

Development of the CAD system for designing non-standard constructions from elastomers

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Abstract: The development of the Computer-Aided Design (CAD) system FORTU-FEM, which is based on the Finite-Element Method (FEM), is considered in the paper. Unlike other CAD systems, which does not allow to its users to change the schema of calculation, FORTU-FEM has the open architecture and allows to engineers to develop the various methods for analysis of non-standard constructions. The example of application of FORTU-FEM for calculation of the tensional and the deformed states of constructions from elastomers is given.

Keywords: finite-element method; FORTU- FEM, CAD

I. INTRODUCTION

The modern CAD systems for exploring properties of materials in the tensional and the deformed conditions, support a number of mathematical methods for approximate calculations (e.g. solving the big systems of algebraic and transcendental equations, the numerical integration and differentiation etc.), but not often give the possibility of realization of non-standard calculations[1, 2]. The common iterative and the step-by-step computation schemes, which are based on the multiple repetition of operations, for the realization of the different non-standard calculations should be taken.

At implementation of the non-standard computations, including solution of the tasks of mechanics of elastomers, the problem of the development of the most effective, if possible, the optimal, calculation scheme arose [7]. Such the scheme on a number of methods of calculus mathematics is based. The possible solution here is to build the different computing algorithms, and then to compare their advantages and shortcomings. Next, at its program implementation, the problems of saving computer memory and of improving performance of calculations to be solved.

Let's note, that in the current stage of material science development it is rather difficult to say beforehand about the optimality of a computing scheme in the concrete conditions. More often a CAD system includes the different computational algorithms, and their advantages and weaknesses are compared by users experimentally. For it, both the final and the intermediate results of calculations have to be investigated on their correspondence to the mechanical sense of the task. This is quite important part of the method, since the errors of rounding and the instability of some calculation algorithms can considerably change the results. The process of the analysis of results is very difficult and labor-intensive, taking sometimes more time, than the whole procedure of calculation.

But in any case at all stages of the development of solution of any non-standard problem of mechanics of elastomers the obligatory involvement of the qualified user is required. User chooses

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the calculation scheme, represents initial and final conditions, selects the software methods, analyses the results of solution, etc. For this reasons the CADs, intended for solving non-standard problems should be developed correspondingly to some principles. In this paper we propose the new approach to development of the CAD for designing the non-standard constructions from elastomers, being in the tensional and the deformed conditions.

II. DEVELOPMENT OF THE CAD SYSTEM FOR DESIGNING NON-STANDARD CONSTRUCTIONS FROM ELASTOMERS

The solution of non-standard tasks needs development of the CAD system having the open architecture, i.e. allowing to users to define own methods. We can allocate the next directions of such the systems development [3]:

- development of the CAD systems for generation of applied programs on the base of the composition of the existing modules, stored in the relevant libraries (software repositories). The computation scheme is offered to users in the form of various scenarios (stereotypic procedures) as the sequence of operations of the automated design together with the elements of included in the CAD a training system [5]. This approach is used quite often now, because it is less labor-consuming in realization of solutions of non-standard problems. However, it has one essential issue: impossibility of development of a new calculation method if the CAD libraries do not contain the corresponding scenario;
- development of the high level problem-oriented programming languages inside a CAD system. Such the approach is a very perspective today, however it requires the considerable resources for development of such the languages, their toolset (interpreters, translators, debuggers etc.), as also teaching users to those languages. And there is a problem of training engineers to use of such the CAD systems, which are much more complex comparatively with traditional ones;
- the direct use of the models of the subject domains as the source languages for development of programs for the solution of the applied tasks. This approach is the most user friendly, however, the development of such the meta-programming CAD systems is also labor-intensive process.

In the first mentioned direction the number of the CAD systems for automation of the process of the analysis of problems of mechanics of the deformed firm bodies is developed today. Among the most popular lets note the COSAR, COSMOS/M [11]; MONOMAH, SCAD Office (plugin for AutoCAD) [6]; LIRA [4]; PROCHNOST-1, etc. [1]

All the mentioned CAD complexes on the solution of the different classes of problems of mechanics of the deformed firm bodies are focused. The convenience of work and the high precision of calculations are their advantages. However, it should be noted, that the effective application of these CAD systems requires the considerable expenditures for the preparation of its users. Besides, these programs are also very expensive. But the main issue that the mentioned CAD systems can't be applied to the solution of the tasks, which methods are not provided by the system.

