Розглядаються сучасні методи і засоби вирішення задачі розрахунку напружено-деформованого стану палубних елементів суден. Проведено аналіз сучасних методів оцінки напружено-деформованого стану суднових пластин на стадії проектування і експлуатації судна. Для цього в якості огляду розглянуті основні програмні комплекси, що дозволяють проводити подібні розрахунки, їх позитивні і негативні сторони. Наведені основні етапи створення програмного забезпечення для проведення розрахунків, заснованих на використанні системи Кармана

Ключові слова: суднові пластини, напружено-деформований стан, система диференціальних рівнянь Кармана, метод кінцевих різниць

Рассматриваются современные методы и средства решения задачи расчета напряженно-деформированного состояния палубных элементов судов. Проведен анализ современных методов оценки напряженно-деформированного состояния судовых пластин на стадии проектирования и эксплуатации судна. Для этого в качестве обзора рассмотрены основные программные комплексы, позволяющие проводить подобные расчеты, их положительные и отрицательные стороны. Приведены основные этапы создания программного обеспечения для проведения расчетов, основанных на использовании системы Кармана

Ключевые слова: судовые пластины, напряженно-деформированное состояние, система дифференциальных уравнений Кармана, метод конечных разностей

UDC 51–74
DOI: 10.15587/1729-4061.2016.66029

RESEARCH OF THE STRESS-STRAIN STATE OF THE CONTAINER SHIP DECK ELEMENTS USING THE KARMAN DIFFERENTIAL EQUATION SYSTEM

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1. Introduction

Structural mechanics of the ship, as an independent science, started at the beginning of the XX century. Based on previous knowledge of the theory of elasticity, the first rules of allowable stresses for surface ships were proposed, strength and stability evaluation methods of the marine floors and backed plates were developed [1]. Most calculation methods have not changed significantly but have been tested in a number of experimental tests and structured in the form of formulas and tables of acceptable values. All of this documentation can be found on the website of the Russian Registry of Shipping [2].

2. Analysis of published data and problem statement

Investigation of the stress-strain state of deck structures is an integral part of the design and operation of the vessel. Methods for solving such problems have appeared for a long time and continue to evolve to this day. The emergence of new methods of payment, as well as the development of the experimental base is due to the growing needs of the industry. A significant role in this development is played by rapidly evolving information technologies to simplify and accelerate many important modeling and calculation steps. The emergence of specialized software allows scientists to implement the methods that existed only on paper. The use of parallel computing technology has enabled the settlement of large-scale structures.

Most modern studies of the stress-strain state of ship structures are based on quite traditional approaches. A mathematical model of a flat slab, running on a bend, as the constructive-orthotropic plate is proposed. This method of calculating the overlap was proposed by Soviet academician in 1934 and developed further. The calculation is performed by the Bubnov-Galerkin method, using specially constructed orthonormal polynomials as basis functions. A comparison of the results of calculation of ship overlap by the proposed model in this paper and the model based on the idea of the method of Navier as the deflections of beams of the main directions and cross beams are equal at the nodal points [3].

Trigonometric methods for studying the stress-strain state of ship structures are widely used [4]. A concept of parametric design of hull structures is defined and an effective approach to solving the problems of parametric design of hull structures through the use of optimizationsearching procedures of mathematical programming apparatus is proposed. Setting and solving the problems of designing the twin side frame with optimization of the position of horizontal platforms, as well as bulkhead plates using a model of finite stiffness plate are reviewed. The problems solving is carried out with a Microsoft Excel "Search of solution" tool [5]. There are multiple examples of the use of different combinations of numerical methods and computer programs for the study of the stress-strain state of the hull elements. Modern programming techniques based on parallel computing are described [6]. The mathematical models of deformation of reinforced shells of revolution, taking into account geometrical and physical nonlinearities, development opportunities creep strain, transverse shear are shown [7]. Ribs are introduced discretely or by the method of structural anisotropy, taking into account the shear and torsional rigidity of the ribs. Three algorithms for studying the mathematical models of deformation of shells: the algorithm based on the Ritz method and iterative processes; an algorithm, based on the gradient method; an algorithm, based on the parameter continuation method are considered. The results of tests of the strength and stability of various types of shells under shear load are shown [8]. The Ritz method mentioned above formed the basis of the current study.

The problem of finding the stress-strain state of the plates for container shipbuilding is especially urgent. Containers are the most convenient to consider, since all loads are formed on the basis of the size and weight of the container. The container is essentially a standardized value and therefore the most convenient in the calculations and modeling. But the demand for these vessels also increases the demand for this type of scientific research. In our time, an economic benefit plays a special role in the transportation of goods, so one of the tasks is to test the strength characteristics of the vessel at a sufficiently high load both during loading operations and during navigation.

In the Russian Federation, the production of container ships is not sufficiently developed. Nevertheless, the use of this type of ship for the transportation of goods is increasing every year. Because of this, many foreign studies have profiled in nature and take into account the nuances of the operation of such vessels [9–11].

All this necessitates the development of research in this direction, taking into account the needs of the industry. For instance, many vessels used for loading bulk cargo, the technical reconstruction are to be used for container transport. This entails the need to develop methods for the analysis of the stress-strain state of the deck elements, taking into account depreciation, operation period and other parameters.

3. Purpose and objectives of the study

The key purpose of this paper is creating a software package, allowing the calculation of loading parameters of the container deck element. The object of research is the deck of a container, and its specific field, used for loading. This is a rather complex structure, consisting of a metal sheet and a set of cross beams forming a stiffener of this design. To simulate the process of loading, deck is considered as a finite element stiffening plate with predetermined parameters (thickness, length, width, coefficient of rigidity, etc.). The load on the plate, resulting from placement of a number of containers, will be considered as a distributed load.

