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Computer Modeling of Inhomogeneous Media Using the Abaqus Software Package

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Keywords: rectangular plate, a modelling, an inhomogeneous environment, a coordinate system x, y, z, a thickness rectangular plate, radius rectangular plate, boundary conditions, software, finite element method, posterior error estimators, triangulation, step-by-step adaptation.

Abstract. The article describes in detail the process of modelling an inhomogeneous environment (in particular, rectangular plate). It should be noted that the modelling of a rectangular plate is justified by the Kirchhoff – Love methods. A special feature of this simulation with the intervention of the Abaqus software package was installed for the first time the setting of different steps at different points in time. We also constructed H-adaptive schemes of finite element methods and their triangulation with different steps and with pre-guaranteed accuracy. When adapting the grid at the places of the greatest errors, a local thickening of the Triangle grid was observed, which ultimately determines that the structure of the desired solutions contains features in the edges of the vertices of the fixed edge. We also found that the proximity to linear growth of the number of nodes and finite elements in the initial stages of adaptation slows down their growth in the final stages. It should also be noted that the proposed H-adaptive schemes of ITU using the Abaqus software package with pre-guaranteed accuracy of calculating approximations showed satisfactory results, since they obtained a final deviation error of 2%. It should be noted that the results obtained with the interventionof the ABAQUS modelling software environment provides an opportunity to study and predict the patterns of structure formation and properties of a structurally inhomogeneous medium (rectangular plate), taking into account the size of structural elements, establishing correlations between components and structure. Also, a detailed description of the step-by-step adaptation results allowed us to generate the reliability of the proposed schemes with different steps.

1 Introduction

Over the past twenty years, computer and information technologies have formulated scientific and technological progress and created the Information Foundation for the development of science [1, 2, 3]. The use of modern software in the study of scientific and engineering problems allowed us to gain a dominant position using the finite element method (FEM) [4, 5, 6]. A successful alternative to it now consists of methods of Limit Integral Equations (LIE) [7, 8, 9]. We can also cite cases when the cooperation of these numerical methods for variational and Integral Equations led to the successful solution of complex problems in the field of computer and mathematical modelling [10, 11], while demonstrating its relevance to research [12, 13].

The development of these fundamental problems is far from final solutions, but the significant achievements of the last twenty years have led to the establishment of two important concepts [14, 15]: 1) stabilized FEM schemes, in which ensuring stability does not underestimate the orders of accuracy of approximations [16]; 2) adaptive FEM schemes, which have established a close relationship between the posterior errors of the obtained approximate solutions and strategies for adapting numerical schemes [17, 18]. On the other hand, the application of Integral Equations involves proving equivalence theorems, as well as constructing and justifying approximate schemes for solving Integral Equations of different classes in the substantially spatial case, complicated by the different nature of nonlinearities, in the presence of open integration surfaces [19, 20]. In addition, various direct and inverse non-stationary problems remain relevant, to which the methods of LIE can be effectively applied [21, 22]. In this regard, there is a need to create perfect numerical methods for solving the corresponding evolutionary problems by computer modelling methods using one - and two-dimensional Integral Equations with different indicators and types of singularities in inhomogeneous media. Thus, the use of computer modelling based on finite element methods and methods of boundary Integral Equations is an urgent task today, as it will allow us to qualitatively investigate and predict the main indicators of the final result.

2 Main Part

Analysis of the structure of various environments using computer technologies was carried out by scientific teams led by [23] and many others [24]. The peculiarity of these works is that with the help of certain mathematical models [25], software packages, as well as developed algorithms, the structure of already formed structurally heterogeneous environments [26, 27] is considered. Traditional processes are mainly characterized by a regulated sequence of certain operations, such as [28, 29]: obtaining an inhomogeneous medium (material), forming, finishing, studying basic properties using finite element methods with software intervention, etc. [30, 31]. Each of these stages significantly affects the quality of the final result, and therefore, among the new and modern conditions of our time, it is important to use computer modelling, which is based on the finite element method, as well as with the help of which it is possible to qualitatively study and predict the main indicators of the final result.

Objective: to substantiate the possibilities of using the Abaqus software package for predicting the structural characteristics of an inhomogeneous environment. And also, build H-adaptive schemes of ITU and their triangulation with different steps using the ABAQUS software package with pre-guaranteed accuracy.

