



RESEARCH ARTICLE

Methods of Designing Structures of Infrastructure Facilities for the Construction of Highways

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Received: Aug 19, 2025

Accepted: Oct 12, 2025

Keywords

Highway
Safety
Design
Road Surface
Operation
Asphalt Concrete
Cement Concrete
Strength
Wear Resistance

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ABSTRACT

The study reviews advanced design and construction methods for highway infrastructure structures based on Russian and international patents and technical literature. The purpose was to identify efficient technologies and materials that enhance durability, wear resistance, and safety of modern highways. The research applied comparative analysis of existing engineering approaches, emphasizing asphalt and cement concrete pavements reinforced with geotextiles, geogrids, and fiber-reinforced concrete. Results demonstrate that multilayer monolithic cement concrete structures and hybrid asphalt-cement systems significantly improve bearing capacity, reduce permeability by up to 40%, and extend service life by 2.5–3 times. Additionally, integrating geomaterials, recycled rubber, and industrial waste lowers environmental impact and construction costs while ensuring frost and water resistance. The study concludes that the proposed technological solutions provide a sustainable, cost-effective framework for designing durable, high-performance highways adaptable to diverse climatic and geological conditions.

INTRODUCTION

The problem of building high-quality highways has been and remains relevant, because highways are the most important component of the transport system, without which no branch of the national economy of the country can function. The number and quality of highways characterize the level of technical development of the country as a whole. A well-constructed highway is a guarantee of safety and comfort not only for drivers, but also for pedestrians. Due to the increase in the number and payload capacity of vehicles and the intensity of traffic on highways, increased requirements are placed on reliability, operability, durability and other characteristics of new and repaired roads.

RESEARCH METHODS

The stages of highway construction are determined depending on the category of road and the place of its construction, then a specific work plan is drawn up and studies are conducted on the economic, technical and natural conditions in which the construction and utilization of the road will be carried out. During the research, maps and terrain are studied, detailed hydrological, engineering, geological and soil surveys are carried out, the need for land acquisition and demolition of buildings on them is assessed, etc. Based on the data obtained, a road project is created that regulates all construction work.

Modern technologies and methods of highway construction in Russia are based on two alternative types of pavements: asphalt concrete and cement concrete (Savchenko and Maksin, 2016). Asphalt concrete was widely used in the 20th century in the construction of highways as a pavement as a common and sought-after material consisting of bitumen, crushed stone, sand and various additives. Most of the highways in Russia are paved with asphalt concrete, which can be delaminated by temperature fluctuations in summer and winter even without much load.

At the same time, asphalt-concrete pavement of highways is the most popular practical implementation in Russia, which is explained by its unique physical and chemical properties. Despite the fact that due to the emergence of new more efficient technologies for the construction of highways, the issues of improving the quality and repair of roads with asphalt pavement continue to remain relevant.

One of the most widespread and demanded building materials in the world is cement concrete. It is actively used for the construction of highways. In many countries around the world, highways are being built with cement concrete instead of asphalt concrete. They are durable and require lower maintenance and repair costs than asphalt concrete roads.

The main advantages of cement concrete road coverings are:

- High durability and bearing capacity;
- The possibility of passing heavy vehicles all year round without restrictions, including in the spring period;
- Long service life;
- Low maintenance costs;
- High coefficient of adhesion and white color ensure road safety;
- Reduction of fuel consumption when driving vehicles on such surfaces;
- Increased reliability of road structures.

In recent years, there has been a noticeable increase in the interest of Russian and foreign companies involved in the design and construction of highways in creating reliable and safe roads using high-quality materials and specialized road equipment.

The road surface is characterized by reduced moisture permeability and increased wear resistance using reinforced monolithic cement concrete (Petrovich et al., 2005), which includes a sandy underlying layer 5 (Fig. 1), waterproofing rolled material 4, monolithic cement concrete 6, geotextile 3, volumetric geogrid 2, fiber-reinforced concrete 1.

