On the software package for predicting residual deformations in the pavement design

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Abstract. The paper describes in greater detail the software package, simulating the residual deformations long-term accumulation process in the road structure under the moving transport load action. The complex is based on a refined model for calculating and designing non-rigid pavements. The residual deformations accumulation problem in the road construction elements and the prominences development is considered in spatial formulation and the full motion system of equations is used. This allows to determine not only the road structures elements points final displacements magnitude in a state of equilibrium, but also to investigate the irreversible movements accumulation evolution in time.

Introduction
The current method for calculating engineering pavements in industry road codes (IRC) 218.046-01 currently in force in the Russian Federation and the CIS countries does not sufficiently take into account the elastic-viscous-plastic properties of the subgrade soil and the pavement structural layers materials. According to the norms, the calculations do not use the spatial formulation of the problem, but its particular case — an axisymmetric model of an elastic half-space. This formulation does not allow to take into account the inertia and a number of axes of a moving car, the impact on the stress-strain state (SSS) of the road final transverse dimensions, the position of the load on the carriageway. The elasticity permissible modulus calculation (determining the number and thickness of the pavement layers) is carried out on a static load, rather than on a real, dynamic load. It also does not take into account the cars movement speed.

This paper uses the following basic design assumptions:
- The problem is considered in spatial formulation;
- The mobile vehicles impact is considered in a dynamic formulation, which, in addition to all, must take into account the movement speed of vehicles and their inertial properties;
- One-time transport effects, as a rule, do not lead to the irreversible deformations’ formation, i.e. the dynamic problem is considered in a quasi-elastic formulation [1, 2, 4];
- Irreversible deformations occur due to the repeated exposure to rolling stock. Accounting for the time factor influence on the appearance and development of irreversible deformations is carried out within the specific materials’ deterministic phenomenological properties framework, that is, the vehicles long-term effect problem is considered in the flow technical hereditary theory framework;
- The pavement layers material model and the subgrade soil should take into account the temperature and humidity factors influence, the computational domain individual fragments oscillation frequency influence and the material aging effect. The change in temperature and humidity in this
work is considered to be a deterministic function of space-time coordinates. The oscillation frequencies from the single vehicles’ effects are determined by dynamic calculations (for each group of cars) in the viscoelastic formulation and by the time of using the hereditary plasticity hypotheses are also deterministic. In this connection, taking into account the temperature, humidity and vibration frequencies effect on the physical and the material mechanical properties can be reduced to the material aging problem;

The pavement design model allows to take into account edge effects, the coating initial unevenness in the longitudinal and the road transverse directions, cracks in the pavement layers during their reconstruction, the shoulders state, the slopes steepness, the embankments and grooves height, the additional structural elements inclusion (for example, pipes and other drainage facilities, etc.). In the work, explicit absolutely stable [5] motion nonlinear equations direct integration schemes [3, 6] were used.

To solve this problem, we used the finite element method (hereinafter referred to as FEM) in the displacement method form, which is currently the most popular method for solving plane and spatial problems in the elasticity and plasticity theory. The FEM allows to consider regions with a complex topology under various boundary conditions.

**Main text**

**The software package structure for predicting residual deformations in road structures**

To predict the residual deformations accumulation in the elements of road structures under the influence of real dynamic loads and climatic factors, a software package has been developed that implements a mechanical-mathematical model on a computer.

The complex is structured by software components that implement various fragments of the algorithm. Communication between the individual programs running in sequence is carried out by transferring data through binary files. A common user interface and a call to individual programs are implemented through a separate control component, implemented in the form of a shell with a graphical interface. All complex modules and components are written within the framework of the object-oriented programming concept and event-driven programming.

The main complex components are:

- A program to predict the traffic flow intensity,
- The program for determining the road structure static response from the individual vehicles standing on the roadway or by the road side,
- The program for determining the dynamic response of the road structure from various types of vehicles,
- Program for determining the reduced load,
- Program for predicting the residual deformations accumulation,
- Auxiliary programs and utilities,
- The reference information modules. These modules perform the basic (regulatory reference) data storage and editing. The data on the geometric dimensions and loads from different types of cars; data on soils and asphalt concrete.

**Purpose and brief description of the main software components**

Traffic forecasting program performs the hourly traffic intensity distribution by car lanes, the flow composition and speed intervals depending on the average annual diurnal dimensions, the traffic flow composition, each lane number and width, taking into account the annual increase in traffic intensity. Its results are used by the program for calculating residual deformations over a long period of time for operating the road. Vehicle data is stored in a separate database. There are several copies of this base. The main copy is located in the reference and regulatory information section of the complex, and is adjusted by the administrator. When creating a project, the base is copied into the project and can be adjusted by the project user. This will allow to avoid the calculation irrelevant results appearance in
case of the common base late adjustment by the administrator in the completed calculations presence. The complex provides the system use of arbitrary data dimension during input.

