DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

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ALTERNATIVE TO SUPERPAVE SYSTEM IN THE FORMATION OF REGIONAL ROAD R&D INSTITUTE

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Statement of the problem. In order to solve complex problems in the field of road construction, the main task in the field of scientific research, which can easily and adequately develop with obtaining real results, is today the formation and development of regional road research institutes or, in extreme cases, research road laboratories.

Results. The advantages and disadvantages of two methodologies on the way to improve the quality and durability of the main structural elements of roads (subgrade and pavement), taking into account many primary and secondary factors, are considered. One of the methodologies is quite well known and provides today the required level of quality of asphalt concrete abroad within the Superpave system. The second methodology is based on a rheological approach to improving the technology of compaction of road-building materials and little is known to road builders.

Conclusions. It has been established that the development of the first methodology of scientific research in our country is very difficult, and the second is quite affordable and feasible on the basis of the formed regional research road organizations. Moreover, the concept of their formation determines the significant advantages of using the second methodology.

Keywords: concept, methodology, road construction materials, quality roads.

Introduction. Research into the accumulated problems in such areas of the road industry as the development of road building materials, technologies for the construction, reconstruction and operation of roads as well as patching, compaction of materials (correct use of sealing means) and quality control of roads currently relies on new scientific approaches. So, the Superpave technology is gaining momentum these days [3, 10, 11] as a whole system of developments that considerably contributed to the development of scientific knowledge in the field of road construction.

In this country, knowledge and expertise in the field of the development of the road network today is largely regulated by the normative documents dating back to the last century or new ones based on them. At the same time, in recent years, they have been replenished as new road-building materials and road-building machines are emerging. Further expansion of scientific research into road construction of the country and its individual regions in order to ensure proper road safety and high quality road construction should be considered within the framework of the interconnected integrated system "Man — machine — working body — object of influence – environment". It should be particularly noted that most associated problems should be solved using the findings of the studies of the rheological properties of road building materials based on the theory of hereditary creep [6, 7, 9, 17— 21]. This is what an innovative approach entails, and Superpave is definitely one.

Structures where different ideas can be quickly tested with the organization of road research laboratories in all regional centers and potentially road research institutes are critically important. Their principles should be based on the use of new, not yet widely employed scientific knowledge including various methodologies, concepts and research methods with the additional availability of specially designed stands, setups and devices.

This principle of the development of research road laboratories or regional road research institutes is the most viable one which reduces the relative degree of uncertainty in scientific and technical potential of the road industry in the regions and contributing to a rapid advancement of transport routes in the region.

In order to address complex problems facing road construction, it is currently crucial to form and develop regional road research institutes and laboratories.

Thus, the development of field research in the road industry of the regions of the country based on road research institutes or road research laboratories employing the most progressive methodological approaches of the road industry is a pressing issue.

The objective of the study is to substantiate the need for the formation of regional road research institutes by means of the most advanced methodological approaches to conducting scientific research contributing to the reduction of a relative degree of uncertainty in scientific and technical potential of the road industry in the regions.

1. Methodology of the rheological approach to improving the compaction technologies for road construction materials. It is well known that the compaction of road construction materials is the major and most important operation in the technological processes of construction and reconstruction of highways. Sealing technologies are central to the bearing capacity which characterizes the strength, stiffness, shear stability and durability of the resulting highway structure.

A variety of tasks is considered here from different methodological standpoints. It should be noted that new approaches to the problems of the road construction industry are constantly sought after and set forth involving the factors that due to objective reasons used to be insufficient or ignored altogether.

Various research institutes, academies and universities, both domestically and abroad, have been and are involved in improving the quality and efficiency of compaction of soil of the subgrade and road asphalt-concrete mixtures.

The first scientist to pay attention to the study of the compaction of asphalt concrete mixture by means of a roller from the standpoint of the theory of hereditary creep was S. N. Ivanchenko [2]. He divided the process of accumulation of reversible and irreversible deformations of the compacted layer in time investigating this process by means of stamp tests of the asphalt concrete mixture using a constant load. A. A. Shestopalov [12] developed the initial principles for the development of irreversible deformations using the rheological approach to the compaction of evacuated asphalt concrete mixtures. It was from that time on in-depth studies of the problem of compaction of road-building materials from rheological positions got underway in this country based on the application of the theory of hereditary creep of elastic-viscous-plastic materials.

