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EVALUATION OF THE EFFECTS OF GENERAL VIBRATION ON THE LOCAL RESISTANCE OF THE HULL, DETERMINED BY CALCULUS

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Abstract: Shipping classification societies often meet with the negative effects of the vibrations upon the local resistance of the ships hulls. This is the reason why it is necessary to device calculus software and to make direct measurements onboard ship, under the supervision of the classification societies that have the right to determine the minimum demands for each stage of design. This paper presents an optimal approach for the evaluation of the effects, able to inhibit superficial methods that ignore, or do not take into account the complexity of the problem.

1. GENERAL CONSIDERATIONS

Naval classification records, in their technical survey work, have shown that they frequently face some problems regarding the negative effects of vibrations on ships. These effects should be linked to new current trends in the shipping industry, while they are a major concern of specialists in research, design and operation, in the naval field.

Considering the new trends in design (expressed by increasing propulsion engine power and hence the propeller load, increasing the ratio Bx/D, C_B and fineness coefficient, as well as of the total displacement Δ, the decrease of the L/Bx, ratio, etc.), and the associated detrimental effects, it was necessary to draw up a guide with officially regulated norms, able to prevent and weaken the consequences of vibrations upon ships. [6, 3]

Among the negative consequences of vibrations on ships, the ones mentioned below are of interest.

- Reducing the safety of the hull due to both inertia (when its magnitude is analogues to the intensity of the action giving rise to the phenomenon), and to the repetition of some actions (which generates, during the working life of a certain structure, a number of cycles of order 10^6 … 10^8). Such actions may be called quasi-static actions, and, while analyzing them it is enough to take into account the external forces and the reactive forces due to structures, without considering the inertia in determining the state of mechanical stress.
- Malfunction or even damage to equipment, systems and equipment on board.
- Diminishing the crew’s work capacity due to fatigue or violation of the ISO norms for the evaluation of the level of vibrations, in terms of labor protection.

For all these reasons there appears the clear need for computer programs and direct measurements on the ship, under the supervision of Classification Registries, which give themselves the right to determine the minimum demands of the ship designer in the calculations required at each stage of design. Also, scientific research and design professionals should join the classification societies, and try to prevent vibrations from the preliminary stages of ship design.

2. METHODOLOGICAL ELEMENTS OF CALCULATION

The structural components belonging to the hull, which can undertake vibration calculation, can be grouped as follows [3, 6]:

- continuous plates, plates with many supporting points, with plane or shaped framework;

- framework elements
- boards
- console like isolated elements (chokes of the propeller shaft, etc)

The limit conditions for the calculation of vibration parameters of the above mentioned structural components can be determined starting from the functional character of these structures and of the disruptive forces acting on therm.

For example, when a non-uniform loads acts on the panel, the anti-symmetric forms of the plane boards and of the small curvature plates, which corresponds to the idealization (see figure 1). Also, for curved plates, the minimum frequency that is characterized by the formation of several semi waves along the edge of the curve and of a semi wave along the straight edge, this phenomenon can be seen in figure 1.

Figure 1.

If a uniform load acts on the panel, the symmetrical forms of vibration are predominant (the neighboring openings vibrate in phase), and the plates act as the ribs are rigidly embedded.

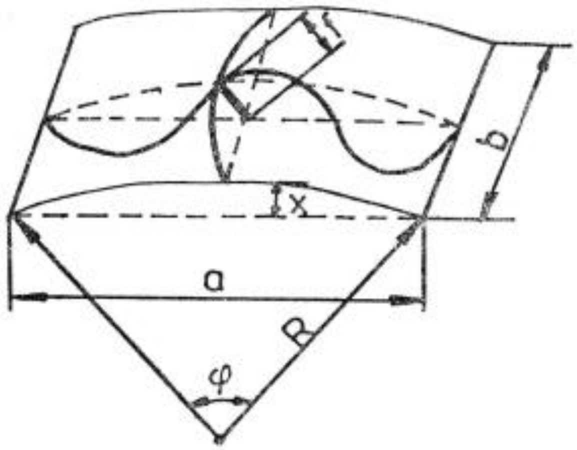

Figure 2.

