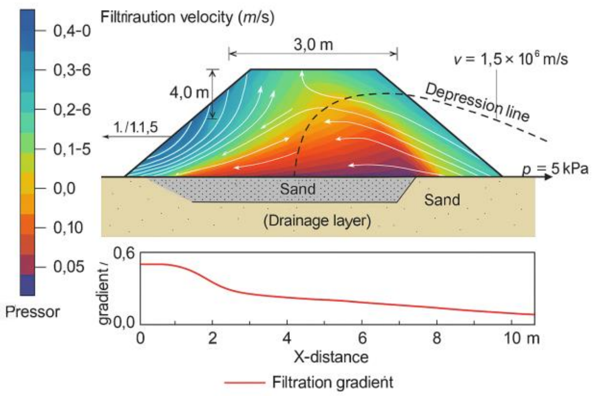

Figure 1. Two - dimensional cross - section of the embankment with dimensions (height, seepage path length, slope angle 1:1.5), boundaries of the seepage flow, and principal parameters

A porous media model was applied using the Navier–Stokes equations, modified to account for the resistance of a porous body (Darcy–Forchheimer):

$$\frac{\partial \rho \vec{u}}{\partial t} + \rho\,(\vec{u}\cdot\nabla)\,\vec{u} = -\nabla p + \mu \nabla^2 \vec{u} - \frac{\mu}{K}\vec{u} - \frac{C_f \rho}{\sqrt{K}}\,|\vec{u}|\,\vec{u}, \quad (1)$$

where: $\vec{u}$ − velocity vector; ρ − water density (1000 $\frac{kg}{m^3}$); μ − ynamic viscosity (0.001 Pa · s); K − medium permeability; C_f − dimensionless resistance coefficient (≈ 1 for sandy loam).

Numerical modeling of seepage processes (CFD, ANSYS Fluent) demonstrated that a two-dimensional problem setup is effective for identifying localized zones of pressure concentration and seepage velocity. This confirms the necessity of using such models in the analysis of embankments under conditions of saturation.

Probabilistic methods of analysis (Monte Carlo simulations and the finite difference method) provide the ability to account for the variability of soil properties and groundwater levels. Unlike the traditional factor of safety (FS), these approaches enable the estimation of quantitative indicators of failure risk, such as the probability of failure (Pf) and the reliability index (β).

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UDC 625.7/8

IMPROVING THE EFFICIENCY OF CRACK REPAIR ON HIGHWAYS USING THE POLYMER ADDITIVE PR FLEX 20

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Abstract. This study focuses on investigating the causes of crack formation on public automobile roads in Kazakhstan and on improving the efficiency of crack repair through the use of the polymer additive PR FLEX 20. The widespread use of asphalt concrete as a road construction material is due to its unique properties; however, its physical and mechanical characteristics are highly dependent on temperature. This leads to various types of surface defects, including rutting during hot periods and, more characteristically, crack formation at low temperatures.
Keywords: road pavement, crack formation, crack resistance, thermal cracking, polymer additives, thermal loads.

In the context of increasing traffic loads and challenging operational conditions, the use of the polymer additive PR Flex 20 represents a promising approach to improving the quality of road pavements.

This modifier significantly enhances the plasticity of asphalt concrete, its resistance to cracking and rutting, and extends the service life of the pavement. PR Flex 20 polymer additives reduce the risk of deformation at elevated temperatures. Thus, the incorporation of polymer additives into asphalt concrete is a relevant and effective solution aimed at improving the quality and durability of road pavements under modern conditions.

PR Flex 20 is a polymer additive produced by the French company PR Industrie, designed to improve the performance characteristics of asphalt concrete. PR Flex 20 is a granular modifier based on a styrene-butadiene-styrene (SBS) polymer combined with an ethylene-butyl acrylate copolymer, pre-encapsulated in bitumen. The technical specifications of the PR Flex 20 polymer additive are presented in Table 1.

Table 1. Technical Characteristics of the PR Flex 20 Polymer Additive

PR Flex 20 is an additive composed of elastomers and plastomers, pre-treated with a specially formulated bitumen. This additive is designed to enhance the performance characteristics and extend the service life of road pavements. It can be introduced into the bitumen prior to its delivery to the mixing plant, or added directly to the mineral aggregates in the mixer before the bitumen is applied.

Figure 1. Granular Form of PR Flex 20

Bitumen modified with PR Flex 20 polymer improves:

Figure 2. Wheel Tracking Device

Figure 3. Sectorial Compactor

- Flexibility of the pavement at low temperatures;
- Resistance to rutting at high temperatures;
- Reduction of bitumen aging;
- Improved thermal stability during asphalt production compared to polymer-bitumen binder (PBB).

The recommended dosage of PR Flex 20 polymer additive is 6–8% by weight of the bitumen binder. PR Flex 20 granules are shown in Figure 1.

Using a rutting test device (Figure 2), laboratory tests were carried out in accordance with ST RK EN 12697-33-2012 [1]. Samples were prepared using a sector compactor (Figure 3) to determine the average rut depth.

The samples were thermostated at ambient temperature for 24 hours, after which they were placed into the rutting test device. The average rut depth was determined according to the ST RK EN 12697-22-2012 [2] test method.

A series of tests were conducted on the prepared samples to determine their physical and mechanical properties. The test results for the SMA samples without polymer additives are presented in Table 2.

Table 2. Physical and Mechanical Properties of SMA Without Polymer Additives

Mix name	**Standard requirement according to GOST 31015-2002 [3]**	**Actual result**
Average density, g/cm³	Not compliant	2,42
Residual porosity, %	**From 2.0 to 4.5**	4,1
Water saturation, %	**From 1.5 to 4.0**	3,2
Compressive strength, MPa:		
at 50 °C	Not less than 0.7	0,9
at 20 °C	Not less than 2.5	2,5
Shear resistance:		
Internal friction coefficient	0,94	0,94
Shear cohesion at 50 °C	0,20	0,21

As a result of the conducted laboratory tests, the main physical and mechanical properties of SMA without modifications were recorded. The obtained values fall within the requirements set by the standard GOST 31015-2002 [3], which formally permits its use in road pavements. However, in practice, considering modern external factors such as increased traffic intensity, unstable temperature conditions, and decreased bitumen quality, these parameters may be insufficient to ensure the required level of reliability and wear resistance of the pavement.

For modification of the SMA mixture, the polymer additive PR Flex 20 was used at a dosage of 6% by weight of the bitumen binder. The aggregate gradation and bitumen content remained unchanged.

Table 3. Physical and Mechanical Properties of Polymer-Modified SMA with PR Flex 20 Additive

Mix name	Standard requirement according to ST RK 2373-2019 [4]	Actual result
Average density, g/cm³	Not compliant	2,41
Residual porosity, %	From 2.0 to 4.5	3,9
Water absorption, %	From 1.0 to 4.0	2,8
Compressive strength, MPa: at 50 °C at 20 °C	 Not less than 1,0 Not less than 2,8	 1,4 3,7
Shear resistance: Internal friction coefficient Shear cohesion at 50 °C	 0,94 0,25	 0,95 0,28
Crack resistance – tensile strength at splitting at 0 °C, MPa:	From 3,5 to 6,0	4,6
Average rut depth, mm	Not more than 3,0	2,40

Particular attention should be paid to the rut depth result: upon completion of the tests, it reached 4.51 mm. Although there are no specific regulatory requirements for this parameter in GOST 31015-2002 [1], such a value indicates a tendency of the pavement to undergo plastic deformations. Considering the actual loads acting on the road network under real operating conditions, this result should be regarded as unfavorable from the standpoint of long-term performance.

The obtained data have been recorded and will be used for comparative analysis with modified samples [5]. The next stage of the study involves evaluating the performance of stone mastic asphalt (SMA) modified with PR Flex 20 polymer additives.

The conducted research demonstrated that the use of the PR Flex 20 polymer additive, which contains plastomeric components, significantly improves resistance to rutting. The recorded rut depth values confirm the effectiveness of this additive in enhancing the deformation resistance of the pavement.

Thus, the incorporation of PR Flex 20 into SMA can be considered a well-justified solution when it is necessary to provide protection against rutting and extend the service life of the road surface.

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UDC 625.7/.8:691.32:628.4

COMPREHENSIVE UTILIZATION OF LIMESTONE CRUSHING SCREENINGS IN ROAD CONSTRUCTION

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Abstract. This study explores the comprehensive utilization of limestone crushing screenings in road construction. Experimental results demonstrate their effective use in carbonate cement, fine-grained carbonate concrete, mineral fillers, and penetrating hardening mixtures. The application of these technologies reduces construction costs by up to 30%, improves road durability, and contributes to sustainable waste recycling in Kazakhstan

Keywords: Limestone screenings; carbonate cement; fine-grained carbonate concrete (FGCC); mineral filler; lime-containing fillers; penetrating hardening mixtures (PHM); road construction; recycling; Kazakhstan.

Carbonate raw material deposits are widely distributed across the Republic of Kazakhstan, with total reserves exceeding 3 billion tons. During the extraction and processing of limestone, up to 30–35% of the material is generated as screenings (fractions of 0.1–5 mm), leading to the accumulation of significant waste volumes. These materials are characterized by a high content of fine particles (~40%) and low energy demand for grinding, which makes them highly suitable for comprehensive utilization [1,2].

At the Kazakh Automobile and Road Institute named after L.B. Goncharov (KazADI), research has been conducted on the integrated processing of limestone crushing screenings as part of carbonate composites, where screenings serve as:

- a binder component in carbonate cement production;
- fine aggregate and filler in efficient fine-grained carbonate concrete (FGCC) used for rigid bases under improved (asphalt concrete) pavements of roads in categories I–IV, as well as for urban streets, industrial access roads, and airfield pavements;
- the main raw material in the production of mineral filler (grade MP-1) in two types: activated (hydrophobic) and non-activated (hydrophilic);
- lime-containing mineral fillers for the development of advanced asphalt concrete mixtures with increased CaO content;
- a component of penetrating hardening mixtures (PHM) based on finely ground carbonate cements.

Research methods. The development of carbonate composites from industrial by-products involved well-established scientific approaches, including:

- sampling of representative waste fractions and raw material analysis;
- evaluation of existing experience in processing technogenic raw materials;
- experimental planning and statistical processing of laboratory results.

Carbonate cement. Qualitative characteristics of technogenic mineral raw materials were determined, and new binder formulations were developed using finely ground Portland cement clinker, carbonate rocks, and a small proportion of gypsum. The optimal carbonate content in cement was found to be 25–30% (in some cases up to 60%), with 5–6% gypsum.

Fine-grained carbonate concrete (FGCC). An efficient FGCC with improved performance was developed based on limestone crushing screenings. It incorporates finely ground limestone filler (specific surface area 450–500 m²/kg) in the range of 10–50% and 0.75% superplasticizer SP-

1 by cement mass. This approach reduces FGCC production costs by 15–30% through the use of carbonate waste.

Mineral filler (grade MP-1). Screenings were subjected to drying and grinding to obtain mineral filler. The chemical composition is presented in Table 1 [2].

Table 1. Chemical composition of limestone-based mineral filler, %

Analyzed material	Chemical composition					
	ппп	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**
Limestone screenings	43.83	0.34	0.05	0.52	54.35	0.65

The resulting filler, used as a mandatory component (up to 18%) in asphalt concrete mixtures, ensures increased density, heat resistance, and durability of road pavements [2].

Lime-containing mineral fillers. Experimental studies demonstrated that increasing CaO content in fillers up to 40% (versus the 3% limit in current standards) enhances asphalt concrete strength, water and frost resistance, deformation stability, and bitumen aging resistance, while expanding the raw material base.

Penetrating hardening mixtures (PHM). The development of PHM based on finely ground carbonate cements enables the construction of durable stabilized bases. Using limestone waste combined with plasticizing additives reduces the material intensity of road structures and improves environmental conditions by recycling mining by-products.

The development and application of the above-mentioned composites represent a highly relevant task for Kazakhstan. Their introduction will reduce the material intensity of road construction, increase durability, and improve the environmental situation by utilizing limestone crushing screenings. The economic effect of implementing these technologies includes cost reduction (up to 30%), an increased profitability index of projects (1.29), and enhanced cost efficiency of road works.

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REVIEW AND ANALYSIS OF THE APPLICATION OF ECO-ROADS STABILIZING ADDITIVE FOR MOISTURE CONTROL IN SOFT SOILS

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Abstract. This article examines the problem of moisture regulation in soft soils during road construction and operation. It demonstrates that the use of the Eco-Roads stabilizing additive reduces water saturation and improves soil strength. The results of experimental studies and international experience are presented, confirming the effectiveness of this technology.

Keywords: soft soils, moisture regulation, stabilizing additive, Eco-Roads, road construction, foreign experience.

One of the main factors determining the reliability and durability of road structures is the moisture content of the base. Overwatering of soft soils leads to loosening, loss of bearing capacity, uneven settlement, and pavement deformation. To minimize the negative impact of water saturation, artificial moisture control methods are used, including drainage systems and the use of special stabilizing additives.

To evaluate the effect of Eco-Roads additive on the properties of soft soils, laboratory tests were conducted in the following areas:

- determination of the coefficient of water absorption and filtration;
- study of changes in tensile strength at different humidity levels;
- freeze-thaw cycle resistance tests;
- Determining the optimal dosage of the additive depending on the type of soil.

Loamy and sandy loam soils, characterized by increased water saturation.

Moisture regulation. Eco-Roads additive demonstrated a hydrophobic effect, reducing capillary rise of moisture by 25–30% compared to control samples.

Strength. Soil compressive strength increased by an average of 35–40%.

Frost resistance. The incidence of destructive cracks during freeze-thaw cycles has been reduced by almost half.

Economic benefits. Using this additive allows for a reduction in the amount of cement and lime by up to 40%, which reduces construction and operating costs.

Foreign experience. World practice shows that methods of stabilizing soft soils using organic and biopolymer additives have a similar mechanism of action to Eco-Roads.

India – organic stabilization of weak clays using enzymatic additives. Enzymatic stabilizers (ESS) reduce capillary rise of moisture and decrease clay plasticity. Effect: reduction of optimal moisture content by 8–12%, increase in CBR by 2–3 times. Used on rural roads with seasonal waterlogging.

