Modern methods and analysis means of stress-strain state of ship structures

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Abstract
The article considers the problem of calculating the stress-strain state of deck elements used for loading. The analysis of modern methods of evaluation of the stress-strain state of ship plates at the design stage and the operation of the vessel. For this, as survey shows the basic software package that allows to carry out such calculations, their positive and negative sides. Based on the fact that most modern calculation methods do not allow an adequate assessment of the error and the physical representation of what is happening, made an attempt to form an algorithm for constructing a software system to solve the problem, based on the solution of the finite difference method of the system of differential equations of Karman, the advantage of which is the simultaneous production of strain and stresses arising in this unit. The results of the operation of such software is presented with plots.
Keywords: SHIP PLATE, STRESS-STRAIN STATE, KARMAN'S SYSTEM

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 IG Bubnov were offered the first rules of allowable stresses for surface ships, developed strength evaluation methods and stability of the marine floors and backed plates [4]. Most calculation methods have not changed significantly, but have been tested 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.

Modern tools used in the design of ships

Ship design is a complex process that must take into account the 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 a variety of such programs is sufficiently large: 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 of the leading industrial enterprises of Russia. [3] 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 can give a rise of negative effects. The computer power may be different, but in any case it is imperfect, resulting in a computational errors occur to estimate that is not possible, because the methods of calculation are hidden from the user. Lack of proper mathematical training specialist in charge of calculation does not allow for analysis of the result values [5]. To all of this added the fact that the most of software is focused to use the Windows operating systems, which entails additional costs for companies, not counting the fact that the price of software is worth millions, not including the cost of staff training. Less widespread software products related to the free libre open-source software. One of the brightest representatives of those is FreeFem ++, so named by analogy with the language, which was written C ++. Freefem ++ - is a program designed to solve mathematical problems based on the finite element method [2]. Freefem ++ can be used on the Windows and on the Linux-based systems. The freedom to choose the operating system, as well as free basis for the use of the product are the main advantages of these decisions, but at the same time the user requires a greater knowledge in the field of mathematical physics and programming, which can be both advantage and disadvantage of such a software.

Mathematical model

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 clearly seen the 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 is invited to consider the finite difference method (grid method). 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 are huge amount of manual calculations related to the dimension of the resulting system of algebraic equations, which solving required years. 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 [9, 10].

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 is considered as an equivalent hull beam, i.e., finite stiffness beam. Mathematical laws, which describe 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 based on Kirchhoff's hypothesis. Since the deformation of the plate w is larger displacements u, v, all movements are considered to be small, and thus can be neglected nonlinear terms with respect to u and v, and replace the 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 $z = const$ relation between displacements and deformations based on the hypothesis established direct normals. 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. 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 - the essence of the intensity of the forces applied to the surface of the median line after reducing her stress [5].

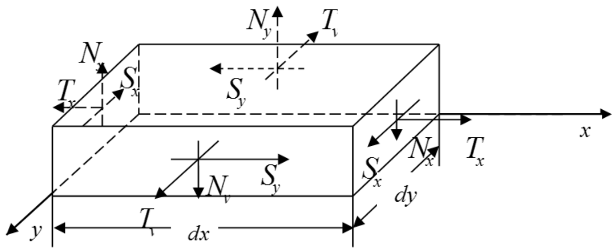


Figure 1. Positive directions of forces in accordance with the rule of signs of stress

On the fig. 1 T_x, T_y - normal force, shows a relationship:

$$T_x = \int_{-h/2}^{h/2} \sigma_x dz; \quad T_y = \int_{-h/2}^{h/2} \sigma_y dz$$

$S = S_x = S_y = \int_{-h/2}^{h/2} \tau_{xy} dz$ - shear force, defined in sections $x = const$, $y = const$ the same formulas determined by the law of pairing shear stresses S_x. N_x, N_y - shearing 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 $x = const$ and $y = const$ operating stress within the unit of length creates the following moments (fig. 2):