In accordance with the set goal the following research objectives are identified:

– the first step is to determine the simulation partition grid scale. Computational complexity will depend on this step, but at the same time, increasing the number of nodes increases the accuracy of the values;

– the second step consists of the construction of a system of nonlinear equations by providing the system of Karman differential equations in the form of finite-difference relations;

– further, there is a substitution in these formulas of finite differences of all the known values of deflections and stresses obtained on the basis of the boundary conditions for a particular case under consideration;

– the final stage is the calculation and analysis of the values and comparison of the results with calculations obtained according to the normative-methodical materials of the Russian Maritime Register of Shipping.

4. Modern tools used in the design of ships

Ship design is a complex process that must take into account a huge number of parameters such as stability, the influence of external forces, susceptibility to corrosion, stresses arising during operation, etc. For most applications, engineering offices are increasingly using specialized software that allows you to lack the deep scientific knowledge, to make the necessary calculations.

Today, there is a large variety of such programs: ANSYS, MatLab, Comsol, WinMachine, SolidWorks, etc. All of these products are not just designs and actually use the tool based on the production companies such as ABB, BMW, Boeing, Caterpillar, Daimler-Chrysler, Exxon, FIAT, Ford, BelAZ, General Electric, Lockheed Martin, Mitsubishi, Siemens, Shell, Volkswagen-Audi and others, and used in many leading industrial enterprises of Russia [12]. The benefits of using such software solutions are quite large. This is the lack of need for a mathematical analysis of the strength characteristics of objects and elements, a visual representation of the most vulnerable areas in terms of strength, obtaining numerical values of the necessary parameters, there is no need for additional expensive and long-term experiments. But all of these advantages may give rise to negative effects. The computer power may be different, but in any case it is imperfect, resulting in computational errors, which are not possible to estimate, because the methods of calculation are hidden from the user. Lack of proper mathematical training of specialists in charge of calculation does not allow the analysis of the result values [13]. In addition, most of software is focused on the use of the Windows operating systems, which entails additional costs for companies, apart from the fact software is worth millions, not including the cost of staff training. Software products related to the free libre open-source software are less widespread. One of the brightest representatives of those is FreeFem ++, named by analogy with the language, which was written in C ++. Freefem ++ is a program designed to solve mathematical problems based on the finite element method [14]. Freefem ++ can be used on the Windows and on the Linux-based systems.

5. Mathematical model of stress-strain state of plates

There are always analytical methods to obtain the result of the formula calculation without errors or inaccuracies that may be explicitly represented and make the appropriate assessment, as an alternative to such software methods of calculation. Among the disadvantages of these methods for solving the problem is the clearly seen impossibility of creating a universal algorithm for calculation and, accordingly, the complexity of building software to solve this problem. As an example of an alternative calculation method, the finite difference method (grid method) is proposed. The idea of the finite difference method is known for a long time, with the relevant works of Euler differential calculus. However, the practical application of this method was very limited because there is a huge amount of manual calculations related to the dimension of the resulting system of algebraic equations, solving which take years [1]. Nowadays, with the advent of modern high-speed computers, the situation has changed radically. This method has become convenient for practical use, and is one of the most effective in solving various problems of mathematical physics. The object of research will be the ship plate, which simulates the flat of the ship. Traditional methods of structural mechanics of the ship in the calculation of stress-strain state are considered as an equivalent hull beam, i. e., finite stiffness beam. Mathematical laws, describing the marine plate problems, will be different from the traditional ones.

In the study of the stress state of the plates we use a Cartesian coordinate system, combining with the median plane of the XOУ plane of the plate. The theory of bending of thin plates is based on the Kirchhoff hypothesis [15]. Since the deformation of the plate w is larger than displacements u, v, all movements are considered to be small, and thus it is possible to neglect nonlinear terms with respect to u and v, and replace two members of the radical binomial. Deformation $\varepsilon_x, \varepsilon_y, \gamma_{xy}$ will have the following form:

$$\begin{cases} \varepsilon_x = \dfrac{\partial u}{\partial x} + \dfrac{1}{2}\left(\dfrac{\partial w}{\partial x}\right)^2, \\ \varepsilon_y = \dfrac{\partial v}{\partial y} + \dfrac{1}{2}\left(\dfrac{\partial w}{\partial y}\right)^2, \\ \gamma_{xy} = \dfrac{\partial u}{\partial y} + \dfrac{\partial v}{\partial x} + \dfrac{\partial w}{\partial x}\cdot\dfrac{\partial w}{\partial y}. \end{cases} \quad (1)$$

For points of plate lying in a layer of $z = \text{const}$ relation between displacements and deformations based on the hypothesis, direct normals are established. The deformations of the middle surface are related by compatibility:

$$\frac{\partial^2 \varepsilon_x}{\partial y^2} + \frac{\partial^2 \varepsilon_y}{\partial x^2} - \frac{\partial^2 \gamma_{xy}}{\partial x \partial y} = \left(\frac{\partial^2 w}{\partial x \partial y}\right)^2 - \frac{\partial^2 w}{\partial x^2}\cdot\frac{\partial^2 w}{\partial y^2}. \quad (2)$$

These dependencies are valid when the deformations are small. Let us consider a cross section perpendicular to the axis Ox and Oy. The state of stress can be characterized by the efforts of the plate (Fig. 1) per unit length of the corresponding section. All of these forces are the essence of the intensity of the forces applied to the surface of the median line after reducing its stress [1].

