Remote monitoring of road structures’ condition as a way to increase the durability of motorway

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Abstract. The calculations of road structures’ elements and the evaluation of reliability of data related to them are necessary for conducting justified and timely repair work, for forecasting the service life of road pavements, as well as for increasing the durability of motorway. Modernization of monitoring system, improvement of instrumental base structures, implementation of innovative methods in road construction allow carrying out more detailed research of road structures’ temperature and humidity conditions, analyzing their deformation stability under real-life conditions, and as a result, increasing measurement accuracy and reliability. Scanning devices used in the process of remote monitoring are characterized by tightness, high reliability and maintainability, their data is automatically read and transmitted to the server [1]. The input data obtained as a result of monitoring road structures’ condition are used to assess the impact of destructive factors of all elements of the system - the motor road, they are used to justify the application and selection of innovative materials and technologies. The obtained information allows imagining the processes that take place inside road structures and analyzing the peculiarities of external and internal factors’ impact on the service life and durability of the road.

1. Introduction
The impacts that make it possible to evaluate the stability of road structure to the accumulation of residual and reversible deformations, as well as the estimate of irreversible displacements in cohesionless materials, are conventionally divided into three types: real dynamic load from moving vehicles; fixed load; tared shock loading. The wide capabilities of measuring sensors used in monitoring process and special software allow assessing deformations from any type of impact on road structures.

The methods of obtaining information in process of remote monitoring are characterized by long-term (for example, accumulation of residual deformations and stresses), accelerated (for example, monitoring carried out at special test sites or stands) and short-term (for example, evaluating the deflection of road structures) observations. As a rule, such devices as georadars (see figure 1) and shock loading units [2] are used in the process of diagnostics, inspection and monitoring of motorway.

2. Theory
No less important from practical view point is the study of the temperature regime of road structures’ operation, the purpose of which may be identifying the absolute minimum and maximum temperature values for the operation of road structures; the daily range (temperature scatter) for the operation of materials in structural layers; identifying the periods of limited traffic load due to the high temperature...
of coating layer and the swampness of roadbed; evaluating the temperature drops - for example, in the coating (they have a direct impact on thermal cracking); estimating the impact of road structure elements’ geometric parameters (different roadfill heights or excavation depths); checking the correspondence of design models to real-life conditions of road operation; identifying the duration (periods) of structures’ operation under extreme conditions (maximum and minimum temperatures) and the duration of operation of roadbed under high humidity conditions; determining the number of drops of the road structure’s operation temperature above and below zero degrees Celsius (see figure 2).

Figure 1. Determining the thickness of road pavement’s structural layers, using a 3D georadar system.

Figure 2. Checking the adequacy of design models and the roadbed:
1 - ambient temperature, 2 - calculated values in coating layer,
3 - temperature obtained by instruments used in monitoring process,
4 - temperature obtained according to formulas

The analysis of instruments applied in this sphere has shown that in many countries such units as «The Multi-Depth Deflectometer (MDD), Multistage Sensor (MS)» [3] are widely used. In process of
this research the advantages and disadvantages of these devices have been evaluated, and they are described in the table 1.

| Advantages                        | Disadvantages                                      |
|-----------------------------------|---------------------------------------------------|
| - presence of a corrugated tube,  | - lack of temperature and humidity sensors;       |
| which prevents moisture ingress   |                                                  |
| and partial collapse of the drilled hole; |                                                  |
| - the unit can be assembled prior to visiting the research and monitoring site; | - violation of the continuity of layers when mounting the devices; |
| - it has got rigid fixing;        | - displacement of the top layer, directly at the top point of the road structure, is not taken into account; |
| - the data can be read at the monitoring site | - unreliable fastening of modules in cohesionless layers; |
|                                   | - employees have to come to the site to read data, as a result, the working cost is high. |

But, despite the listed disadvantages, the devices used in the research served as the basis for implementing an innovative system for remote monitoring of road structures’ condition.

The instrumental base is used to obtain adequate input data, which can be further applied in the monitoring calculation base, and can be used to make recommendations on the service life of the motor road under study. Monitoring data are needed to make comparisons with development goals and criteria, and to assess the effectiveness and efficiency of measures taken.

3. Experiment

Wide use of innovative technologies is currently restrained by lack of data on the impact of these technologies on the operational condition of motorway [4]. Such data are necessary for an appropriate feasibility study of the effectiveness of new technologies’ use. It is extremely important to develop comprehensive implementation programs that will allow monitoring the technologies at every stage, starting with trial design and construction.

Reliability should be taken as the criterion for assessing the technical condition of motorway. This criterion has a number of advantages; it is recommended for use in the monitoring calculation base. It is associated with time, can be used for any property of the object (strength, deformability, etc.), can be described mathematically, and can be used as the basis for forecasting the options of the condition of motorway, which is really vital for monitoring process.

