The subsystems design of methods for solving a problem of non-stationary waves propagation in solid bodies

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Abstract. In this paper is considered the design of information subsystem of method bicharacteristics, and also their numerical solution and computer visualization. The bicharacteristics method is one of the most convenient methods for software creating. This information subsystem combines the results of the solutions of practical tasks in the dynamics of a homogeneous elastic media, with the aim of creating digital collections for use in calculations of building constructions in engineering practice and also in problems of mechanical engineering and in general for researches in respective industries.

1 Introduction

Today world progress in information technologies, widespread introduction of computer facilities and new level of developments of applied and scientific researchers have made significant changes in the organization of scientific process. There was opportunity to solve many physical experiments and complex challenges in the field of economy, ecology, physics, biology, etc. with the help of appropriate software, computer simulation and visualization.

Examples of such implementations can serve a variety of electronic library with online access that contains unique text-based information, and non-specific, for example, a microfilm. [1,2].

In this paper is considered the association of private methods for solving problems of solid mechanics in one information subsystem.

The need for qualitative and quantitative analysis of the dynamic effects of the stress- strained state is increasing because of the connection with the various fields of engineering, structural elements, working in the dynamic load duty. As a result of the dynamic loads an elastic wave takes place in the testing body. And a reliable calculation of it helps in evaluating the strength and reliability of the entire design and technology.

Nowadays the numerical methods of spatial characteristics, finite element, the boundary integral equation and etc. are used for solving dynamic problems in elastic media [3-6].

In this paper is considered the design of information subsystem which integrates implemented methods and numerical and graphical results.

In this paper, we offer the bicharacteristicsmethod with the usage of ideas of splitting method for solution of the homogeneous isotropic elastic body. The advantage of this method is that it allows approaching the maximum dependence domain of the final and differential equation to the dependence area of the initial differential equation [3,4].

Novelty of development of a subsystem consists in use of a numerical method of bicharacteristics which is one of the most convenient for an application creation.

2 Statement of problem

In this paper we consider the solution of problems relating to the propagation of non-stationary waves in solid bodies, and combining the results in one subsystem to development a digital library in the future.

This subsystem is intended for physicists, engineers who engages in calculations of building constructions and solves different problems of mechanical engineering and others.

The functionality of this subsystem allows the use of the proposed methods, and manage through changing parameters such as density, temperature, and other, for their own research.

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3 The method of calculating the spatial characteristics

Currently, for solving dynamic problems in elastic medium there widely used the numerical methods of spatial characteristics [10], finite element [1], the boundary integral equation [2] and etc.One of the most convenient methods in applications is bicharacteristics method with the use of splitting method ideas [5,6,7]. This method allows approaching dependence domain of the final and differential equation to the dependence area of the initial differential equation as much as possible.

In this paper we reviewed the non-stationary problem solution of the homogeneous isotropic elastic body dynamics in the Cartesian coordinate system using the bicharacteristics method. Let us introduce the following notations:

x_i – Cartesian coordinates, t - time, σ_{ij} – tension tensor, ϑ_i– velocity vector, u_i – displacement vector. Let us consider an elastic semi-strip of final width which in the Cartesian system of coordinates x_1Ox_2 occupies the area of $0 < x_2 < \infty$, $|x_1 < l|$. In the initial time point the body is at state of rest.

$$\vartheta_i = 0, \sigma_{ij} = 0, \text{ (i,j=1,2)} \tag{1}$$

At any other time on the site $N_1 \le x_2 \le N_2$, $x_1 = l$ of border BN the uniformly distributed transient normal load *f(t)* has its influence, which varies according to sine law

$$\sigma_{22}(t) = \begin{cases} -A\sin(\omega t) O \le t \le S_1 \\ 0,\ t \ge S_1 \end{cases} \qquad \sigma_{21}(t) = 0. \tag{2}$$

Where S_1– loadings action time and $\omega = \pi/S_1$. The other part of the semi-strip border is free from any influence:

$$\sigma_{11}(t) = 0, \quad \sigma_{12}(t) = 0, \quad x_1 = 0, \quad |x_1| \ge l,$$
$$\sigma_{22}(t) = 0, \quad \sigma_{21}(t) = 0, \quad 0 \le x_1 \notin (N_1, N_2) | x_2 | = l \tag{3}$$

Under existing conditions it is necessary to investigate an elastic body tension at *t>0.*

A. The defining equations. In order to solve the problem along with entry and boundary conditions, we used the system of the equations consisting of the movement and ratios equations of the generalized Hooke's law:

$$\sigma_{i\beta,\beta} = \rho \frac{\partial^2 u_i}{\partial t^2}, \tag{4}$$

$$\sigma_{ij} = \lambda u_{\beta,\beta}\delta_{ij} + \mu\left(u_{i,j} + u_{j,i}\right) \tag{5}$$

Where ρ – density, λ, μ – Lama's constants, δ_{ij} – Kronecker delta.