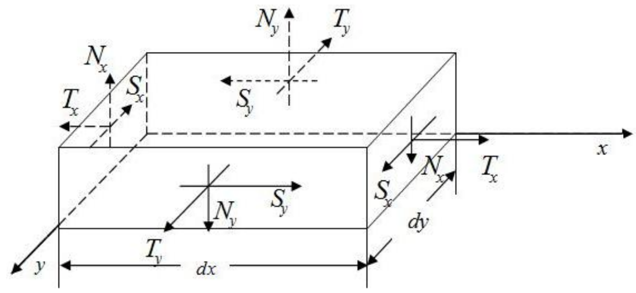


Fig. 1. Positive directions of forces in accordance with the rule of signs of stress

In Fig. 1, T_x, T_y are normal forces, shown in a relationship:

$$T_x = \int_{-h/2}^{h/2} \sigma_x dz,$$

$$T_y = \int_{-h/2}^{h/2} \sigma_y dz. \quad (3)$$

$S = S_x = S_y = \int_{-h/2}^{h/2} \tau_{xy} dz$ are shear forces, defined in sections $x = \text{const}$, $y = \text{const}$, the same formulas are determined by the law of pairing shear stresses S_x. N_x, N_y are shear forces:

$$N_x = \int_{-h/2}^{h/2} \tau_{xz} dz; \quad N_x = \int_{-h/2}^{h/2} \tau_{yz} dz. \quad (4)$$

In the sections $x = \text{const}$ and $y = \text{const}$, operating stress within the unit of length creates the following moments (Fig. 2):

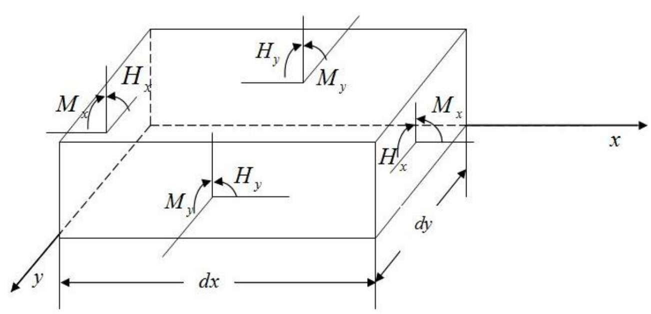


Fig. 2. Positive direction of moments

M_x, M_y are bending moments, acting in sections $x = \text{const}$ and $y = \text{const}$:

$$M_x = \int_{-h/2}^{h/2} \sigma_x \cdot z dz, \quad M_y = \int_{-h/2}^{h/2} \sigma_y \cdot z dz. \quad (5)$$

$H = H_x = H_y$ are toque moments in sections x const, $y = \text{const}$:

$$H = \int_{-h/2}^{h/2} \tau_{xy} \cdot z dz. \quad (6)$$

With the vanishing of the main vector and the main moment, we obtain the scalar equations of equilibrium:

$$\begin{cases} \frac{\partial T_x}{\partial x}+\frac{\partial S}{\partial y}=\frac{\partial}{\partial x}\left(N_x\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(N_y\frac{\partial w}{\partial x}\right)+q\frac{\partial w}{\partial x}, \\ \frac{\partial S}{\partial x}+\frac{\partial T_y}{\partial y}=\frac{\partial}{\partial x}\left(N_x\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial y}\left(N_y\frac{\partial w}{\partial y}\right)+q\frac{\partial w}{\partial y}, \\ \frac{\partial N_x}{\partial x}+\frac{\partial N_y}{\partial y}=-\frac{\partial}{\partial x}\left(S\frac{\partial w}{\partial y}\right)-\frac{\partial}{\partial y}\left(S\frac{\partial w}{\partial x}\right)-\frac{\partial}{\partial x}\left(T_x\frac{\partial w}{\partial x}\right)-\frac{\partial}{\partial y}\left(T_y\frac{\partial w}{\partial y}\right)-q, \end{cases} \tag{7}$$

$$N_x=\frac{\partial M_x}{\partial x}+\frac{\partial H}{\partial y};\qquad N_y=\frac{\partial M_y}{\partial y}+\frac{\partial H}{\partial x}. \tag{8}$$

Using the Airy stress function allows determining the stress from the formulas:

$$\sigma_x=\frac{T_x}{h}=\frac{\partial^2\Phi}{\partial y^2};\quad \sigma_y=\frac{T_y}{h}=\frac{\partial^2\Phi}{\partial x^2};\quad \tau_{xy}=\frac{S}{h}=-\frac{\partial^2\Phi}{\partial x\partial y}. \tag{9}$$

The system of equations becomes equivalent to the single equation:

$$\frac{\partial^2 M_x}{\partial x^2}+2\frac{\partial^2 H}{\partial x\partial y}+\frac{\partial^2 M_y}{\partial y^2}= =-q-h\left(\frac{\partial^2\Phi}{\partial y^2}\cdot\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2\Phi}{\partial x^2}\cdot\frac{\partial^2 w}{\partial y^2}-2\frac{\partial^2\Phi}{\partial x\partial y}\cdot\frac{\partial^2 w}{\partial x\partial y}\right). \tag{10}$$

Thus, the behavior of the plate is described by two resolving equations: the equilibrium equation (10) and strain compatibility equation (2). The left side of the equilibrium equation can be expressed only through a deformation, in the strain compatibility equation – only through the Airy function. Using the Hooke's law for isotropic materials, the strain compatibility equation (2) can be represented as follows:

$$\Delta\Delta\Phi=E\left[\left(\frac{\partial^2 w}{\partial x\partial y}\right)^2-\frac{\partial^2 w}{\partial x^2}\cdot\frac{\partial^2 w}{\partial y^2}\right]. \tag{11}$$