The construction of the pavement is carried out in four stages. At the first stage, a sandy underlying layer 5 is arranged and waterproofing rolled material 4 is laid on it. At the second stage, a layer of monolithic cement concrete 6 is laid, on top of which a geotextile 3 is placed. At the third stage, a volumetric geogrid 2 is laid out and the formed cells are filled with monolithic cement concrete 6. At the fourth stage, a layer of fiber-reinforced concrete 1 is laid. At the same time, the start of laying each subsequent layer of cement concrete should not exceed the setting time of the cement; this leads to the production of a cement-concrete monolith with a conditional depth division into three layers reinforced in accordance with the specifics of each of them. The top layer provides impact resistance, water resistance and reduces abrasion. It is reinforced with fibers that are randomly arranged and evenly distributed throughout the volume, with interlocking effects and rigid anchoring in concrete. The middle layer provides compressive durability during elastic deformation. It is reinforced with a volumetric honeycomb-shaped geogrid of the georif type to create rabbit elements between adjacent concrete blocks, which acts as a permanent formwork during layer formation and as technological seams in the concrete monolith. The bottom layer carries tension stresses when bending. It is reinforced with a horizontally arranged geotextile with the possibility of fibers carrying tension stresses in the longitudinal and transverse directions.

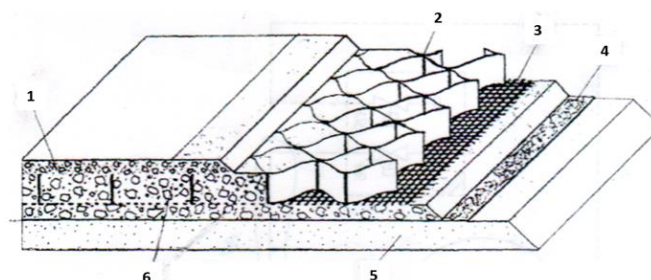


Fig. 1. The construction of a road surface using reinforced monolithic cement concrete

RESULTS

The construction of the road surface is characterized by increased wear resistance and bending durability and makes it possible to operate without a rigid base.

A method of constructing a road surface with anchoring layers of asphalt concrete pavement and cement-concrete base provides an increase in the bearing capacity and durability of the road surface of a highway (Vysotsky and Saltykov, 2016). It includes the structure of a base layer of cement-concrete mixture with the creation of a wavy profile of a cellular structure on its surface by pressing rigid discretely arranged indentation devices (stamps) in the form of inverted truncated large straight cones or regular pyramids of established technological parameters into a layer of an uncured mixture and extracting from it.

The use of a designed method for the construction of pavement with anchoring layers of asphalt concrete pavement and cement concrete base makes it possible to increase the durability of pavement by increasing its potential energy, the energy of structural bonds of cement concrete and composite volumetric combination of layers, as well as to reduce the stresses arising in pavement from the impact of a moving load by directional decomposition of kinetic energy.

To increase the pace of construction, reduce the cost of work, and increase the stability of the road surface from the effects of climatic factors, a method has been developed for the construction of highways (Samusev and Samusev, 2017), which allows the use of serial work tools and the ability to work in parallel at all stages of construction, significantly reduce the time and expand the scope of use.

The construction of a highway begins with leveling the surface according to the planned road markings.

The first (preliminary) stage of construction is drilling wells 1 (fig. 2) for pile foundations. Drilling is carried out by mass-produced drilling rigs mounted on an automobile or tracked track. The drilling depth of well 1 is assumed to be 300-500 mm below the soil freezing depth. Immediately after drilling each well 1, a metal mesh 2 is inserted into it along the perimeter/circumference/ to prevent the walls of the well 1 from crumbling.

Following the drilling stage of wells 1, work is carried out on the second stage: the construction of inventory formwork 6 in each transverse row of wells 1, the installation of fittings 3 in the body of the support beam 4 above wells 1, the filling of wells 1 and the support beam 4 with a concrete mixture.

The shape of the upper part of the formwork 6 must correspond to the design profile of the road.

The pile foundation (wells 1 in the transverse row and the support beam 4) is filled using concrete pumps. Concrete is delivered by automatic concrete mixers.

The third stage of work: The laying of reinforced concrete slabs 5 on pile foundations is carried out after the pile foundations gain strength. The slabs 5 are laid using cranes. The joints of the plates 5 and the support beams 4 are fixed with the reinforcement elements 3 of the pile foundations.

At the fourth stage of the work, the joints of reinforced concrete slabs 5 are poured onto the support beams 4, after which the asphalt concrete pavement is laid onto the slabs 5.