After the non-dimensional variables integration, the motion equations (4) and correlations of the generalized Hooke's law differentiated by time (5) take the following form:

$$\left\{\dot{\vartheta}_1 = \sigma_{11,1} + \sigma_{12,2}, \dot{\vartheta}_1 = \sigma_{21,1} + \sigma_{22,2}, \dot{\sigma}_{11} = \vartheta_{1,1} + \gamma_{11}\sigma_{2,2}, \dot{\sigma}_{22} = \gamma_{11}\vartheta_{1,1} + \sigma_{2,2}, \dot{\sigma}_{12} = \gamma_{12}^2(\vartheta_{1,2} + \vartheta_{2,1})\right\} \tag{6}$$

Indexes after the comma denote the partial derivatives on Cartesian coordinates and the point from the top shows the partial derivatives on time.

*B. The equations of bicharacteristics.*In order to obtain bicharacteristics equation and conditions on them, let us split the two-dimensional system (6) on the single-dimensional one. Applying ideas of K.A.Bagrinovski and S.K.Godunov on splitting multidimensional t-hyperbolic systems on single-dimensional systems where $x_k = const$ [9], we will have:

$$\begin{Bmatrix} \dot{v}_i - \sigma_{ij,j} = a_{ij} \\ \dot{\sigma}_{ij} - \lambda_{ij}^2 v_{i,j} = b_{ij} \end{Bmatrix} \tag{7}$$

From here, using notorious methods to obtain differential bicharacteristics equations and conditions on them, we obtain:

$$dx_j = \pm\lambda_{ij}dt,$$
$$d\sigma_{ij} \mp \lambda_{ij}dv_i = \left(b_{ij} \mp \lambda_{ij}a_{ij}\right)dt \tag{8}$$

*C. Selection of a point scheme and a pattern.*This body is divided into square cells, sides of which are $\Delta x_1 = \Delta x_2 = h$. In the double points, the function values ϑ_i, σ_{ij} are searched at various time points with step of τ. The dot grid (on the basis of which the difference scheme is built, other than those mentioned double points) contains points formed by the intersection of bicharacteristics with hyperplanes $t = const$.

D. Resolving differential equations. The integration of equations (6) from the point O to the point A and the relations (8) from the point $E_{ij}^{\pm}$ to the point A by trapezoid method allows us to obtain the expression of the following form.

$$\vartheta_i = \vartheta_i^0 + \frac{\tau}{2}(\sigma_{ij,j} + a_{ij} + \dot{\vartheta_i^0}),$$
$$\sigma_{ij} = \sigma_{ij}^0 + \frac{\tau}{2}(\lambda_{ij}^2 v_{i,j} + b_{ij} + \dot{\sigma_{ij}^0}), \tag{9}$$

$$\sigma_{ij} - \sigma_{ij}^{\pm} \mp \lambda_{ij}(v_i + v_i^{\pm}) = \frac{\tau}{2}(b_{ij} + b_{ij}^{\pm} \mp \lambda_{ij}[a_{ij} + a_{ij}^{\pm}]) \tag{10}$$

Excluding from (9) ϑ_i, σ_{ij} by means of (10), we will receive:

$$\lambda_{ij}^2 v_{i,j} \mp \lambda_{ij}\sigma_{ij,j} = b_{ij}^{\pm} - \sigma_{ij}^0 \pm \lambda_{ij}(v_i^0 - a_{ij}^{\pm} + \frac{2}{\tau}(\sigma_{ij}^{\pm} - \sigma_{ij}^0 \pm \lambda_{ij}[v_i^0 - v_i^{\pm}]) \tag{11}$$

Values of unknown quantities in non-nodal points of expression (12) are calculated on Taylor's formula near a double point of 0 with accuracy to the second order concerning a step τ, therefore, we will have:

$$\lambda_{ij}^2 v_{i,j} \mp \lambda_{ij}\sigma_{ij,j} = \lambda_{ij}^2(v_{i,j}^0 + \tau\dot{v}_{i,j}^0) \mp \lambda_{ij}(\sigma_{ij,j}^0 + \tau\dot{\sigma}_{ij,j}^0 \quad (12)$$

Summing up and subtracting each system equation (13) with identical indexes pair, we will receive

$$v_{i,j} = v_{i,j}^0 + \tau(\sigma_{ij,jj}^0 + a_{ij,j}^0)$$
$$\sigma_{ij,j} = \sigma_{ij,j}^0 + \tau(\lambda_{ij}^2 v_{i,jj}^0 + b_{ij,j}^0) \quad (13)$$

Procedure of receiving the equations allowing systems in double points of the studied body in time moment $t = t_n + \tau$ is various for internal, boundary and angular points of the studied area. We should recognize that the given problem in general case should be investigated as part of an axially symmetric deformation. However, the numerous experimental results confirm that during the process of well compaction, any geometric shape of the well base (rectangle, triangle, circle, etc.) affects only the numerical results. Qualitatively, the deformation process is practically repeated almost in all cases. With this in mind, and having developed an algorithm for solving the location of planar linear dynamic problems of deformable bodies, the process of soil compaction was investigated in this paper [7-9].