Brazil – the use of biopolymers to strengthen sandy loams. Xanthan and starch biopolymers were used. Effect: reduction in filtration coefficient by up to 40%, increase in strength by 30–50%, and improved resistance to wet-dry cycles. Used in the construction of local roads.

International experience confirms the effectiveness of organic and enzymatic additives for regulating moisture and strengthening weak soils, which strengthens the rationale for using Eco-Roads. Eco-Roads stabilizing additive regulates moisture in soft soils, reduces water saturation, and increases the strength and durability of roadbeds. The combination of domestic and international experience demonstrates the potential for implementing this technology in regions with variable groundwater levels and unfavorable climatic conditions.

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CALCULATION OF THE STABILITY OF SLOPES OF HIGH EMBANKMENTS AND DEEP CUTTINGS

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Abstract. The «CREDO OTKOS» program solves problems related to analyzing the stability of earthworks when designing foundations for buildings and structures, as well as roads and railways. The program has a database of sandy and silty-clay soils, which can be supplemented with new soils and their physical and mechanical characteristics can be refined. This is the most reliable method, for example, for reconstruction or detailed design of subgrades in complex soil and geological conditions.
Keywords: slope stability, high embankments, deep excavations, «CREDO OTKOS», motorway.

The CREDO OTKOS program solves problems related to analyzing the stability of earthworks when designing foundations for buildings and structures, as well as roads and railways. The program has a database of sandy and silty-clay soils, which can be supplemented with new soils and their physical and mechanical characteristics can be refined [1]. This is the most reliable method, for example, for reconstruction or detailed design of subgrades in complex soil and geological conditions.

When creating a soil model, it is possible to specify all the physical and mechanical characteristics of the soil without recalculation. The parameter fields are available for editing. The initial data for performing the task of assessing the stability of the subgrade are: general data on the object; data on the structure and soils of the subgrade; data on the foundation soils.

Finite element modeling [2] in the CREDO OTKOS program solves soil mechanics problems and performs slope stability calculations [3], including: Calculation of the thickness of the equivalent soil layer according to GOST R 52748-2007 (from the standard load NK).

The thickness of the equivalent soil layer Ne, m when calculating the stability of embankment slopes from vehicle loads (from the standard load NK) is calculated using the formula:

$$Н_э = \frac{4 \cdot 18 \cdot К}{(D + 0{,}2) \cdot (C + 0{,}8) \cdot \gamma_{gr}}$$

*where **K** is the load class of the load, kN, **D** is the load base of the load, m, **C** is the load width of the load, m, γ_{gr} is the specific weight of the soil, kN/m^3.*

Calculation of the equivalent layer thickness using the classical method (taking into account various methodological recommendations, guidelines, and other regulatory documents). User-defined equivalent layer thickness. Search for a dangerous slip curve using the coordinate descent method. Calculation of subgrade stability using the modified Terzaghi method for each slip curve, including division of the sliding mass into blocks, calculation of the area and weight of blocks taking into account the parameters of each layer of the subgrade in each block, calculation of shear forces, friction and adhesion forces in each block, calculation of shear and holding moments.

Calculation of embankment stability, including embankments on weak foundations using reinforcing layers of geosynthetic materials according to calculation schemes and formulas in accordance with ODM 218.5.003-2010 “Recommendations for the use of geosynthetic materials in the construction and repair of motor roads”.

Based on the results of the calculations, the program can create a drawing showing the entire slope design scheme or individual fragments of this scheme (Fig. 1).

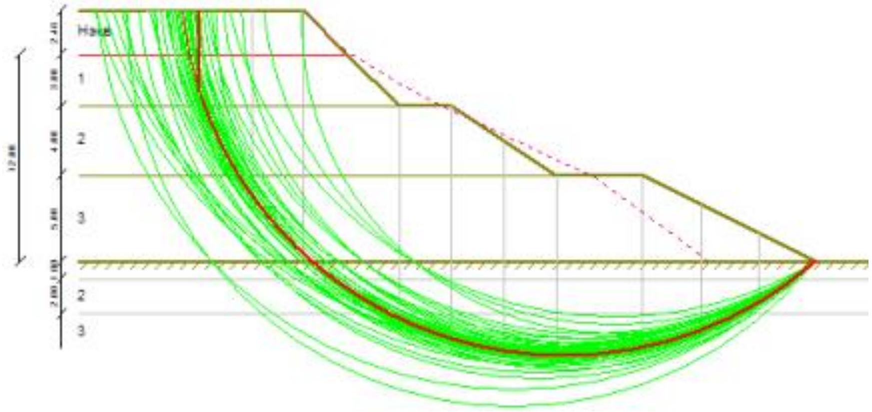

Figure 1. Embankment slope design diagram

The calculation results can also be presented in the form of reports, which include data on external loads, embankment and foundation reinforcement, and geosynthetic materials (Table 1).

Table 1. Calculation results for embankment and foundation reinforcement

Equivalent layer determined in accordance with GOST R 52748-2007			Parameters and calculation method for geosynthetic material in reinforcement		
			Calculation method for geosynthetic material	foundations	slope embankments
Load class for NK	kN	8,3		ODM 218.5.003-2010	
Load track width for NK	m	2,70	Geosynthetic material grade	Gaospan TNPE 250	Gaospan TN 80
Load base for NK	m	3,60	Long-term strength, kN/m	119,00	22,00
Constant load	t/m	1,0	Tensile strength, kN/m	≥250	≥80
Thickness of the conditional equivalent soil layer	m	2,48	Relative elongation along the length of the material E_{max}, %	10	15

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MODERN METHODS OF ROAD DRAINAGE ORGANIZATION IN THE REPUBLIC OF KAZAKHSTAN

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Abstract. The article analyzes existing research and publications on road drainage systems and the methodologies applied in the design of highways. It also provides recommendations for organizing drainage systems aimed at reducing the impact of precipitation on pavement durability and minimizing the negative effects of wastewater on the environment.
Keywords: highway, drainage system, roadside ditch, longitudinal slope, capacity, ecology.

Under modern safety and environmental requirements, the organization of drainage from highways is one of the most important tasks of the transport sector [1]. Improper diversion of surface and groundwater accelerates the destruction of pavements, reduces structural performance, and increases environmental pollution from wash-off products. In the Republic of Kazakhstan, outdated standard solutions developed decades ago are still widely used without considering technological advances or new climatic conditions.

The study analyzes existing methods of road drainage. Systematic research on surface water diversion began in the mid-20th century. The first attempt to generalize design methods was made by A.K. Biryulya [2]; significant contributions were later made by B.F. Perevoznikov, A.A. Ilyina [3,4,5,8,9], and foreign scholars such as L. Hughes, P.C. Clark [11], S.A. O'Flaherty, and W. Dumbleton [12]. Their solutions corresponded to their time, when environmental and groundwater protection issues were not yet priorities.

The most common drainage method in Kazakhstan is the construction of earth ditches of various profiles, whose shape and size depend on the route conditions. For low embankments, side ditches are designed, with or without reinforcement, depending on the intensity of flows. These solutions are simple and inexpensive, but their advantages largely end there. At the same time, there is no comprehensive analysis of how excess runoff affects the durability of road structures or how polluted waters infiltrate soil and groundwater, causing environmental degradation.

In the 1980s, structures aimed at improving drainage appeared, with system capacity as the key parameter. Capacity depends on material roughness, geometry and depth of channels, and longitudinal slope. However, insufficient consideration of these factors leads to moisture accumulation on the roadway, reduced pavement life, and increased environmental damage. As a result, these designs were not widely implemented and were scarcely reflected in regulatory documents.

Defining modern technologies to improve drainage efficiency and environmental performance. Modern technologies can significantly increase drainage efficiency:

– The use of geosynthetic materials prevents silting and clogging of drainage layers, extending their service life.

– Polymer-concrete channels provide high water flow rates even with minimal longitudinal slopes, ensuring impermeability, frost resistance, and chemical stability.

– New-generation modular drainage systems are easy to install and adapt to climate conditions, allowing designers to flexibly respond to regional specifics.

An integrated approach also includes filter pipes, collectors, and multi-stage runoff treatment systems that reduce environmental stress on natural water bodies.

Regular monitoring and maintenance of drainage infrastructure are essential. Modern diagnostic methods, such as video inspection and remote sensors, allow early detection of defects. In addition to engineering solutions, biotechnical approaches are increasingly used: reinforcing slopes with vegetation and selecting plant species adapted to local climates to slow surface runoff. This combination increases pavement stability and project sustainability.

A promising direction is the installation of rainwater harvesting systems and modern stormwater collectors, which not only ensure timely water removal but also enable more efficient water use [4].

The analysis showed that road drainage systems in Kazakhstan require comprehensive modernization.

Recommendations:

1. Develop a national program for the improvement of highway drainage systems, including updating regulations and introducing digital forecasting and monitoring tools.
2. Expand the use of geosynthetic materials and modular structures to ensure easy installation, climate adaptation, and reduced operating costs.
3. Introduce rainwater collection and reuse systems to conserve water resources and reduce the load on natural water bodies.
4. Regularly monitor drainage infrastructure using advanced technologies such as video diagnostics, moisture sensors, and digital data platforms.
5. Ensure environmental safety by incorporating filtration and treatment elements in drainage systems to prevent polluted runoff from entering soil and water bodies.

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EXPERIMENTAL STUDY OF THE REPAIR STOCK CONDITION AND CRACK FORMATION IN CRANKSHAFTS

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Abstract. The wear of component surfaces can be eliminated by various methods, such as machining to a repair size, installing an additional repair part, surfacing, metal spraying, and others. There are numerous methods for repairing and restoring crankshafts. The choice of a specific method for restoring component surfaces is influenced by the operating conditions of the part, the quality of its surface, the production program, and economic feasibility. An experimental study of the repair stock condition and crack formation in crankshafts was carried out in collaboration with *LLP* Almaty Auto Center "KamAZ" and KazADI named after L.B. Goncharov. The analysis showed that, during the overhaul of KamAZ-740 engines, approximately 1% of engines undergo their first overhaul and about 3% a repeated overhaul due to crankshaft failures. In addition, 6–7% of crankshafts with fatigue cracks are admitted to overhaul, of which 40% cannot be restored by regrinding to a repair size. Therefore, along with wear resistance, the service life of crankshafts is determined by their fatigue strength.

Keywords: crankshaft; sliding bearing; tribology; elastic deformation; bearing failure

In collaboration with LLP Almaty Auto Center "KamAZ" and KazADI named after L.B. Goncharov, a series of studies was conducted, the analysis of which is presented below.

According to the analysis, during the overhaul (OH) of KamAZ-740 engines, approximately 1% of engines undergo their first OH, and about 3% require a repeated OH due to crankshaft (CS) failures. In addition, 6–7% of crankshafts with fatigue cracks are admitted to overhaul, of which 40% cannot be restored by regrinding to a repair size. Consequently, along with wear resistance, the service life of a crankshaft is also determined by its fatigue strength.

The results of fatigue tests of crankshafts and specimens under bending are shown in Figures 1 and 2.

Table 1 presents the parameters of the exponential dependence, the values of the endurance limit moment at $N_б$ = 107, and the values of M_{-1}^{∞} according to the mathematical model [67].

From Table 4.1 it is evident that the error of approximating the experimental results by an exponential dependence (judging by the r^2 parameter) is insignificant. Figure 4.1 shows the confidence region at a confidence probability of p = 0,9. It can be observed that the curves for steels of Russian, Japanese, and German production practically fall within this region. The differences in the endurance limit moment for these steels are also insignificant (4…4.5%).

Table 1. Parameters of the Exponential Dependence of the Number of Cycles to Failure on the Amplitude of the Bending Moment

Characteristics of Crankshafts	Number of tests	Parameters				
		$N_o \cdot 10^{-6}$	b	r^2	M_{-1}^{∞}	M_{-1}^{∞}
					кН·м	
New, made of Russian steel	89	692,56	1,0303	0,939	4,05	4,53
New, made of Japanese steel	19	393,59	0,9401	0,798	3,90	4,28
New, made of German steel	36	6442	1,6644	0,874	3,88	3,54
Normally worn	105	233,27	0,9692	0,982	3,25	3,43
Critically worn (failure-related wear)	33	432,25	1,3345	0,906	2,82	3,97
New, 4th repair size	8	12147	1,7445	0,975	4,06	4,27

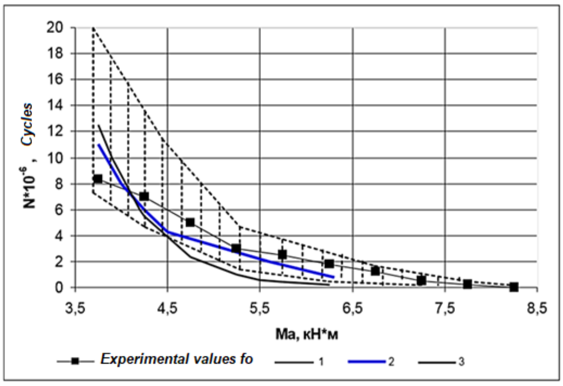

Figure 1. Bending fatigue curves of new crankshafts (CS) of KamAZ-740 engines made of steel: 1 – Russian production; 2 – Japanese production; 3 – German production. The shaded area represents the confidence region at a confidence probability of *p* = 0,9

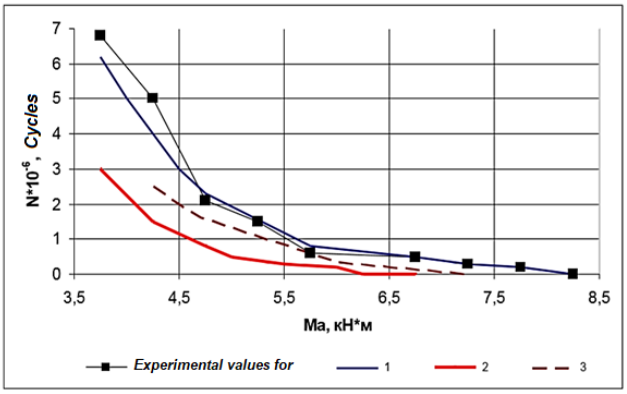

Figure 2. Bending fatigue curves of KamAZ-740 engine crankshafts: 1 – normally worn; 2 – critically worn (failure-related wear); 3 – new, reground to the 4th repair size.

