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Mathematical Foundations and Software Simulation of Stress-Strain State of the Plate Container Ship

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ABSTRACT

The article is devoted to construction of mathematical models for analysis of stress-strain state of the ship's plate. The model is based on the theory of plates pocket on the basis of mathematical models created a complex software, which together allow us to speak about building a handy tool both for research and for practical use, which allows to quickly calculate and evaluate the fatigue-stress state of the ship's deck. As a practical example taken container for which it was solve stress-strain state of its hatches, taking into account load containers on deck.

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 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. 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. In addition to classical methods of calculation, came from the strength of materials, there are also methods of mathematical physics. They are quite raspraneny and provide great opportunities for the application.

Changing the shape and size of the hull or its parts caused by external forces or other influences (e.g., heating, cooling). Distinguish between General and local deformation. When the overall body is deformed as the hollow beam of variable cross section and may have a common longitudinal bending, transverse shear total and total torsion. General buckling is characterized by changes of curvature of the neutral axis of the hull in the vertical and horizontal planes of the ship, the total transverse shear - rotation normal to the cross section of the hull relative to the neutral axis, and the total torsion - angle of twist relative cross sections of the hull.

The peculiarity of the manufacture of ship hull structures, having large dimensions, is the use of a significant amount of manual fitting works at all stages of the technological process (in the manufacture of nodes, sections, during the construction of the hull on the slipway). Fitting work impact the quality and increase the manufacturing cost of structures. Residual welding deformations and stresses can have an impact on technological and structural strength and therefore, further development and improvement of methods of calculation of welding deformations and stresses, it is important to assess the impact of "technological factor", strength of ship hull structures.

Also it is necessary to conduct studies of errors in the manufacture of hull constructions and the possibility of reducing the amount of fit during Assembly of the mounting housing connections based on probabilistic dependencies, volume fit from the values of the tolerances of the sizes of sections), the toler-

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ances of the sections from the base plane and the tolerances on the displacement of the connected elements.

2. 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. 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.

3. 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.

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, ie, finite stiffness beam. Mathematical laws, which 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 XOY 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 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 ε_x,ε_y,γ_{xy} will have the following form:

$$\begin{cases} \varepsilon_x = \frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 \\ \varepsilon_y = \frac{\partial v}{\partial y} + \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2 \\ \varepsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x}\cdot\frac{\partial w}{\partial y} \end{cases} \tag{1}$$

For points of plate lying in a layer relation between displacements and deformations based on the hypothesis established direct normals. The deformations of the middle surface are related by compatibility:

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

These dependencies are valid when the deformations are small. Consider a cross section perpendicular to the axis and . 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.

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

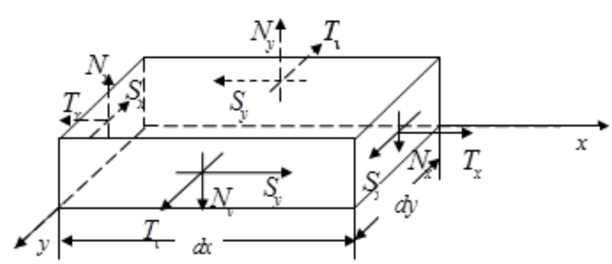
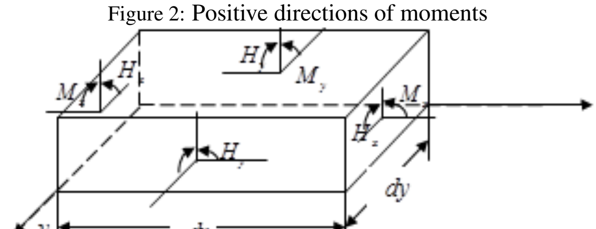


Figure 2: Positive directions of moments



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

$$T_x = \int_{\frac{-h}{2}}^{\frac{h}{2}} \sigma_x dz; \quad T_y = \int_{\frac{-h}{2}}^{\frac{h}{2}} \sigma_y dz \tag{3}$$

