

Development of Information System with a Digital Library Based on the Bicharacteristics Numerical Method

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Abstract: This study discusses the development of an information system based on bicharacteristics method. The bicharacteristics method is one of the most convenient methods for Software development. The developed information system has a digital collection of solutions visualization of particular problems in the dynamics of homogeneous elastic media. This information system is used in the calculation of building structures in engineering practice as well as in engineering problems and generally for research in their respective industries.

Key words: Software, development, system, problems, engineering, research

INTRODUCTION

The rapid development of computer technology and its implementation in almost all spheres of our life has led to the fact that today a qualified specialist in any field of knowledge has to navigate the world of computers and possess the necessary software.

Today, the world's progress in the field of information technology, the widespread introduction of computer technology and a new level of development and application of scientific research have made remarkable changes in the organization of the scientific process.

The opportunity arose to solve many physical experiments and challenges in the field of economy, ecology, physics, biology, etc. with the help of appropriate software, computer modeling and visualization (Arms, 2000).

Like any specialist any particular area is not possible without knowledge of specialized Software and modern engineering is not possible without knowledge of Computer-Aids Design systems (CAD-Computer Aids Design), automatic production (CAM-Computer Aids Manufacturing) and automated engineering analysis (CAE-Computer Aids Engineering). These CAD/CAM systems like Auto CAD, DUCT, Pro/Engineer, Unigraphics and SolidsWorks widely used for computer modeling of complex shapes with the subsequent release of drawings and generation of control programs. However, these specialized numerical modeling packages

have not developed means of engineering analysis. 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.

Now a days the numerical methods of spatial characteristics, finite element, the boundary integral equation and etc are used for solving dynamic problems in elastic media.

We want to offer the bicharacteristics method 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.

The study considered the development of an information system which integrates numerical and graphical results of specific problems of waves propagation in solids. The specialists from engineering field have an opportunity to solve a number of the following tasks as forecasting the state of the objects located in seismically active zones, research strength building structure under dynamic loading, the estimation of strength and reliability of the design and technology, etc. with this information system. The novelty of this

research work is to use in the calculation of the bicharacteristics numerical method which is one of the most convenient for development applications.

Literature review: Now a days, the numerical methods of spatial characteristics, finite element, the boundary integral equation and, etc are used for solving dynamic problems in elastic media.

Currently for solving dynamic problems in elastic media used numerical methods of spatial characteristics, finite element, the boundary integral equation and, etc., difference method using the method of spatial characteristics of the proposed Clifton for the study of planar dynamical problems and Recker developed to study the advance of elastic waves in isotropic bodies rectangular in shape (Reker, 1970). One of the most convenient methods in applications is bicharacteristics method with the use of splitting method ideas which developed in it allows approaching as much as possible dependence domain of the final and differential equation to the dependence area of the initial differential equation (Lee *et al.*, 2013).

Statement of the problem: To develop an information system designed to solve the problems related to the non-stationary wave's propagation in solids and to combine obtained the numerical and graphical results in one digital collection.

This information system is designed for physicists and engineers involved in design of structures who solves different problems of mechanical engineering and others for the prediction and calculation.

The functionality of this software system should allow the user to obtain the necessary visualization of wave propagation in the management of inputs.

MATERIALS AND METHODS

The method of calculating the spatial characteristics: Let us introduce the following notations: x_i -Cartesian coordinates, t -time, σ_{ij} -tension tensor, ϑ_i -velocity vector, u_i -displacement vector (Lee *et al.*, 2013).