It is worth noting that the value of M_{-1}^{∞} [69, 70, 71] for new crankshafts (CS) reground to the 4th repair size differs only slightly, which is explained by the minor change in the section modulus of the web [68]. However, the fatigue curve parameters differ significantly for normally worn and especially for critically worn CS (Figure 4.2, Table 4.1). For normally worn CS, M_{-1}^{∞} is 25% lower compared to new ones, while for critically worn CS it is reduced by 44%.

The decrease in fatigue strength of these groups of crankshafts is caused by: accumulation of fatigue damage (in the form of cracks) during operation; reduction in journal hardness due to scoring; deviations in grinding regimes and journal geometry (fillet radii).

The hardness analysis of 28 journals from the repair stock revealed specific features. On normally worn journals, the average hardness decreases only slightly across repair sizes, from 56.5 to 54 HRC (a 4–5% drop), remaining within the tolerance of 47–63 HRC [69]. All journals without scoring have hardness within the tolerance field, averaging 57 HRC. On journals with scoring, the average hardness is 45 HRC, with 64% of them falling below the lower limit. Therefore, such journals require strengthening after regrinding.

When regrinding journals to repair size, deviations from the required fillet radii occur. For new CS, the fillet radius of connecting rod journals was within 3.5–4 mm (average 3.98 mm) with a tolerance of 4±0.154 \pm 0.154±0.15 mm, and the fillet radius of main journals was within 2.5–3 mm (average 2.94 mm) with a tolerance of 3±0.153 \pm 0.153±0.15 mm. For reground CS, the connecting rod journal radii varied from 2 to 4.5 mm (average 3.8 mm, with 15% outside the tolerance field), while the main journal radii ranged from 2 to 3.5 mm (average 2.66 mm, with 22%

outside the tolerance field). Moreover, cases of non-circular fillets were detected (5%). All these factors increase stress concentration and reduce the fatigue strength of crankshafts.

Similar results were obtained from fatigue tests under symmetrical torsion, as presented in Figure 3 and Table 2.

Table 2. Parameters of the exponential dependence of the number of cycles to failure on the amplitude of the torsional moment

Characteristics of Crankshafts	**Number of shafts**	**Parameters**			
		$N_o \cdot 10^{-6}$	b	r^2	M_{-1}^{∞}, кН·м
New	32	381,14	0,5155	0,984	6,90
Normally worn	13	1129,9	0,6889	0,998	6,70
Critically worn (failure-related wear)	15	917,34	0,713	0,967	6,29

In Figure 4.3, the shaded area represents the confidence region at a confidence probability of p=0.9. As can be seen from Figure 4.3, all three curves fall within the 90% confidence region. Therefore, the differences in parameters are insignificant. For normally worn crankshafts (CS), the torsional endurance limit moment is on average 3% lower than for new ones, while for critically worn CS it is reduced by 10%.

Thus, the main factor affecting the residual service life is the fatigue strength of the crankshaft under bending. As a result of fatigue damage accumulated during operation, both the fatigue strength and the residual service life of CS decrease. In cases of critical journal damage, the fatigue strength and residual service life are reduced most significantly (by 44%). The quality of journal grinding during repair (in particular, the fillet radius) also has a substantial impact on fatigue strength.

The characteristics of fatigue curves show variation caused by differences in supply batches, steel grades, and technological regimes. These factors must be taken into account when determining the overall durability of the crankshaft.

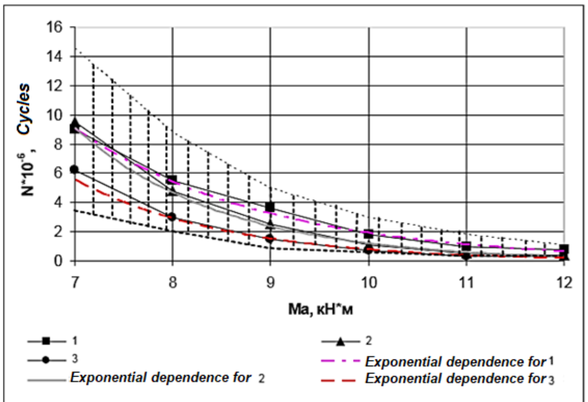

Figure 3. Fatigue curves of crankshafts under torsion: 1 – new; 2 – normally worn; 3 – critically worn

Crankshafts with different fatigue limits exhibit variations in the depth of the hardened layer of the fillet along radius R4 at an angle of 45º to the surface (R4 45º). Within a single journal, differences in the hardened layer depth along R4 45º were also observed. The crack initiation point likewise originates along the R4 45º radius.

The depth of the hardened fillet layer hhh along R4 45º corresponding to crankshafts with different endurance limits is as follows: $2M_{bend}$ = 9 кН·м, h = 2,4 мм; $2M_{bend}$ = 7 кН·м. h = 0,9 mm.

At the same time, the depth of the hardened layer complies with the manufacturer's drawing requirements, h=0.8…3.0mm.

Thus, a dependence of the bending endurance limit of the crankshaft on the depth of the hardened fillet layer has been identified, even when the shaft is manufactured from high-quality steel. Within the drawing-specified range of hardened layer depth, the stability of crankshaft quality is not ensured. Therefore, the minimum depth of the hardened fillet layer at an angle of 45º to the journal surface should be no less than 2 mm.

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UDC 625.8:551.583:536.2

THEORETICAL AND EXPERIMENTAL ASPECTS OF URBAN ROAD MAINTENANCE IN LARGE CITIES

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Abstract. Urban expansion has led to noticeable alterations in local climates of cities, commonly manifesting as urban heat islands. Dense development and extensive road networks create a broad "thermal belt" within the city, marked by its own meteorological conditions. In rural open areas, much of the solar radiation is reflected, but in cities, dark asphalt pavements, concrete buildings, and rooftops absorb significantly more solar energy and later re-radiate it as heat. Asphalt concrete pavements on a sunny summer day can reach surface temperatures 30–40°C higher than the ambient air. This absorbed heat is released during the evening and night, elevating urban air temperatures. Additional heat comes from anthropogenic sources such as industrial facilities and power plants whose waste heat warms the urban air. Another critical factor is the accumulation of airborne pollutants. City air contains considerable dust and particulate matter from traffic and other activities. Although dust can reflect some sunlight, it impedes the loss of heat by trapping long-wave radiation, thus contributing to heat accumulation in the urban environment. In effect, a warm aerosol "dome" (on the order of a few hundred meters thick) often forms over cities, suppressing convective ventilation and further elevating near-surface temperatures. Collectively, these factors – heat-absorbing infrastructure and pollution – explain why cities remain warmer than their surroundings, especially at night, confirming the strong influence of road pavements and built surfaces on the microclimate.

Keywords: reorganization, infrastructure, design principles

Thermal conductivity and heat capacity of road materials determine how they store and transfer heat, thereby influencing the microclimate. Heat transfer in pavements occurs downward by conduction and upward by convective exchange with the air. During the day, solar energy and vehicle exhaust heat the pavement structure; at night this heat is released back into the air. Asphalt and concrete, being dense materials, conduct heat readily into their layers. By contrast, materials with lower thermal conductivity (e.g. dry or porous materials) transmit heat more slowly and thus release less heat to the atmosphere. Indeed, the study finds that pavements made of materials with low thermal conductivity have a smaller impact on urban air temperature. Many construction materials (brick, concrete, etc.) are porous and contain air-filled voids; since air has a very low thermal conductivity, porosity reduces a material's overall heat conductivity. Thus, incorporating more porous layers in the road structure can diminish the heat flux transferred into the air.

Heat retention (related to heat capacity) is another key property. Materials with high specific heat can absorb more energy without a large temperature rise, moderating temperature swings. Asphalt concrete has a lower heat capacity than natural aggregates like gravel. This means asphalt surfaces heat up and cool down faster, reaching higher peak temperatures under the sun. Natural gravel or soil, with higher heat capacity and often lighter color, heats less intensely. Consequently, asphalt surfaces can induce higher peak surface temperatures relative to the air, compared to more natural surfacings. For example, the maximum difference between air temperature and road surface temperature was observed to be 4–5°C for an asphalt-covered road in Almaty, versus only about 1–2°C for an equivalent gravel-surfaced road. In general, using materials with favorable thermal properties (lower conductivity and higher heat capacity) in the pavement can mitigate urban heat buildup.

Moisture significantly affects the thermal behavior of road materials and the urban atmosphere. Moisture content within pavement layers increases their thermal conductivity – wet materials conduct heat much more readily than dry ones. Thus, a wet road structure transfers heat faster into the ground or air than a dry structure. Field measurements confirmed that the more humid climate of Almaty leads to higher overall thermal conductivity in its road materials, resulting in greater temperature fluctuations, whereas arid conditions in Kyzylorda reduce heat transfer rates. Moisture at the surface also plays a climatic role: in cities, rapid runoff on paved surfaces means less water is available for evaporation, a cooling process. The article notes that evaporation is suppressed in urban areas compared to rural surroundings, leaving a portion of solar energy unspent – energy that would otherwise go into evaporating water instead remains as sensible heat in the city. This contributes to higher urban air temperatures, since each gram of water not evaporated retains about 600 calories of heat in the environment.

Pollution from road maintenance practices also impacts the microclimate and environmental health of cities. In winter, highway agencies often spread inert anti-icing materials (sand, crushed stone, etc.) to improve traction on icy roads. The study highlights that these inert materials accumulate on road sides and surfaces if not properly cleaned, leading to significant pollution of the street environment. The absence of strict norms for timely removal of this debris in some cities exacerbates the issue. This residual sand/dust not only detracts from urban cleanliness but can influence microclimate by darkening surfaces (changing albedo) and adding to airborne particulate levels. Combined with heavy traffic, it results in dust-laden air in busy zones. These particles, as noted, reflect some sunlight yet also prevent heat from escaping efficiently, thereby helping to trap warmth near the surface. In summary, high moisture content can enhance heat transfer in pavement materials, whereas pollution – especially dust and leftover anti-icing grit – contributes to heat retention and reduced cooling of the urban atmosphere.

To quantify these effects, Nurakhova *et al.* conducted field experiments in two Kazakh cities with contrasting climates: Almaty (more humid, milder winters) and Kyzylorda (drier, more extreme temperatures). In October 2024, temperature measurements were taken over 24-hour cycles for different road pavement structures: one with a standard asphalt concrete surface and one without asphalt (a gravel or natural soil surface). The results revealed clear differences in thermal behavior:

In Almaty, the daily (diurnal) temperature swing of the ground under a gravel road (no asphalt) was about 5–6°C, whereas under an asphalt-covered road it was 11–12°C – roughly double. This indicates that the asphalt-surfaced structure conducts and stores heat to a greater extent, releasing more heat over the day. The gravel surface, with lower thermal conductivity, dampened the soil temperature fluctuations.

In Kyzylorda, a similar pattern was observed but with slightly smaller magnitudes: the ground beneath a road without asphalt varied by about 4–5°C daily, compared to 9–10°C under an asphalt pavement. The smaller amplitude in Kyzylorda (compared to Almaty) is attributed to climate differences – notably, Almaty's higher humidity increases the thermal conductivity of its road materials, amplifying temperature variations.

The experiments also compared how quickly the road surface itself heated and cooled. In both cities, the asphalt-covered road surface heated up more rapidly and to higher temperatures than the non-asphalt (gravel) surface during the day, and then cooled down over a longer period at night. This is explained by asphalt's lower heat capacity and dark color: it absorbs a lot of heat quickly but also releases it over an extended time. The gravel or natural surface, having higher heat capacity, warmed more slowly and to a lesser peak temperature. Consequently, the asphalt road exhibited a larger difference between air temperature and road surface temperature at midday (as noted, up to 6–7°C in Kyzylorda and 4–5°C in Almaty), whereas the gravel road's surface stayed closer to ambient air temperature (only 2–3°C above air). After sunset, the asphalt pavement continued to release stored heat for hours. The study noted that heat dissipation from the asphalt pavement lasted around 12 hours in Almaty and even 15 hours in Kyzylorda into the night, sustaining warmer air temperatures well into late evening.

Overall, the field data confirm that pavement type and composition can substantially affect the urban thermal regime. Asphalt pavements, due to higher thermal conductivity and lower heat capacity, inject more heat into both the ground and air, intensifying the urban heat island effect, especially under humid conditions. In contrast, more permeable or reflective road surfaces (like light-colored gravel or soil) lessen this effect by limiting heat absorption and accelerating cooling.

In summary, this theoretical and experimental study demonstrates the significant role of road construction and maintenance in shaping a city's microclimate. Key findings include:

Materials Matter: Road coverings made of materials with lower thermal conductivity produce a smaller urban heat island effect. Conversely, conventional asphalt with higher conductivity contributes more heat to the urban air. Using more porous materials in road layers can reduce heat flux into the atmosphere.

Moisture Effects: The degree of moisture in pavement layers greatly influences heat transfer – wet materials conduct and retain more heat. Moreover, reduced evaporation in cities means less natural cooling, leaving extra heat energy to warm the air.

Pollution and Maintenance: Urban pollution, including dust and residual inert anti-icing materials from winter road maintenance, can exacerbate heat retention. Particulates trap heat and should be managed through proper street cleaning and design (e.g. effective curb and drainage design).

By understanding these factors, city planners and engineers can devise strategies to mitigate urban heat accumulation – for example, by selecting road materials with suitable thermal properties, improving drainage and cleaning to remove insulating dust layers, and considering urban greening or high-albedo surfaces. The research from Almaty and Kyzylorda provides empirical evidence that seemingly small differences in road composition and upkeep can translate into meaningful microclimatic changes. These insights are valuable for developing sustainable urban infrastructure that moderates local climate extremes and improves urban living conditions.

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GREEN LOGISTICS IN ROAD CONSTRUCTION: STRATEGIES FOR OPTIMIZING TRANSPORTATION AND USING RECYCLED MATERIALS

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Abstract. In the context of global climate change and stricter international environmental standards, the implementation of "green logistics" principles in road construction becomes a strategic necessity. The paper examines the key directions of greening logistics: optimization of transportation through digital management systems and low-carbon vehicles, the use of recycled materials (reclaimed asphalt pavement, recycled concrete, industrial by-products), as well as innovative concepts of sustainable development (Circular Economy, Green Transport Corridors, Smart Infrastructure). Special attention is given to the prospects for Kazakhstan and Central Asian countries, where the development of green logistics can reduce the carbon footprint of transport corridors, improve resource efficiency, and integrate the region into global sustainable supply chains. The analysis demonstrates that the cumulative effect of adopting green technologies results not only in environmental but also significant economic benefits, including cost reduction and enhanced competitiveness of road infrastructure.