Materials. Modelling was performed in the Abaqus software package, which has the following modules: Part, Property, Assembly, Step, Interaction, Load, Mesh, Job, Visualization, Sketch. To simulate a structurally inhomogeneous environment, we used the Visualization module. As a sample, a rectangular plate was used, which was developed in the coordinate system x, y, z, thickness H (h) and radius R. It should be noted that a rectangular plate is an object that is bounded by two planes, the distance between which (the thickness between the planes) is much smaller than its other dimensions. From the point of view of modelling, a plate can be considered as a partial case of a shell with certain radii of curvature, which tend to infinity in magnitude and the final result of which should be the use of the finite element method. In Figure 1 shows a simulation of a rectangular plate in the coordinate system x, y, and z, as well as thickness H (h) and radius R.

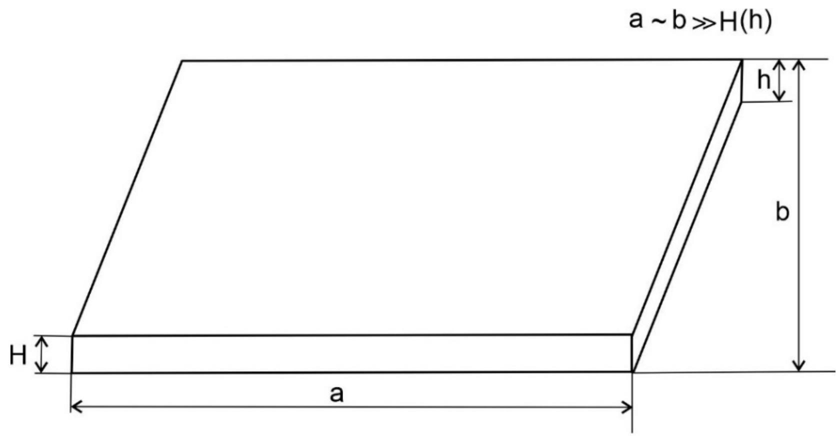

Fig. 1. Modelling of a rectangular plate in the *x*, *y*, and *z* coordinate system

Structural elements are represented as piezoelectric plates of the same thickness δ and radius $r_0 \leq R$. The outer and inner surfaces are bordered by a passive layer that is coated with infinitely thin solid electrodes. The plate is affected by an axisymmetric surface pressure evenly distributed along the radius $P = P_0 \cos(\omega t)$, which changes over time t with a circular frequency ω close to the natural frequency. In addition, the functions of electrical potentials $\psi(h/2 + \delta) - \psi(-h/2 - \delta) = R_e(2\, V_a^{iwt})$ with the mechanical load frequency, where: $V_a = V_a' + i\, V_a''$, and the perturbation process occurs. Modeling the behavior of a rectangular plate is based on the Kirchhoff – Lav hypotheses, and is reduced to solving Ordinary Differential Equations.

Using the Visualization module of the Abaqus software package and the above material, we analyzed the vibrations of a rectangular plate, the results of which are shown in (Figure 2, 3, 4, and 5).

