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INTEGRATED MODELING AND FORECASTING OF THE STABILITY AND STRENGTH OF THE CONSTRUCTION OF THE MOTOR ROAD USING MODERN TECHNOLOGIES

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Abstract: The distinctive paper discusses the possibility of obtaining methods of the highest quality and correct calculations for assessing the transport and operational status of a particular road using corresponding mathematical model.

Keywords: mathematical modeling, highways, CAD, modern technologies for the diagnosis of highways

КОМПЛЕКСНОЕ МОДЕЛИРОВАНИЕ И ПРОГНОЗИРОВАНИЕ УСТОЙЧИВОСТИ И ПРОЧНОСТИ КОНСТРУКЦИИ АВТОМОБИЛЬНОЙ ДОРОГИ С ИСПОЛЬЗОВАНИЕМ СОВРЕМЕННЫХ ТЕХНОЛОГИЙ

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Аннотация: В статье рассматривается возможность получения методики наиболее качественных и корректных расчётов, для оценки транспортно-эксплуатационного состояния участка автомобильной дороги с помощью математической модели.

Ключевые слова: математическое моделирование, автомобильные дороги, САПР, современные технологии диагностики автомобильных дорог

INTRODUCTION

The road is a set of structural elements intended for movement with established speeds, loads and dimensions of cars and other land vehicles transporting passengers and (or) cargo, as well as land plots provided for their placement [1].

In order to determine as accurately as possible the stability of the road bed and the strength of the pavement, a complex of calculations is necessary, the outcome of which determines the characteristics and design parameters affecting all the structural elements of the road. The reliability parameters of the pavement determine the security of its working condition during the established service life, which is the basis for determining the period between repairs.

In Russia, the period between repairs was developed by the «Soyuzdornii» in the period 1950-1955. and approved by the Resolution of the Council of Ministers of the RSFSR 7.03.61 No. 210 as standards for capital and medium repair, respectively, of road pavements and coatings. These standards were valid until 1988, regardless of the estimated service life taken in the design of road pavements (Instructions DBC 46-60, DBC 46-72, DBC 46-83). According to these standards, the estimated service lives were approximately 20% less, which could be one of the reasons for poor quality repairs of roads. In 1988, regional and sectoral norms for the period between repairs of non-rigid pavements and coatings, developed by «GiproDornii» with the

participation of research, design and other organizations, were put into effect [2].

Capital and lightweight pavement with an improved coating is designed so that over the period between repairs there are no damage and inadmissible, in terms of the violations of the requirements for flatness of coverage, residual deformations provided by the existing regulatory documents, and that the impact of natural factors does not lead to unacceptable changes in its elements [3].

In all cases, solutions of the theory of elasticity are used to estimate the stress state of a structure [3].

The assessment of the overall stability of the roadbed and slopes is to compare the calculated values of the indicators of sustainability with their normative values. For the standard indicator of overall sustainability should be taken as a generalized sustainability factor, determined taking into account the following factors, taking into account [11]:

- reliability of data on the strength and deformative characteristics of the soils of the considered array;
- road category;
- degree of responsibility of the projected object;
- compliance of the design scheme with natural engineering and geological conditions;
- type of soil and its purpose;
- features of the calculation method.

The roadbed is subject to dynamic and static loads from the rolling stock; own weight of the canvas and the complex of natural factors (climatic, hydrological, hydrogeological).

1. EXPERIMENTAL PART

The purpose of the study is to determine the transport and operational (taking into account the climatic characteristics) and the strength parameters of the road to create a mathematical model that reflects the current state of the structure.

The task of the study is to build a mathematical model for the construction of a highway, its automation, for the operational determination of

the transport performance indicators of this road and period between repairs.

The research technique is a complex of models, including calculations of dynamic and static loads from rolling stock, soil mechanics and a complex of natural factors.

The object of study: public road.

The subject of study: transport and operational, strength and climatic parameters of the road.

The graphical user interface of the control program of such a mathematical model will include two working windows: Input and Output.

In the input window (Figure 1) it is required to enter the road data, most of which are determined at the design stage. These data include the prospective traffic intensity, which sets the five-year and ten-year forecasts.

Input window

Parameters of the highway

Perspective movement intensity (car/day):

Freight traffic:

Light (up to 2 tons): 11

Medium (from 2.1 to 6 tons): 12

Heavy (from 6.1 to 8 tons): 12

Single (more than 8 tons): 47

Road trains: 40

Passenger traffic:

Cars: 354

Buses (minibuses): 8

Total units shown: 773

Soils of the roadbed:

Pebble soil with loamy solids up to 30%

Light loam dusty semi-hard

Standard Static Axle Load, kN: 115

Regulatory static load on the surface of the coating from the wheel of the calculated car, Q calc, kN: 57.5

Climatic characteristics:

Road-climatic zone: 1

Type of terrain for humidification conditions: 2

Type of terrain for moistening: 1

Calculate

Figure 1. Input window for known road parameters.