From our point of view, for increasing reliability and efficiency of the CAD systems, the synthesis of the two last directions is the most interesting, because a user knows the language of own subject domain and so can master the corresponding problem-oriented programming language rather quickly. In the same time, the probability of emergence of programs errors in the case of application of such the approach also is less.

It Zaporizhzhia National University, Ukraine, the CAD system FORTU-FEM [1] for solving the different tasks of mechanics were developed. FORTU-FEM is based on the finite elements method (FEM). In the Fig. 1 the general scheme of FORTU-FEM CAD is shown.

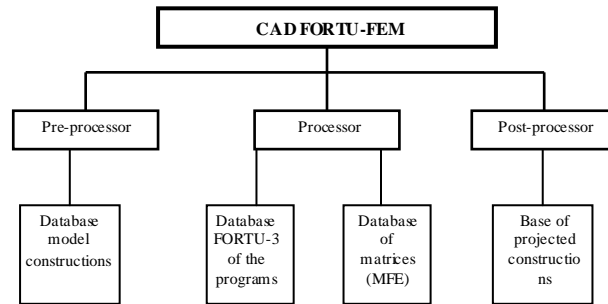


Figure 1. Structure of computer-aided design FORTU-FEM

The design principles of FORTU-FEM are differ from the existing CAD systems. The idea here is that by the given set of initial data and by the large-block scheme of the solution in the interactive mode a user can realize own process of the numerical solution and the analysis. So FORTU-FEM supports user at all stages, starting from the setting the initial information, development of own methods of calculation and finishing the analyses of the numerical results of solution of the intension and deformation states of a body.

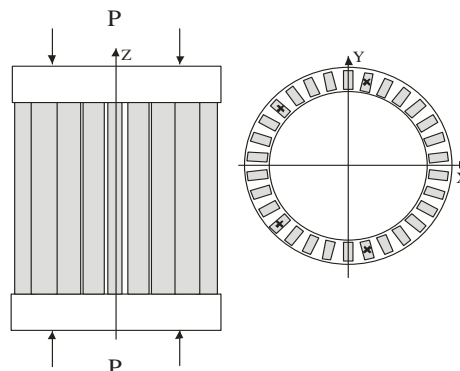
The FORTU-FEM combines the several directions in development of the problem-oriented CAD tools: the specialized source language allows to the user-nonprogrammer to formalize the description of the specific task of mathematical physics and also to implement the method of calculation correspondingly the computing scheme. As the mathematical base of the offered method for description and solutions of the problems of mechanics the variations calculus is taken, allowing to describe in the most general formal form the energetic variation principle and the method of its minimization. Using this approach for description of tasks allows completely abstract from the type and the method of solution at the initial stage. For development of the computing scheme it is necessary only to describe the rules of inferring the main relations of the variation functional and to choose the method to find its minimum.

The FORTU-FEM system is open and this allows us to expand its functionality. Our impact in improving of FORTU-FEM is the development of the module for calculation of the constructions being in the tensional the deformed states, on the base of the method of moment diagrams [2]. Let's consider the example which shows the advantages of using our module for modelling elastomers.

III. CONTACT INTERACTION OF A COMPRESSION RING AND A DISCRETE BASE

In the design of electrical transformers the problem of contact interaction of compression rings and a discrete base – pole-mounted pillars arises (Fig. 2). One of the objectives of a design of electrical transformer is definition of the optimal placement of brackets – compression ring seals. Through them the load P is given to the rings. The problem is that with the wrong choice of points of the load application the contact forces are unevenly distributed on discrete base, which significantly deteriorates the strength characteristics of the transformer.

We solve this task with the help of FORTU-FEM system. The ring and the base are made of orthotropic material – corrugated cardboard. The FEM model obtained with the help of ANSYS system [10] and consist of 9920 nodes and 29484 FE in the form of a tetrahedron (Fig. 3).