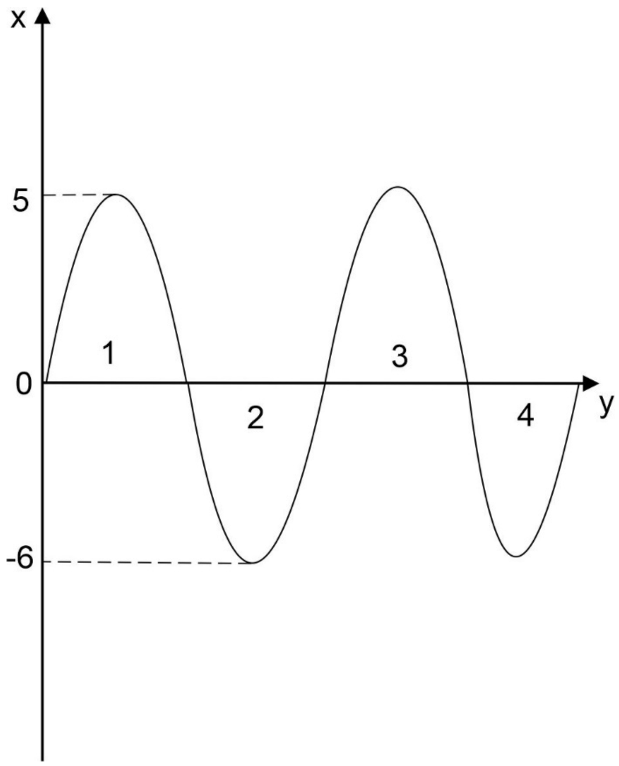

Fig. 2. Vibrations of a rectangular plate at a time t = 2 ºC

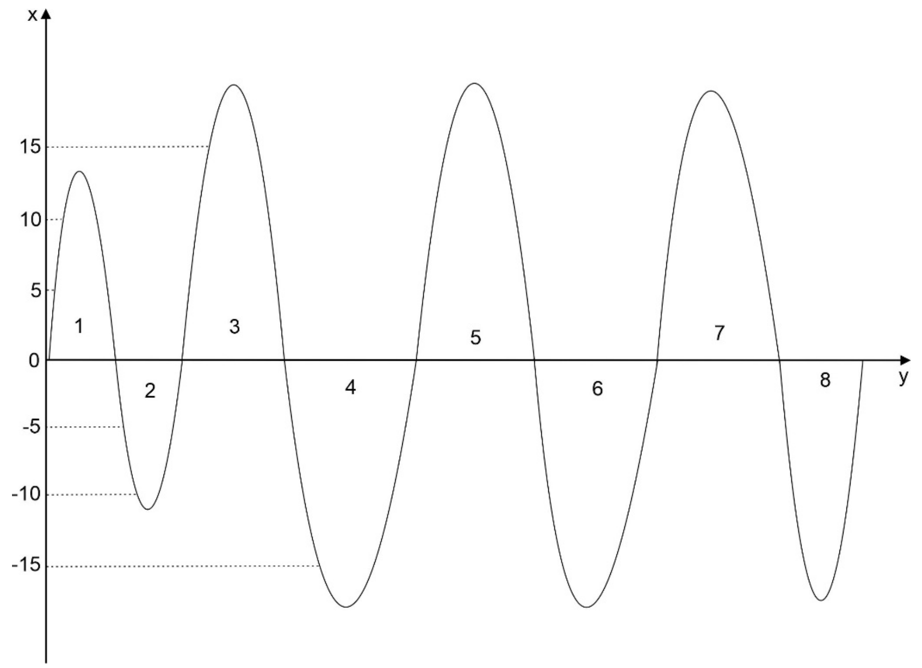

Fig. 3. Vibrations of a rectangular plate at a time t = 5 ºC

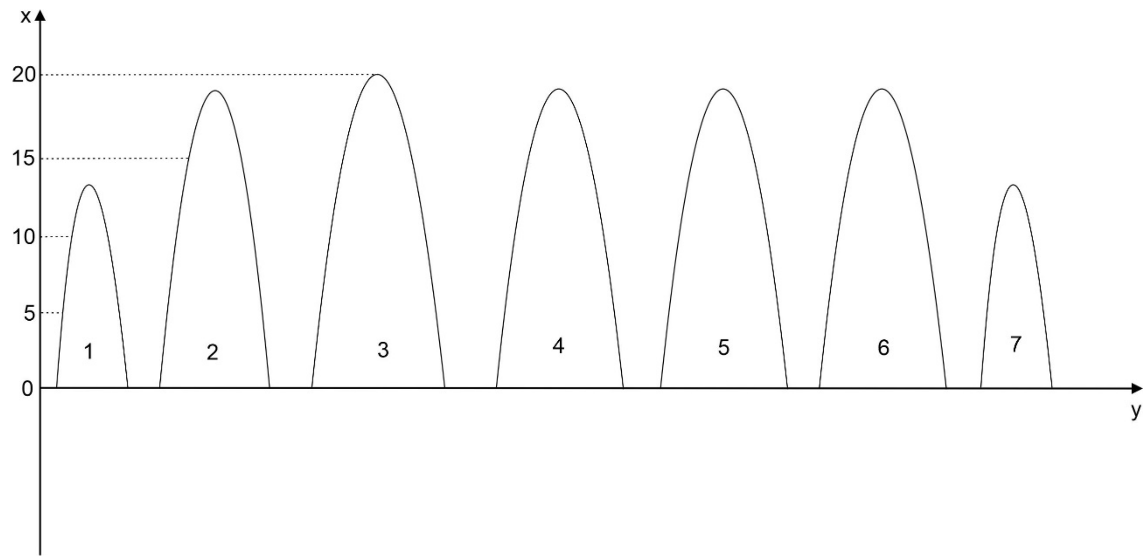

Fig. 4. Vibrations of a rectangular plate at a time t = 10 ºC

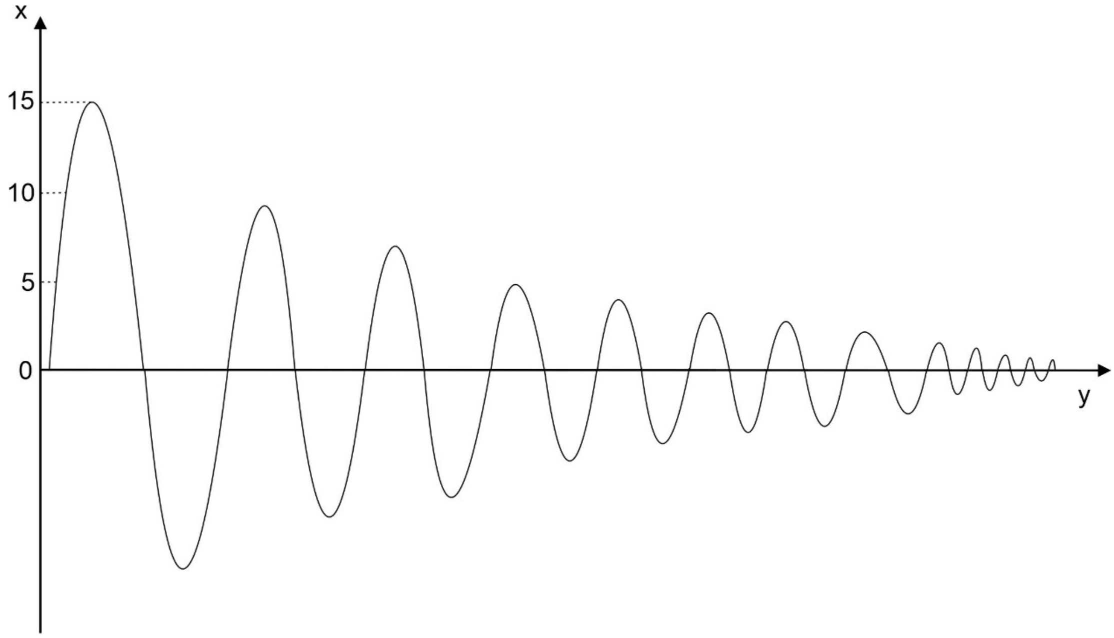

Fig. 5. Vibrations of a rectangular plate at a time t = 15 ºC

It should be noted that from Fig. 2, 3, 4, and 5 show that the rectangular plate shows the results of oscillation at time points: t = 2 °C, t = 5 °C, t = 10 °C, and t = 15 °C. Planar structural elements of an inhomogeneous medium were given with a small thickness compared to other measurements. It should also be noted that the typical ratio of plate thickness to rectangular plate width is less than 0.1.

Tests. From the material discussed above, we examined our rectangular plate, which was made of an inhomogeneous material (lithium niobate), measuring 2×2 cm, one side of which was fixed and grounded, that is, equal to: Ω = (0,002)×(0,002). The following parameters were also set: u (x, 0) = 0, p (x, 0) = 0. On the vertical side, x = 0.01 and there was a force that was equal to: g = 5·106 Н/м^2. The initial triangulation consisted of 32 finite elements. In this case, using linear approximations generates 25 nodes. It should also be noted that the accuracy level was set to 5 %. Figures 6 and 7 show triangulations that were obtained as a result of adapting the grid in places with the greatest errors. As expected, the highest error values are recognized by PEE (a posteriori error estimators) on the elements around the fixed boundary. Actually, on their set, a local thickening of the grid of triangles occurs sequentially, which ultimately identifies that the structure of the desired solutions contains features in the vicinity of the vertices of the fixed edge. Moreover, the difference in the structures of the constructed grid at the edges of these vertices clearly indicates a difference in the local behaviour of the solution in these regions: the node distribution control system thickens the grid near the loaded edge of the plate. In Fig. 6 and 7 present the obtained triangulations with k = 0 and k = 3 in the Abaqus software package.

