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IMPROVEMENT OF METHODS FOR REDUCING DEFORMATIONS IN ASPHALT CONCRETE ROAD SURFACES UNDER THE IMPACT OF HEAVY VEHICLES

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Abstract

This article analyzes the causes of permanent deformation, rutting, shear displacement, and cracking in asphalt concrete pavements under repeated and dynamic loads generated by heavy vehicles. It is shown that pavement deformation is affected not only by the magnitude and repetition of traffic loads but also by the composition of asphalt concrete, temperature, moisture, subgrade density, and the load-distribution capacity of pavement layers. To reduce deformation, an integrated method is proposed based on modifying bitumen with the "Kraton D1186" polymer and the "SP-OEP" surface-active structure-forming additive, increasing the strength of pavement layers, and stabilizing the moisture-density condition of the subgrade. This approach improves the resistance of asphalt concrete to shear, high temperatures, water, and cracking, reduces permanent deformation, and extends the service life of the pavement.

Keywords: Asphalt concrete, heavy vehicle, dynamic load, permanent deformation, rutting, shear displacement, pavement, modified bitumen, polymer, surface-active additive.

Annotatsiya

Ushbu maqolada og'ir transport vositalaridan tushadigan takroriy va dinamik yuklar ta'sirida asfaltbeton yo'l qoplamalarida yuzaga keladigan qoldiq deformatsiyalar, g'ildirak izlari, siljishlar hamda yoriqlarning hosil bo'lish sabablari tahlil qilingan. Qoplamaning deformatsiyalanishiga transport yukining miqdori va takrorlanishi bilan birga, asfaltbetonning tarkibi, harorat, namlik, yo'l

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poyining zichligi va to‘shama qatlamlarining yukni taqsimlash xususiyatlari ta’sir qilishi ko‘rsatib berilgan. Deformatsiyalarni kamaytirish maqsadida bitumni “Kraton D1186” polimeri va “SP-OEP” sirt-faol struktura hosil qiluvchi qo‘shimchasi bilan modifikatsiyalash, yo‘l to‘shamasi qatlamlarining mustahkamligini oshirish hamda yo‘l poyining namlik-zichlik holatini barqarorlashtirishga asoslangan kompleks usul taklif etilgan. Ushbu yondashuv asfaltbetonning siljishga, yuqori haroratga, suvga va yorilishga chidamliligini oshirish, qoldiq deformatsiyalarni kamaytirish hamda yo‘l qoplamasining xizmat muddatini uzaytirishga xizmat qiladi.

Kalit so‘zlar: asfaltbeton, og‘ir transport vositasi, dinamik yuk, qoldiq deformatsiya, g‘ildirak izi, siljish, yo‘l qoplamasi, modifikatsiyalangan bitum, polimer, sirt-faol qo‘shimcha.

Аннотация

В статье проанализированы причины образования остаточных деформаций, колеи, сдвигов и трещин в асфальтобетонных дорожных покрытиях под воздействием повторных и динамических нагрузок от тяжёлых транспортных средств. Показано, что на деформирование покрытия наряду с величиной и повторяемостью транспортной нагрузки влияют состав асфальтобетона, температура, влажность, плотность земляного полотна и способность слоёв дорожной одежды распределять нагрузку. Для снижения деформаций предложен комплексный метод, основанный на модифицировании битума полимером «Kraton D1186» и поверхностно-активной структурообразующей добавкой «SP-OEP», повышении прочности слоёв дорожной одежды, а также стабилизации влажностно-плотностного состояния земляного полотна. Предлагаемый подход способствует повышению устойчивости асфальтобетона к сдвигу, высоким температурам, воздействию воды и образованию трещин, снижению остаточных деформаций и увеличению срока службы дорожного покрытия.

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Ключевые слова: асфальтобетон, тяжёлое транспортное средство, динамическая нагрузка, остаточная деформация, колея, сдвиг, дорожное покрытие, модифицированный битум, полимер, поверхностно-активная добавка.