Keywords:green logistics, road construction, sustainable development, recycled materials, transportation, digitalization, circular economy, Kazakhstan, Central Asia.

In the context of global climate change and stricter environmental standards, sustainable development has become a strategic priority. According to OECD (2022), the energy and transport sectors together account for over 50% of global greenhouse gas emissions, including CO_2 and others, making them key sources of climate risks. Within the transport sector, 23% of global energy-related CO_2 emissions are generated. Road construction is a resource-intensive process, with up to 40% of project costs attributed to material transportation (McKinnon, 2018). In this context, logistics is the most vulnerable link, both economically and environmentally. The concept of "green logistics" helps reduce the carbon footprint and improve efficiency through transport optimization, digital management systems, and the use of recycled materials. International experience shows that such measures can cut fuel consumption by 10–15% and CO_2 emissions by 10–20%. Thus, implementing green logistics in road construction is not only an environmental but also an economic necessity.

The concept of "green logistics" reflects a strategic approach to organizing transport and supply processes aimed at reducing environmental impact and optimizing resource use. In road construction, it is particularly important since logistics operations account for a significant share of costs and carbon footprint. The main directions include:

1. **Transport optimization** — use of digital systems (TMS, ERP) to reduce empty runs and fuel consumption, cutting CO_2 emissions by 10–20%.
2. **Use of recycled materials** — reclaimed asphalt, concrete, and industrial waste lower project costs by 10–12% and emissions by 15–20%, contributing to the circular economy.
3. **Innovative concepts** — Circular Economy, Green Transport Corridors, and Smart Infrastructure based on IoT, alternative fuels, and digital technologies ensure both environmental sustainability and economic efficiency.

Prospects for Kazakhstan and Central Asia. Green logistics in road construction holds significant potential for Kazakhstan and the Central Asian region. Given the vast transport corridors and the importance of transit, a key priority is the optimization of transportation through digital management systems (TMS, ERP) and the adoption of electric and hybrid vehicles. This will help reduce fuel costs and lower the carbon footprint along international routes of the Middle Corridor. Another strategic direction is the use of recycled materials such as reclaimed asphalt, recycled concrete, and construction waste, which decreases project costs and supports the development of a circular economy. Additional opportunities arise from innovative concepts of sustainable development, including the creation of green transport corridors, the use of alternative fuels on China–Europe routes, and the introduction of smart infrastructure and digital monitoring systems. These measures will not only enhance environmental sustainability and economic efficiency but also strengthen the region's role in the international transport system and contribute to achieving national climate goals.

The analysis has demonstrated that the concept of "green logistics" represents a crucial element in the sustainable transformation of road construction. The integration of measures such as transport optimization, the use of recycled materials, and the adoption of digital technologies provides a foundation for reducing the carbon footprint and ensuring the rational use of natural resources. The combined effect manifests not only in ecological outcomes but also in substantial economic benefits, including reduced construction costs, extended life cycles of road infrastructure, and overall improvement of transport system efficiency. International practice confirms that the implementation of innovative and resource-efficient solutions has become a key condition for the sector's development under global climate challenges and the transition to a low-carbon economy. For Kazakhstan, these approaches are of particular importance, as they create opportunities for integration into international transport corridors, enhancement of the competitiveness of national infrastructure, and the achievement of strategic climate objectives.

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NICKEL PHOSPHATE CATALYSTS FOR REDUCING THE CARBON FOOTPRINT IN ROAD MATERIALS PRODUCTION

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Abstract. Current trends in road construction require reducing the carbon footprint at all stages of the road infrastructure life cycle. Particular attention is given to the production and modification of bituminous binders, where conventional high-temperature processes are accompanied by significant CO_2 emissions. This study explores the potential of nickel phosphate catalysts in upgrading heavy hydrocarbon fractions and oil sludge to obtain fractions suitable for producing more sustainable road materials. Nickel phosphides and phosphates demonstrate high activity in hydrodeoxygenation, hydrocracking, and asphaltene destruction reactions, thereby improving the H/C ratio and reducing sulfur-containing compounds. The integration of such catalysts into petroleum refining schemes and their use for valorizing oil sludge as a secondary resource are also considered. Life cycle assessment (LCA) analysis indicates that catalytic pre-treatment can reduce the carbon footprint of road material production by 20–40 %, depending on the scenario and feedstock composition. Thus, nickel phosphate catalysts may become a key element of the road sector decarbonization strategy, ensuring both a reduction in carbon emissions and improved performance characteristics of road pavements.

Keywords: Sustainable road construction; lifecycle assessment; carbon reduction; nickel phosphate catalysts; oil sludge valorization; Kazakhstan; Central Asia.

The construction sector is among the largest consumers of natural resources and energy, with road infrastructure accounting for a major share of global greenhouse gas (GHG) emissions across its life cycle. Production of road materials, particularly bituminous binders, is highly energy-intensive and relies on conventional high-temperature processes that emit significant amounts of CO_2. With road networks expanding rapidly worldwide, the decarbonization of bitumen production has become a key research priority.

One promising pathway is the catalytic upgrading of heavy petroleum fractions and oil residues into high-quality fractions suitable for bitumen modification. Nickel-based catalysts, particularly nickel phosphides and phosphates, have shown strong potential in hydrodeoxygenation, hydrocracking, desulfurization, and asphaltene transformation. These reactions improve the hydrogen-to-carbon (H/C) ratio, lower heteroatom content, and enhance the rheological and durability characteristics of binders. Unlike conventional sulfided catalysts, nickel phosphates offer high stability under milder conditions and avoid continuous sulfurization, thereby reducing secondary emissions and operational hazards.

This study examines the role of nickel phosphate catalysts in producing sustainable road materials. Special attention is given to their application in upgrading heavy hydrocarbons and valorizing oil sludge, as well as to the environmental benefits estimated through life cycle assessment (LCA).

Conventional bitumen production depends on high processing temperatures, typically 150–180 °C, which contribute directly to CO_2 emissions. The need for improved pavement durability has also stimulated the use of polymer additives, further increasing resource and energy consumption. Thus, there is an urgent demand for technological innovations that provide high-quality binders at reduced carbon cost.

Nickel phosphate catalysts provide a valuable solution by enabling efficient hydroprocessing of heavy hydrocarbon fractions. These catalysts are highly active in hydrodeoxygenation, hydrocracking, and desulfurization, facilitating the removal of oxygen, sulfur, and nitrogen species while breaking down complex asphaltenes. The resulting fractions are lighter, more stable, and environmentally cleaner, with properties well-suited for blending into modified bitumen. Compared to traditional sulfided catalysts, nickel phosphate systems operate under milder conditions, generate fewer toxic by-products, and maintain structural stability during prolonged operation.

In parallel, the use of nickel phosphate catalysts offers new opportunities for valorizing oil sludge, a hazardous waste generated in large quantities during petroleum refining and storage. Oil sludge is rich in hydrocarbons but poses serious disposal challenges, often managed through costly incineration or landfilling. Catalytic upgrading transforms oil sludge into lighter fractions, reducing environmental burdens while creating a secondary resource for road binder production. This approach aligns with circular economy principles by turning waste into feedstock, thus lowering both disposal costs and the carbon footprint of road infrastructure.

Life cycle assessment further highlights the advantages of catalytic upgrading. Studies suggest that pre-treatment of heavy fractions and sludge using nickel phosphate catalysts can reduce the carbon footprint of bitumen production by 20–40 %, depending on feedstock composition and process integration. These reductions arise from lower operating energy demands, reduced emissions of CO_2, SO_2, and VOCs, and the substitution of waste-derived feedstocks for virgin materials. Importantly, such strategies directly support national and regional commitments to carbon neutrality, particularly in rapidly developing regions such as Central Asia, where road networks are expanding.

Overall, nickel phosphate catalysts represent an effective technological pathway toward sustainable infrastructure. By simultaneously improving product quality, reducing emissions, and enabling waste valorization, they provide a practical means of lowering the environmental footprint of road construction.

Nickel phosphate catalysts hold significant promise for advancing the sustainability of road construction materials. Their effectiveness in hydroprocessing enables the conversion of heavy fractions and oil sludge into upgraded products suitable for bitumen modification, resulting in reduced emissions and improved binder performance. Life cycle analysis confirms that catalytic pre-treatment can achieve meaningful reductions in carbon footprint, positioning these catalysts as key elements of future decarbonization strategies.

Further research should focus on scaling catalytic processes to industrial levels, optimizing operating conditions, and performing region-specific LCA to assess their broader economic and environmental impacts. By doing so, nickel phosphate catalysts may become an integral part of low-carbon road infrastructure in Kazakhstan, Central Asia, and beyond.

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INNOVATIVE MATERIALS AND AUTONOMOUS ENERGY-SAVING SOLUTIONS TO INCREASE THE RELIABILITY AND SUSTAINABILITY OF ROAD MACHINERY UNDER LOW-TEMPERATURE CONDITIONS

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Abstract. This paper presents a comprehensive solution for improving the reliability of road machinery in high-altitude and low-temperature conditions. Failures of hydraulic drives at sub-zero temperatures remain a critical issue. The proposed approach combines frost-resistant polymeric materials for hydraulic components with an autonomous modular siphon-type micro hydropower plant. The plant, operating on water discharge from moraine lakes, provides renewable energy for monitoring, lighting, and temporary facilities, including serpentine roads. Calculations show that at a head of 300 m and flow rates of 5–20 L/s, the unit generates 9.6–38.3 kW, sufficient for autonomous power supply. The novelty lies in integrating material science with renewable hydropower to enhance reliability and sustainability of transport infrastructure.

Keywords: siphon micro hydropower plant; autonomous energy supply; hydraulic drives; frost-resistant polymeric materials; serpentine roads; high-mountain regions; sustainable road infrastructure

The operation of construction and road machinery under low temperatures and in high-altitude environments remains one of the most challenging tasks for Kazakhstan's transport sector. Hydraulic drives are prone to failures at sub-zero temperatures, and the service life of components is significantly reduced [1,2]. At the same time, the international community (in particular, PIARC and the European Commission) emphasizes the need to reduce the carbon footprint of road construction machinery, which requires the integration of renewable energy sources [3].

Modern studies show that the use of polymeric and metallic materials with improved frost and wear resistance can partially enhance the reliability of hydraulic drives [4]. Experimental studies confirm that certain polymers, when sliding against steel and duralumin in a lubricated environment, demonstrate reduced friction coefficients and stable wear resistance [7], which makes them promising for hydraulic systems. However, existing solutions do not fully consider the combined impact of climatic factors and do not address the issue of autonomous energy supply.

In the field of hydropower, patents such as RU 2714634 C2, CN201526405U, and US9752550B2 describe small hydropower systems. Nevertheless, these designs do not ensure reliable operation at sub-zero temperatures, nor do they provide modularity or remote monitoring.

This work proposes a comprehensive solution that includes:

- The use of innovative polymeric and metallic materials in the hydraulic drives of road machinery;
- The application of an **autonomous modular siphon-type micro hydropower plant** as a renewable energy source for powering hydraulic systems, monitoring, and auxiliary equipment.

The power of the installation is calculated using the formula:

$$N = \eta \cdot \rho \cdot g \cdot Q \cdot H$$

where η is the efficiency, $\rho = 1000$ kg/m³, $g = 9.81$ m/s², Q - flow rate (m³/s), H - head (m).

Table 1. Output power of the autonomous siphon micro hydropower plant at different water flow rates (H = 300 m, η = 0.65)

№	Q, L/s	Q, m³/s	Power, kW
1	5	0.005	9.6
2	10	0.01	19.1
3	15	0.015	28.7
4	20	0.02	38.3

As shown in Table 1, at a head of 300 m even a minimal flow rate (5 L/s) provides about 10 kW, which is sufficient for autonomous hydraulic power supply.

Table 2. Heat losses in a siphon pipeline (length 100 m) depending on insulation thickness at ΔT = 22 K

№	Insulation thickness, mm	Specific losses, W/m	Total losses, kW
1	30	11.5	1.15
2	50	7.9	0.79
3	70	6.0	0.6

As can be seen from Table 2, increasing insulation thickness reduces heat losses by almost half. Even with a minimum thickness of 30 mm, the heating requirement does not exceed 12% of the system's output.

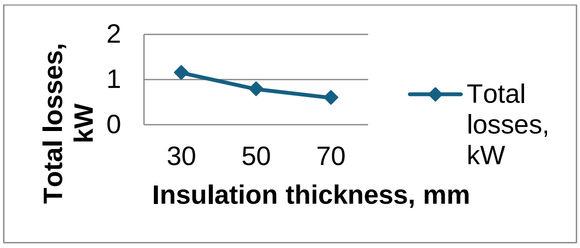

Figure 1. Dependence of heat loss on insulation thickness

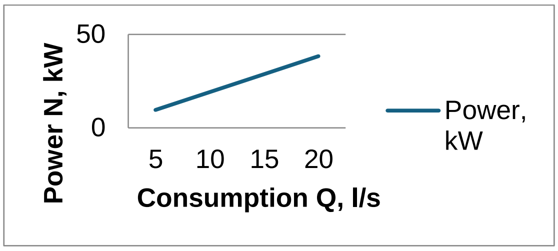

Figure 2. Power dependence on water flow

Scientific Novelty

The novelty of this research lies in the integration of two areas:

- the use of frost-resistant materials for hydraulic drive components of road machinery, supported by international tribological studies on selected polymers [7];
- the implementation of an autonomous modular siphon-type micro hydropower plant as an energy source.

For the first time, a comprehensive solution is proposed that simultaneously increases the reliability of hydraulic systems and reduces the carbon footprint of road construction machinery.

The results confirm the efficiency of the proposed approach:

- the installation output power ranges from 9.6 to 38.3 kW;
- the heating requirement does not exceed 12% of the total energy output;
- the use of frost-resistant materials increases the operational reliability of hydraulic drives.

Thus, the proposed solution can be recommended for implementation in Kazakhstan's road infrastructure, aligning with international trends in sustainable development and decarbonization.