Introducing the expression for the bending and twisting moments in the equilibrium equation (10), we can get a differential equation of the form:

$$D\Delta\Delta w=q+h\left(\frac{\partial^2\Phi}{\partial y^2}\cdot\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2\Phi}{\partial x^2}\cdot\frac{\partial^2 w}{\partial y^2}-2\frac{\partial^2\Phi}{\partial x\partial y}\cdot\frac{\partial^2 w}{\partial x\partial y}\right). \tag{12}$$

The two equations (11) and (12) provide a resolution system of differential equations of the Karman plate theory:

$$\begin{cases} \Delta\Delta\Phi=E\left[\left(\frac{\partial^2 w}{\partial x\partial y}\right)^2-\frac{\partial^2 w}{\partial x^2}\cdot\frac{\partial^2 w}{\partial y^2}\right], \\ D\Delta\Delta w=p(x,y)+h\cdot\left(\frac{\partial^2\Phi}{\partial y^2}\cdot\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2\Phi}{\partial x^2}\cdot\frac{\partial^2 w}{\partial y^2}-2\frac{\partial^2\Phi}{\partial x\partial y}\cdot\frac{\partial^2 w}{\partial x\partial y}\right), \end{cases} \tag{13}$$

where

$$\Delta\Delta=\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)=\frac{\partial^4}{\partial x^4}+2\frac{\partial^4}{\partial x^2\partial y^2}+\frac{\partial^4}{\partial y^4}.$$

This system of equations isn't widely used for practical calculations, and its solutions brought to the numerical reference data are scarce because of the complexity of the calculations for solving systems with a large number of unknowns [1]. In modern conditions of rapid development of information technology, such calculations can be trusted computing [16].

6. Software construction and example of the proposed model

For example, implementation of the decision of the system uses the task of loading a container with some of the cargo. The "Khudozhnik Saryan" ship type was taken (Fig. 3).

It has 6 holds of various sizes (Fig. 4). Each hold has a closed hatch, which in turn is placed in the same load. The greatest interest for calculating hatches are the fourth and the third holds, as their dimensions are sufficiently large and the load is adequately high. These hatches consist of four identical elements 12.96 m long and 10.7 m wide.

Let us consider the layout of sixteen twenty-foot containers in two stacks of 8 each (Fig. 5).

In the simulation, the problem of deformation of plates of the main deck is supposed to free support, then the boundary conditions have no bending moments and deformations at the edges of the plate:

$$\begin{aligned} & w\big|_\Gamma=0, \\ & \left.\frac{\partial^2 w}{\partial x^2}+\nu\frac{\partial^2 w}{\partial y^2}\right|_{\Gamma_1}=0, \\ & \left.\frac{\partial^2 w}{\partial y^2}+\nu\frac{\partial^2 w}{\partial x^2}\right|_{\Gamma_2}=0, \end{aligned} \tag{14}$$

where Γ is the edge of the plate, and $\Gamma=\Gamma_1\cup\Gamma_2$, where Γ_1 is the edge of the plate which is parallel to the axis Oy, and Γ_2 – Ox.

Boundary conditions for the Airy function:

$$\begin{aligned} & \frac{\partial^2\Phi}{\partial y^2}\cdot\cos\left(\widehat{n,x}\right)+\frac{\partial^2\Phi}{\partial x\partial y}\cdot\cos\left(\widehat{n,y}\right)=F_1, \\ & -\frac{\partial^2\Phi}{\partial x\partial y}\cdot\cos\left(\widehat{n,x}\right)-\frac{\partial^2\Phi}{\partial x^2}\cdot\cos\left(\widehat{n,y}\right)=F_2, \end{aligned} \tag{15}$$

where F_1 and F_2 are stresses on Γ.

To solve this system, it is proposed to use the finite difference method. The idea of the finite difference method (method of grids) for the approximate numerical solution of the boundary value problem for the two-dimensional differential equation in partial derivatives is that: on the plane in the region in which the solution is sought, the grid area consisting of identical cells and is an approximation of the area is constructed; given partial differential equation is replaced by derivatives in the nodes of the grid with the corresponding finite-difference equation; taking into account the boundary conditions are set to the desired solution to the boundary nodes field.

Solving the resulting system of finite-difference algebraic equations, we obtain the values of the unknown function at the grid points, i. e. approximate numerical solution of the problem. Selecting the grid area is dependent on a specific task, but we must always strive to ensure that the contour grid area is well approximated by the contour area.