Let us consider an elastic semi-strip of final width which in the Cartesian system of coordinates $x_1 \times x_2$ occupies the area of $|x_1| < 1$ (Fig. 1). In the initial time point the body is at state of rest:

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

At any other time on the site $N_1 \leq x_2 \leq N_2, x_1 = 1$ of border BN the uniformly distributed transient normal load $f(t)$ has its influence which varies according to sine law:

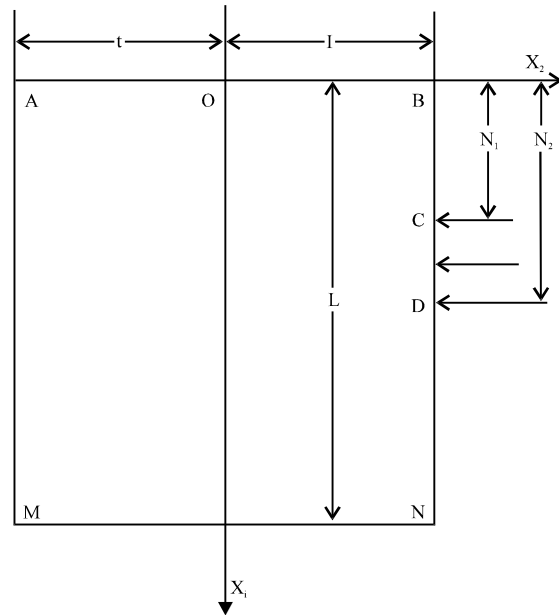


Fig. 1: The elastic semi-strip

$$\sigma_{22}(t) = \begin{cases} -A \sin(\omega t), 0 \leq t \leq S_1 \\ 0, t \geq S_1 \end{cases} \tag{2}$$

$$\sigma_{21}(t) = 0$$

where, S_1 loadings action time and $\omega = \pi/S_1$. The other part of the semi trip border is free from any influence:

$$\begin{aligned} \sigma_{12}(t) = 0, \sigma_{11}(t) = 0 \\ \sigma_{21}(t) = 0 \sigma_{22}(t) = 0 \end{aligned} \tag{3}$$

$$x_1 = 0, 0 \leq x_1 \notin (N_1, N_2), |x_2| = 1$$

Under existing conditions it is necessary to investigate an elastic body tension at $t > 0$ (Akhmetova *et al.*, 2016).

The defining equations: In order to solve the problem along with entry and boundary conditions we used the system of the equation consisting of the movement and ratios equations of the generalized Hooke's law (Akhmetova *et al.*, 2016):

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

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

Where:
 ρ = Density
 λ, μ = Lama's constants

σ_{ij} = Kronecker delta and required sizes are entered (9). For convenience independent immense variables:

$$\begin{aligned} \bar{t} &= \frac{tc_1}{b}, \bar{x}_i = \frac{x_i}{b}, \bar{\vartheta}_i = \frac{1}{c_1} \frac{\partial u_i}{\partial t}, \bar{\sigma}_{ij} = \frac{\sigma_{ij}}{\rho c_1^2}, \\ \gamma_{12} &= \frac{c_2}{c_1}, \gamma_{11} = 1 - 2\gamma_{21}^2 \quad (i, j = 1, 2) \end{aligned} \quad (6)$$

Where, b-reference length:

$$c_1 = \sqrt{\frac{\lambda + 2\mu}{\rho}}, c_{2A} \sqrt{\frac{\mu}{\rho}} - \text{datum speeds} \quad (7)$$

After the non-dimensional variables integration, the motion Eq. 4 and differentiated by time correlation of the generalized Hooke's law Eq. 8 takes the form:

$$\begin{cases} \dot{\vartheta}_1 = \dot{\sigma}_{11,1} + \sigma_{12,2} \\ \dot{v}_1 = \sigma_{21,1} + \sigma_{22,2} \\ \dot{\sigma}_{11} = \vartheta_{1,1} + \gamma_{11}\sigma_{2,2} \\ \dot{\sigma}_{22} = \gamma_{11}\vartheta_{1,1} + \sigma_{2,2} \\ \dot{\sigma}_{12} = \gamma_{12}^2 (\vartheta_{1,2} + \vartheta_{2,1}) \end{cases} \quad (8)$$