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TRENDS IN THE DEVELOPMENT OF SUSTAINABLE ROAD INFRASTRUCTURE IN THE CONTEXT OF ECONOMIC ANALYSIS AND MARKETING STRATEGIES

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Abstract. The paper examines trends in the development of sustainable road infrastructure with an emphasis on the introduction of green technologies into the activities of road construction companies in Kazakhstan. An analysis of the greenhouse gas (GHG) emissions structure shows that road transport accounts for up to 84% of CO_2 emissions and more than 95% of CH_4 emissions, making it the main target for decarbonization. Key measures to reduce the carbon footprint are described, including the use of recycled and low-carbon materials, energy-efficient road construction and maintenance technologies, as well as the creation of infrastructure for electric vehicles, hydrogen, and gas-powered transport. The methodological framework includes comparative economic analysis, life cycle assessment of road infrastructure, and scenario forecasting up to 2060. The results demonstrate that the introduction of sustainable technologies reduces operating costs, extends road service life, and improves environmental performance. Particular attention is paid to marketing strategies aimed at shaping the image of a “green” business, strengthening public and investor trust, and enhancing the international competitiveness of road construction companies. The conclusion is made that sustainable road construction is becoming not only an environmental but also an economic priority for Kazakhstan’s development.

Keywords: sustainable road infrastructure, green technologies, road construction companies, marketing strategies, decarbonization, electric vehicles.

The development of transport infrastructure is one of the key factors of economic growth and mobility. However, traditional approaches to road construction and operation are associated with high levels of greenhouse gas emissions, significant consumption of natural resources, and rising operating costs.

From an economic perspective, the introduction of green technologies into road construction companies creates opportunities to optimize road life cycle costs, reduce transport operating expenses, and enhance national competitiveness. The marketing dimension plays an equally important role: positioning sustainable projects as “green” increases investor trust, attracts international grants and investment, and builds positive public perception of environmentally oriented solutions.

Thus, sustainable road infrastructure development should be considered not only a technological but also an economic and marketing challenge, determining the prospects for successful decarbonization of the transport sector and Kazakhstan’s integration into global “green growth” trends

Kazakhstan’s transport sector is one of the largest sources of greenhouse gas emissions. According to emission structure analysis, road transport accounts for up to 84% of total CO_2 and more than 95% of CH_4 emissions. This concentration of pollutants in a single sector makes transport and road infrastructure the priority target for green technologies.

At the same time, road construction remains a capital-intensive industry where traditional technologies lead to high operating costs, and road durability often falls short of design standards. This requires a revision of strategies for design, planning, and life cycle management of infrastructure.

The introduction of environmentally friendly technologies requires significant investment at the construction and modernization stages. However, the long-term economic effect is reflected in:

reduced operating costs due to more durable road surfaces; lower fuel expenses thanks to infrastructure development for electric vehicles and alternative fuel transport; diversification of the domestic fuel market and reduced dependence on oil products; lower external healthcare costs due to reduced air pollution. Thus, green technologies can transform road construction from a cost-intensive sector into a source of savings and competitiveness.

A significant barrier to innovation adoption remains business and public skepticism about their effectiveness and high upfront costs. In this context, marketing strategies become a crucial tool for industry transformation. They include: building the image of road construction companies as “green” brands operating in accordance with international ESG standards; attracting investors by demonstrating the benefits of sustainable technologies (long-term payback, risk reduction, access to international grants and funds);raising public awareness of the advantages of public transport, electric vehicles, and cycling infrastructure; employing green marketing in both the public and private sectors to promote eco-friendly solutions.

To achieve transport sector decarbonization by 2060, comprehensive measures are required: development of charging stations for electric vehicles and fueling stations for CNG, LNG, and hydrogen-powered vehicles; renewal of the passenger car fleet with a transition to electric transport; introduction of road materials with a reduced carbon footprint (recycled and modified asphalts); integration of digital traffic and logistics management technologies to reduce travel time and emissions.

Such policies demand coordinated action by government, business, and society, supported by tax incentives, subsidies for innovative projects, and public–private partnerships. The use of low-carbon construction technologies and durable materials can reduce operating costs by 15–20% through extended road service life.

The adoption of gas-powered and electric vehicles reduces household fuel costs by 25–30% in the long term. Fuel market diversification strengthens the country’s energy security and reduces dependence on oil imports. Positioning road construction companies as green brands enhances their investment appeal and opens access to international climate funds. The use of green marketing tools builds positive public perception and encourages a shift from private cars to public transport and electric mobility. Companies applying ESG approaches demonstrate increased competitiveness in international tenders and projects.

The rollout of charging and gas fueling networks creates new market segments, providing a multiplier effect for the economy. The integration of digital traffic management technologies can reduce the transport sector’s carbon footprint by 8–12% through congestion reduction and logistics optimization.

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INNOVATIVE ROBOTIC TECHNOLOGIES FOR CLEANING SPLIT-PHASE OVERHEAD CONDUCTORS

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Abstract. Overhead transmission lines (OHTLs) are subject to pollution and grease hardening, which increase corona losses, reduce conductor lifetime, and raise failure risks. According to the International Energy Agency (IEA, 2022), global transmission and distribution losses reach about 8% of generated electricity. This paper provides a comparative analysis of global robotic solutions, highlights their limitations, and proposes a robotic system for cleaning split-phase conductors. A methodology for assessing the energy and environmental effect of the technology is presented.

Keywords: OHTL, robotics, corona losses, infrastructure maintenance, energy efficiency, sustainable development

The energy infrastructure of the 21st century faces high technological losses during electricity transmission. According to the IEA, global losses exceed 2600 TWh annually. In countries with extreme climates (Kazakhstan, Canada, China, Russia), conductor pollution, icing, and grease degradation are significant factors.

The development of robotic technologies for automated conductor cleaning is therefore relevant both for increasing the reliability of power systems and in the context of global decarbonization.

A number of robotic systems have been developed worldwide. Their comparative characteristics are presented in Table 1.

Table 1. Comparative analysis of global solutions vs. proposed concept (✓ – available, ✗ – absent, ◐ – partial)

Criterion / Solution	Sky Sweeper	Line Ranger	Expliner	State Grid	KEPCO	Siemens	Proposed Solution
Live-line operation	✗	✓	✓	✓	✓	✓	✓
Pollution cleaning	◐	✗	✗	◐ (icing)	◐	✗	✓ (dirt + grease)
Split-phase capability	✗	✗	✗	✗	✗	✗	✓
Obstacle crossing	✗	◐	✓	✓	✓	✗	✓
Harsh climate resistance	✗	✗	✗	◐ (frost)	◐	✗	✓
Scalability	✗	✗	✗	✓	◐	✓	✓

1. Robotic movement concept.

The prototype is based on a wheel–roller mechanism with two driving wheels alternating traction and a pressing roller ensuring fixation. This provides: movement along a single conductor; resistance to wind oscillations; minimization of slippage on sagging spans.

2. Two-stage cleaning: *Chemical stage* - spraying liquid to dissolve hardened grease and dust; *Mechanical stage* - brush cleaning on the return pass.

3. Operating algorithm: "Robot installation → spraying → soaking → reverse pass with brushes → repositioning to parallel conductor."

Model of Corona Losses vs Pollution

Corona losses (P_c) are estimated by simplified dependence:

$$P_c = k \cdot (E - E_0)^2 \cdot f(L, C)$$

where E is field intensity at the conductor surface, E_0 is the critical intensity, L is line length, C is the pollution coefficient ($0 \leq C \leq 1$).

For heavily polluted conductors, $C \approx 1$; For clean ones, $C \approx 0.2–0.3$.

Robotic cleaning reduces *C* in two stages

Chemical treatment –20–30% reduction. Mechanical cleaning –20–30% additional reduction.

Thus, C decreases from ~1 to 0.4–0.5, corresponding to corona loss reduction by 30–50%.

Comparative analysis. Global systems lack the ability to: operate on split-phase conductors; remove hardened grease; withstand dust, wind, and frost.

Modeling results: 20% cleaning → ~10% reduction in losses; 40% cleaning → ~25% reduction; 50% cleaning → ~37% reduction.

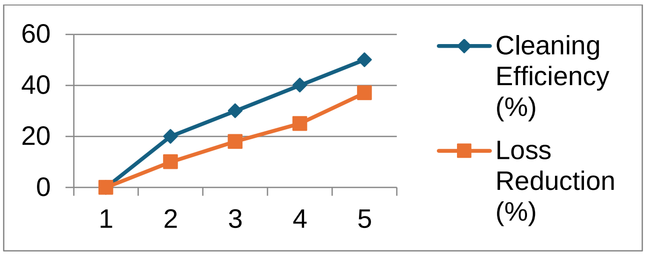

Figure 1. Reduction of corona losses vs degree of conductor cleaning

These results confirm high efficiency of the robotic concept even with partial cleaning.

First proposed approach for robotic cleaning of split-phase conductors under extreme climatic conditions. Developed model linking pollution coefficient and corona losses, including robotic intervention. Quantitative assessment of energy and environmental effect (loss reduction, CO_2 decrease). Concept suitable as the basis for patent application (two-stage cleaning mechanism and split-phase navigation) and PhD dissertation.

The proposed methodology not only reduces corona losses by up to 37% but also forms the basis for a new class of robotic OHTL maintenance technologies. The work combines: relevance for global power systems (sustainability, loss reduction, decarbonization); strong patent potential; academic value for PhD-level research.

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EVALUATING ROAD SNOW ACCUMULATION FOR ENHANCED TRAFFIC SAFETY

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Abstract. Winter conditions significantly affect the operational performance of highways, leading to reduced traffic safety and efficiency. Low temperatures, snow deposits, and surface slipperiness cause a decline in the technical and economic indicators of roads, primarily due to reduced vehicle speeds and decreased pavement friction. The thickness of the snow cover has a direct impact on traffic conditions: while a 2 cm layer does not restrict vehicle movement, a 5–10 cm layer results in a reduction of traffic speeds to 50 km/h or lower. Such conditions substantially increase the probability of traffic accidents. Therefore, accurate assessment of road snowdrift susceptibility and the development of protective measures for transport infrastructure are essential to ensure stable traffic flow and enhance road safety. The present study focuses on defining methods for determining snow accumulation on roads and proposes practical approaches for improving safety measures in winter road maintenance.

Keywords: snowdrift susceptibility, right-of-way strip *of the roadbed*, wind rose, air humidity, snow density, road traffic safety.

Before determining the volume of snowdrift on the right-of-way strip or the slipperiness of the road surface, tests are carried out related to the study of snow mechanics. Snow cover is a type of snow-ice formation that develops on roads. Previous research indicates significant differences in the density of snow cover across the Northern, Eastern, and Southern regions of Kazakhstan, determined by meteorological conditions, the time of snowfall, and the duration of snow persistence. The density of freshly fallen snow under calm weather conditions depends on its type and physical characteristics.

The changes in snow density and porosity are largely influenced by time and air humidity. Figure 1 below shows the dynamics of snow density variation over time.

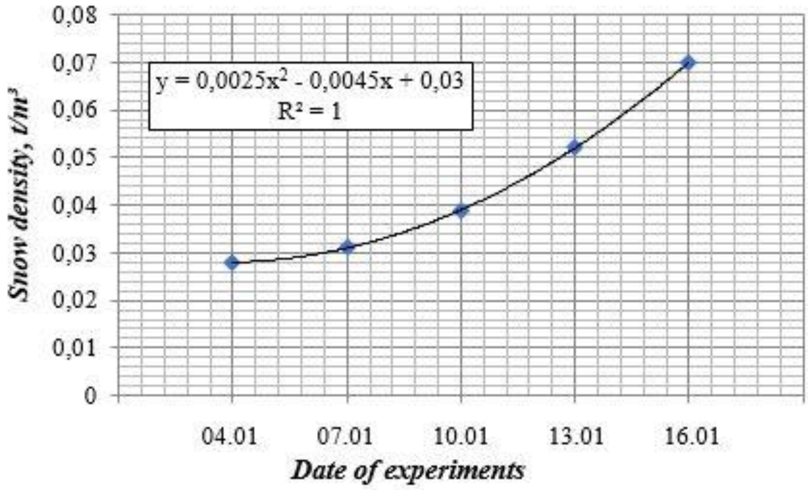
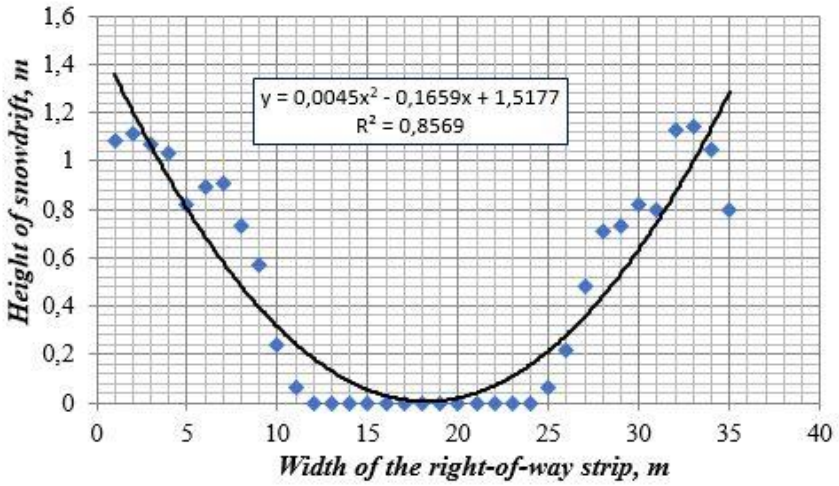


Figure 1. Dynamics of snow density increase over time

Field studies of snowdrift susceptibility were carried out at two test sections of highways. The first section is located on the “Almaty–Ust-Kamenogorsk” road (km 1124), which passes through hilly terrain and belongs to category Ib. The prevailing wind direction at this section is northwest (75–90°). The second section is situated at km 24+500 of the "Ust-Kamenogorsk–Ridder" road, also classified as category Ib. Tree plantations are located along the right-of-way strip, while the prevailing wind direction is northwest, with deviations ranging from 55° to 110° relative to the road axis. This section also passes through hilly terrain.