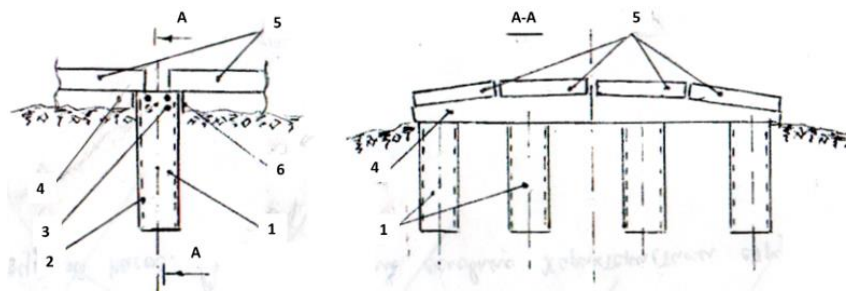


Fig. 2. A road construction scheme with drilling of wells for pile foundations

All four stages of work in time can be carried out simultaneously, which makes it possible to significantly increase the pace of road construction with the possibility of using serial equipment.

The highway (Fedyuk et al., 2019), which contains layers of pavement, crushed stone, sand, geofabric and foundation soil, is characterized by increased solidity and high dynamic strength characteristics. A geotextile made of polypropylene fibers is laid between the ground of the base and a layer of sand over the entire area of the base. Additionally, a flat triaxial hexagonal polymer geotextile with triangular cells ranging in size from 35x35x35 to 60x60x60 mm is laid between the layers of sand and crushed stone. Geopolymer concrete was used as a road surface.

Thus, the developed highway has the following advantages:

- Increased dynamic durability characteristics by 43-48%
- water and vapor permeability characteristics are reduced by 21-41%;
- By reducing permeability, frost resistance is optimized, respectively, it increases the service life of the road by 2.5-3 times;
- Due to the rational use of geomaterials, less crushed stone is used (by 12-15%);
- Reduction of labor and material costs for construction is achieved due to the absence of sealing operations;
- The use of geomaterials makes it possible to abandon traditional materials, which produce environmental pollution.

The highway (Bellavin, 2015), the design of which is shown in Figure 3, differs in reduced operating costs.

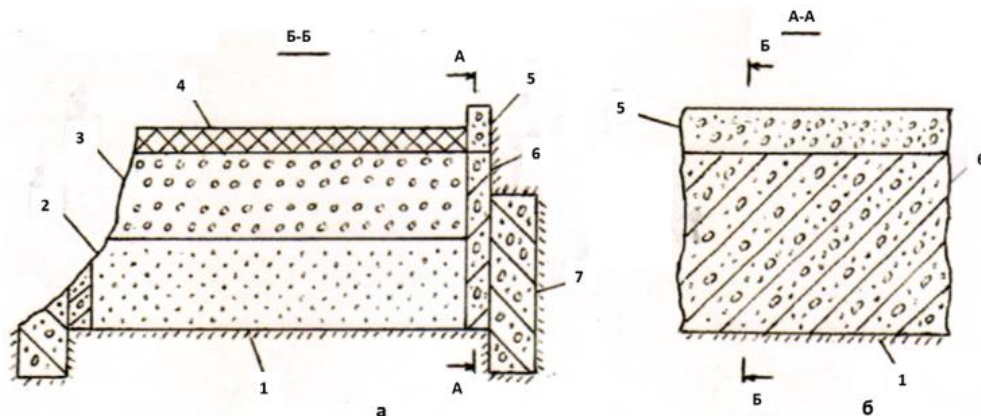


Fig. 3. A structural diagram of a highway made of reinforced concrete piles and slabs: a is a transverse section of the road structure, b is a longitudinal section of the road structure

Reinforced concrete piles 7 are driven into the ground of the earth bed 1. Reinforced concrete slabs 6 are attached to piles 7, mounted on the ground of the earth bed 1. A layer of sand 2 is located between the plates 6 on the ground of the earth bed. A layer of crushed stone 3 is located on the sand layer 2. The height of the 6 slabs is equal to the sum of the heights of the sand and gravel layers. Reinforcement strips 5 are located on plates 6. A layer of asphalt concrete 4 is located between the reinforcement strips 5 on the rubble 3. The operation of the designed highway is as follows. In spring, the plates 6 prevent water from penetrating into the sand 2 from under the rubble 3. Similarly, sand 2 and crushed stone 3 do not change shape under asphalt concrete 4 due to the pressure of cars.