Hence we can safely say that the Superpave technology which started being developed only in the 1980—90s with the participation of the Institute of Asphalt and leading US universities based on the positions of nonlinear deformation and the study of the rheological properties of asphalt concrete was developed a lot later. In addition, as will be shown below, the Superpave system is one of the forms of a rheological approach in this country to be capable of assessing the deformation properties from the viewpoint of investigating the complex volumetric stress-strain of road construction materials.

Subsequently, apart from asphalt concrete mixtures, the soils of the subgrade of highways were also examined from a unified methodological standpoint using the suggested rheological approach by means of the theory of hereditary creep of elastic-viscous-plastic materials with nonlinear properties [4, 5, 8, 17, 18, 20, 21].

The developed methodology of the rheological approach to the improvement of compaction technologies for road construction materials allows for the influence of various factors including those that were not previously considered at all, but the efficiency of their compaction can significantly depend on them. These factors are as follows:

— the change of the speed of the acting loads in time and the time of their impact on the compacted material fixed with integral equations of connection with the developed deformations (vertical, longitudinal, transverse and angular ones);

— exponential-power functions of creep and relaxation rates characterizing the rheological features of the compacted material;

— experimental data in the form of regression equations compiled based on the assumptions of the similarity of the creep curves of the compacted material fixing the influence of such parameters of the compaction process as temperature, density and thickness of the compacted layer, vibration parameters and claws of compactors;

— the type of inter-axle differential and the formula of the wheeled vehicle or the type of suspension and the form of pressure distribution on the ground of the tracked vehicle;

— modes of movement of seals (leading, led, etc.).

It should be noted that the known factors affecting the intensity and quality of compaction are also taken into consideration in the suggested methodology. These include: machine weight and contact pressures under the seal; the size and shape of the seal; vibration parameters of dynamic seals; the speed of movement of the sealing means; number of trail passes; condition parameters of the compacted layers of road construction materials (type and moisture content of the soil, thickness and density of the compacted layer, type, grade and temperature of the asphalt concrete mixture, linear and shear deformation modules of the compacted layers); environmental parameters (air temperature, wind speed).

At the same time, the above regression equations characterizing the change in the shear and linear deformation moduli as well as the coefficient of lateral deformation of the compacted layer obtained using laboratory data while modeling the process of loading a layer of road asphalt concrete mixture or soil by means of a flat stamp make it possible to preserve the invariance of methods for identifying the major characteristics of the compacted layer as well as to obtain a universal model, which is the foundation for modeling specific technological processes of compaction of road construction materials. It is using the theory of deformation of nonlinear elastic-viscous-plastic materials by means of the theory of hereditary creep that the formation of the considered methodology of the rheological approach relies on.

The methodological foundations for improving the technologies of compaction of road construction materials must be considered and prioritized in road construction technologies. According to some studies, it was found that depending on the time of interaction of the seal with the material the accuracy in calculating the indicators of the compaction process can be increased by 3 ... 8 times [5, 8].

Given all the above features and factors, the components of stress and strain deviators are calculated for calculating the stress-strain of road construction materials. A critical feature of the

analytical description of the compaction of road construction materials is its diversity. Here, special cases of compaction are described by means of substituting the corresponding values of the model parameters into the solution of the general problem of compaction theory serving as a methodological foundation for a reliable assessment of the indicators of technological processes of compaction of road construction materials.

The above methodology includes mathematical models reflecting the essence and dynamics of processes; methods for identifying indicators for evaluating the compaction process for various operating conditions; recommendations for improving the quality and efficiency of compaction of road construction materials.

Intensification and improvement of the quality of the compaction process within the framework of the above methodology can be achieved by combining two independent directions which can develop independently:

— changing the rheological characteristics of road construction materials (parameters of the creep rate functions and deformation moduli) and increasing their strength properties by means of selecting compositions or using new physical effects in road construction and technologies in the production of road construction materials;

— in specific conditions of work, variation in the parameters of the sealing technological processes, including the operating modes and parameters of the used sealing means provided that the stress-strain of the materials corresponds to their load-bearing capacity. At the same time, the patterns of its change under various seals should be considered based on the use of analytical dependencies, similarity functions, identified under laboratory conditions and the applied efficiency criteria.

This will also lead to the development of competitive technologies for compaction of road construction materials while reducing material, technical, labor and fuel and energy resources.