Snowdrift measurements were carried out along the right-of-way strip of the roadbed at 1 m intervals across both longitudinal and transverse profiles. As a result, data were obtained for 31 points, establishing a correlation between the height of snowdrifts and the width of the roadbed right-of-way, as illustrated in Figure 2.

a)



b)

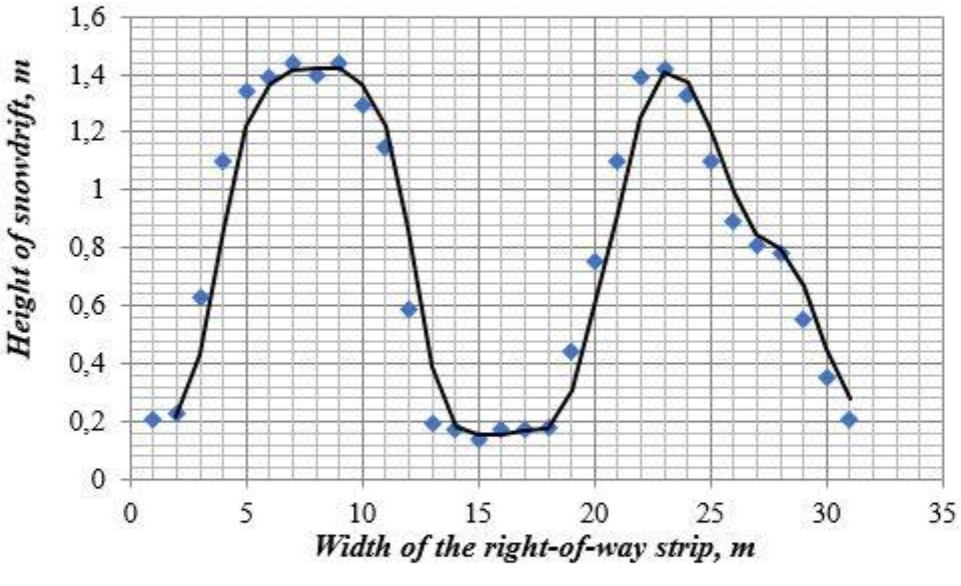


Figure 2. Snowdrift volume by the width of the right-of-way strip: a – section of the "Ust-Kamenogorsk–Ridder" highway; b – section of the "Almaty–Ust-Kamenogorsk" highway

The studies showed that the formation of snowdrifts in cut sections follows certain patterns, whereas on embankments it is of a chaotic nature and depends on the terrain and the presence of tree plantations. To reduce the height of snowdrifts in cut sections, it is recommended to install snow-protection structures on the upper edge of the slope on the windward side at an angle of 90°.

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STUDY OF THE CHARACTERISTICS OF INCREASING SALT RESISTANCE OF CEMENT CONCRETE PAVEMENTS IN THE OPERATION OF HIGHWAYS

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Abstract. As is known, the use of cement concrete pavements is increasingly practiced not only in the field of industrial construction but also in the construction of highways. Every year, positive experience in the operation of cement concrete pavements on highways is accumulated in various countries around the world. Undoubtedly, cement concrete pavements are more durable and resistant compared to asphalt concrete pavements; however, they require periodic repairs and proper maintenance. Cement concrete pavement on the highways of the Republic of Kazakhstan has been widely used from 2006 to 2017. To date, their total length amounts to 1.6 thousand kilometers. The service life of a concrete road is 25–30 years, while the service life of asphalt concrete pavement is 9–20 years. Concrete roads are often constructed on heavy-traffic sections. In particular, in the Republic of Kazakhstan, the international transport corridor *"Western Europe – Western China"* was designed to ensure the movement of heavy-duty trucks over a long period, which is why cement concrete was used in the road construction. However, practice and time have shown that during the operation of such pavements, a number of significant shortcomings were revealed. Damage to temperature joints appeared, which, under the influence of moisture, frost, and dynamic loads, developed into potholes, raveling, and corrosion of the pavement. Such damages resulted from poor maintenance of highways, as well as natural wear and tear.

Keywords: Anti-icing material, corrosion, cement concrete pavement

Concrete highways are successfully operated in Canada, Sweden, the USA, Germany, Korea, and China — countries with climatic conditions similar to those of Kazakhstan. In foothill areas, on roads with rigid pavement, slipperiness often occurs in winter. To combat this phenomenon, in addition to sand-salt mixtures, various types of salt-based compounds are applied, which allow the elimination of snow and ice deposits within 10 minutes.

The maintenance of highways with cement concrete pavement in winter is the most difficult. To perform these works, preventive and protective measures are taken. Several methods are applied for protection: frictional, combined, and chemical.

Based on the above-mentioned maintenance problems, and in accordance with Article 238 of the Environmental Code prohibiting the use of table salt for anti-icing treatment, the Research Institute JSC *KazdorNII* developed two types of anti-icing materials — liquid and solid — under the brand *"QSMART-ANTIGLAZE."*

A solid, powdery material of white color. It acts upon contact with snow and ice. Effectively destroys ice, compacted snow, and prevents the formation of ice crust. Application method: Clean the surface from loose snow, evenly apply the agent to the surface. After the ice dissolves, perform mechanical cleaning. Consumption is approximately 150–250 g/m².

Liquid type (patented): A colorless liquid. It acts upon contact with snow and ice. Effectively destroys ice, compacted snow, and prevents the formation of ice crust. It can be used even before the onset of extreme subzero temperatures to prevent icing. Application method: Clean the surface from loose snow, evenly apply the agent to the surface. After the ice dissolves, perform mechanical cleaning. Consumption is approximately 250–600 ml/m².

Advantages of *QSMART-ANTIGLAZE* Anti-Icing Reagents

- **Reduction of accidents** (due to high speed of ice removal and long-lasting effect)
- **Lower consumption** (proportionally reduced consumption due to high melting capacity)

- **Corrosion reaction** (lower corrosive activity to steel due to the low corrosivity of magnesium chloride and urea)
- **Stormwater drainage** (no clogging of storm sewer systems with sand deposits)
- **Cost reduction** (lower expenses associated with the preparation of sand-salt mixtures, cleaning, and removal of deposits)
- **Decarbonization** (does not leave white marks on asphalt and shoes, does not harm soil and vehicles, non-toxic product)

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UDC 625.7

PERSPECTIVES OF SUSTAINABLE ROAD CONSTRUCTION: FROM DESIGN TO OPERATION

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Abstract. Sustainable road construction is becoming a strategic priority in the context of climate change, environmental regulations, and the global transition to a low-carbon economy. This paper explores perspectives of sustainable development in road infrastructure, covering the full lifecycle from design to operation. The study highlights innovative design methods, application of environmentally friendly materials, energy-efficient construction technologies, and digital monitoring systems during operation. Particular attention is paid to the integration of carbon reduction strategies, lifecycle assessment tools, and the role of digitalization in ensuring efficient asset management. The prospects for Kazakhstan and Central Asia demonstrate the importance of adopting international best practices while considering regional specifics, contributing to both ecological sustainability and economic competitiveness.

Keywords: sustainable road construction, lifecycle assessment, carbon reduction, digitalization, innovation.

The road construction sector is one of the largest consumers of natural resources and sources of CO_2 emissions worldwide. According to the IPCC (2022), transportation accounts for nearly a quarter of global energy-related CO_2 emissions, making sustainability a critical challenge. Sustainable road construction seeks to minimize environmental impacts while ensuring economic efficiency and social benefits. This approach requires a comprehensive perspective covering all stages: design, construction, maintenance, and operation. By implementing eco-friendly materials, innovative technologies, and advanced digital solutions, it is possible to reduce the carbon footprint, extend infrastructure service life, and improve overall performance.

At the design stage, sustainable road construction requires the integration of advanced digital tools and methodologies. Building Information Modeling (BIM) and Geographic Information Systems (GIS) provide a holistic view of project parameters, allowing engineers to simulate various scenarios and predict long-term environmental effects. Lifecycle assessment (LCA) is increasingly applied to evaluate the environmental impact of materials, energy consumption, and waste generation across the entire lifespan of road infrastructure. Optimization of material use, such as the selection of locally available and renewable resources, helps reduce transport distances, costs, and associated carbon emissions. Furthermore, the introduction of performance-based specifications encourages innovation in materials and design approaches, ensuring that sustainability criteria are embedded from the earliest project stages.

During the construction phase, the emphasis shifts to the practical implementation of sustainable technologies. Recycled and low-carbon materials, such as reclaimed asphalt pavement (RAP), recycled concrete aggregates (RCA), industrial by-products (fly ash, slag), and bio-based binders, are increasingly used to reduce both cost and environmental footprint. Energy-efficient machinery, including hybrid and electric construction equipment, contributes to lowering fuel consumption and emissions. “Green logistics” principles, supported by digital transport management systems (TMS), play a critical role in minimizing transportation inefficiencies, reducing empty runs, and optimizing delivery routes. International experience highlights that these measures can reduce project costs by 10–15% and CO_2 emissions by up to 20%, while simultaneously increasing resource efficiency and improving overall construction productivity.

In the operational phase, sustainability is supported through innovative maintenance and monitoring approaches. Predictive maintenance strategies, enabled by sensors and real-time data collection, allow for early detection of defects and timely interventions, thereby extending the service life of road assets. Digital twin technology enables continuous monitoring and optimization of infrastructure performance, while smart road solutions—such as intelligent traffic management systems, energy-harvesting pavements, and IoT-enabled safety features—improve both efficiency and user experience. These tools not only reduce operational costs but also enhance road safety, reliability, and environmental performance throughout the lifecycle of the infrastructure.

For Kazakhstan and Central Asia, the adoption of sustainable road construction practices carries particular significance. The region's geographic position as a transit hub within the Middle Corridor of international trade routes creates both opportunities and challenges. The implementation of green transport corridors, where low-emission vehicles and renewable energy infrastructure are prioritized, can reduce the environmental impact of transit flows and strengthen regional competitiveness. Circular economy principles—such as recycling construction waste, extending material life cycles, and promoting closed-loop supply chains—support the rational use of resources and reduce dependence on imports. Finally, digital asset management systems provide a strategic foundation for long-term planning, enabling governments and road agencies to align infrastructure development with national climate commitments and international sustainability standards.

Sustainable road construction requires a systemic approach that covers all stages of the lifecycle, from design to operation. The integration of innovative technologies, recycled materials, digitalization, and lifecycle assessment methods provides a foundation for reducing environmental impacts and improving efficiency. For Kazakhstan, the adoption of sustainable practices in road construction is not only an ecological necessity but also a strategic opportunity for economic growth and international integration.

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ANALYSIS OF THE POSSIBILITY OF INCREASING THE CAPACITY OF MAIN STREETS BASED ON IMPROVEMENT OF THE URBAN TRANSPORT PARKING SYSTEM

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The experience of making significant changes to city highways in order to increase the intensity of traffic is practically characteristic of cities. Deceleration of priority intensity on main streets in certain periods of traffic was provided by the system of intercepting parking.

Thus, the increase in the intensity of traffic and the decrease in the amount of delays of vehicles, which simultaneously depend on the intersection, are proposed to be substantiated by the system of intercepting parking in the study.

One of the most effective tools for managing urban traffic load is the **Park and Ride system**. These facilities are located on the outskirts of the city or near major transportation hubs (such as metro stations, railway platforms, transfer points, bus stations, coach terminals, etc.) and are designed to encourage drivers to switch from private cars to public transportation before entering the city center. This approach helps to **reduce traffic flow intensity in congested areas**, improve the environmental situation, and increase the overall throughput capacity of the urban road network.

This article aims to **analyze the possibilities for improving the efficiency of urban transportation** by enhancing the Park and Ride system within the city. The research focuses on the following:

- the current state of Park and Ride facilities in a number of cities;
- key performance indicators of such parking systems (convenient location, access to public transportation, pricing policies, and informational support);
- modern approaches to the operation of Park and Ride facilities using digital technologies.

One of the most important success factors for these parking facilities is **integration with public transport**: high quality, regularity, and convenience of routes significantly increase the motivation for drivers to switch from private cars to urban transport. In addition, pricing policy plays a significant role — such as discounts or free parking when using public transportation, flexible tariffs, and the ability to pay via mobile applications.

The article also discusses **intelligent parking management systems** that allow real-time monitoring of availability, reservation of parking spaces, and navigation of drivers to the nearest available spots. The implementation of such systems improves user convenience and reduces the time spent searching for parking, which in turn also affects traffic flows.

Thus, the **development and improvement of Park and Ride systems** can become a key direction in the strategy of sustainable urban mobility. Well-designed parking complexes located at city entry points and in strategic locations within the urban area help to redistribute traffic, reduce the load on central districts, and increase the overall flow intensity on major urban arteries.

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UDC 125.875 (2)

DEVELOPMENT OF AN INFORMATION SYSTEM FOR MODELING EMERGENCY SITUATIONS IN THE CONTEXT OF DIGITAL TRANSFORMATION TASKS IN THE TRANSPORT SECTOR

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Abstract. Road traffic safety and reducing fatalities from road traffic accidents (RTAs) is a priority task in Kazakhstan, Russia, and globally [1]. The modern trend of transitioning to intelligent vehicle control does not exclude the possibility of failures in transport systems. Safety assessment in emergency situations caused by collisions with road safety facilities requires the use of modern innovative information technologies and the creation of specialized digital design environments for road safety structures based on simulation modeling of emergency situations, considering numerous requirements and constraints. Scientific and practical research and development in this area are being conducted at KazADI named after L.B. Goncharov in cooperation with MADI (State Technical University) by a joint scientific team. This article examines the concept, principles, structure, and criteria for organizing the core system of digital transformation—an intelligent decision support information system—based on the developed virtual tools.

Keywords: road barriers, road infrastructure elements (RIE), virtual testing, digital transformation, intelligent technologies, digital design, information systems, intelligent information systems

The transition to a fundamentally new “digital economy” technology poses a large-scale and innovative challenge of digital transformation to all economic sectors. Known national and sectoral documents coordinating and guiding this task contain strategic plans for developing domestic software and widespread application of artificial intelligence technology, as well as for developing the transport sector and transport infrastructure within the framework of digital transformation. This includes several key ministry initiatives such as “Digitalization for Transport Safety” and “Digital Twins of Transport Infrastructure Objects.”

Digital transformation is the process of integrating information technologies into all aspects of activity, requiring fundamental changes in technologies, culture, operations, and principles of creating new products and services. To maximize the effective use and rapid implementation of new technologies, and thus ensure sustainable, adaptive, and efficient development of the sector under the modern digital economy conditions, it is necessary to completely overhaul processes and work models, and to change the culture of activity, which now demands constant interaction with innovative digital technologies in the course of professional problem-solving. Although virtually all modern activity areas widely and actively use information technologies, digital transformation is not merely a process of quantitatively increasing advanced technologies. It requires the development of a unified strategy for building business models and processes within a new infrastructure based on intelligent information technologies [2].