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

The equations of bicharacteristics: In order to obtain bicharacteristics equation and conditions on them, let us split the two-dimensional system (10) 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 const $x_k =$ we will have:

$$\begin{cases} \dot{\vartheta}_1 - \sigma_{ij,j} = \alpha_{ij} \\ \dot{\sigma}_{ij} - \lambda_{ij}^2 \vartheta_{i,j} = b_{ij} \end{cases} \quad (9)$$

where, $b_{ij} = (\gamma_{11} \delta_{ij} + \gamma_{12}^2) (1 - \delta_{ij}) \vartheta_{p,k}$; $i, j, k, p = 1, 2; p \neq i, k \neq j$
From here, using notorious methods to obtain differential bicharacteristics equations and conditions on them we obtain (Fig. 2 and 3):

$$\begin{aligned} dx_j &= \pm \lambda_{ij} dt \\ d\sigma_{ij} \mp \lambda_{ij} d\vartheta_i &= (b_{ij} \mp \lambda_{ij} a_{ij}) dt \end{aligned} \quad (10)$$

Selection of a point scheme and a pattern: This body is divided into square cells, sides of which are $\Delta x_1 = \Delta x_2 = h$.

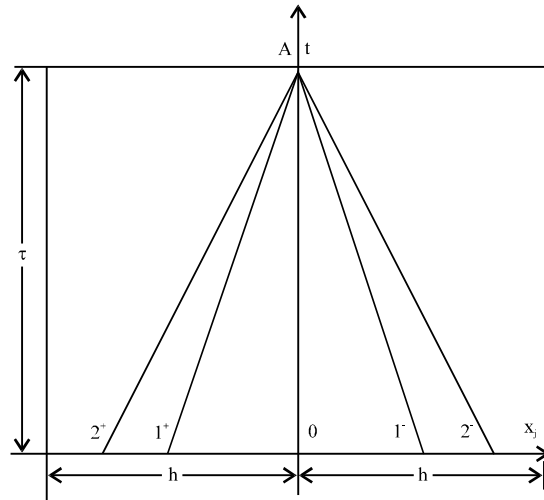


Fig. 2: The view bicharacteristics on plane

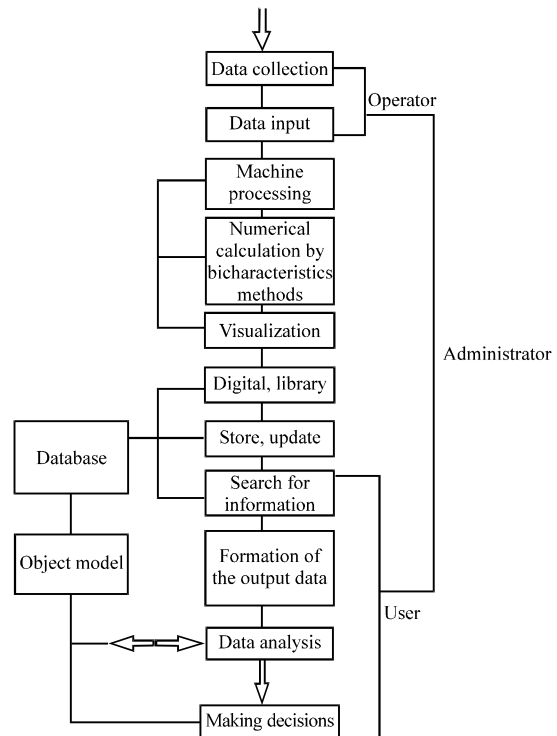


Fig. 3: The technological process of information system

In the double points, the function value 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 $t = \text{const}$.

Accepted pattern consisting of O node and E_{ij}^+ points, separated from the point O to the distance $\gamma_{ij} \tau$. In the future ϑ_i, σ_{ij} values of the functions at the point O is

attributed to the upper mark “0” in the points E_{ij}^+ -subindex «ij» and the upper sign «±», appropriate (for example σ_i^+ and point A is not attributed to the additional index (Akhmetova *et al.*, 2016).