Introduction

The increase in the volume of freight traffic in road transport, the increase in the number of heavy goods vehicles and the increase in the intensity of traffic flow are increasing the requirements for the technical and operational condition of roads. The strength and long-term service life of roads directly depend on the properties of the materials used in the base and subgrade layers, the quality of construction work, transport loads, temperature, humidity and atmospheric conditions [1].

Repetitive dynamic loads from the wheels of heavy vehicles primarily affect the top layer of asphalt concrete pavement. These loads are transmitted through the pavement to the lower layers of the roadbed and the subgrade. When the pavement layers do not have sufficient strength or cannot evenly distribute the load over a large area, residual deformations, wheel marks, displacements, subsidence and cracks appear in the pavement. These defects worsen the smoothness of the pavement, reduce the speed of vehicles and negatively affect road safety.

Deformation of asphalt concrete pavements is not determined only by the amount of traffic load. The softening of the pavement under the influence of temperature, the decrease in the viscosity of bitumen, the weakening of the bond between the mineral materials in the asphalt concrete and the bitumen, and excessive wetting of the pavement and the roadbed accelerate the deformation process. Especially in high temperature conditions, the slow movement of heavy vehicles, frequent braking and acceleration lead to an increase in shear forces in the asphalt concrete layers.

The stability of the road base is one of the important factors determining the resistance of the asphalt concrete pavement to deformation. When the road base is not sufficiently compacted, the soil structure becomes loose when it is wetted by precipitation, groundwater and water vapor. As a result, the road base deforms

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under its own weight and the load from vehicles. This leads to uneven subsidence and cracks in the pavement and subgrade layers [1].

One of the effective ways to improve the resistance of asphalt concrete pavements to shear and residual deformation is to modify bitumen with polymer and surfactant structure-forming additives. Previous studies have shown that the combined use of the polymer "Kraton D1186" and the surfactant "SP-OEP" increases the viscosity of bitumen, heat resistance, adhesion to mineral materials, and shear resistance of asphalt concrete [2–10].

However, modifying the asphalt concrete composition alone is not enough to eliminate all deformations caused by heavy vehicles. In order to ensure the strength of the pavement, it is necessary to comprehensively consider, in addition to the asphalt concrete composition, the thickness and modulus of elasticity of the base layers, the density of the road base, its moisture protection, and the distribution of the transport load across the layers. The purpose of the study is to analyze these factors in a single system and improve a comprehensive method aimed at reducing deformations.

RESEARCH MATERIALS AND METHODS

The object of the study was asphalt concrete pavements, on which heavy vehicles regularly travel. The subject of the study is the residual deformations that occur in asphalt concrete pavements under the influence of repeated static and dynamic loads of vehicles, high temperature, humidity, and roadbed instability, and methods for reducing them.

The study used scientific works on the deformation of asphalt concrete pavements, a textbook on the design of highways, and results on the properties of bitumen modified with polymer and surfactant additives. The data were studied using systematic, comparative, and analytical methods. No new laboratory experiments were claimed; the conclusions were based on a cross-analysis of data from existing sources.

The evaluation criteria were the vehicle axle load, the effect of wheel pressure on the pavement surface, the repetition of loading, the resistance of asphalt concrete to high temperature shear, the modulus of elasticity of the pavement and base layers, the viscosity of bitumen, the adhesive bond in the bitumen-mineral system, the density and moisture content of the road base, and the load distribution ability of the layers.

The layered design principle was used to assess the condition of the roadbed under load. The force from the vehicle wheel is initially absorbed by the asphalt concrete pavement, and then transmitted to the roadbed, reduced by the base and additional base layers. The resistance of the layers to deformation was qualitatively assessed depending on their modulus of elasticity, thickness, and interconnection.

The properties of asphalt concrete based on ordinary road bitumen and asphalt concrete modified with the polymer "Kraton D1186" and the surfactant "SP-OEP" were compared. The viscosity, softening temperature, adhesion to mineral materials, shear, water, frost and cracking resistance were taken into account.