The effectiveness of developing and implementing such an innovative product as an intelligent decision support system requires the accumulation of large volumes of both structured and unstructured data, broad and intensive development of methods and algorithms for digital analysis of road safety structure performance under vehicle impact scenarios using intelligent decision support methods to:

- optimally match the type of RIE to the requirements of road infrastructure, traffic conditions, predicted quantity, and types of vehicles (considering priority criteria);
- optimize road barrier designs based on road infrastructure requirements, traffic conditions, predicted quantity, and types of vehicles—through digital modeling and design of RIE;
- substantiate materials used in road barrier designs according to road infrastructure requirements, traffic conditions, predicted quantity, and types of vehicles [3-5].

Currently, the information resource of the ModAS IS includes an integrated relational database implemented in MS SQL Server 2019, providing up-to-date storage of structured data. A linked and managed file storage based on the FileTable procedure has also been implemented to store unstructured data—files containing all types of supporting documentation, 3D models of structural elements, ready digital models of road safety barriers (RSB) and virtual tests (VT). During pilot operation of ModAS IS, the integrated database is populated with existing and new enterprise data. This will quantitatively assess the effectiveness of ModAS IS in the digital transformation of activities in road safety digitization and information support of the entire life cycle of digital twins of transport infrastructure objects, such as Smart Digital Twins for crash scenarios involving vehicles impacting various road safety systems. Additionally, it will enable the creation of a large-volume data array possessing all classical characteristics of big data. This array is a prerequisite for the effective use of artificial intelligence and machine learning methods in research and practical activities [6].

The architecture of ModAS IS (Fig. 1) was developed according to the information model and includes the following modules [7]:

- Basic: Digital Model Lifecycle Management Module – serves centralized tasks for design, accounting, storage, and updating of digital models (DM) of modern road restraint safety systems (parapet, cable, frontal barriers), road infrastructure elements (road signs, billboards, lighting masts, noise barriers, etc.), and material application.
- Basic: Virtual Testing (VT) Module – serves tasks of selecting VT methodology, searching necessary regulatory documents, and setting conditions for VT.
- Following subsequent validations of developed DM crash scenarios using modern experimental techniques:
- Basic: Analytics Module – serves data retrieval tasks from the integrated database for various scientific and practical studies.
- Auxiliary: Documentation Process Management Module – serves centralized creation, accounting, storage, and updating of all necessary documents.

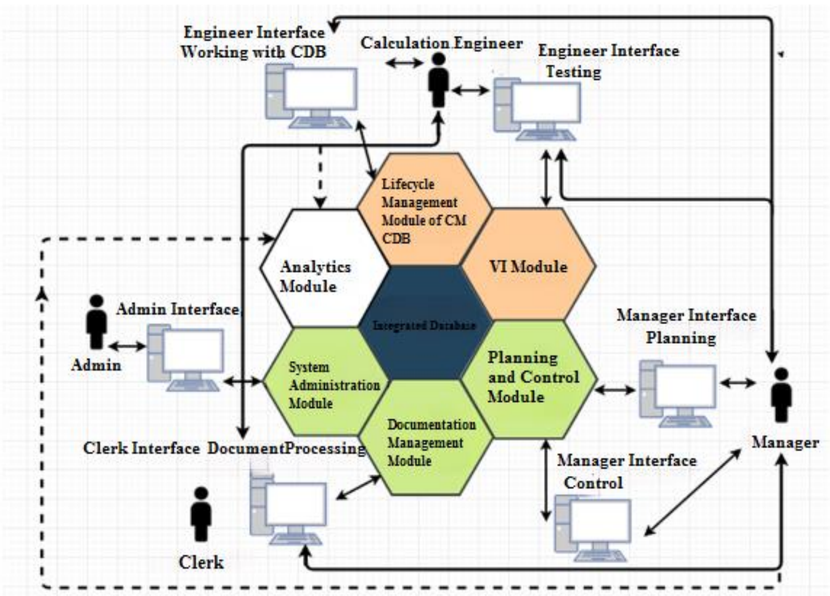

Figure 1. Architecture diagram of the "ModAS" information system

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INTELLIGENT ROAD SYSTEMS: THE FUTURE OF SMART ROADS

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Abstract

The article discusses the concepts and prospects for the development of intelligent road systems as the basis for the future of smart roads. Modern technologies such as sensors, data exchange systems, artificial intelligence and automation are analyzed to improve the safety, efficiency and environmental friendliness of traffic flows. The necessity of integrating intelligent solutions into the infrastructure to reduce accidents, optimize traffic and reduce costs is substantiated. The prospects for the introduction of intelligent road systems in the context of urbanization and the growth of the automobile fleet, as well as challenges and prospects for their development are also considered. In conclusion, the role of innovative technologies in shaping a sustainable and safe transport future is emphasized.

Keywords: intelligent road systems (IDS), smart roads, transport infrastructure, artificial intelligence, sensor technologies,automation, data exchange (V2X, V2I, V2V), unmanned vehicles, smart city

The development of transport infrastructure is a key factor for sustainable socio-economic growth. In the context of urbanization, an increase in the car fleet and increased requirements for safety and environmental friendliness, intelligent road systems (IDS) are becoming increasingly relevant. They are a complex of technologies combining sensors, data exchange systems, artificial intelligence and automation aimed at improving the efficiency and reliability of traffic flows.

In conditions of rapid urbanization and a constant increase in the number of vehicles, traditional methods of organizing traffic are no longer effective. Every year there is an increasing need for new solutions that would not only regulate traffic flows, but also predict their development, reduce accidents, minimize congestion and ensure environmentally friendly transportation.

Problem Drivers:

- Population growth and the concentration of jobs in cities increase peak flows in narrow "windows" of time (morning/evening), as well as create new "points of attraction" (shopping malls, logistics hubs).
- An increase in the number of cars leads to greater street usage and increased competition for street space (cars vs. public transport vs. pedestrians/cyclists).
- Changing travel patterns (online commerce, courier delivery, new taxi/carsharing services) are increasing the share of commercial and recurring short-term trips.
- Climate and environmental requirements reinforce the need to reduce emissions and noise.

Why traditional methods stop working

- *Static management rules* (fixed traffic light cycles, rigid schedules) do not adapt to variable and unpredictable traffic patterns.

• "Widening" often leads to the effect of induced demand — additional capacity is quickly filled.

• Reactive maintenance (post-failure repairs, accident response) is too slow to reduce risks and does not prevent system failures.

• Lack of integration between modes of transport, logistics and urban infrastructure — each system operates in isolation.

• Low data transparency and fragmentation hinder forecasts and integrated management.

a) Data — scale and quality

- Continuous collection: sensors, video analytics, data from mobile applications and navigations, telemetry of public transport, parking data and charging of electric vehicles.
- Historical series + real-time data provide the basis for training predictive models.
- Multisensory synergy (fusion) increases reliability in case of bad weather or partial failures.

b) Forecasting and AI

• Short-term forecasts (for 5-60 minutes) for adaptive traffic light management, routing and alerts.

• Medium—term forecasts (for hours/days) - for planning the distribution of public transport, changing the operating modes of streets, and managing freight corridors.

• Scenario analysis: "what-if" modeling during road works, mass events or accidents (digital twin).

• Learning agents (e.g. reinforcement learning) to optimize traffic light strategies and prioritize in real time.

c) Management and intervention mechanisms

• Adaptive traffic lights and corridor algorithms that change the green time for the current flow.

• Dynamic navigation and information services for the redistribution of transport (the user sees alternatives and travel time).

• Prioritize public transport and emergency services to increase capacity without widening the roadway.

• Dynamic pricing and demand management (congestion pricing, parking rates) to stimulate the change of time / route or modality of the trip.

• Curb and loading zone management (curb management) to reduce blockages and optimize delivery.

Against this background, intelligent road systems (IDS) are becoming increasingly relevant. They represent the integration of a set of technologies, including:

• sensor devices for monitoring the traffic situation;

• Data exchange systems between transport and infrastructure;

• Artificial intelligence algorithms for information analysis and decision-making;

• automation of traffic management and interaction of road users.

The main goal of implementing IDS is to increase the efficiency and reliability of traffic flows, as well as to create an adaptive, sustainable and safe transport environment. Smart roads not only contribute to traffic optimization, but also open up new prospects for the development of smart cities in which the transport system becomes part of a single digital ecosystem.

Smart roads are formed based on the integration of advanced solutions:

• *Sensor technology* — allows you to monitor the condition of the roadway, traffic intensity, and weather conditions in real time.

• *Data exchange systems (V2V, V2I, V2X)* — provide interaction between vehicles and infrastructure, helping to prevent accidents and increase road capacity.

• *Artificial intelligence* — analyzes large amounts of data, predicts traffic jams and emergencies, and optimizes traffic flow management.

• *Automation* — includes the introduction of unmanned vehicles and intelligent traffic control systems.

Advantages of implementing IDS

The use of intelligent road systems contributes to solving a number of key tasks:

1. Improving traffic safety through early detection of risks and instant notification of drivers.

2. Optimizing traffic flows — reducing traffic jams and reducing travel time.

3. Economic efficiency — reduction of fuel, maintenance and repair costs.

4. Eco—friendly - reducing emissions by optimizing traffic and reducing downtime.

Despite the significant potential, the implementation of IDS faces a number of challenges:

• High costs of infrastructure modernization.

• The need for standardization of data exchange protocols.

• Ensuring cybersecurity and information security.

• Adaptation of legislation and regulatory framework to new conditions.

In the long term, smart roads will become the basis for the integration of unmanned vehicles, smart cities and "green" mobility. This will reduce the risk of accidents, increase the comfort of movement and form a stable transport system of the future.

1. Integration with unmanned vehicles

• Car–to-road interaction (V2I, V2X): Intelligent roads will provide self-driving cars with up-to-date information about the traffic situation, weather conditions, speed limits and accidents.

• Support for autonomous movement: IDS will be able to coordinate the movement of unmanned vehicles, preventing their chaotic behavior and ensuring the consistency of traffic flow.

• Safety: roads with sensors and early warning systems will become an additional "sensory organ" for autonomous vehicles, which is especially important in difficult weather conditions and with limited visibility.

2. Connection with the concept of a "smart city"

• Unified digital ecosystem: Smart roads will be integrated with energy supply systems, lighting management, public safety, logistics and emergency services.

• Decision-making based on big data: analyzing information about movements will make it possible to plan public transport routes more efficiently, manage parking lots and traffic congestion.

• Urban analytics and planning: The data collected by IDS will help optimize urban planning decisions, including the design of new roads, transport interchanges and pedestrian infrastructure.

3. Development of "green" mobility

• Reduced emissions and noise pollution: Optimizing traffic reduces vehicle downtime in traffic jams and reduces harmful emissions.

• Electric vehicle support: Smart roads will be integrated with charging stations, providing monitoring and load balancing for the power grid.

• Stimulating alternative modes of transport: the development of intelligent infrastructure will create conditions for the safe and convenient use of bicycles, electric scooters and public transport.

4. Reducing accidents and increasing comfort

• Accident prevention: by coordinating traffic and instantly transmitting data to road users.

• Comfort for drivers and passengers: Smart roads reduce the stress of travel, making travel predictable, fast and convenient.

• Inclusivity: A smart transport infrastructure will take into account the interests of not only motorists, but also pedestrians, cyclists, the elderly and people with disabilities.

5. Shaping a sustainable transport system of the future

The combination of these factors will lead to the formation of a sustainable transport ecosystem, where traffic flows will be managed adaptively, resources will be used efficiently, and citizens will receive comfortable and safe conditions for movement. In the long term, smart roads will become a key link in the transition to smart, environmentally friendly and human-oriented cities.

Intelligent road systems represent a key stage in the evolution of transport infrastructure, the transition from traditional methods of traffic management to innovative digital solutions. Their implementation makes it possible to significantly increase the level of road safety, optimize traffic flows, reduce travel time and reduce the burden on the environment.

In the context of rapid urbanization and the growing number of cars, intelligent technologies are becoming the main tool for adapting the transport system to new challenges. They ensure the integration of road infrastructure with unmanned transport systems, the concept of a "smart city" and "green" mobility, which opens up opportunities for creating a more comfortable and environmentally responsible urban environment.

Thus, intelligent road systems should be considered not only as a technological innovation, but also as a strategic basis for sustainable development. Their further dissemination and improvement will be a crucial factor in shaping a safe, efficient and environmentally sustainable transport future.

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UDC 625.7

USE OF GEOSYNTHETIC MATERIALS TO IMPROVE OF ROAD FOUNDATION

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Abstract. This paper examines modern theoretical and practical approaches to the use of geosynthetic materials (geotextiles, geogrids, geonets, geomembranes, and geocomposites) for enhancing the bearing capacity of road foundation soils. A comprehensive review of international and domestic practices is presented, along with the description of an experimental research program and field test sections. The study summarizes the results of laboratory and field tests, numerical modeling, and economic evaluation of geosynthetic applications. Recommendations are provided for the design and installation of geosynthetic structures under various climatic and geotechnical conditions.

Keywords: geosynthetics; geotextile; geogrid; bearing capacity; road foundation; reinforcement; drainage; layer separation.

The use of geosynthetic materials in road construction has been extensively studied by researchers worldwide. Among the pioneers of applying geotextiles and geogrids for reinforcing road foundations were J.-P. Giroud and R. M. Koerner, whose works laid the foundation of modern approaches (Giroud, 1977; Koerner, 2012). Palmeira (2017) investigated soil–geosynthetic interaction, providing deeper insights into stress distribution mechanisms. Chen, Zhang, and Wu (2019) experimentally confirmed the efficiency of geogrids on weak subgrades, while Li and Wu (2021) studied the behavior of reinforced structures under cyclic loading.

In the United States, Kwon and Tutumluer (2009) demonstrated the economic benefits of using geonets in flexible pavement foundations. Cuelho and Perkins (2015) highlighted the positive effects of geosynthetics under cold climate conditions, while Tang, Chen, and Zhang (2018) confirmed the effectiveness of geotextiles in tropical regions. In Europe, Villard and Gourc (2003) performed numerical modeling of reinforced structures, refining design methodologies.