Resolving differential equations: The integration of Eq. 8 from the point O to the point A and the relations Eq. 10 from the point E_{ij}^+ to the point A by trapezoid method allows us to obtain the expression of the following form:

$$\vartheta_i = \vartheta_i^0 + \frac{\tau}{2\sigma_{ij,j} + a_{ij} + \vartheta_i^0} \quad (11)$$

$$\sigma_{ij} = \sigma_{ij}^0 + \frac{\tau}{2} \lambda_{ij}^2 \vartheta_{i,j} + b_{ij} + \sigma_{ij}^0 \quad (12)$$

Values of unknown quantities in non-nodal points of Eq. 13 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:

$$\lambda_{ij}^2 \vartheta_{i,j} \mp \lambda_{ij} \sigma_{ij,j} = \lambda_{ij}^2 (\vartheta_{i,j}^0 + \tau \vartheta_{i,j}^0) \mp \lambda_{ij} (\sigma_{ij,j}^0 + \tau \sigma_{ij,j}^0) \quad (13)$$

Summing up and subtracting each system Eq. 13 with identical indexes pair we will receive:

$$\vartheta_{i,j} = \vartheta_{i,j}^0 + \tau (\sigma_{ij,j}^0 + a_{ij}^0), \sigma_{i,j} = \sigma_{ij,j}^0 + \tau (\lambda_{ij}^2 v_{i,j}^0 + b_{ij}^0) \quad (14)$$

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.

Resolving differential equations for area internal points: Unknown derivatives $\sigma_{ij,j}, \vartheta_{i,j}, a_{ij}, b_{ij}$ on layer $t = t_n + \tau$ are sought for from equations system (Eq. 12). Functions derivatives in the right part of the equations system (Eq. 8 and 14) on a square grid for knot x_1^0, x_2^0, t_0 are approximated by the central differences.

Resolving differential equations for area points: The differential equations for boundary points of boundary the studied area (excepting angular) obtained by means of the equations system (Eq. 12 and 14) on the calculated or preset values of required sizes on a temporary layer $t_n + \tau$ ($n = 1, 2, \dots, N$). In calculations can’t be used conditions (Eq. 14) on two characteristics which aren’t belonging to body area. Thereby in comparison with internal points, Eq. number 11 is reduced on two.

The remained equation population (Eq. 12 and 14) and 2 boundary conditions is the isolated linear system concerning thirteen indeterminate. For derivative functions approximation are used differences “forward” and “back”.

Resolving differential equations for area angular points: Angular points are considered as crossing of 2 boundary lines. Therefore in these points the conditions have to be fulfilled. They are specified on these two boundary lines. In an angular point of the studied area four boundary functions are defined. Then, Eq. 12, 14 and boundary conditions identically defined the sought quantity in angular points of the studied area. Here on borders of a condition are defined by tension σ_{11}, σ_{12} and σ_{21}, σ_{22} . By paring law relationship of tangent tension in angular points have only three linearly-independent boundary conditions and thereby, the number of the defined boundary conditions becomes for one unit less. However, calculations by differences approximation “forward” and “back” the defined boundary functions allows to make the closed the equation system (Akhmetova *et al.*, 2016).

RESULTS AND DISCUSSION

Development of information system: 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.

Under the information system is understood as an interconnected set of tools, methods and personnel used for the storage, processing and output of information in order to achieve this goal. The modern understanding of the information system is to use as the main technical means of information processing PC. It is necessary to understand the difference between computers and information systems. Computers equipped with specialized software are the technical facilities and tools for information systems. The information system is unthinkable without the staff interacting with computers and telecommunications (Molina *et al.*, 2009).

