Simulation of wave processes in the multilayer structure surface layer properties identification by the finite element method

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Abstract. The modeling of a layered structure in a finite element Ansys complex is considered. The model is an imitation of a layered pavement design. The design consists of 10 layers, each of which has a certain fixed list of properties. We consider the simulation in the form of a simplified, flat statement of the problem. Simulated dynamic analysis under shock. The wave field of displacements in a certain part of the structure is analyzed. The correlation between the amplitude of the field displacement in a certain region of the surface layer and the variation of its elastic modulus is considered. Based on a numerical experiment, an approach to estimating the characteristics of a layer is constructed.

Introduction
The main methods of analyzing the behavior of building structures can be divided into analytical and numerical. The first group includes methods based on the integration of differential equilibrium equations of structural elements under various conditions of their deformation. Exact analytical methods are practically applicable only in the case of a small number of elements that make up the structure. In this case, the method of forces and the method of displacements in matrix form, well developed in structural mechanics, are used [1]. For complex spatial structures, it is easiest to apply numerical analysis methods, the main ones being the boundary element method [2], the finite difference method and the finite element method (FEM) [3, 4, 5].

To establish the homogeneity of the structure of materials, the vibro-diagnostic method of research has proven itself well. This method is non-destructive and can be used both to identify defects in the structure of the material, and to assess the effectiveness of restoring the integrity of the structure of the structure and its individual sections [6, 7].

Examples of modeling elements of simple structures in solving problems of identifying defect parameters, design properties are presented in [8-19]. Both simple analytical models and more complex models using the finite element method in various packages are considered. Experimental modeling is also used to confirm numerical calculations.

Modeling
When developing on the basis of the FEM of a computational model of a soil massif (in a flat or spatial formulation), the question of the correct choice of a representative limited volume of a semi-bound structure is the question. When formulating and solving a planar problem, this problem is technically solved somewhat easier, therefore, the main attention is paid to just such a formulation of the problem. At the same time, the results obtained in the development of a flat model are an important source material for creating a spatial model. The correctness of the choice of the size of the representative volume is checked by comparing the main wave characteristics in a given part of the structure obtained for a layered half-space without breaking the structure by analytical methods as a result of calculation by the FEM model.

The aim of the work is to build FE model and develop principles for solving the problem of identifying the parameters of layers in a multilayer structure.

Consider the problem in a flat statement. As a simulated structure, an element of a road multilayered structure is selected that includes 10 layers. The upper, selected structural element has inclined ends. All layers are rigidly coupled with each other and with the underlying half-space (Figures 1, 2). As input parameters, we consider the surface displacement field as a result of short-term pulsed exposure. A pulse in the form of a force \( P \) of unit amplitude is applied at point 1 (Figure 2a). The wave field is analyzed, due to the area adjacent to the point of impact on the surface of layer 1 (Figure 2.b). The study of the characteristics of waves propagating in a layered structure is carried out on the basis of the FEM implementation using the Ansys software package.

![Figure 1. Layout of a layered structure](image)  

**Table 1. Layer Parameters**

| Layers of construction | Thickness, [m] | \( E \), [MPa] | \( \rho \), [kg/m\(^3\)] | \( \nu \) | depot ratio |
|------------------------|---------------|---------------|----------------|------|-------------|
| Asphalt concrete (1)   | 0.2           | 2150          | 2250           | 0.33 | 6 \( e^{-4} \) |
| Fractions (unrelated materials) (2) | 0.5 | 283 | 1900 | 0.33 | 5 \( e^{-4} \) |
| Mound (3)              | 3             | 47            | 1700           | 0.33 | 5 \( e^{-4} \) |
| Layer (4)              | 5             | 47            | 1700           | 0.33 | 5 \( e^{-4} \) |
| Half-space (5..10)     | 5             | 350           | 1770           | 0.33 | 4.5 \( e^{-4} \) |

Due to impulse loading, a wave of displacements of surface points of the structure arises. In the process of solving the problem, lateral displacements are analyzed at the control points A1-A5 of the structure at a certain time interval. In figure 3 (a) shows transverse displacements at various points on surface points. The time interval 0.005 \( sec \) is analyzed.
Figure 2. (a) Impulse load diagram in the form of a force P applied at point 1. (b) The distribution of the amplitudes of the displacements of the running transverse wave at different points at different points in time (A1-A5).

Figure 3 (a) Calculated vibration amplitudes at 5 different points depending on the density of the first layer. (b) Dependence of vibration amplitudes at points A1 and A3 on the elastic modulus of the first layer.

Analysis
The analysis of oscillations at points A1-A5 shows that the oscillation wave when passing over the surface changes the amplitude. At point A1, depending on the variation of the elastic modulus of the first layer, its dependence on the elastic modulus varies nonlinearly. At points A2-A5, with the oscillation amplitudes, linearity depends on different variations of the elastic modulus. Figure 3(b) shows an example of the dependence of the oscillation amplitudes on the elastic modulus of the first layer for the first and third points.

Summary
The problem of unsteady excitation of oscillations in a layered structure is considered. The results of transverse displacements at the control points of the structure during the propagation of a wave from pulsed excitation at a certain point are given. When modeling as an analyzed, a period of time was considered in which the effects of backward wave transmission are not taken into account. The use of optimization in the Ansys complex allowed us to speed up the process of solving the problem. But this task requires comparison with a model using 3D full-bodied elements.

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