Fig. 3. The "Khudozhnik Saryan" ship type

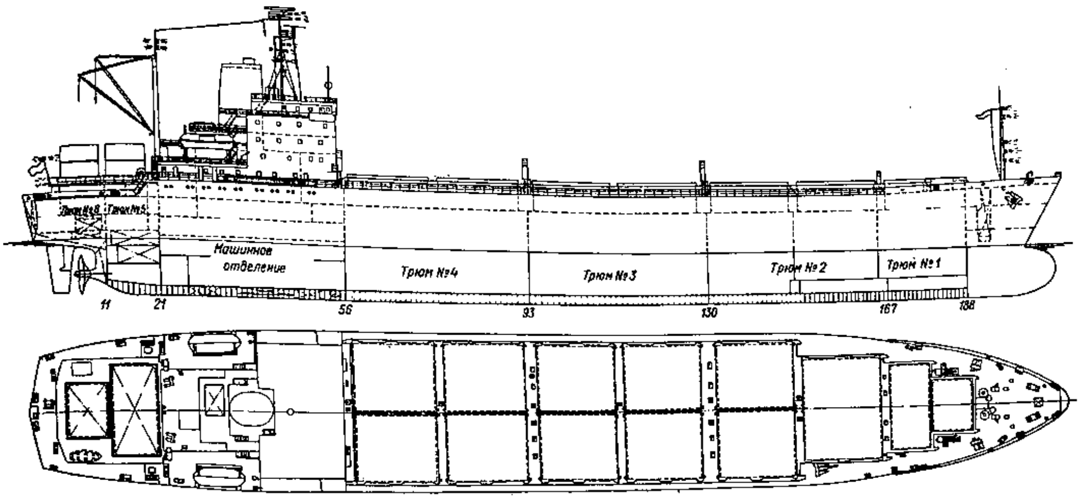


Fig. 4. The scheme of the "Khudozhnik Saryan" type ship

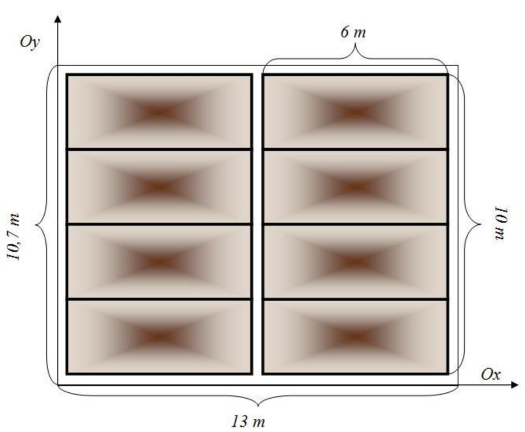


Fig. 5. The layout of containers

Replacing the system (13) of derivatives by difference quotients:

$$\frac{\partial^2 f}{\partial x^2} \approx \frac{f(x+h_x,y)-2f(x,y)+f(x-h_x,y)}{h_x^2},$$

$$\frac{\partial^2 f}{\partial y^2} \approx \frac{f(x,y+h_y)-2f(x,y)+f(x,y-h_y)}{h_y^2},$$

$$\frac{\partial^2 f}{\partial x \partial y} \approx \frac{f(x+h_x,y+h_y)-f(x-h_x,y+h_y)-f(x+h_x,y-h_y)}{h_x h_y} + \frac{f(x-h_x,y-h_y)}{h_x h_y},$$

$$\frac{\partial^4 f}{\partial x^4} \approx \frac{f(x-2h_x,y)-4f(x-h_x,y)+6f(x,y)-4f(x+h_x,y)}{h_x^4} + \frac{f(x+2h_x,y)}{h_x^4},$$

$$\frac{\partial^4 f}{\partial y^4} \approx \frac{f(x,y-2h_y)-4f(x,y-h_y)+6f(x,y)-4f(x,y+h_y)}{h_y^4} + \frac{f(x,y+2h_y)}{h_y^4},$$

$$\frac{\partial^4 f}{\partial x^2 \partial y^2} \approx \frac{f(x+h_x,y+h_y)-2f(x+h_x,y)}{h_x^2 h_y^2} + \frac{f(x+h_x,y-h_y)-2f(x,y+h_y)+4f(x,y)-2f(x,y-h_y)}{h_x^2 h_y^2} + \frac{f(x-h_x,y+h_y)-2f(x-h_x,y)+f(x-h_x,y-h_y)}{h_x^2 h_y^2},$$

we obtain the resolution of equations for each node in the grid partition.

Software was developed based on this mathematical model, which consists of two modules: user workplace and calculation module. The first module is focused on the user, therefore, it was written in the Visual Basic for Applications environment for ease of use (Fig. 6).

Thus, all the necessary data entry is done in the familiar MS Office Excel interface (Fig. 7).

