

A Software Suite for Modeling the Dynamics of Structurally Inhomogeneous Shells

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Abstract: On the basis of the principle of modularity, an algorithm and software package for dynamic calculation of structurally-inhomogeneous multiply connected shell units that are the elements of hydro-technical structures are developed in the paper. The purpose of the module is to carry out certain transformations of the initial (source) information into a unique result. The development prospects of construction of various hydro-technical structures, aircraft, rocket and space machinery, shipbuilding, chemical engineering and many other branches of modern technology are characterized by a complication of design decisions in projecting and calculation of objects that present multiply connected spatial shell structures subjected to static and dynamic effects. Multiply connected structures, (such as hydro-technical structures), usually include a wide range of elastic and visco-elastic deformable elements with significantly different rheological properties in the form of blocks of plate stacks, tubular, cylindrical and prismatic shell structures of complex geometry, with attached masses, various types of reinforcement, supports, containing a large number of elastic and visco-elastic couplings with significantly different functions of heredity. Obviously, the search for exact analytical solutions to dynamic problems for structurally inhomogeneous visco-elastic shell structures is doomed to failure, the only possibility of engineering implementation is to build numerical and numerical-analytical algorithms with the subsequent use of modern computers. The solution to dynamic problems involves a numerical simulation of the stress-strain state (SSS) of the structures under consideration.

Keywords: software, deformable elements, visco-elastic, stress-strain state, dynamic effects, discrete-continuous model.

Introduction

The development of a unified approach to solving the problems of the dynamics and interaction of multiply connected structurally-inhomogeneous shell structures, which are an arbitrary composition of multilayer shells of revolution and rings, the creation and implementation of an appropriate software package with a high level of automation of all stages of calculations oriented to computer use significantly increase the design efficiency and are a major scientific problem of great economic importance. This paper is dedicated to solving this problem.

To solve boundary value problems of the theory of shells, the behavior of which can be described by a system of ordinary differential equations of the first order, the method of numerical integration

(MNI), based on reducing the boundary value problem to a number of Cauchy problems, turned out to be the most effective one. In 1961, S.K. Godunov [3] proposed the MNI with ortho-normalization of a solution at intermediate points, which later made a leap in solving boundary value problems in the mechanics of a deformable rigid body.

The orthogonal sweep method (OSM), although less general compared to the FEM, has a greater simplicity, compactness, and flexibility, which make it possible to quickly restructure the software when proceeding to solve new problems.

All this was the basis for its effective application in the present paper and, accordingly, an extension to the solution of boundary value problems with complex quantities.

For the first time in solving the problems of determining the stress-strain state of shells of revolution, the method was used by Ya.M. Grigorenko and his students [4, 5, 6, 7, 8, 9]; V.P., Myachenkov, and A.N. Frolov suggested using this method to solve the problems of stability and vibrations of shells of revolution [10]; V.P. Maltsev and V.I. Myachenkov used it to solve the dynamics problems of shells of revolution [11].

In publications by Ya.M. Grigorenko, V.I. Myachenkov, A.N. Frolov, V.P. Maltsev, and others [12] the MHI was thoroughly researched and brought to a universal form to be used in solving a variety of problems in structural mechanics and mechanics of a deformable rigid body.

The success achieved in the development of the MNI based on orthogonal sweep made it possible to use a modification of the displacement method in A.V. Aleksandrov's form [13] to create methodological foundations for calculating multiply connected structurally-inhomogeneous shell structures, in particular, the ones interacting with soil or fluid.

Moreover, the statement and numerical implementation of the proposed methodology are developed and generalized in the framework of the mathematical theory of viscoelasticity [16], modern methods of averaging, and freezing [14, 15], variational principles of the dynamics. They are based on a single approach that uses a discrete-continuous model of the structure and the orthogonal sweep method, generalized on the solution of complex boundary value problems, for calculating the stiffness matrices of shell elements.

2 Method

The main project operations, the performance ability of which is provided by the developed software package, are as follows:

- the formation of a geometrical model of the structure and the nomination of materials;
- the description of environmental factors acting on the structure;
- the formation of the design scheme of a structure;
- the formation of a structure model in terms of the mechanics of a deformable rigid body;
- the determination of the stress-strain state, critical loads and dynamic characteristics of a structure;
- the formation of a visual model of the structure and its response to environmental factors;
- the formation of design documentation;
- the generation of information for the structure archive;
- the search for a rational technical decision.

The construction of algorithms and software is based on the principle of modularity.

A module is a sequence of logically related operations that performs a specific function and designed as an independent subprogram. The purpose of the module is to carry out certain transformations of the initial (source) information into a unique result.