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Figure 2. Contact interaction of a compression ring and a discrete base

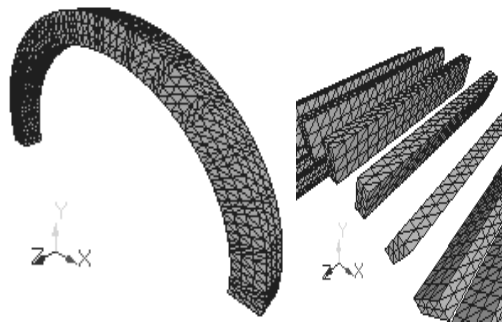


Figure 3. A discrete model of the ring and the base

Fig. 4 shows the distribution of vertical displacements w along the compression ring and the discrete base. Light grey on the compression ring area shows its backlog from the bottom (two bottom base pillars are not involved in the contact). Fig. 5 is a graph of the distribution of contact forces on the pillars, and Fig. 6 – the impact of contact force on the shape of the ring. It is clearly seen that with this type of loading, the part of the ring is behind the pillars (there are no contact forces on two pillars).

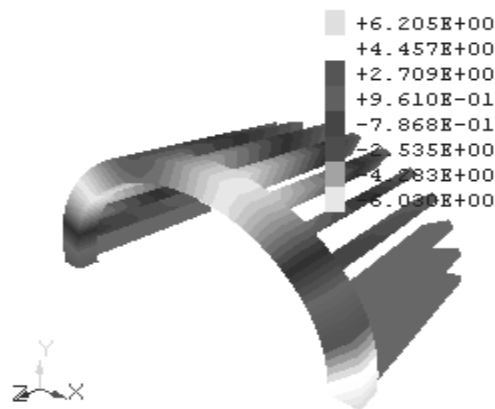


Figure 4. The distribution of displacements w in the ring and the base

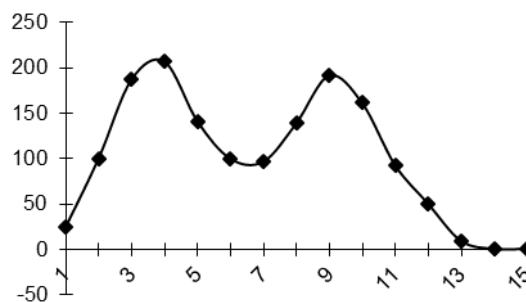


Figure 5. The distribution of contact forces on the pillar's base

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Figure 6. The distribution of contact forces on the ring

Fig. 7 is an enlarged view, showing a gap between the ring and pillars.

The comparison of the results obtained in systems FORTU-FEM and ANSYS, showed their good correlation.

IV. CONTACT INTERACTION OF THE SHELL AND CRADLE

When transporting or storing in a horizontal position shell structures are set on circular columns – cradles (Fig. 8.). Interaction of reinforced shell structures and cradles through pillar's frames whose length along the axis of the shell is comparable with the width of cradles, but less than the radius of the shell and the size of the contact area.

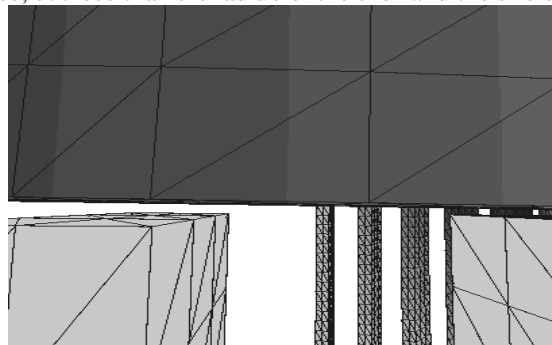


Figure 7. The lagging of the ring from the bottom

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Figure. 8. The distribution of stresses in the inclusion zone

This task was solved with the help of FORTU-FEM system in three-dimensional setting for the three cases: in one, two and three cradles according to the length of the shell (Fig. 9).