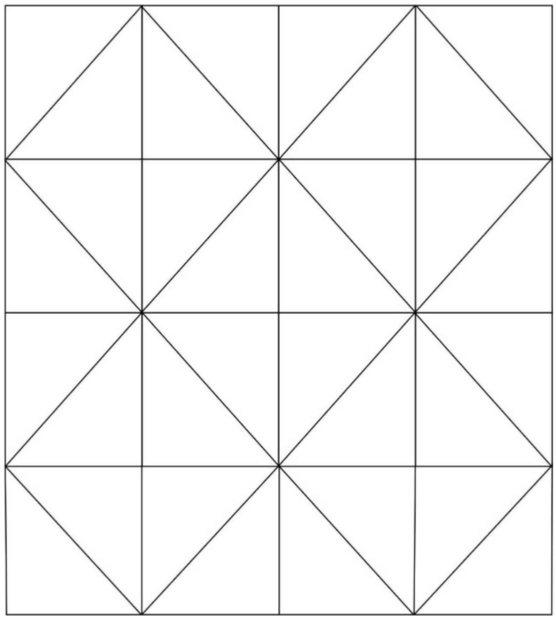

Fig. 6. Constructed triangulations with k = 0

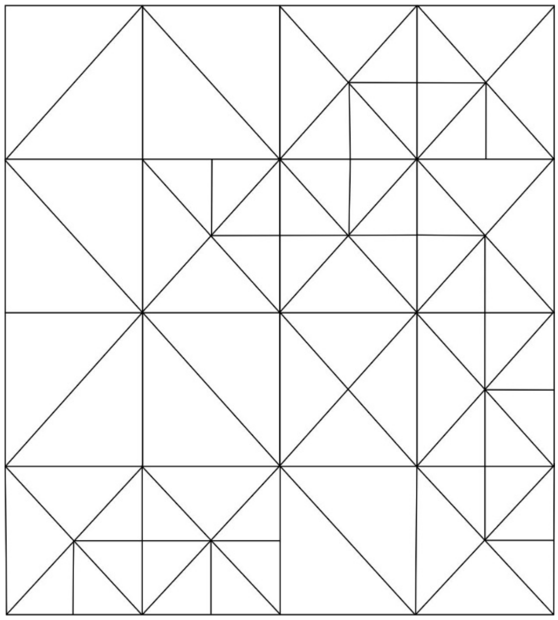

Fig. 7. Constructed triangulations with k = 3

The resulting graph, which is shown in Fig. 6 shows that the proximity to linear growth of the number of nodes and finite elements in the initial stages of adaptation slows down their growth in the final stages. In accordance with this, the calculated values of the energy norm of the FEM approximations monotonically increase, which in the last steps coincide with an accuracy of 6 Significant Digits. Therefore, the sequence of relative errors forms a non-increasing numerical sequence that decreases with increasing divisions, which is shown in Figure 7. In Fig. 8 and 9 represent triangulations with k = 6 and k = 9.