The impact of heavy vehicles on asphalt concrete pavement The impact of heavy vehicles on asphalt concrete pavement is manifested through vertical and horizontal forces transmitted from vehicle wheels. Vertical forces depend on the total weight of the vehicle and the load distribution on the axles, while horizontal forces arise during acceleration, braking and turning of the vehicle. The repeated impact of these forces changes the structural state of the asphalt concrete pavement, creating irreversible deformations over time.

The load from the wheel initially creates a local compressive stress in the upper layer of the pavement. This stress should be distributed over a larger area as it is transmitted downward through the pavement and base layers, and its value should decrease. If the thickness and modulus of elasticity of the asphalt concrete layer are insufficient, the load is transmitted to the lower layers without being fully attenuated. As a result, excessive stress is created in the base of the road, which leads to subsidence of the layers and sagging of the pavement [1].

As the load on the axle of the vehicle increases, the amount of stress and deformation in the pavement also increases. If the deformation of the asphalt concrete pavement is not fully restored after each load, small residual deformations accumulate. As a result, tracks are formed along the direction of movement of the wheels.

Wheel rutting can occur as a result of plastic deformation in the upper layer, compaction of the subgrade layers, or subsidence of the roadbed. In plastic

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deformation of the upper layer, the asphalt concrete moves sideways from under the wheels and bulges appear at the edges of the rut. In deformation of the subgrade and subgrade, vertical subsidence of all layers is observed.

The load resistance of asphalt concrete is directly dependent on temperature. At high temperatures, the viscosity of bitumen decreases, and the plasticity of asphalt concrete increases. Under such conditions, mineral grains move together under the influence of repeated loads from heavy vehicles. Especially in sections where the transport moves slowly, stops or brakes frequently, the duration of the load increases.

The effect of moisture increases the negative impact of heavy traffic loads. Water entering through cracks and pores in the coating weakens the adhesive bond between bitumen and mineral materials. Excessive wetting of the base and subgrade reduces their load-bearing capacity. The porosity of an uncompacted base decreases under repeated loads, leading to uneven settlement and cracking.

Improving methods for reducing deformations Reinforcing only the top layer of the pavement is not enough to reduce deformations caused by heavy vehicles. The pavement, the base layers of the roadbed and the roadbed are a single structural system that together absorb the traffic load. The improved approach combines modifying the asphalt concrete composition, improving the load distribution properties of the layers and ensuring the stability of the roadbed.

To increase the stability of asphalt concrete under the influence of high temperatures and repeated traffic loads, it is important to modify the road bitumen with polymer and surfactant structure-forming additives. The polymer “Kraton D1186” forms an elastic structure in the bitumen composition, increases the viscosity and softening temperature of the binder. As a result, asphalt concrete better maintains its structural stability at high temperatures [3–6].

The surface-active structure-forming additive “SP-OEP” enhances the adhesion of bitumen to the surface of mineral materials. Strengthening the adhesive bond reduces the separation of the bitumen layer under the influence of water. While the polymer increases elasticity and heat resistance, the surface-active additive improves the bitumen-mineral bond; thus, their effects complement each other. To increase the deformation resistance of the coating, the thickness and modulus of elasticity of the roadbed layers should be selected in accordance with the

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transport loads. When the strength of the base layer is increased, the force from the wheel is distributed over a larger surface of the roadbed. This reduces the stress generated in the roadbed and limits the subsidence and bending of the coating. The bond between the coating and the base layers also affects the deformation resistance. If the adhesion is insufficient, the layers can slide against each other during braking and acceleration. Therefore, it is necessary to clean the surface of the layers, evenly spread the binding material, and perform laying and compaction work based on technological requirements. To ensure the stability of the road base, the soil should be compacted at optimal moisture in layers of the specified thickness. Slopes, ditches, and necessary drainage systems should be created to drain surface water. In areas with close groundwater, it is advisable to use layers that limit capillary rise.