During the highway construction, asphalt concrete is used for the construction of the upper layers of road clothing in all climatic zones (Prokopets and Ivanova, 2009), including crushed stone, sand, mineral powder, viscous petroleum bitumen and finely ground rubber crumbs. It contains finely ground rubber crumbs in the form of a mixture of mechanically activated rubber crumbs with a fraction size from 0.071 mm to 0.100 mm and sand obtained by co-processing them in a disintegrator at a mass ratio of 1:2. The ratio of components in asphalt concrete is, by weight %: crushed stone 42-43, sand 35-36, mineral powder 12.8-13.2, viscous petroleum bitumen 5.5-6.0, specified rubber crumb 1.0, specified sand 2.0. The use of the developed asphalt concrete composition makes it

possible to recycle 30-35 tons of tire rubber chips per kilometer of road surface, does not require significant reconfiguration of technological equipment for the manufacture of asphalt concrete, and allows obtaining asphalt concrete of improved quality.

The technical result achieved in the implementation of the method of arranging layers of road clothing for transport infrastructure (Gorbunov et al., 2018) consists in:

- Accelerating the pace of construction, major and current repairs of infrastructure projects;
- Increasing the inter-repair service life;
- The ability to start operation immediately after the end of the sealing equipment;
- The presence of an irreversible effect of a constant set of load-bearing capacity during operation;
- Reducing water saturation up to full water resistance.

To achieve this technical result, it is proposed to arrange layers of road clothes from a mixture containing mineral materials, a binder and technological additives taken in reasonable quantities, followed by mixing and compaction, and at least one component from the group containing asphalt aggregate concrete mixtures, anthropogenic soil, clay soils, waste is used as mineral materials. construction and demolition of buildings, treated soil, artificial soils, sandy soils or mixtures thereof, and ready-to-use polyfillers are used as binders.

Polyester, polypropylene, fiberglass or a mixture thereof are used as technological additives. Additionally, local mineral soils with a plasticity index of less than 22 can also be used as mineral materials. A mixture of polyfillers can be used as a binder.

Additionally, round fibers made of polyester, polypropylene, fiberglass or mixtures thereof with a fiber length of 12 to 35 mm and a diameter of 10 to 15 microns can also be used as technological additives. Mixing of components can be carried out on the way to the construction site using mobile batching plants.

Ensures the production of strong structured layers of the pavement structure, connected both to each other and between layers, increasing the uniform stability of the layers of pavement during operation by ensuring a continuous increase in the strength of the layers of pavement over time, a method for the construction of highways (Arsenyev and Osnovin, 2013), including the construction of ditches and drainage devices, the preparation of a soil roadbed, the construction of a sub-base layer and the road surface, while the main layer is formed between the sub-base layer and the road surface, and the preparation of the soil base is carried out by leveling it with a binder coating and then rolling it, and in the absence of a soil base, it is pre-formed by applying a mixture of sand, slag and / or coal mining waste, water and a binder additive, and the sub-base layer is formed from a mixture of cement, sand, fine fraction filler, or fine gravel, or thermal power plants waste, water, a binder, laid, leveled and compacted, then either coated or sprayed with a binder, followed by compaction with needle rollers to a density of at least 1600 kg / m³, and the main layer of the road coatings are formed from natural gravel, sand, and/or sandy clays, stabilizers in the form of cement, and/or lime, and/or bitumen, and/or asphalt concrete, and a binder.

DISCUSSION

Thus, the developed method of highway construction provides a durable, wear-resistant and flexible monolithic highway structure, with increased water resistance, frost-resistant to temperature changes up to minus 50 degrees, since the proposed binders ensure the stitching of ingredients by penetrating long-fiber needle bonds.