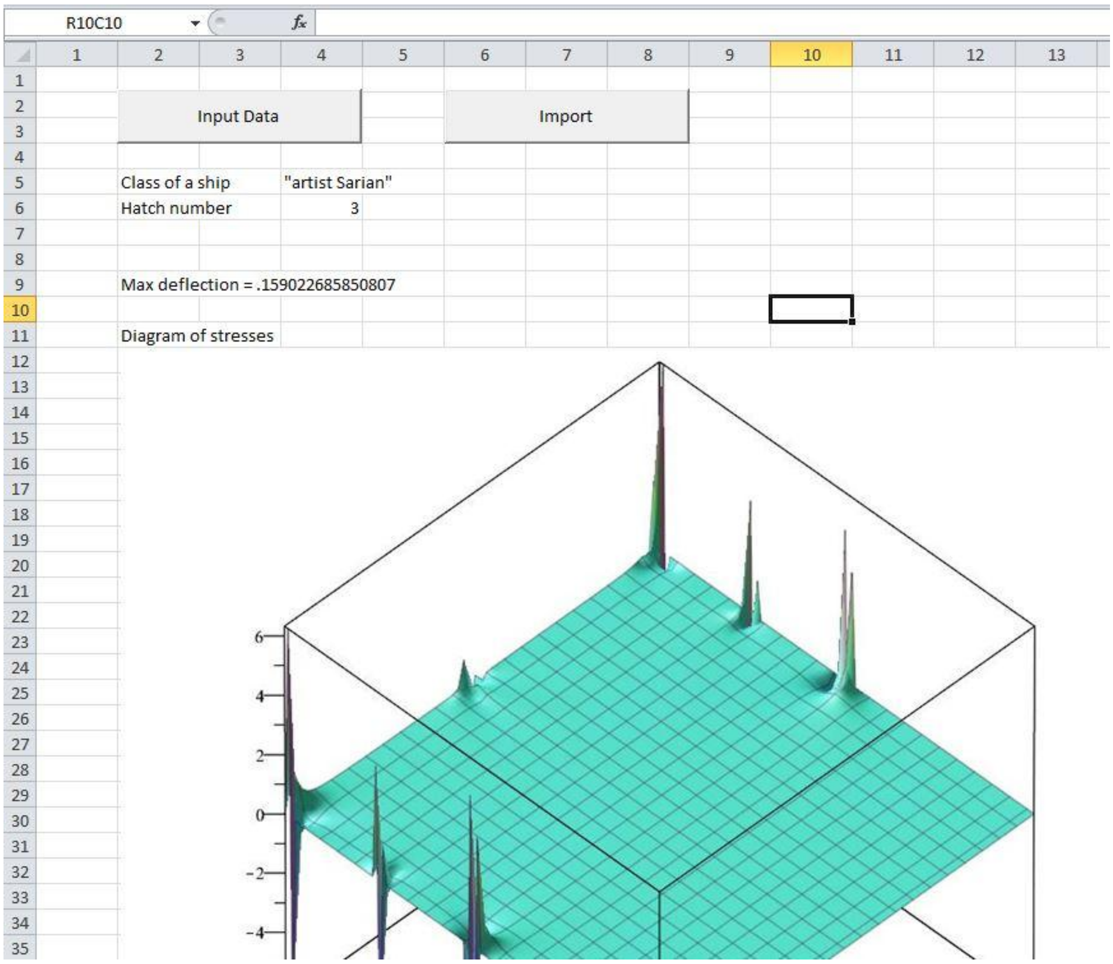


Fig. 6. User workplace module

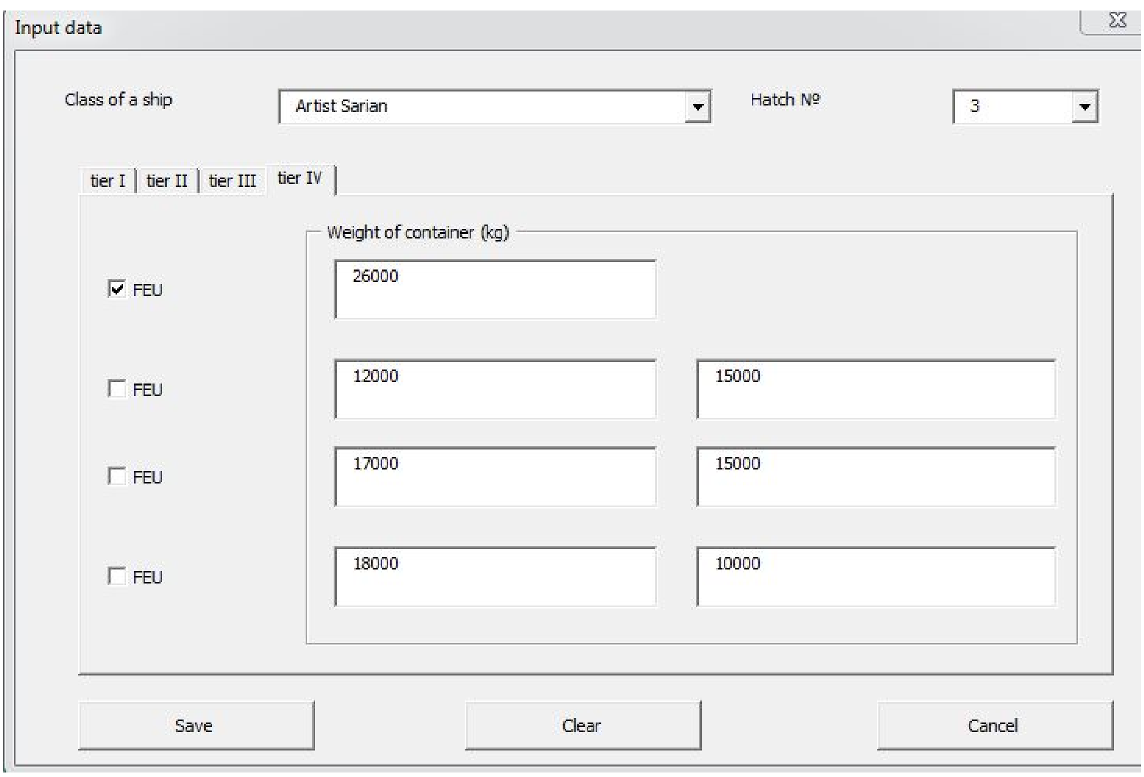


Fig. 7. Data entry window

For this, special controls were developed (buttons, windows, etc.). After the data entry and pressing the save-button, the data is formed as a package and sent to the calculation module, which carried out the necessary calculations. The calculation module was developed using the specialized mathematical software Maple (Fig. 8).

Using this software, you can get different kinds of simulation. In view of these conditions, software package was installed, as a result of which the numerical values of strain and stresses, as well as corresponding graphs were obtained (Fig. 9, *a–c*).

The figures are graphs of deflections and stresses resulting from loading. There are is a diagram of the strain state on Fig. 9, *a*, and on Fig. 9, *b*, *c* we can see the graph of stresses. For the diagram of stresses, as the values of the axes, grid partitioning steps are used ($\frac{X}{h_x}$ and $\frac{Y}{h_y}$, where and Y are the parameters of the plate, h_x and h_y are the steps for the grid). The maximum deflection in this example (with step $h_x = 0.2$ and $h_y = 0.1$) was 0.159022 meter and the highest stresses is achieved at the corners of the plate and maximum stresses were 5.7324 MPa.