$S = S_x = S_y = \int_{\frac{-h}{2}}^{\frac{h}{2}} \tau_{xy} dz$ 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:

$$N_x = \int_{\frac{-h}{2}}^{\frac{h}{2}} \tau_x dz; \quad N_y = \int_{\frac{-h}{2}}^{\frac{h}{2}} \tau_y dz \tag{4}$$

In the sections $x = const$ and $y = const$ operating stress within the unit of length creates the following moments (fig.2):

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

$$M_x = \int_{\frac{-h}{2}}^{\frac{h}{2}} \sigma_x \cdot z dz; \quad M_y = \int_{\frac{-h}{2}}^{\frac{h}{2}} \sigma_y \cdot z dz \tag{5}$$

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

$$H = \int_{\frac{-h}{2}}^{\frac{h}{2}} \tau_{xy} \cdot z dz \tag{6}$$

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

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

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

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

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

The system of equations become equivalent to the single equation:

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

Thus, the behavior of the plate is described by two resolving equations: the 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:

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

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

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

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

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

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

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. In modern conditions of rapid development of information technology, such calculations can be trusted computing.

4. 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'. It has 6 holds various sizes (Fig. 3). 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. With the help of modern software will make evaluations and calculations.

View on the scheme of arrangement of sixteen twenty-foot containers in two stacks of 8 each (Fig. 4)

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:

$$\begin{aligned} w|_r &= 0 \\ \left.\frac{\partial^2 w}{\partial x^2} + v\frac{\partial^2 w}{\partial y^2}\right|_{\Gamma 1} &= 0 \\ \left.\frac{\partial^2 w}{\partial y^2} + v\frac{\partial^2 w}{\partial x^2}\right|_{\Gamma 2} &= 0 \end{aligned} \tag{14}$$

Figure 3: Scheme of the ship as 'Artist Saryan'