The improved complex method consists of the following stages: determining the composition of the traffic flow and the load on the road; selecting asphalt concrete suitable for local temperature and humidity conditions; modifying bitumen with polymers and surfactants; determining the coating and base layers according to the design load; ensuring interlayer bonding and high-quality compaction; protecting the roadbed from moisture; and monitoring wheel marks, cracks, and subsidence during operation.

Results and their discussion

The results of the comparative analysis showed that deformation is a complex process based on the interaction between traffic load, temperature, humidity, asphalt concrete composition, strength of the base layers and stability of the road base. In ordinary bitumen-based asphalt concrete, the softening of the binder at high temperatures creates conditions for the displacement of mineral grains. In sections where heavy traffic moves slowly or brakes frequently, the duration of the action of vertical and shear forces increases.

The improvement of the viscosity and high-temperature stability of bitumen modified with the polymer “Kraton D1186” increases the resistance of asphalt concrete to plastic flow. The additive “SP-OEP” strengthens the adhesive bond between bitumen and mineral materials. The combined use of a polymer and a surfactant additive has been evaluated as a promising approach to increase

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resistance to the combined effects of heavy traffic loads, high temperatures, and humidity [3–10].

However, modifying the top layer cannot eliminate the defects in the lower layers and the roadbed. If the base layers do not have sufficient strength or the roadbed is excessively wetted, the overall settlement of the structure will continue under the influence of traffic loads. Therefore, it is necessary to provide a single system of modified asphalt concrete, a solid base and a stable roadbed.

The qualitative comparative results of the analyzed options are presented in Table 1.

Table 1. Comparative assessment of asphalt concrete options in terms of quality

Evaluation indicator	Ordinary asphalt concrete	Polymer asphalt concrete	Polymer and SFM asphalt concrete
High temperature stability	Relatively low	High	High
Elastic recovery	Low	High	High
Adhesion to mineral materials	Not enough	Improved	High
Water resistance	Relatively low	Improved	High
Slip resistance	Low	High	High
Possibility of residual deformation	High	Decreased	Significantly decreased

The comparative assessment in the table shows that modified asphalt concrete has higher operational stability compared to regular asphalt concrete. This result is not a quantitative laboratory test, but a qualitative generalization of the conclusions from the sources used. In the practical project, the exact amount of additives, mixture composition and technological regime should be determined based on laboratory tests and current standards.

The analysis revealed that the effectiveness of deformation reduction depends on three structural conditions: modified asphalt concrete resistant to high temperatures and shear; a solid base that distributes the design load; and a road

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base with a stable moisture and density state. Failure of one of the elements can reduce the service life of the entire structure.

CONCLUSION AND RECOMMENDATIONS

1. Repetitive vertical and horizontal loads from heavy vehicles cause compression, displacement, and permanent deformation in asphalt concrete pavement; high temperatures accelerate this process.
2. Wheel ruts are formed not only by the plastic flow of the pavement, but also by the compaction of the base layers and the subsidence of the wetted roadbed.
3. The polymer "Kraton D1186" improves the elasticity, viscosity and heat resistance of bitumen, while the additive "SP-OEP" improves the adhesive bond in the bitumen-mineral system.
4. Asphalt concrete modification is not a stand-alone solution; the joint operation of the pavement, base, and subgrade must be ensured.
5. The design load, traffic intensity, and loading frequency on high-speed roads should be taken as initial design data.
6. The thickness and modulus of elasticity of the coating and base layers must be selected in accordance with the design loads, and interlayer adhesion and technological compaction must be controlled.
7. Compacting the road base in layers at optimal moisture levels, draining surface and groundwater, and timely repairing initial cracks will limit the development of deformations.
8. It is advisable to use modified asphalt concrete with increased skid resistance at intersections, stops, climbs, and sections where heavy vehicles frequently brake.

In general, to reduce deformations under the influence of heavy vehicles, it is necessary to form a single integrated system of modified asphalt concrete, strong and effectively distributing base layers, and a high-quality compacted and moisture-protected road base. The proposed approach serves to increase the operational stability of the pavement and extend its service life.

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