Therefore the use of the development of the rheology of road construction materials, the analysis of the resulting insights into their changing properties using the suggested efficiency criteria given the intensity of change and the time of action of the sealing loads, identifying and considering the design features of the machines as well as the operating conditions are currently critical in the nearest future by means of selecting the technological parameters of the compaction processes including the technological modes of operation of the seals.

Using the developed mathematical models of the interaction of a rigid drum, pneumatic wheel and caterpillar mover with compacted road construction materials makes it possible to accounts for a lot of the conflicting results of various investigations. So, in particular, it has al-

ready been established that the maximum efficiency of using vibratory rollers for compacting hot asphalt concrete mixtures is in the range of speeds from 0.4 to 0.85 m/sec, which corresponds to an increased value of their mass. This corresponds to the general tendency for their mass to increase. It was also found that their use with constant vibration parameters is possible only at an intermediate stage of compaction in road construction. Besides, it was found that for wheel seals, under certain conditions of work, an increase in the speed of their movement can lead to that in the density of the compacted material accompanied by a decrease in the track depth.

All of the above provisions, which are significant advances in improving the quality and safety of highways, can be successfully developed and applied only locally, in regional research institutes or research road laboratories directly related to local road construction materials, actual road construction machines of functioning road organizations as well as to the actual weather and climatic, economic, geoinformation, geophysical and other conditions of the regions.

2. **Features of using the Superpave system in the regions of the Russian Federation.** The American Superpave system, whose main advantage is the development of an appropriate technology for designing asphalt concrete mixes for road surfaces with increased performance characteristics, has been slow to emerge in this country due to a number of economic, technical and scientific reasons. The positive aspects of Superpave technology have already been noted a lot both in the press and at conferences, symposia and other science events. In this article, the author attempts to identify the main disadvantages which, he argues, cannot allow widespread distribution in the regions of Russia, both in terms of their scientific knowledge and economic characteristics.

First, there is a clear non-invariance of the methods developed in this system for identifying the rheological characteristics of compacted materials. The point is that fundamental characteristics obtained in scientific laboratories, such as the moduli of linear and shear deformation during deformation of the asphalt concrete mix, as well as the coefficient of lateral deformation of the compacted material are identified using standard samples of the resulting asphalt concrete. I.e., this is asphalt concrete formed in the laboratory on presses and stands, as a rule, only by vertical load, and not under the influence of real compactors of road construction machines, when the stressed-deformable state and structure of the compacted road-building material will be different. At the same time, it is not specified at what point in time of the action of loads these characteristics are determined. After all, it is well known, for ex-

ample, that deformation moduli can be instantaneous, current and long-term [4-6] and depend both on the factors of time and loading rate, the parameters of the state of the layer of the compacted material and other factors discussed in the article. Besides, the technology under consideration does not allow for the transition from the obtained results of stamping tests to the actual results of the interaction of road construction material with various compactors operating in a construction site.

Secondly, there is no simultaneous accounting of the time and nature of changes in the acting loads from the deformers (seals). The question of the influence of the speed of movement of compaction machines as the major technological factor is not allowed for in this technology. Here, the nature of the change in the acting loads is seen as considering the parameters of vibration, the rolling mode of the roller drum, mode of force action of the compacted means [1, 4—6], etc. These factors considerably affect the formation of the structure of the compacted material, its density, strength and other indicators that are critical to the performance and durability of asphalt concrete.

Thirdly, simplified dependencies and regularities are selected that define the rheological features of compacted material which are not sufficiently accurate. It employs simplified rheological models that roughly describe the compaction behavior of the material.

Fourth, linear and plane models of material compaction are considered, volumetric models are not taken into consideration. So, e.g., when a pneumatic roller operates in the vertical, longitudinal and transverse directions, various force effects are manifested where the corresponding stress-strain of the material and the corresponding structure of the material are formed.

Fifth, the preparation of laboratory samples in a rotary (gyroscopic) compaction device also does not correspond to the actual conditions of structure formation, changes in the volume and density of asphalt concrete. Rotation speed and rotation angle are not quantitatively substantiated.

Sixth, the Superpave computer software system, which includes algorithms for predicting longevity indicators, is still far from being complete and has not been experimentally confirmed yet, and thus is need of further improvement.

Seventh, the separation of stone material into 12 fractions in the design of durable asphalt concrete requires a serious restructuring of the operating equipment of asphalt and cement concrete plants, including crushing and screening equipment, warehouses for storing fractions, transport and mixing systems, etc. From an economic standpoint, for the regions of Russia, this is a daunting task for the coming years, if not decades.