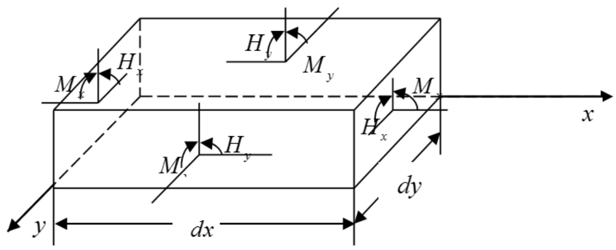


Figure 2. Positive direction of moments

M_x, - bending moments, acting in sections $y = const$ and $y = const$:

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

$H = H_x = H_y$ - toque moments in sections $x = const$, $y = const$:

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

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

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

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

Using Airy stress function, allows to determine the stress from the formulas:

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

The system of equations become equivalent to the single equation:

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

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

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

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

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

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

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

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 large number of unknowns. [1] In modern conditions of rapid development of information technology, such calculations can be trusted computing.

Building software and example of the proposed model

For example, implementation of the decision of the system use the task of loading a container with some of the cargo. As the ship type was taken “Artist Saryan” (Fig. 3).

Figure 3. The appearance of the vessel type “Artist

It has 6 holds of various sizes (Fig. 4). Each hold 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.

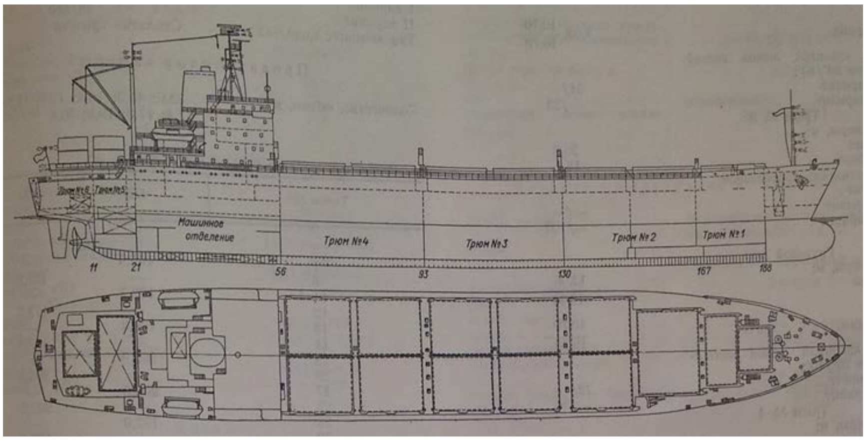


Figure 4. Scheme of the ship such as “Artist Saryan”

View on the scheme of arrangement of sixteen twenty-foot containers in two stacks of 8 each (Fig. 5).

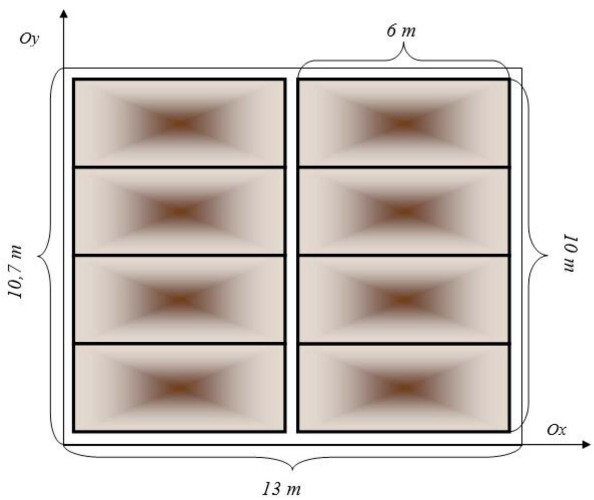


Figure 5. The layout containers

In the simulation the problem of deformation 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:

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

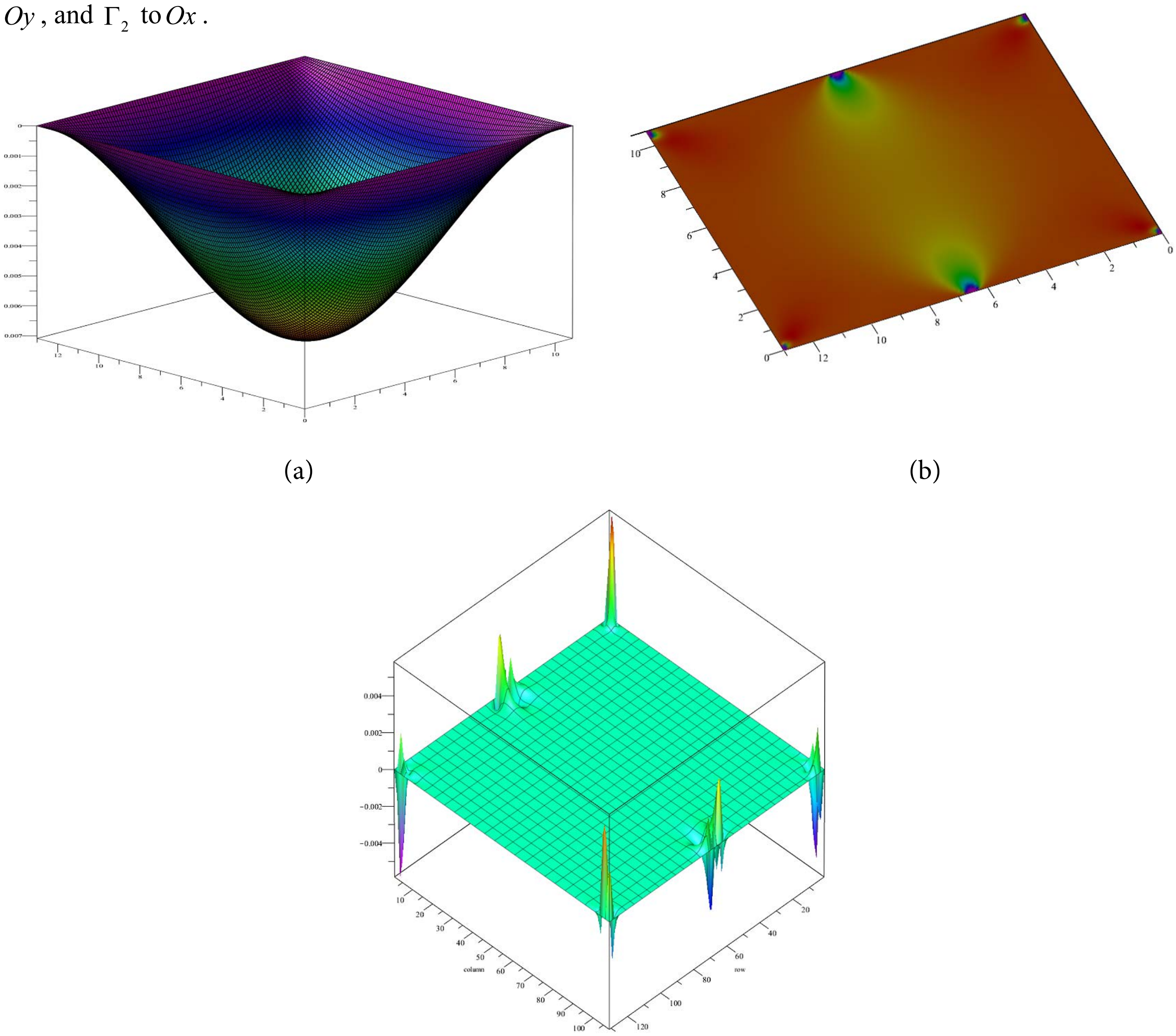
where Γ - edge of the plate, and $\Gamma = \Gamma_1 \cup \Gamma_2$, where Γ_1 - edge of plate which are parallel to the axe Oy, and Γ_2 to Ox.

Boundary conditions for Airy function:

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

where F_1 and F_2 - stresses on Γ.

On the basis of the specialized software, you can get different kinds of simulations [6-8]. In view of these conditions there was established software package, as a result of which the numerical values have been obtained strain and stresses, as well as corresponding graphs (Fig. 6).



(a) (b) (c)

Figure 6. The diagram of strain state (A), Airy function (B) and the graph of stresses (C)

The maximum deflection in this example was 0.00708907 meter and the highest stresses is achieved at the corners of the plate. Accuracy of the method in this case will be equal to h^2, where h - step decomposition.

Conclusion

As a result of this work have been formulated some mathematical basis for calculating the stress-strain state of the ship's deck plates covers a container, was created support software automates the process of calculation and visualization of results. This calculation was carried out without taking into account the cross-beam set for which the plate is mounted. Accounting for this fact affect 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 action.

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