The distribution of contact forces depends on the hardness of the cradle, place of application of concentrated reactions (the angle of placing the pillar of the cradle β) and the cradle's angle of contact α .

In case of equal radii of curvature of contact surfaces, the shell structure and the cradle along the axis of the shell and at a constant length along the axis of the shell cradle, the angle of contact defines the boundary of the contact area. The value of the contact area can only decrease due to the lag of the support bulkhead from the cradle [10]. The solution to this task lies in the selection of design parameters that minimize the area of the shell gap from the cradle.

Fig. 10 shows the finite element model of the shell and the different cradles. A discrete model of the shell consists of 5904 nodes and 17280 FE (finite elements) in the form of a tetrahedron. Overall dimension of the problem for the shell and a cradle is 7462 nodes and 21,600 FE.

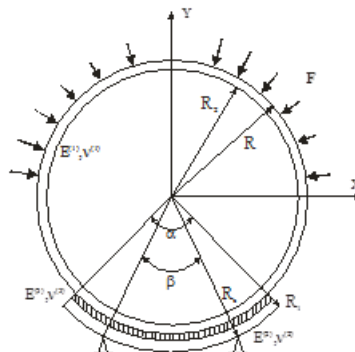


Figure. 9. Contact interaction of the shell and cradle

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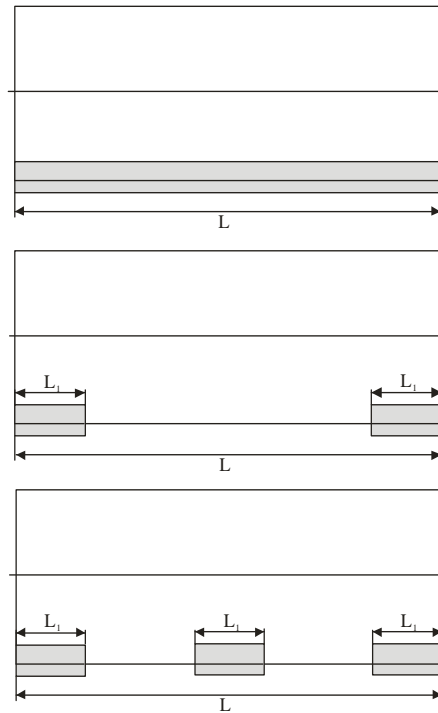


Figure 10. Various forms of cradles

The task was solved with the following geometric parameters: $R = R_c = 1.5$ m, $R_1 = 1.6$ m, $R_2 = 1.4$ m, $L = 10$ m, $L_1 = 1$ m.

Fig. 13 shows the distribution of the vertical component of displacement v along the shell and the cradles.

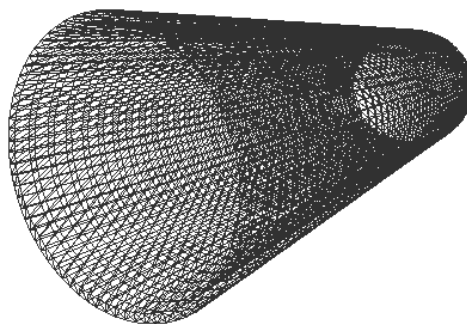


Figure 11. A discrete model of the shell

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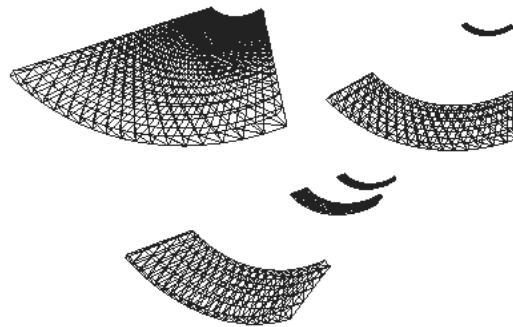


Figure 12. A discrete model of cradles

In the case of a single cradle the solution obtained with the help of FORTU-FEM qualitatively coincides with the known solution for the planar case, described in [8, 9].