Also, in addition to the critical points and the graphic representation of the current load, all the calculated coordinates of the grid nodes of the partition are saved as a separate text file (Table 1, 2).

Table 1

The values of deflection

The values of deflection, w (m)							
grid point	0	1	2	3	4	...	107
0	0	0	0	0	0	...	0
1	0	0.00043379	0.00086647	0.00129695	0.00172423	...	0
2	0	0.00086400	0.00172584	0.00258324	0.00343427	...	0
3	0	0.00128639	0.00256962	0.00384641	0.00511391	...	0
4	0	0.00169794	0.00339180	0.00507743	0.00675113	...	0
5	0	0.00209632	0.00418773	0.00626930	0.00833652	...	0
6	0	0.00247965	0.00495367	0.00741635	0.00986251	...	0
7	0	0.00284643	0.00568654	0.00851398	0.01132288	...	0
8	0	0.00319537	0.00638381	0.00955835	0.01271252	...	0
...	...	...	...	...	...	...	0
65	0	0	0	0	0	0	0

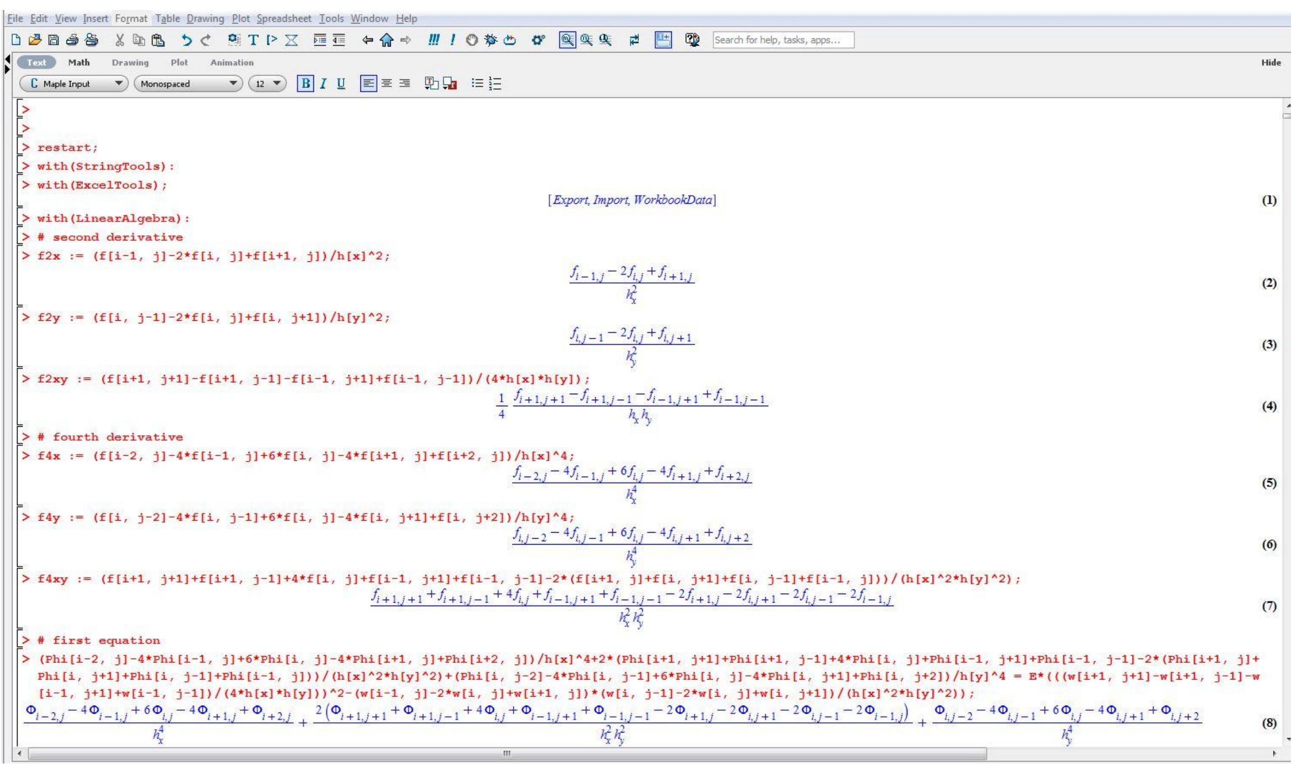
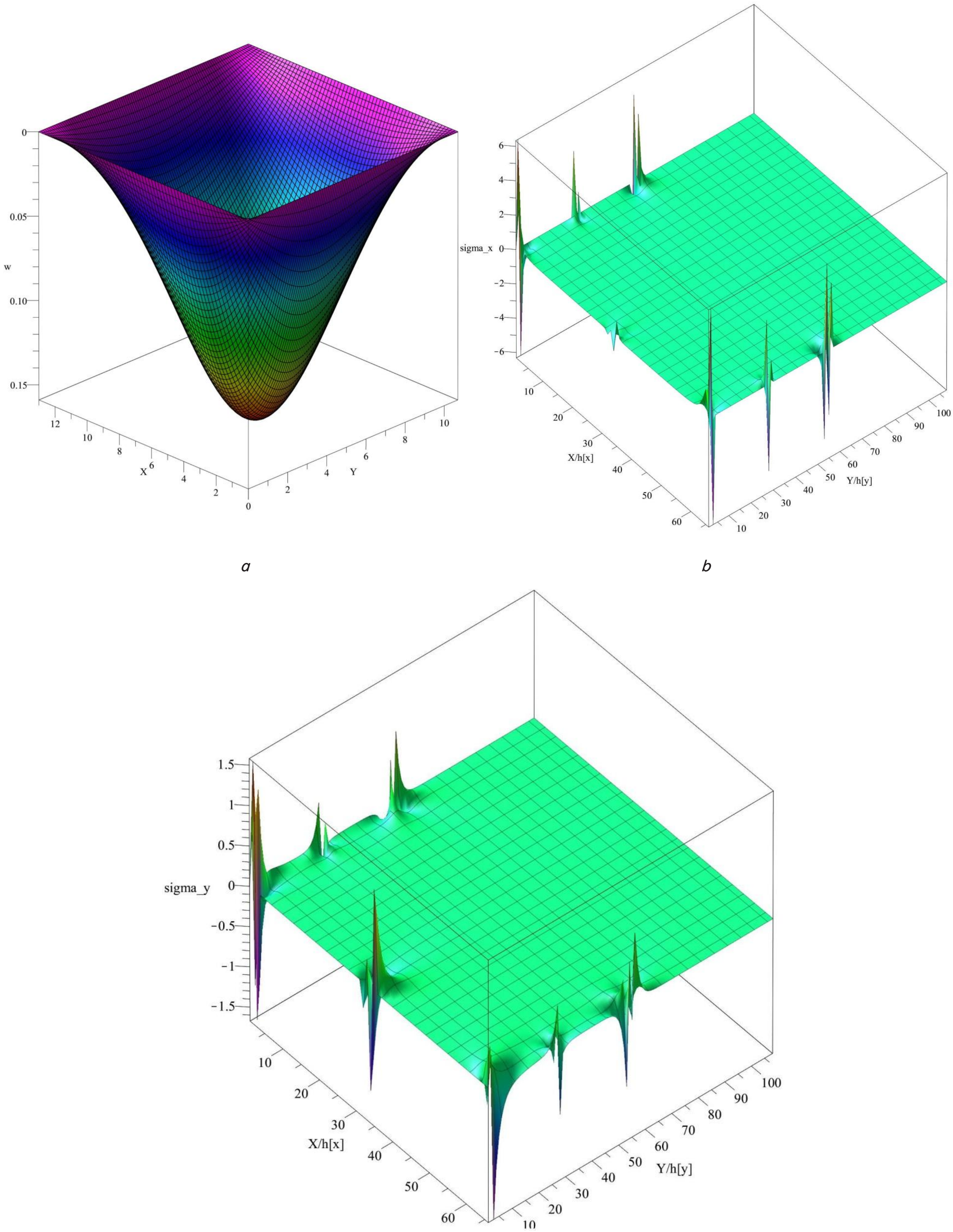