The design scheme of a highway constructed according to the construction method (Arsenyev and Osnovin, 2013) is shown in Fig. 4 and consists of an existing natural or bulk ground foundation 1, a sub-base layer 2, a main layer 3 and a road surface 4, roadsides 5, drainage outlets 6. From the axis of symmetry of the road to the roadsides, the road has a slope of 1-2 degrees, which ensures the drainage of water during heavy precipitation. In this regard, the road surface is less exposed to water, and therefore to its penetration, and consequently to the growth of cracks during temperature changes. The presence of shungite binder in any layer of the road in the amount of 0.2-4 wt.% of the total weight of the binder additive containing dolomite and silicon oxides reduces the porosity of the

resulting mixtures, which also contributes to the formation of monolithic structures and the appearance of a plexus effect, and therefore eliminates the influence of precipitation, and therefore increases the service life of the road. The presence of a wollastonite binder additive in any layer in an amount of 0.2-2.5 wt.% of the binder additive, with its characteristic needle-like crystal shape, also provides good reinforcement of the mixture, and when mixed, it is evenly distributed over the volume of the mixture and binds it.

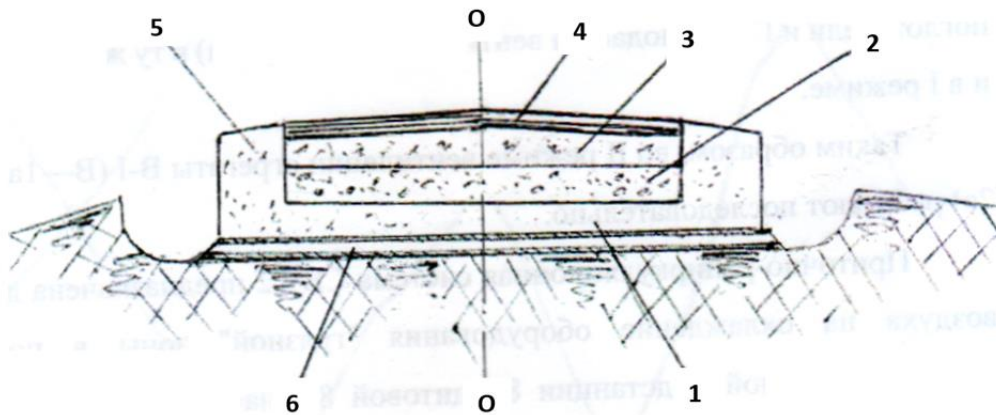


Fig. 4. A road layout with large structured layers and increased water resistance and resistance to temperature changes

The composition for strengthening dusty clay soils (Khabibullina and Beshenov, 2013), used in road and airfield construction, is characterized by increased durability, water and frost resistance. The composition for soil reinforcement includes quicklime, slag powder, solid oil sludge of the following composition, % by weight: asphalt-resinous substances 5-13, paraffins 18-40, hydrocarbons 4-6, mechanical impurities 35-60, water 2-12 with the following component ratio, wt.h.: pulverized clay soil - 100, solid oil sludge of the specified composition - 1023, quicklime - 5-9, slag powder - 3-7, water - 12-24.

The use of the composition provides increased durability, reduced frost heaving of dusty clay soils, reduced the cost of road construction, increased environmental safety and the release of territories for the reproduction of forest and agricultural land.

What reduces construction time and provides durable road revetment is the method of road construction (Evseev and Severyanov, 2012) on weak waterlogged soils, mainly in swamps, including the division of the site intended for road construction into sequentially located construction sites, the delivery of bulk material to the construction site by technological transport. The formation of the road revetment is carried out as follows: The bulk material is packed into a durable material, forming a continuous strip of a given length, and layers of pavement are formed by laying the strip in rows along or across the construction site. The construction method is characterized by high productivity at low labor and energy costs.

It allows to increase the load-bearing capacity and operational reliability of the pavement structure while reducing its material consumption, labor intensity and cost, increase the durability of the highway without major repairs, improve traffic safety on mountain roads in adverse weather conditions, the highway structure (Chernyavets, 2023), including a soil roadbed, an sub-base layer, a reinforced load-bearing layer placed on it, and roadsides with a channel-type air and drainage structure, slopes with drainage ditches, in which the bearing layer is reinforced with a two-tier power flooring, each tier of which is made of non-removable modular elements that are connected to each other.