Eighth, the implementation of the technology requires complex and expensive laboratory equipment, which is costly to maintain, as well as highly qualified operators. The mass of experimental samples of asphalt concrete is from 7 to 20 kg, which is unacceptable for the work of female operators from the point of view of labor safety.

Thus, the analysis of the obvious shortcomings of the complex Superpave system showed the need for further study and elimination. However, within the framework of the applied methodology in order to ensure the quality and durability of asphalt concrete pavements, Superpave technology is not quite effective in multiple respects.

3. The concept of forming regional road research institutes. Analyzing the two methodologies considered in this article, aimed at ensuring the quality and durability of the subgrade and road surfaces, it can be argued that they have a lot in common, but there are also major differences in the developed approaches.

Due to undeniable difficulties, first of all including those pertaining to complex and expensive laboratory equipment, as well as the restructuring of the operating equipment of asphalt and cement concrete plants, including crushing and screening equipment, the development of Superpave technology in the regions currently seems challenging and almost impossible. The development of regional road research institutes or, for the first time, research road laboratories employing the methodology of the rheological approach to improving the technologies of compaction of road construction materials appears to be manageable. At the same time, the following advantages of the methodology are the following.

Firstly, for any composition of the asphalt concrete mixture during the construction of road surfaces, for any type of soil during the construction of the subgrade, the methodology allows one to ensure the achievement of the required density and the formation of an optimal structure in conditions of compaction of road construction materials, ensuring the selection of the required compaction means, their parameters and modes operate.

Secondly, in the study of rheological, strength and structural characteristics used in the construction or renovation of roads of local materials and soils, expensive equipment is not required. Regional road research institutes or road research laboratories can manufacture such equipment independently, e.g., similar or modified to the known and approved equipment [13–16] which can be portable and provide the necessary measurements in actual conditions of road construction.

Thirdly, there is no need to rebuild the operating equipment of asphalt and cement concrete plants, including crushing and screening equipment.

Fourthly, both the principle of quantitative assessment of compaction processes based on the actual operating conditions of the used compaction equipment with specific parameters and operating modes, and the principle of joint consideration of the time factor, the characteristics of local compacted materials and an adequate response to the nature of the existing loads from the compactors.

Fifth, the suggested methodology for assessing the deformation characteristics of road-building materials makes it possible to investigate their rheological characteristics through individual elements of interaction with various compactors when the physical essence of these interactions is based on general laws of physics and solved by means of modern applied mechanics. It was found that in the physical modeling of the process of loading a layer of road construction material by means of a flat stamp, there is an analytical possibility of transition to the description of the process of its deformation in the interaction with various compaction equipment. This being the case, it becomes possible to identify the coefficient of transverse deformation through the functions of volumetric and shear creep during deformation of the compacted layer by means of a stamp using the studies of the functions of rates of longitudinal and transverse creep, and the calculated values of the parameters of the material of the compacted layer are invariant how they are identified.

The suggested concept improves the quality and durability of highways while saving material, financial and other resources:

— the resources saved by the optimal change in the stress-strain of the compacted layer of material (structure of the compacted layer, energy consumption and material consumption of the compaction means used during operation, optimal deformations and density, etc.);

— resources saved due to the integration of management, production and organizational processes (selection of the most rational sets of machines and their distribution among work objects while specifying the parameters of compactors and technological modes of operation of machines;

— resources for maintaining and repairing compacting equipment while choosing the optimal operating modes that reduce the intensity of various loads during machine operation;

— resources by saving fuel consumption (e.g., according to the criteria of the minimum number of passes), improving the quality and productivity (e.g., the quality of compaction of road construction materials, improving their structural performance, strength, load-bearing capacity and durability).

Conclusions. A concept has been developed for the formation of regional research institutes or research road laboratories using a new methodological approach in the field of road construction for investigating technological processes of compaction of road construction materials.

This approach has been transformed into the methodology of a rheological approach to improving compaction technologies for road construction materials when a comprehensive solution to the problems of compaction theory is implemented relying on the development of their rheology and an analytical description of the processes of interaction of road construction materials with various compactors.

The efficiency of the concept is due to the fact that it entails a deeper insight into the physical essence of compaction processes, contributes to its better understanding and allows the ways of influencing the processes to be identified in order to improve the quality and efficiency of compaction of road construction materials by improving compaction technologies.

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