Fig. 8. Maple-based calculation module



a *b*

c

Fig. 9. The diagrams of the results: *a* — strain state, *b* — graph of normal stresses (sigma_x),
c — graph of normal stresses (sigma_y)

Table 2

The values of stresses

The values of stresses (MPa)			
grid point	sigma_x	sigma_y	tau_xy
[0, 0]	0	0	0
[1, 0]	2.44590902	1.58065443	0
[2, 0]	–0.50252158	–1.58065443	0
[3, 0]	0.15767301	0	0
[4, 0]	0.10809930	0	0
[5, 0]	0.05684742	0	0
[6, 0]	0.03123504	0	0
[7, 0]	0.01882148	0	0
[8, 0]	0.01253101	0	0
[9, 0]	0.00917052	0	0
[10, 0]	0.00726727	0	0
etc	...	...	...

In order to know the numerical value of a quantity, it should be multiplied by the corresponding coordinates of the step. For example, the quantity of deflection in the point with coordinates (6.8 m; 0.1 m) will be equal to w [34, 1]=0.00501182.

For analysis of the results, we can use a collection of normative-methodical materials [2]. In the eleventh book, there is a section devoted to the calculation of the strength characteristics of the vessel and evaluation of the calculation results. According to these materials, the maximum allowable normal stresses are calculated according to the formula (16).

$$\sigma_Э = 0{,}19 n_\sigma \left(s'/b\right)^2, \qquad (16)$$

where s' is the actual thickness of the plate; b is the lower side of the plate; n_σ is the type of loading.

In our case, $n_\sigma = \dfrac{8{,}8}{\psi + 1{,}1}$, where $\psi \in [0;1]$.

Calculating the value of this formula, we obtain the value of maximum stress of 7,7727 MPa, which does not exceed the values, which we get from our program.

5. Conclusions

As a result of this work:

1. The field of the study was defined. The object of the study is the container ship deck element. The plate that is rigidly fixed on the perimeter, so the boundary conditions are appropriate values.

2. For the convenience of calculation, the optimum grid spacing was determined, in order to approach the real values. The used step allowed accurate calculation of the partition, but this step can be increased if necessary, but in this case, and the calculation time will increase considerably.

3. Software which can automate the process of calculation and visualization of results was developed. With the use of a program complex test calculations and presented the results of the stress-strain state were held. Calculations were carried out in accordance with the collection of normative-methodical materials. The results were compared, with the result that it can be stated about the possibility of the proposed method of calculation.

4. This calculation was carried out without taking into account the cross-beam set for which the plate is mounted. Accounting for this fact affects the result and thereby improve the accuracy. Given all the design features of the deck, it is possible, on the basis of the proposed models to create a universal software to calculate the fatigue-stress state of the deck of a ship, and to choose the right function of the load can be seen loads of any type, not just the container. The data obtained will help to draw a conclusion not only on the current loading of the deck element, but also to assess the likelihood of damage in the future and the need to take appropriate measures.

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