The profile of each modular element in the section is made in the form of an open trapezoid containing a closed base and an open base with flangings, by means of which the modular elements are connected to each tier of the power flooring, the lower tier of the power flooring is laid on the sub-base level with a closed base to form caissons, and the upper tier of the power flooring is installed between the caissons with a closed base to form voids between the tiers of the power flooring and with the formation of additional caissons for the placement of reinforcing frames, and

the power flooring is placed from the axis of the road in both directions at an angle of 3-15% and is removed from the roadside.

The upper tier of the power flooring is installed with an outlet above the lower tier of the power flooring and is a protective visor, while the highway on mountain slopes additionally contains gabion to protect the highway from rockfall and landslides from rocks, which includes a metal mesh frame filled with stones, rounded stones of round or oval shape are laid in the lower layer, and in the upper layer — angular in the form of jagged stones. A protective buffer made of reinforced concrete is placed between the lower boundary of the slope and the gabion, in which automobile tires are fixed in pairs, protruding 1/3 from the reinforced concrete mixture, the protective buffer is placed in a trench, the upper surface of the reinforced concrete base is located on the horizon of the highway. A second protective buffer made of reinforced concrete is placed on the median strip, in which car tires are fixed in pairs, protruding 1/3 from the reinforced concrete mixture, the second protective buffer is also placed in the trench, and the upper surface of the reinforced concrete base is also located on the horizon of the highway. The construction of the highway makes it possible to improve the environmental situation in operational area.

The problem of disposal, neutralization and processing of oil industry waste, oil sludge, is extremely relevant both in the environmental aspect and in the use of waste as a secondary raw material, in order to extract valuable hydrocarbon components from them and obtain useful materials in various fields, including road construction.

The technological scheme of the oil industry waste disposal method in road construction (Ilyina and Ilyin, 2023) is as follows: the delivery of oil sludge from the storage pond 1 (Fig. 5) by loader 2 to the preparation and storage site 3, natural drying of the extracted sludge, if necessary, the supply of sludge by loader 4 to the pre-treatment plant 6, including a hopper with a loading grid 7 cells of 50 mm, on the side of which there is a hatch 5 for removing solid inclusions, the sludge is processed by a horizontally positioned bladed mixing and grinding screw 8 along the entire length of the mixer at a rotational speed of 100-150 rpm for 1-3 minutes, providing an outlet for oil sludge homogenized in composition and humidity, transferring the sludge to a conveyor belt 9 for transportation to the place of work by a dump truck 11 or a loader in a stack to the preparation and storage site, monitoring the compliance of the prepared sludge in terms of granulometric composition, density, mass fraction of petroleum products, mechanical impurities and water, compliance with the maximum specific effective activity of natural radionuclides.

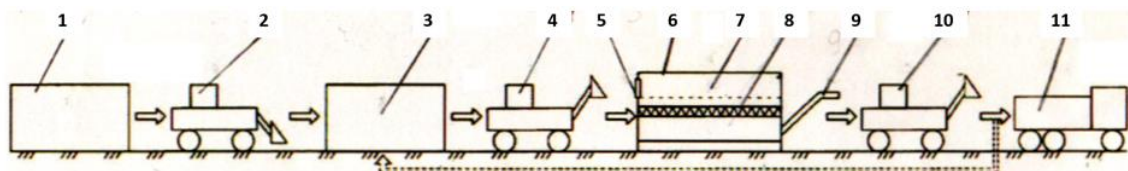


Fig. 5. Technological scheme of the oil industry waste disposal method in road construction

The asphalt concrete pavement recycling combine (Movin, 2014), which contains an asphalt pavement pickup unit connected to the platform by means of a saddle joint, which are mounted on pneumatic rollers, is distinguished by its expanded functionality, simplified design, convenient and reliable operation.

The asphalt pavement pickup unit is made in the form of a wedge-shaped sled. Triangular cutouts in the front are made on the upper plane of the pickup unit. The upper part of the unit is made in the form of a blade that turns into the tunnel. The pickup unit turns on the heater of the asphalt concrete surface to be removed before the guillotine. The guillotine is suspended on steel ropes, which are selected by a winch with a telfer ratchet mechanism on a monorail for dismantling well floors. Connecting rods-blades are fixed on the cranks of the crankshaft, directed into the triangular cutouts of the pickup unit and mounted on supports. Hammers are mounted on plate springs on the shaft of the hammer crusher for asphalt concrete debris.