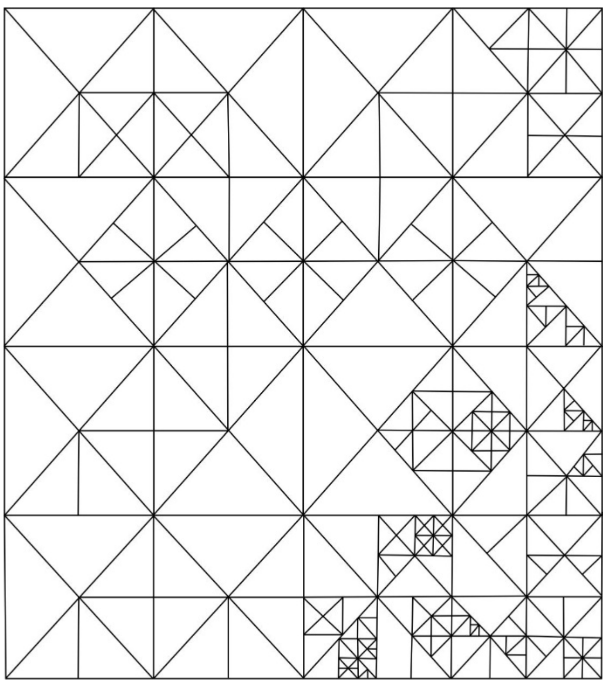

Fig. 8. Constructed triangulations with k = 6

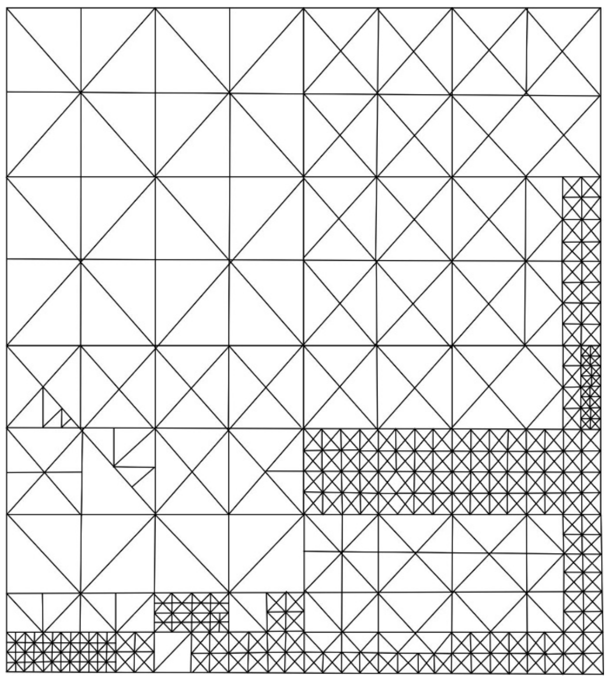

Fig. 9. Constructed triangulations with k = 9

From the above experimental results, we present a step – by – step adaptation, the results of which are presented in the form of Table 1. It should be noted that k – is the number of the adaptation step; M_h – is the number of finite elements; N_h – is the number of division nodes.

Table 1. Step-by-step adaptation results

k	N_h	M_h	$min\ h_k$	$max\ h_k$	$\|\delta_h\|F \times 10^{-6}$	$\|e_h\|F \times 10^{-6}$	δ_h, [%]	p_h
0	25	32	0.35355	0.35355	294878	26243	8.9	
1	36	52	0.17678	0.35355	307219	18547	6.0	1.90
2	52	77	0.12500	0.35355	312277	16146	5.2	1.33
3	71	109	0.08839	0.35355	313242	16349	5.2	0.91
4	92	144	0.04419	0.35355	315418	12628	4.0	1.12
5	111	171	0.03125	0.35355	315680	12497	4.0	0.99
6	126	196	0.02210	0.25000	316217	11248	3.6	1.05
7	139	216	0.02210	0.25000	316551	11283	3.6	0.98
8	157	247	0.01563	0.25000	316964	11042	3.5	0.94
9	178	281	0.01105	0.25000	317252	10519	3.3	0.93
10	189	301	0.01105	0.25000	317407	10447	3.3	0.91
11	203	326	0.01105	0.25000	317548	10132	3.2	0.91
12	215	346	0.00781	0.25000	317744	9739	3.1	0.92
13	227	367	0.00552	0.25000	317823	9487	3.0	0.92
14	237	385	0.00552	0.25000	317964	9262	2.9	0.92
15	243	397	0.00552	0.25000	318041	9282	2.9	0.91
16	251	411	0.00552	0.25000	318089	9105	2.9	0.92
17	252	412	0.00552	0.25000	318089	9091	2.9	0.93

In Figure 10 and 11 present the results of step-by-step adaptation.