Figure 1 presents:

1. Average annual daily perspective traffic intensity, reduced to a passenger car.

The methods used to account for the intensity of traffic flow on roads are intended to obtain and accumulate information on the total number of vehicles and the composition of traffic flow, passing per unit time through the cross section of the road in each of the permitted directions of movement.

Accounting for the intensity of movement is carried out in two ways: automatically or visually. According to the duration, the accounting for the intensity of movement is divided into long-term and short-term [4].

2. Subgrade soil. The most commonly used local soils occurring in the upper layers of the earth's surface. In laboratory conditions, check the suitability of certain soils for use in the device of the roadbed.

The soils by nature of structural bonds are divided into the following classes: rock, dispersed and frozen.

The class of rocky soils includes soils with rigid structural bonds (crystallization and cementation) [5]. Such soils are preferred for the construction of roads (provide maximum strength and stability).

The class of dispersed soils are soils with physical, physicochemical, or mechanical structural bonds.

Soils with mechanical structural bonds are distinguished into a subclass of loose (loose) soils, and soils with physical and physico-chemical structural bonds into a subclass of cohesive soils. For road construction, weak soils are distinguished from a cohesive subclass of soils — soils with low mechanical properties: shear strength under natural conditions is less than 0.075 MPa (rotary cut) and / or the slump modulus is more than 50 mm / m with a load of 0.25 MPa (deformation modulus below 5.0 MPa) [5].

The class of frozen soils includes soils that possess, along with structural bonds of non-frozen soils, cryogenic bonds (due to ice).

3. Regulatory loads. The regulatory load from motor vehicles on public roads is shown in Figure 2.

In Figure 2 depicted:

d – base for AK load, m;

c – is the load gauge width, m;

q – uniformly distributed load along the track along the road (structure), kN / m;

D – the base for the load NK, m

The regulatory AK load (Figure 2a) includes one biaxial bogie with an axle load of 10 K (kN) and evenly distributed along the road.

Regulatory load NK (Figure 2b) is presented in the form of a single four-axle truck with a load on each axis of 18 K (kN) [6].

Calculated loading schemes are divided into:

- loading schemes when calculating pavements;
- loading schemes for the calculation of the subgrade;
- loading schemes for the calculation of the structures of bridge structures.

When calculating the stability of the embankment slopes (1), the load from the vehicles is reduced to the equivalent soil layer of the subgrade. The thickness of the equivalent layer of soil N_e , m, is calculated by the formula:

$$N_e = \frac{18K}{(d + 0,2)(c + 0,8)\gamma_{sp}} \quad (1)$$

where 18K is the regulatory burden of NC, kN;

d – base of normative load of NC, m;

c – gauge of the standard load of NC, m;

γ_s – specific gravity of the soil, kN / m³.

When calculating embankment settlement (2), the regulatory load is assumed to be in the form of a standard load that is in a static position (Figure 2a). A uniformly distributed load along the road, imitating the movement of a column of vehicles, is not taken into account in this calculation [6].

The load from vehicles is reduced to an equivalent layer of subgrade soil. The thickness of the equivalent layer of soil h_e , m, is calculated by the formula:

Figure 2. Scheme of the regulatory load for the calculation of pavement, roadbed, retaining walls and bridge structures: a) car wheel load AK; b) heavy single car load NK.

$$h_e = \frac{n}{B_{rb}\gamma_s} \left(\frac{10K}{d + 0,2} \right) \quad (2)$$

where n is the number of lanes;

B_{rb} – width of the road bed, m;

γ_s – specific gravity of the soil, kN / m³;

10K – AK regulatory load for the calculation of embankment sediments, kN;

d – base of regulatory load AK, m.

4. Climatic, hydrological, hydrogeological conditions of the area.

The terrain, climatic, hydrological and hydrogeological conditions have a significant impact on

the construction and operation of roads. These conditions directly affect the main types of deformations of the road structure, the main cause of which is the increase and over moistening of the subgrade soil, i.e. violation of its water-thermal regime (over-wetting of the embankment soils can cause a process of “heaving” (lifting) of the soil, erosion and scouring of the base or the embankments themselves).

The climatic characteristics of the road are determined based on the climatic conditions of the area in which the work will be performed. Our country, as well as the post-Soviet space, is

subdivided in road construction into road-climatic zones (RCZ) [1]. Most of the parameters (in particular, temperature indicators, calculation of the timing of the thaw) are known or can be determined from building climatology (SP 131.13330.2012).