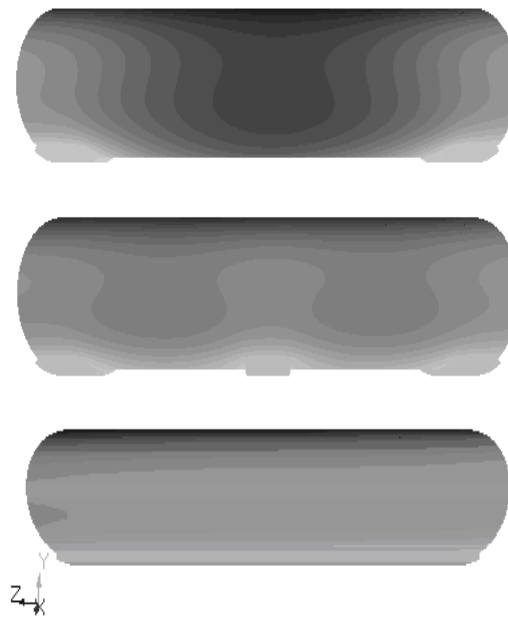


Figure 13. The distribution of displacements v

It was also shown that in $\frac{E_1(R-R_2)^3}{E_2(R_1-R)^3} \approx 10^{-2}$ the contact efforts will be focused only on the edges of the contact area.

To change the nature of the contact between the skin and the cradles a soft elastic layer is introduced. Fig. 14 shows the distribution of displacements on v and cradle's shell, as well as on the aluminium interlayer ($R = 1.5$ m, $R_1 = 1.8$ m, $R_2 = 1.4$ m, $R_c = 1.6$ m, $L = 10$ m, $L_1 = 1$ m) in the case of two cradles. Fig. 15 shows graphs of the distribution of contact forces over the layers of cradles.

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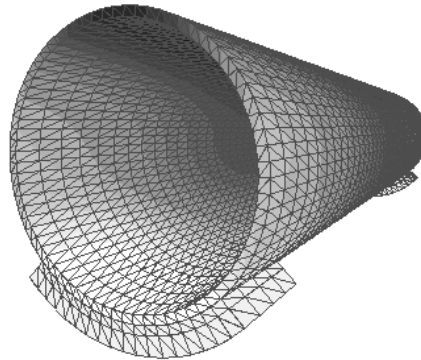


Figure 14. The distribution of displacements along the shell, the interlayer and the cradle

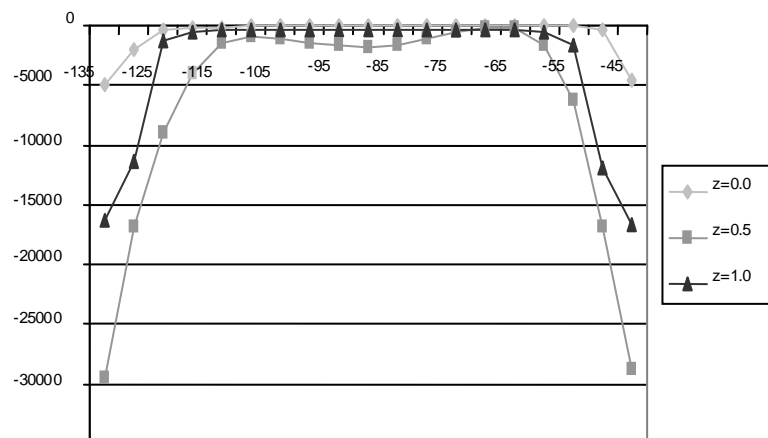


Figure 15. The distribution of the contact forces

V. . CONCLUSIONS AND PROSPECTS FOR THE FUTURE RESEARCH

The given analysis of the problems of development of the CAD systems for designing non-standard constructions from elastomers allows to draw the next conclusion. The methods of calculation of the tensional and the deformed states of constructions from elastomers become more and more complex, starting from formulation of tasks, and finishing by the implementation and analyses of the solutions. The necessity of the consideration of complex tasks, especially in the domain of mechanics of elastomers, requires the development of the open CAD systems, allowing to find the solution by the combination of different methods and approaches. And so, the main direction of our work is the further developing the CAD system, allowing to its users to define the new effective methods of calculations.

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