4 The computer visualization bicharacteristics method for the special case

As an example of solving one of the problems with using the method bicharacteristics implemented in Fortran and obtained graphical visualization of normal and tangent tensions isolines in several moment of time. On figures 1 and 2 you can see the isolines of normal σ_{11} and tangent σ_{12} tension corresponding to a time point $t = 20\tau$.

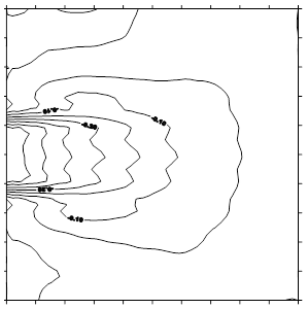

Figure 1. Isolines of normal tension

During this time, the boundary perturbance extending from influence local site travel a distance *10h* and reach opposite border.

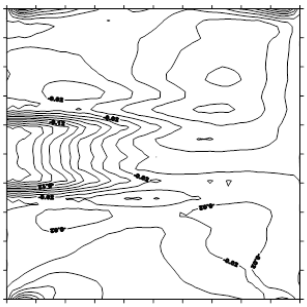

Figure 2. Isolines of tangent tension

In a timepoint of *t=40τ* tension fields symmetry, characteristic for *t=20τ*, to an axis of $x_1 = 12h$ are still looked through near a symmetry axis. With removal from this axis symmetry of isolines are broken. This result is explained by influence on nature of distribution of tension from a free end AB in the field of $x_1 \leq N_1$ and absence of similar effects in the field of $x_1 \leq N_2$[10].

5 The design of Information Subsystem

In order to classify the obtained solutions and their graphic images, it was decided to combine them into one information system, the core of which is a digital library containing a collection of software and analytical methods of wave propagation for different environmental settings and their corresponding graphic image.

This system allows physicists, engineers and related professionals to use the methods and manage through changing parameters such as density, temperature and others, for their own studies.

During architecture selection and database creation, solved such tasks as the creation of infrastructure and technological solutions and access as to the actual methods and graphical solutions. Therefore, interface design is another direction in building an information system. In our case the interface of the program needs to solve both user and functional tasks [11].

In [12] considered a system development of user interfaces. This work belongs to the early studies. It was supposed to develop an integrated environment for the creation and management of various user interfaces. This system is called the system user interface design (UIDS - User Interface Development Systems). For the first time interactive communication between human and machine was proposed by W. Newman in 1968.

Simple interfaces designed standard components, which occurs by the user directly. Modern software products have complex interfaces containing various styles of user interaction. For example, the management object that represents application data, support for graphical data representation, management dialog boxes, etc. Than bigger the app, the more tools and interface features integrated into it, the harder it is amenable to the study of the interface.

One of the common methods of developing user interfaces is the model-based design, consisting of several

stages (Fig.3) [13]. In the first stage, organizational and collaborative tasks are modeled using high-level specifications. In the second stage, tasks are specified and the level of detail increases. And finally, the last stage is modeled by the interaction between individual user and the application using the system tree of parallel tasks [14].

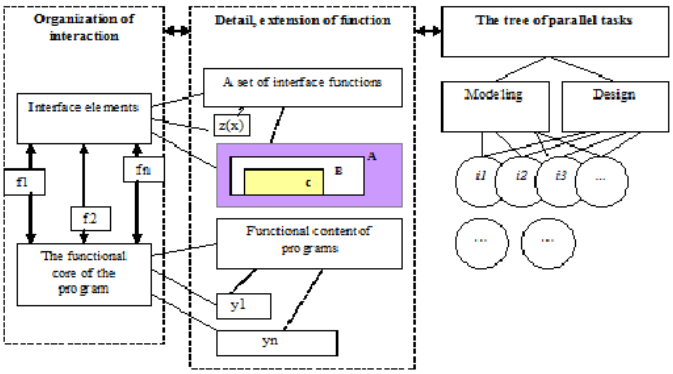

Figure 3. The abstract model of interface design

6 Final remarks

The main purpose of this subsystem is designed to bring together the spatial characteristics of methods and their graphic solutions.

The software subsystem technology is implemented in Java in the database development environment - Microsoft SQL Server.

The digital collection of this subsystem includes numerical methods for transient wave propagation in solids and their visualization.

During further research it is planned to expand a set of methods by calculation of waves in solid media.

This subsystem will be of interest to various researchers not only as a finished instrument, but also from the point of view of further optimization of the algorithms.

7 Conclusions

In the design and construction of engineering structures for more economical use of materials it is necessary to consider not only the statistical burden on facilities , but also dynamic, which may occur , for example , at the location of facilities in areas with high seismic activity. Power dynamic load cannot be determined without a full study of the space- time picture of the state of stress of the object appearing in the propagation of elastic waves in solids.

In this paper, information subsystem was proposed, which is a digital collection of numerical methods bicharacteristics for solving problems of dynamic wave propagation in an elastic medium.

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