The saturation of the subgrade with moisture is an extremely dangerous phenomenon, in which the strength of the pavement, the stability of the subgrade and the base of the embankments significantly decrease [7].

Sources of moistening of the roadbed are:

- precipitations;
- water inflow from melting snow;
- capillary rise from the groundwater level;
- condensation of water vapor from the air;
- movement of film water.

All of the above parameters maximally affect the quality of both the transport and operational indicators of the road and the road itself as a whole. For a more accurate determination of all key parameters of a highway, it is necessary to track their interdependence as much as possible and to obtain an objective assessment of their condition at the level of accuracy that is now offered by modern diagnostic and examination technologies. This approach will eliminate the development of the situation that exists today, when a lot of calculations are made to assess the transport and operational state, which do not allow to evaluate the current state of the structure, but only in general reflect its suitability for further operation. Considered promising is building, for example, RIM (Road Information Modeling) model [12], which would reflect not only the state of operation, but also the early stages of the road life cycle, which would allow it to be built as quickly and correctly as possible. without departing from the standards, automated to adjust projects and track the entire financial side. Therefore, the construction of a mathematical model that could take into account almost all (affecting the performance) parameters of the road, will be very relevant to the idea of what will happen at the next stage of the life cycle of this design. Based on this model, we can assess the current state and take steps in ad-

vance to eliminate construction defects and extend the life of the road.

Such a model (Figure 3) will not only display the existing (actual) situation, but also recommend ways to eliminate various defects that prevent further road operation. This will allow taking measures (according to the current regulatory documents and methodological recommendations), based on the current situation. Further, this model is rebuilt taking into account the already applied recommendations for continuing to conduct assessment of the state of this object.

Figure 3 presents:

1. The entered parameters of the road, which directly affect the construction of a complex of mathematical models of the road. To maximize the assessment of the transport and operational condition of the road, many more other parameters are required, including the geometrical parameters (in Figure 3, are not presented, but conditionally available), affecting:

- width of the carriageway, the main fortified surface of the road and fortifications;
- width of roadsides, incl. fortified; the type and condition of the curb reinforcement;
- longitudinal slopes;
- transverse slopes of the roadway and shoulders;
- the radii of the curves in the plan and the slope of the turn;
- the height of the embankment, the depth of excavation and the slopes of their slopes; condition of the roadbed;

distance of visibility of the road surface in the plan and profile.

2. Time scale. The main function of the technique based on complex mathematical modeling will be the ability to predict the state of the road after some time it is in operational mode. By moving the timeline slider, you can monitor the transport and operational condition of the road a dozen years ahead. When 20% of the selected section of the road does not meet the regulatory requirements, it will become impossible to switch the time scale and the program will offer recommendations on how to increase the period between repairs.

Figure 3. Window for displaying the state of the road with the display of problem areas.

For example, if the thickness of the coating layer became unsatisfactory, options would be offered (at the expense of the maintenance of the selected road section) for surface treatment, patching, and other works to restore the worn out coating layer, and if sources of wetting of the roadbed and / or road pavement, then the optimal longitudinal and transverse slopes of the roadway, the steepness the slopes of the roadbed and the longitudinal slopes of the cuvettes (control of their contamination).

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3. Straightened plan of the road section. This plan will be the result of calculations of a complex of mathematical models, which will display (visually) all problem areas that do not meet regulatory requirements (highlighted in red). Areas that were restored by the recommendations proposed by this program are highlighted in blue. If the total volume of the restored and unsatisfactory road sections becomes more than 80%, repair will be assigned by the program (time interval, from the beginning of the calculation to its end, and will be the lifetime of the road section).

Building a plan on which geometric parameters are displayed (widths, elevations, longitudinal and transverse slopes, curve radii) is possible in such domestic CAD systems as:

- CAD CREDO;
- CAD AD Robur;
- CAD AD IndorCAD / Road.

In recent years, in connection with the rapid development of geographic information systems

(GIS), the question of their applicability, along with CAD, in computer-aided design of highways is being considered.

With significant external similarities GIS and CAD have fundamental differences.

One of the fundamental differences between GIS and CAD is that a graphic primitive in a GIS is an independent object with its own attributes, and in CAD it is only a graphic tool, i.e. part of the object, and therefore its attributes, as a rule, does not have.

In CAD, objects are usually formed from several graphic primitives, lining up in a hierarchy using grouping. The profound difference between the CAD model and the relational data model does not allow the full preservation of CAD drawings in modern databases and does not allow analyzing the attributes of objects.

In the road industry, the presence of attribute support is the most important in solving problems of diagnostics, certification, inventory, road cadastre. In connection with the scarcity of the capabilities of the attribute description of CAD, it seems most appropriate to create information systems for highways based on GIS [8].