Statistical characteristics of the parameters of motorway were used as input data in this research. The algorithms for calculating the statistical characteristics of the parameters were reduced to using linearization methods, enumeration with account of Monte Carlo technique. In the research the authors have determined the probability of destruction and the reliability of trouble-free operation of the pavement: during the period when the road was put into operation; after the expiration of the 1st and 15th years of operation of the structure.

RMS deviation of the required elastic modulus for dependence value was calculated using Formula 1

$$\sigma_{np} = \bar{N}_{np} \cdot E_{np}$$  \hspace{1cm} (1)

The minimal value of elastic modulus, at which, after opening the road for traffic, the road’s destruction will reach 50%, was calculated using Formula 2

$$E_{min} = \sqrt{\frac{E_{np}^2 + (25 \cdot C_i^2 - 1) \cdot (E_{np}^2 - 25 \cdot \sigma_{np}^2) - E_{np}}{25 \cdot C_i^2 - 1}}$$  \hspace{1cm} (2)

The parameter $\sigma_n$ was calculated using Formula 3
\[
\sigma_m = C_V \cdot E_m
\]  
(3)

The reliability value of road pavement at the moment of putting the road into operation was found using Formula 4

\[
Z = \frac{E_{mp} - E_m}{\sqrt{\sigma^2_{mp} + \sigma^2_m}}
\]  
(4)

Using the known tables, depending on the parameter \( Z \), \( W \) (reliability value) was determined.

The probability of road pavement destruction in the beginning of the first year of operation was determined using Formula 5

\[
P = 1 - W
\]  
(5)

- \( E_{mp} \) - required modulus of elasticity
- \( C_V \) - coefficient of variation of the total elastic modulus
- \( \bar{N}_{mp} \) - parameter of traffic intensity and composition

The probability of destruction and reliability after the expiration of the first year of operation of the road, and after 15 years of operation of the pavement expire, were determined in a similar way.

In the course of the research it has been found out that during the first months of road operation about 14 m² out of every 10 000 m² of the road structure will be destroyed (subsidence cracks, etc.) By the end of the first year of operation of the pavement, there will be about 4.1 m² of destruction per 1000 m² of coating. By the end of 15 years of operation, 18 m² of every 100 m² of coating will be destroyed.

Also, within the framework of this research, the reliability of road capacity was assessed. In this research the investigated and calculated parameters depended on road condition and type of traffic. The ensured vehicle speed was determined by permissible risk value, which is an objective characteristic used to calculate the speed of traffic flow, taking into account traffic safety.

### 4. Results and discussion

As a result of the research, the areas for applying the monitoring of road structures’ condition have been determined, according to instrumental base data and calculations:
- maximum and minimum temperatures for selecting binder type;
- daily range of materials operation in structural layers for identifying possible co-use in adjacent layers of materials with different deformative properties from temperature effects;
- identifying periods and justified scheduling of measures to restrict traffic of vehicles with high axle load in hot summer time and in spring-autumn time when the roadbed (working layer) is swamp;
- identifying the areas where, due to this or that reason, asphalt-concrete layers of the coating have got different temperatures, which may lead to the formation of thermal cracks;
- identifying the sections of motorway (high road fill) that need additional thermal insulation layers;
- identifying the sections of motorway where additional measures are required to ensure drainage;
- checking the adequacy of the design models for forecasting temperature regimes of asphalt-concrete layers of the coating and humidity of the roadbed;
- identifying fatigue manifestations in the process of material aging caused by road operation under extreme conditions (extremely low and high temperatures, swampness of roadbed, etc.);
- determining the number of drops of the road structure layers’ operation temperature above and below zero degrees Celsius, in order to forecast the frost resistance of the road pavement’s structural layers.

In general, the use of data obtained as a result of monitoring opens up wide opportunities for improving the quality indicators of motorway. The wider the scope of such research, the more data will come from objects under study, the more objective picture of the operation of road structures under different climatic, geological and hydrogeological conditions can be obtained by different specialists in the field of road construction and design.
5. Conclusion

Except the purely practical benefits described above, monitoring will allow the accumulation of data for future adjustment of design models and methods for road structures’ design, taking into account the variety of factors that have got an impact on motorway under their real-life operation conditions.

The information obtained as a result of monitoring, related to the rate of accumulating residual deformations in separate layers and to temperature-humidity regime, can serve as input data for the development and implementation of a new additional criterion describing the requirement for maximum permissible residual deformations of layers of road structures.

Data analysis has made it possible and will make it possible in future to understand the peculiar features of the impact of external and internal factors on the service life and durability of both the road section under study and of other motorway.

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