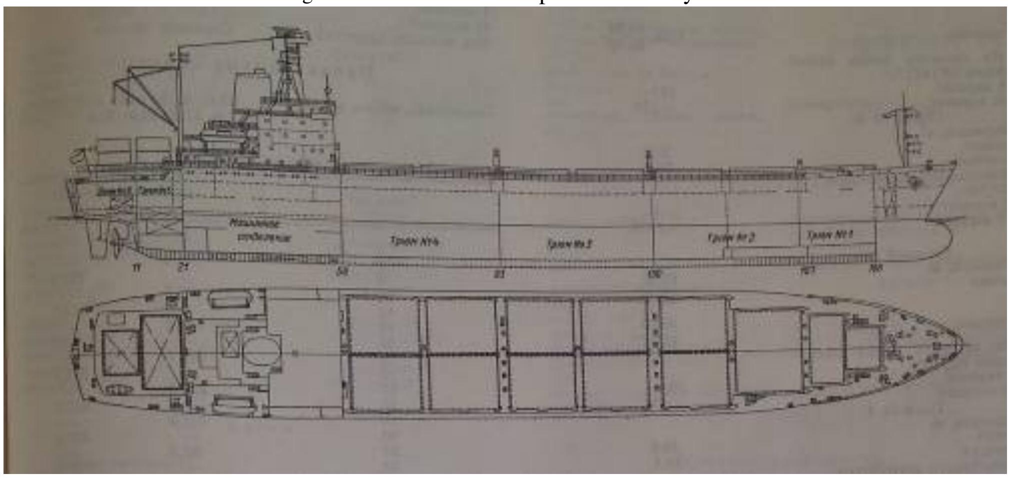


Figure 4: The layout containers

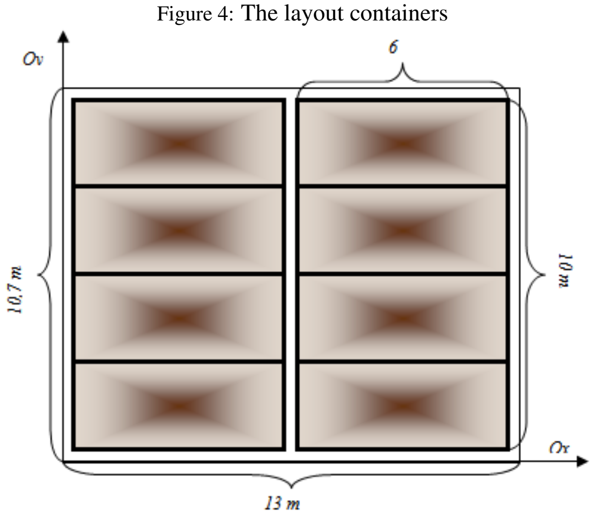
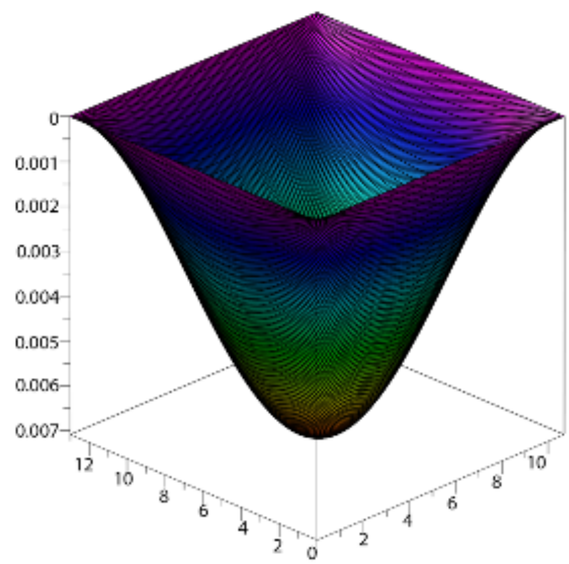


Figure 5: The diagram of strain state



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

Boundary conditions for Airy function:

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

where F_1 , F_2 - stresses on Γ.

In view of these conditions has been established software package, as a result of which the numerical values have been obtained strain and stresses, as well as corresponding graphs (Fig. 5)

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.

In generalizing risk assessments, it is recommended to analyze uncertainty and accuracy of the results. In most cases, a source of uncertainty in the case of the processes of deformation will be incomplete data on production technology, reliability and precise operation of the equipment as well as human errors. In order to interpret the results of the risk assessment properly, it is recommended to understand the nature of the uncertainties and their causes. Sources of uncertainty are recommended to be identified and evaluated and results to be presented. The authors carried out a qualitative and quantitative risk assessment. Qualitative risk analysis reveals the sources and causes of risk, stages and work in the course of which a risk may arise (finding potential risk areas, identifying activities associated with risks, finding practical benefits and negative effects of identified risks). Quantitative analysis provides numerical values of both individual risks and for the entire facility. It is also possible to calculate the potential damage and to develop a system of preventive measures aimed at minimizing the occurrence of risk situations. In the risk analysis, risk matrix and generic risk assessment algorithm were used.

5. Discussion

As this article is written in preparation of the thesis, it is important for me the question of novelty, so I would like to clarify some points of novelty. As already noted - grid method is not new, and Karman system itself does not have a scientific novelty, but the use of these components in shipbuilding original enough for today. The fact is that at present the most common methods of calculation, came to shipbuilding of the resistance of materials, i.e., normative documents of the Russian Maritime Register consists of ready-made formulas. This in turn leads to the fact that for the calculation of stress-strain state, we need some time to take advantage of these formulas to calculate values at each point of the plate. Using a system of Karman, we can get these values in one pass, but the calculations become more laborious and lengthy. For this involved using a special information software. The situation described in his book, VA Lean: '... computational work using this system are few and difficult, and therefore not very applicable in practice.' An alternative method can serve a variety of simulation packages, e.g., ANSYS, Solidworks etc. Using this method as well, but not always possible to penetrate deep into the" calculations. So we have a big field of methods with the same problems and each attempt brings more accuracy and versatility.

6. 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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