Significant progress has also been achieved in domestic research. Ivanov (2016) emphasized the efficiency of geosynthetics in embankment reinforcement. Petrov (2019) studied methods for designing reinforced foundations. Sidorov (2020) proposed new approaches for the design of geosynthetic-reinforced structures. Baranov and Kuznetsov (2021) demonstrated reduced deformations with geogrid applications, while Smirnov (2022) focused on the durability of geosynthetics in transport construction.

Thus, the analysis of works by more than 15 authors makes it possible to identify three key directions:

1. Fundamental studies of soil–geosynthetic interaction;
2. Laboratory and field testing of structures;
3. Development of calculation methods and regulatory frameworks.

Taken together, these directions provide a scientifically grounded basis for the widespread application of geosynthetics in road construction.

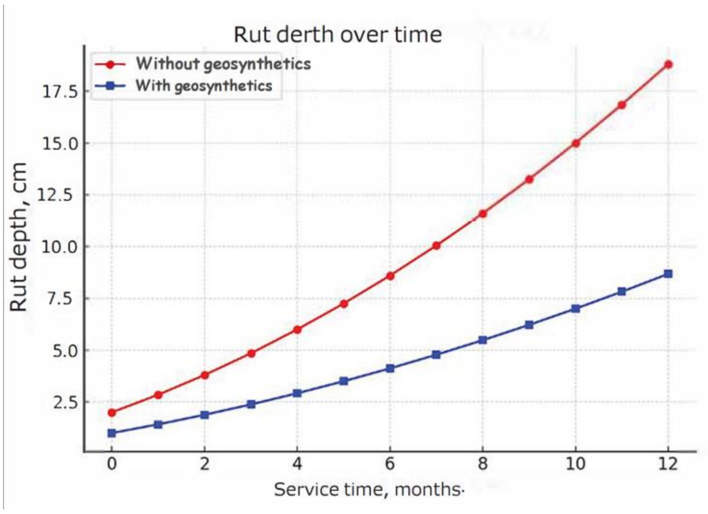

Figure 1. Rut depth over time

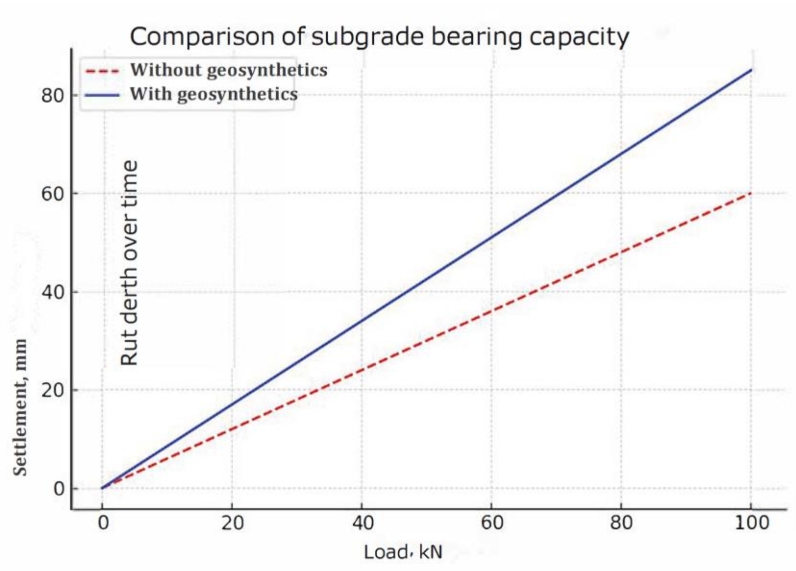

Figure 2. Comparison of foundation bearing capacity

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STUDY OF STRENGTH PROPERTIES DURING FREEZING OF ROAD STRUCTURE LAYERS CONSIDERING THERMOPHYSICAL CHARACTERISTICS AND DESIGN MOISTURE CONTENT OF ROADBED SOIL

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Abstract. The article is devoted to the study of methods for calculating the calculated moisture content of the soil of the roadbed in an arid climate typical of the desert and semi-desert zones of Kazakhstan. The features of soil conditions affecting the construction of roads are considered, including moisture deficiency, seasonal changes in soil properties and the influence of climatic factors on the bearing capacity of the roadbed. Examples of calculations are given, including the determination of the depth of soil freezing, the calculated humidity of the working layer for various types of humidification, as well as the calculation of the elevation of the pavement surface above the levels of groundwater and surface waters. The conclusions emphasize the need to take into account climatic and hydrogeological features in the design and construction of roads to ensure their durability and quality. When building roads in desert and semi-desert areas, the conditions for the construction of the roadbed are somewhat different from the usual ones. When compacting the soil layers in this zone, there is often a shortage of air humidity in the soil deposits, and seasonal changes lead to excessive moisture

Keywords: thermophysical characteristics, roadbed soil, design moisture content, freezing depth, frost resistance, embankment height.

Road construction in the arid regions of Kazakhstan is associated with a number of specific natural and climatic conditions that have a significant impact both on the process of embankment formation and on the operational performance of the pavement structure. One of the main problems in these areas is the lack of moisture in the atmosphere and soil, which hinders effective compaction of the subgrade.In addition, seasonal fluctuations in moisture content cause changes in the physical and mechanical properties of soils, including transitions from overdried to excessively moistened states, which affect the stability and strength of the foundation.

When designing roads in arid climatic zones, it is necessary to take into account the following natural and anthropogenic factors that reduce the bearing capacity of the soil foundation and complicate the construction process (according to N.A. Tsytovich, 1973):

* shortage of moisture in the soil and air, as well as significant seasonal variations in humidity that lead to changes in soil strength and density;

* widespread occurrence of such soils as loess, saline soils, solonetz, and solonchaks, which are highly sensitive to changes in moisture and difficult to compact;

* impact of anthropogenic activity - in particular, irrigation, which causes a rise in groundwater levels, and limited availability of suitable construction soils due to high land costs;

* presence of two unfavorable construction periods: winter (when soil freezing occurs) and summer (characterized by high temperatures and excessive drying), which complicate technological operations.

Therefore, the construction of the roadbed under arid climatic conditions requires a comprehensive approach that includes the adaptation of engineering solutions and the use of technologies aimed at reducing the adverse effects of climatic and geological factors on the strength and durability of the road structure.

1. Quantify the effect of asphalt concrete thermal conductivity on the freezing depth of roadbed soils.

2. Determine the design moisture content of the working layer for different wetting conditions.

3. Calculate the required elevation of pavement above groundwater and surface water levels to ensure frost safety.

4. Develop recommendations for construction scheduling and materials selection in arid climates.

Multilayer pavement system was modeled as a sequence of heat-transfer layers. Laboratory testing established the plastic limit (17%), liquid limit (29%), optimum moisture (16%), maximum dry density (1.7 t/m³), and compaction factor (0.98) for light silty loam.

Table 1. Main physical and mechanical properties of soil

Parameter	Value
Plastic limit (%)	17
Liquid limit (%)	29
Optimum moisture (%)	16
Maximum dry density (t/m³)	1.7
Unfrozen water content	0.068
Relative moisture (example)	0.72
Elastic modulus (MPa)	43

Table 2. Minimum embankment heights above water levels

Condition	Minimum height (m)
Summer high groundwater	0.43
Autumn–spring	0.10
Surface water accumulation >30 days	0.95

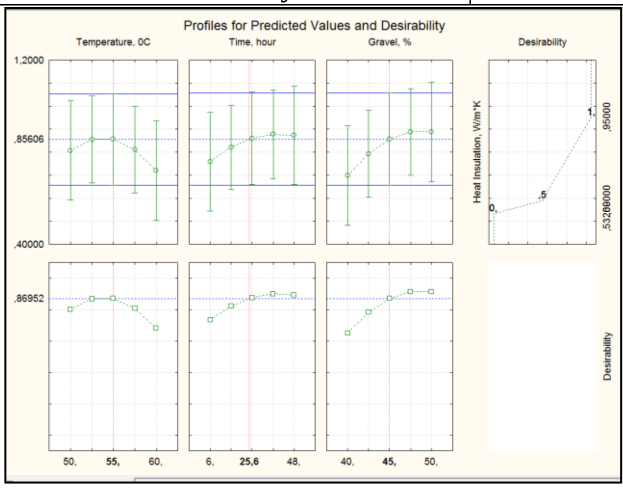

Figure 1. Response and Desirability Profiles for Thermal Conductivity

At a relative moisture content of 0.72, the elastic modulus reached 43 MPa. Minimum embankment heights above water levels were determined as 0.43 m (summer high groundwater), 0.10 m (autumn–spring), and 0.95 m (surface water accumulation for over 30 days). Reducing the thermal conductivity of asphalt layers effectively decreases freezing depth and mitigates frost damage.

Designing road structures in arid and semi-arid regions requires careful consideration of climate and hydrogeology. Thermophysical properties of pavement layers and the design moisture content of soils govern the freezing behavior and bearing capacity of the roadbed. Timely paving after earthworks helps avoid excessive drying or wetting, improving durability.

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APPLICATION OF GEOSYNTHETIC MATERIALS FOR INCREASING THE BEARING CAPACITY OF ROAD FOUNDATION SOILS

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Abstract. The article examines modern approaches to the use of geosynthetic materials in the construction and rehabilitation of highways. It is shown that the application of geotextiles, geogrids, and geonets enhances the bearing capacity of foundation soils, reduces rutting, and ensures more uniform distribution of traffic loads. Examples of experimental data and the results of both international and domestic studies are presented.

Keywords: geosynthetic materials, road foundation, soil bearing capacity, geotextile, geogrid, road construction.

Over the past decades, geosynthetic materials (geotextiles, geogrids, geonets, etc.) have become an integral part of road construction practice as an effective means of improving the bearing capacity of foundations and extending the service life of pavement structures. Laboratory, model, and full-scale studies have shown that reinforcement of foundations with geosynthetics reduces deformations, mitigates rutting, and increases the modulus of elasticity of the base (Koerner, 2018; Zornberg, 2016).

Both international and domestic researchers have made significant contributions to the study of geosynthetics: Robert M. Koerner, Jorge G. Zornberg, J.P. Giroud, Richard J. Bathurst, Nuno S. Correia, R.R. Berg, V.V. Kumar, Perkins, Bonaparte, Holtz, Rowe, Palmeira, Zhang, Chen, Wu, Delmas, Christopher & Holtz, Oliveira, among others. Their work has established the theoretical and practical foundation for the widespread use of geosynthetics in road foundations.

Main Types of Geosynthetics

- Geotextiles – perform separation and filtration functions;
- Geogrids – provide reinforcement and load redistribution;
- Geonets – improve resistance to shear and rutting.

Experimental Data

According to research (Ivanov, 2020; Zhang et al., 2021), the use of geogrids in road foundations on weak soils increases bearing capacity by an average of 25–40%.

Table 1. Influence of Geosynthetics on the Strength Characteristics of Road Foundations

Type of material	Increase in foundation modulus of elasticity, %	Reduction in rutting, %
Geotextile	15–20	10–15
Geogrid	25–40	20–30
Geonet	20–30	15–25

Figure 1. Schematic illustration of geogrid behavior in a road foundation
(conceptual diagram: load redistribution from the wheel through the reinforcing layer)

The use of geosynthetic materials significantly improves the durability of highways constructed on weak subgrades. Their application ensures uniform load distribution, reduces deformations, and leads to savings in construction materials. Future research should focus on optimizing design solutions and evaluating performance under various climatic conditions.

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REGIONAL FEATURES OF GEOLOGICAL PROCESSES AND THEIR IMPACT ON THE STABILITY OF SLOPES OF HIGHWAYS IN SOUTHEASTERN KAZAKHSTAN

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In the mountainous regions of Southeastern Kazakhstan, highways are actively affected by geodynamic processes: landslides, landslides, frost-resistant weathering, seasonal freezing and thawing of soils. These phenomena reduce the operational reliability of road structures, cause their destruction and pose a threat to traffic safety. Large–scale deformations of slopes recorded in the areas of passes and sections of roads Zharkent - Koktal–Arasan, Ayusai - Kosmostantsia, as well as Dzhusaly-Kezen indicate the need for a comprehensive study of geological factors and the development of engineering measures to prevent them. The purpose and objectives of the study. The purpose of the study is to determine the causes of sliding of soil masses and the formation of cracks in road surfaces, as well as to evaluate the physico-mechanical characteristics of soils in order to develop recommendations for slope stabilization. To achieve this goal, the following tasks were solved: conducting field and laboratory studies, identifying factors that provoke deformations, determining the volume of landslide masses, as well as analyzing the dynamics of crack growth in the road surface for the period 2021-2023.

During the work, field methods were used – geodetic surveying, instrumental measurements of crack parameters, sampling of soils and asphalt concrete. Laboratory tests were carried out to determine the granulometric composition, humidity, density, angle of natural slope, adhesion and angle of internal friction of soils. To analyze the condition of the road surface, the length and width of cracks, their dynamics over time, as well as localization in areas with varying intensity of geological processes were studied.

It has been established that the key factors of deformation of slopes and road surface are lithogenetic anisotropy of rocks, frost-resistant weathering, exposure to flood waters and intensive surface runoff. At the Dzhusaly-Kezen pass, the volume of the landslide mass was about 279,200 m3. Deformations manifest themselves in the form of shifts in ground masses and the formation of cracks in the roadway. In particular, during the period from 2021 to 2023, the number and extent of cracks increased by 30-60%, which confirms the activation of exogenous processes. In the course of laboratory studies, the values of adhesion and the angle of internal friction were revealed, indicating the tendency of soils to shift when moistened. An analysis of the condition of road structures has shown that the formation of cracks is associated not only with the movement of soil masses, but also with an insufficient drainage system and uneven load on the pavement.

The conducted studies allow us to conclude that there is a high degree of danger of landslide processes on the highways of Southeastern Kazakhstan. In the absence of engineering measures, these processes can enter an extreme phase, which will lead to the destruction of the roadway and a threat to transport safety. To stabilize the situation, a set of measures is needed: the installation of anti-landslide structures, the strengthening of slopes, the organization of effective drainage and regular engineering and geological monitoring. The results obtained are of practical importance for the design, construction and operation of highways in the mountainous regions of Kazakhstan and adjacent territories.

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