When the shaft rotates, the hammers move along a curved plane. The hammers strain the plate spring. The plate spring bends when rolling along a rounded bump with a varying distance to the shaft to tighten the springs in order to sharply strike the asphalt scrap on the pickup unit blade. Vibrators — compactors of the road base, accumulators of asphalt concrete scrap, which is sifted

through grids installed in the bottom of the tunnel, are used to level the base for future asphalt pavement. The conveyor loads and lifts asphalt concrete scrap into the melting furnace. The melting furnace melts and optimizes the asphalt-concrete mixture with the addition of bitumen or a reducing agent.

An asphalt concrete coating melting furnace, an overhead crane for installing new well floors at the level of the future road surface, a bitumen heating tank for optimizing the asphalt mixture, a conveyor for shipping excess asphalt mixture to the side, an asphalt mixture storage hopper, an asphalt paver, a slit calibrator for the fraction of the asphalt mixture being laid with the removal of large fractions, an inclined removal tray of the calibrated fraction are installed on the platform. The engine of the harvester units drive is installed in the pickup unit.

The asphalt concrete road recirculation combine has the following advantages:

- Reliability and ease of use;
- Expansion of functionality;
- Absolute full utilization of the resource of previously laid asphalt concrete material;
- Minimizing transportation to the road repair site;
- Improving the quality of asphalt concrete pavement by maintaining the temperature regime of the laid asphalt concrete mixture;
- Exclusion of the mud pump, which reduces the adhesion of the laid layers of asphalt concrete;
- Elimination of costs for the preparation of crushed stone, sand extraction and bitumen production for the preparation of asphalt concrete mix;
- Restoration of the bearing capacity of the base, eliminating the repair of the coating;
- Increase the service life of the road while reducing repair costs.

CONCLUSION

Highways are an important infrastructure for the transportation needs of society. They play a key role in the country's economic development and social connectivity. The construction, operation and maintenance of highways require compliance with certain requirements and standards. The use of high-quality materials and specialized machinery helps to save money and provides the opportunity to build reliable and safe modern highways.

The development and improvement of highways contribute to the goals of integrated development and development of the country's territories.

The importance of highways cannot be overestimated, because the development of the country's economy depends on their development and length.

The methods and equipment proposed in the article that are most suitable in each specific situation for the construction of high-quality highways from patents and scientific and technical literature are characterized by high technical and economic indicators.

Glossary

Concrete pump: A machine for delivering concrete mix under pressure to the installation site.

Hammers: Impact elements of a hammer grinder mounted on a shaft and rotating to destroy the material.

Wollastonite: A mineral with a needle-like crystal structure used for reinforcement and reduction of shrinkage of concrete mixes.

Geotextile / Geogrid / Geofabric: Synthetic materials used in road construction for reinforcement, filtration and drainage.

Road revetment: A structure consisting of several layers (covering, base, underlayer) that ensures the strength and durability of the road.

Needle rollers: A technique for compacting soils and coatings, equipped with protruding elements in the form of spikes that improve the quality of compaction.

Asphalt concrete recirculation combines: An installation that allows you to remove old asphalt pavement, recycle and re-lay it on site.

Mechanically activated rubber crumb: Crushed rubber subjected to additional mechanical treatment to improve the properties of asphalt concrete.

Oil sludge: Oil industry waste containing hydrocarbons and mineral impurities.

Formwork: A form (temporary or permanent) that holds the concrete mix until it hardens.

Polyfilizers: Modern synthetic binders used to stabilize and harden road foundations (soils).

Telpher: A mechanism for lifting and moving loads, moving along a guide (rails or beam).

Fiber-reinforced concrete: Concrete reinforced with short fibers (fibers) to increase its strength and resistance to cracking.

Shungite: A natural material with a high carbon base, used as an additive in building mixes to improve water and frost resistance, as a binder with hydrophobic properties.

Slit calibrator: Equipment for sorting material into fractions.

Acknowledgements

The article was prepared within the framework of the 1st stage of the research work realized at the expense of the federal budget (source of financing - The Ministry of Science and Higher Education of the Russian Federation) on the topic: « The use of public neural networks for the automated generation of elements of street and road transport infrastructure» (code of the scientific theme FSFM-2025-0004).

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