The development and use of the information system aimed at solving these problems: the structure of the information system, its functionality should be consistent with the developer’s objectives; the information system should be controlled by the people to deal and used with them; the production of accurate, reliable, timely and systematic information (Mao, 1989; Samoylova *et al.*, 2016).

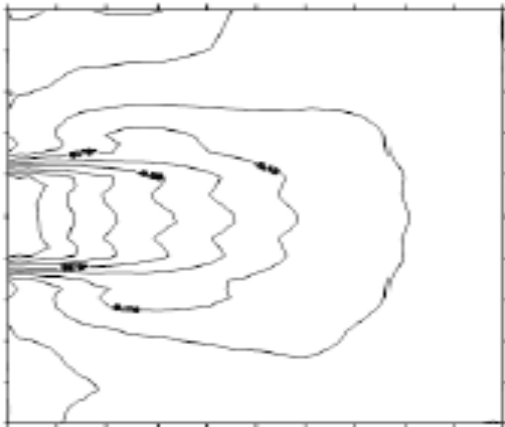


Fig. 4: Isolines of normal tension

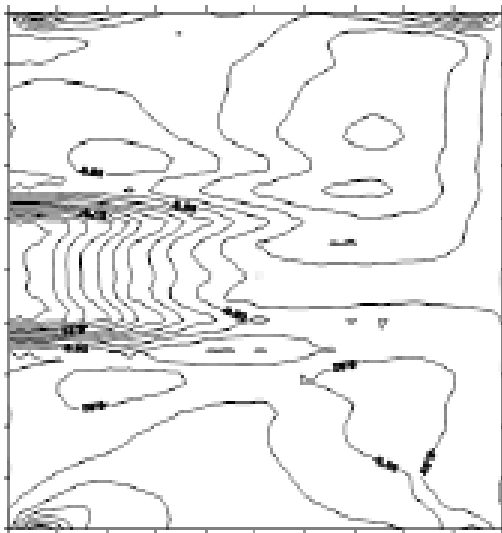


Fig. 5: Isolines of tangent tension

Similarly for the creation and use of the information system you must the first to understand the structure, function and organization policies, goals and management decisions made, computer technology opportunities (Lee and Park, 2015).

Developing information system must begin with an analysis of subject area, data collection and select the method of calculation. Specially designed information system is that the core of this system is the visualization component. The bicharacteristics numerical method was chosen for numerical and graphical solutions. The obtained visualizations are forming a digital collection which is stored in a digital library (Liu *et al.*, 2015; Owens *et al.*, 2013; Rambach *et al.*, 2016).

Figure 3 the structure of the aggregate technological displayed process of information system or the presentation of an automated information system as a set of functional subsystem-collection, input, processing, storage, retrieval and dissemination of information.

Analysis of the results: Developed information system has its own digital library which stores graphic solutions of problems wave propagation in solids.

Figure 4 and 5 you can see the isolines of normal and tangent tension corresponding to a time point. Bicharacteristics method was used to solve this problem, numerical calculation was obtained by using the Fortran. During this time, the boundary perturbation extending from influence local site travel a distance 10 h and reach opposite border (Akhmetova *et al.*, 2016).

CONCLUSION

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 study, the information system has been proposed which is a digital collection of graphic solutions of the problems of non-stationary waves propagation in solids.

Of the study had been calculated numerical calculations of non-stationary waves propagation in solids based on bicharacteristics method and imaging were obtained for each particular case of numerical solutions which have been combined in to one digital collection set up an information system.

The specialists from the field of engineering have the opportunity to solve a number of the following tasks as forecasting the state of the objects located in seismically active zones, research strength building structure under dynamic loading, the estimation of strength and reliability of the design and technology, etc. with the help of the developed information system.

RECOMENDATION

In the course of further research is planned to expand the range of methods for the calculation of waves in solid media. This system will be of interest to various researchers not only as a ready tool but from the viewpoint of further optimization algorithms.

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