When calculating the pavement design, the most popular (in Russia) is the module of the Topomatic Robur software complex - the Robur Topomatic - Road apparel, where the initial values, in addition to the previously mentioned design, are also such material characteristics as: Elastic moduli (MPa) - on elastic deflection, shear, stretching when bending; Volumetric weight (kg / cubic meter); Characteristics for the calculation of shear - the angle of internal friction, adhesion (MPa) (also, the same characteristics in statics); Characteristics for the calculation of tensile bending and Characteristics of geosynthetics for the reinforcement of the coating (additional parameter). In the CREDO and IndorCAD / Road software packages, there are also software modules for the calculation of pavements that are not inferior to "Robur Topomatic - Road pant" for most of the key points.

4. Button recommendations to help increase the period between repairs of the road. According to the results of calculations for a certain period of

operation, red zones will be allocated - sections of the road that do not meet regulatory requirements. After the appearance of these zones, it will be possible to get recommendations on the elimination of such problem areas.

At the moment, it is not possible to predict as accurately as possible the transport and operational indicators of the road for the years ahead due to the absence of a clear model of the behavior of all the structural elements of such a structure. Today, to assess the quality and condition of highways, inspection and diagnostics are carried out using road laboratories and other engineering equipment. Such checks produce:

- when putting the road into operation after construction in order to determine the initial actual transport and operational condition and comparison with regulatory requirements;
- periodically in the process of operation to monitor the dynamics of changes in the state of the road, to predict this change and to plan repairs and maintenance;
- when developing an action plan or a project for reconstruction, major repair or repair to determine the expected transport and operational status, compare it with regulatory requirements and evaluate the effectiveness of the planned work;
- after the execution of works on the reconstruction, overhaul and repair in the areas where these works are carried out in order to determine the actual change in the transport and operational condition of the roads.

According to the results of diagnostics and assessment of the condition of the roads during operation, they identify sections of roads that do not meet the regulatory requirements for their transport and operational condition and, guided by the "Classification of Works for the Repair and Maintenance of Public Roads", determine the types and composition of the main works and maintenance measures, repair and reconstruction in order to increase their transport and operational status to the required level [9].

In order to accurately assess the situation that occurs over a period of several years and not rely

on additional measures for the seasonal and annual survey and diagnostics, it is necessary to assess the existing situation as thoroughly and objectively as possible, highlighting all key parameters at the post-construction stage, when all executive documents and acts accompanying the commissioning of the object, as well as to conduct a large-scale survey (but only once during the period between repairs). In this case, there is a theoretical possibility to study the erected structure in order to predict its state in the future (implementation in order to predict its state).

One example of obtaining a detailed and objective assessment of the current situation is the technology of the American company Bentley Systems.

To automate the process of managing engineering data, the American company Bentley Systems has created the Bentley ProjectWise platform. After geodetic surveys, the customer uses ProjectWise to get a cloud of laser scanning points for a part of the route.

Streaming uploading did not allow downloading the entire file, which may require a significant amount of electronic memory of significant computational resources, but only the necessary points in a certain area. As you move along the information model, additional points are loaded.

A single engineering data management platform accommodates an infinite number of attribute information about a road object. The evenness of the coating, rutting, cracks, pits, the coefficient of adhesion, the modulus of elasticity of the layers of asphalt concrete and so on - all this information is collected in a convenient form in one place and is automatically updated. That is, all the project participants have a clear picture of the current state of the object, and the data can be used again and again at all stages of its life cycle [10].

5. The rest, calculated by a complex of mathematical models, parameters.

2. MAIN CONCLUSIONS

The article presents a review material, which provides a justification of the relevance of the goal of scientific research by the authors, which is to develop a unified mathematical model reflecting the full state of the linear road object, taking into account the strength and stability of its structural elements, as well as the interaction with the soil foundation.

Figure 4. The result of laser scanning with subsequent analysis of the road pavement.

Figure 5. Drawing a digital terrain model from the resulting point cloud using Project Wise.

Figure 6. Working with the information model in Bentley Project Wise.

For the practical implementation of this model, it is supposed to create on its basis an automated technology that allows you to manage the prepa-

ration of production, road-building equipment (for example, C-V2X, Trimble GCS technologies), time and resources, to produce high-

quality building control, and also to do an executive survey in the framework of the project under consideration.

Thus, using the proposed model, it will be possible to assess the transport and operational status, taking into account all the characteristic causes that affect the destruction of the road. In the promising future, such models will be an integral part of the automation of a global project for the production of roads (design, construction and operation). The implementation of such model is a solvable problem at the present time; however, it requires the study and consideration of a large number of factors.

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