The program for determining the static response of the road structure from the individual vehicles standing on the roadway or by the road side. As the complex part plays a supporting role for determining the reduced quasi-static load on the dynamic solutions results.

The program for determining the dynamic response of road construction from various types of vehicles runs repeatedly. This varies the vehicles types, the speed of their movement, the position on the roadway. The program can be run as independent. However, as a part of the complex, the program is automatically repeatedly launched by the complex control shell. It uses the results of forecasting the traffic flow intensity. The program implements an explicit absolutely stable scheme for integrating the motion equations. The scheme was developed taking into account the loads and masses moving along the structure. It makes sense to perform a dynamic calculation for an individual car for analyzing a dynamic task directly, i.e., at this point the user is interested only in the road structure stress-strain state results at the moment of a separate car passing by. The vehicle type is determined from the base table of vehicles entered into the complex. In the dialog box that opens after selecting “A single car”, the user sets the car type, its speed and position on the roadway.

In the version of the dynamic problem “Calculated Intensity” a series of dynamic calculations will be performed.

All calculations are automatically performed for those types of vehicles that are present at least once in the traffic intensity calculation tables. Under the type of vehicle not only the type of car is meant, but also the options for its position on the carriageway when driving at different speeds. At the same time, it doesn’t matter what number of passes per hour is predicted for a particular type of car. The main thing is to obtain the basic dynamic solutions from the passage of a separate car. Since a series of dynamic calculations is performed here, instead of the separate calculation results file name, the results folder is indicated. The file names are generated automatically for each vehicle and consist of the vehicle type name, supplemented by underlining the speed value and distance from the roadway edge. At the same time, the individual transport units’ parameters will be selected automatically using the base vehicles table and the traffic forecast results.

The program for predicting the accumulation of residual deformations and determining the development of road surface irregularities uses the following data: reduced quasi-static load (varying in time by hours of the day and months), physical, mechanical and geometric parameters of the road structure, physical-mechanical materials characteristics (including their rheological parameters ), data on changes in temperature and humidity in time. The algorithm is based on methods for solving the plasticity hereditary theory nonlinear problems [7-10].

The program complex algorithm provides the use of a database in which information is stored on the rheological characteristics of road-building materials, including fortified mineral materials of various grades, inorganic and complex binder. These data are obtained from a series of laboratory experiments. Also, for software package adequate work and the developed mechanic-mathematical model implementation, data on the accumulation of residual deformations in the coherent layers of road structures are necessary. In order to obtain such data, it is necessary to conduct experimental studies of the cohesive road-building materials creep, including from various mixtures of stone materials reinforced with mineral and complex binders with the establishment of the residual strain dependence on the various loads and temperatures effects.

**Some examples of using the software package**

Here are some results of using the complex.

Figure 1 shows a number of points movements on the surface of a cross section of a highway while driving a three-axle truck at a speed of 40 km / h (a) and 80 (b) km / h.

Figure 2 shows the diagrams of the maximum displacements on the highway cross-section surface while driving a three-axle truck at a speed of 40 km / h (a) and 80 (b) km / h.
Figure 3 shows the predicted increase in the maximum track depth with varying pavement design. The maximum gauge is obtained using the regulatory method for calculating the road structures. Strengthening which can significantly reduce the track in time development.

![Graph showing track depth vs pavement design](image1)

**Figure 1.** Dynamic movement on the cross section surface when driving a truck.  
*a*) - speed 40km / h;  
*b*) - speed 80km / h
Figure 2. The maximum displacements plot on the surface of the section when driving a truck. a) - speed 40km / h; b) - speed 80km / h

Figure 3. The forecast development of the track depth in time when using the original and reinforced pavement design.
1. The pavement design variant,
2. A variant with the macadam layer replacement by a layer of reinforced macadam-sand mixture, $E = 8000$ mPa,
3. A variant with the macadam layer replacement by a layer of reinforced macadam-sand mixture, $E = 6000$ mPa.

Summary
The main spatial domain discretization method is the finite element method (FEM), which allows to take into account the system topology and arbitrary boundary conditions complex form.

The complex implemented modeling of several types of effects: modeling of dynamic effects, determining equivalent static effects and long-term calculation of non-linear creep to determine irreversible deformations.

The use of the complex allows to simulate the pavement behavior with prominences in the road structure composition, the new materials use and the road optimization.

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