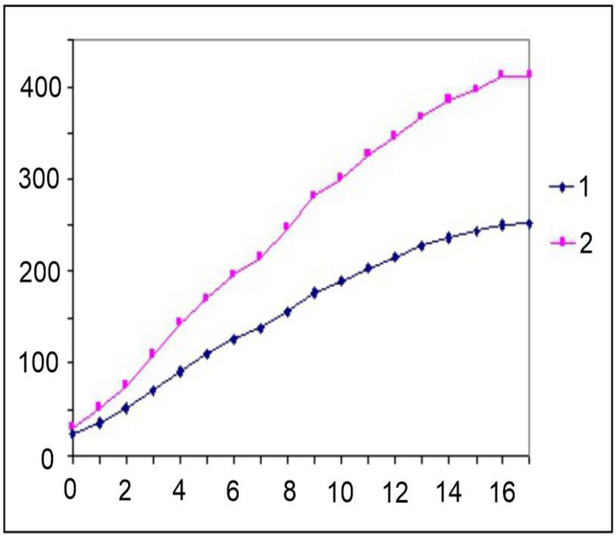

Fig. 10. Convergence of recurrent separation adaptation using the Abaqus software package, where: 1 – M_h, 2 – N_h

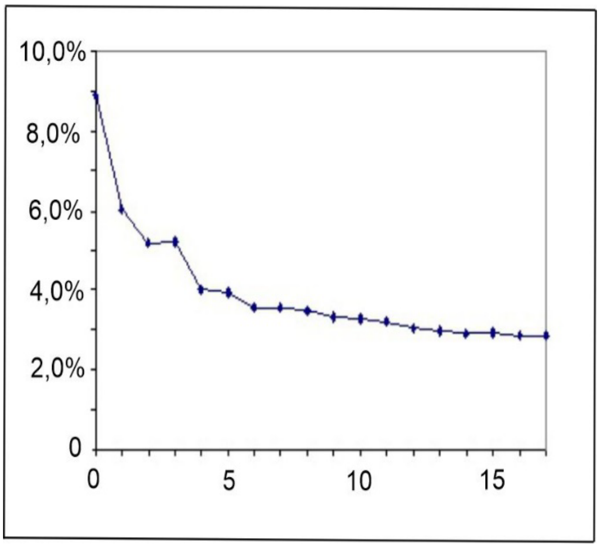

Fig. 11. Results of convergence of relative errors δ_h

Consequently, the proposed h-adaptive schemes of FEM using the Abaqus software package for solving two-dimensional stationary problems with pre-guaranteed accuracy of approximation calculation showed satisfactory results, since they obtained a final deviation error of 2 %. Also, a detailed description of the step-by-step adaptation results allowed us to generate the reliability of the proposed schemes with different steps.

3 Conclusion

The organization of the ABAQUS modelling software environment provides an opportunity to study and predict the patterns of structure formation and properties of a structurally inhomogeneous medium, taking into account the size of structural elements, establishing correlations between components, structure; and is also used to analyze the stress-strain state under mechanical and thermal loads, the basis for which is the finite element method (FEM). Also, the article describes in detail the process of modelling an inhomogeneous environment (in particular, rectangular plate). It should be noted that the modelling of a rectangular plate is justified by the Kirchhoff – Love methods. A special feature of this simulation with the intervention of the Abaqus software package was installed for the first time the setting of different steps at different points in time. This made it possible to reduce time spent on conducting large-scale experiments. It should also be noted that computer modelling of inhomogeneous media using the Abaqus software package for the use of FEM can solve a number of problems:

1) ensuring an appropriate margin of stability of approximations in order to guarantee their reliable application to a wide range of problems, in particular, singularly perturbed ones;
2) ensuring the efficiency of calculating FEM approximations with a pre - set accuracy;
3) vary the variational formulation of the problem based on the properties of bubble functions within acceptable limits;
4) predict the main indicators of the final result;
5) prediction of the patterns of formation of the structure of inhomogeneous environment, taking into account the sizes and shapes;
6) establishment of correlation relations between components, structure and properties of structurally inhomogeneous environment (in particular, rectangular plate).

To obtain more reliable data, we plan to make a description material models in the finite element package, the dimension of the problem. This will enable more accurate results. Also, this will make it possible to improve the mathematical model and obtain more adequate results.

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