In this paper, all moduli are designed as the procedures written in the algorithmic language python.

An example of a module is the procedure for solving a system of linear algebraic equations

$$[A] \vec{x} = \vec{b} \quad (1)$$

by the Gauss method.

The title of this procedure is:

```
GAUSS : PROC ( N, A, B, /*RESULT*/ X);
      DCL, (A (*, *) , (B , X)(*)) FLOAT ( 16 );
/* N – system order;
A( N,N ) – matrix [A],
B( N ) –right-hand sides vector ( B ) ;
X( N ) –the unknowns vector ( X ) */
```

Using this procedure as an example, the basic principles of module construction can be demonstrated.

1. Each module should be self-documented, i.e. all formal parameters of the procedure should be described in the text of the module. This helps to avoid describing formal parameters far from the text.

2. Each module can be called from anywhere in the program or from any other module by its name. For example, to solve a system of linear algebraic equations

$$[C] \vec{q} = \vec{d} \quad (2)$$

GAUSS procedure call is made using the operator

```
CALL GAUSS (K, C, D, Y);
```

The actual parameters K, C, D before calling the GAUSS procedure must have the following value:

K is the system order (2)

C (K, K) FLOAT (16) is an array of matrix coefficients [C];

D (K) FLOAT (16) is an array of vector components $\vec{d}$;

Fulfilling this procedure, the results of the solving system (2) are available in the Y(K) FLOAT 16 array.

3 Results and discussions

1. The module must have one input-output. The programming experience shows that it is more preferable to use several almost identical modules than one module with several inputs and outputs. The uniqueness of the input-output guarantees the closure of the module and simplifies the maintenance of programs.

2. The module should be small in volume; the text should be placed on one-two (maximum three) listing pages to be visible to the programmer (user).

3. The construction of moduli should guarantee the possibility of their replacement. Suppose that for some reason the Gauss method is not suitable for solving a system of linear algebraic equations (1), in this case the GAUSS procedure text can be replaced with another without changing the procedure title. A program (its text may contain more than one thousand statements) that calls a newly written module will not change at all. A separately compiled new module will be automatically included into this program as a result of the joint compilation. The programmer does not even need to know where this module is located and why it is called.

4. Each module must be written according to the rules corresponding to the rules of the algorithmic languages of publications. This greatly facilitates the reading, and the understanding of the functional purpose and algorithm of the program.

Algorithmic input of initial data. The principle of algorithmic input of source data is important for the construction of algorithms and software. It consists in the fact that along with the numeric input, the functional input of the source information is carried out.

In this case, the formal parameters of the procedure that implements any algorithm for solving the dynamics of structurally inhomogeneous multiply connected axisymmetric and prismatic shell structures include the formal parameters, which in turn are procedures. The functional purpose of these procedures is to calculate the source data continuously changing along the generatrix, such as the geometrical and mechanical characteristics of the shell structure element, external loads acting on it, etc.

Methods used in the solution algorithm. The use of a discrete-continuous design scheme for the structurally inhomogeneous shell structures under consideration determines the main method for solving the problems of the dynamics and strength.

In the general scheme of solving problems, the orthogonal sweep method of S.K. Godunov dominates. Consider the general scheme of the algorithms used in this subsystem on the example of the linear problem of determining the stress-strain state and vibrations of an axisymmetric structurally inhomogeneous structure under axisymmetric loading.

Formalized description of structurally-inhomogeneous shell structures. The principle of algorithmic input of source information is one of the basic principles for describing the geometrical and mechanical characteristics of a structure when constructing algorithms for solving dynamics problems considered in this paper. This principle is used to describe the loads acting on the structure. In this case, the parameters of the procedure that implements one or another algorithm for solving the dynamics of structurally-inhomogeneous shell structures include formal parameters, which in turn are procedures. The functional purpose of these procedures is to calculate the initial data design elements continuously varying along the generatrix of the axisymmetric shell elements or along the guide of the prismatic shell elements. These initial data are the geometrical or stiffness characteristics of the element, external loads acting on it, the dependence of these loads on time, etc. The algorithmic input of initial data allows describing substantially different rheological properties of materials of all elements of the structure under consideration.

4 Conclusions

Numerical and experimental studies show satisfactory accuracy and convergence of algorithms and developed software systems in solving the problems of the dynamics of structurally-inhomogeneous shell structures. For the class of structures under consideration, qualitative and quantitative agreement is obtained in numerical experiments between the basic results and the laws of strain processes in structurally inhomogeneous systems.

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