The pulsatory pressures generated by propellers are characterized unevenness, and their maximum values reach significant values (up to kN/m^2, or even more). The calculation of vibrations of the structural components within the propeller's area of action has two stages, as seen below:

- free vibration calculation and resonance frequency check of the disturbing forces;
- calculation of vibrations maintained by the pulsatile pressures generated by the propellers

Typically, the calculation of vibration of the hull, within the propeller's area should be made for the most unfavorable cases, as follows: own frequencies of the plate are determined for asymmetrical vibrations (minimum frequency); calculation of maintained vibrations is made for the symmetrical shapes (the area of maximum bending moments of the plate will coincide with the minimum resistance to stress, i.e. point were the frame is welded to the shell).

Outside the area of pulsatory pressures generated by the propeller, the distribution of disturbing forces has a different character, as follows: within the area of maximum wave length of the vertical vibration of longitudinal bending of the hull, and at the mid-width of the bottom, at some distance off the bilge, the intensity of the accompanying inertia is almost uniform (see figure 3), in the bends area, the forms of general vibrations, acting on different parts off the bends, acts in antiphase, their intensity is not important, though. If the frame of the hull is smooth, then at the distributions mentioned, the most likely forms of the vibrations of plates and bars that tie them are asymmetrical along the hull; they are symmetrical in the transverse direction, this is true in a longitudinal framing system, they are symmetrical along the hull in the area of maximum wave length, and asymmetrical in the area of general vibration bends, in a transverse framing system.

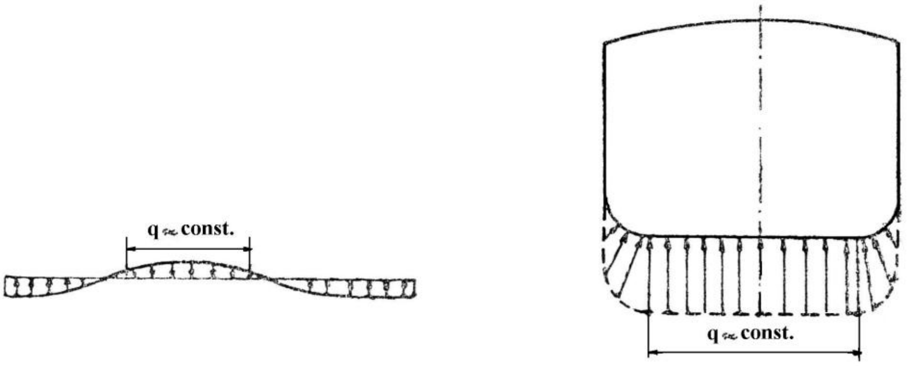

Figure 3.

The boundary conditions for a floor are determined by analyzing its joint operation together with adjacent structures, taking into account the forces acting on it. The supporting coefficients for console - like structures are determined by fixing the support section, and they are based on traditional principles of structural mechanics. The safety coefficients are then determined for free vibration frequencies, as well as, for maintained vibration amplitudes, leaving apart the resonance to the disruptive forces and sufficient strength for their action. The safety coefficients take into account the following technological factors:

- residual stresses after welding;
- plate bending as a result of deformation appeared after welding and assembly of the structure;
- the difference between the real thickness of the plate sheet and the one adopted in the project, as well as the distances between the supporting beams;

Based on the analysis of the resonance curves existing in today’s shipbuilding, encompassing the abovementioned factors, the percentages of the safety coefficients have the following values: 1.5 for plates and 1.3 for frame elements and stiffening ribs.

Resistance to vibration of structures outside the manifestation of pulsatory pressures generated by the operation of the propellers is considered secured if it leaves apart the resonance to the frequency of general vibrations of the hull when the ship is underway, considering the above mentioned coefficients.

If, for some reason, it is not possible to avoid resonance, it is necessary to calculate the vibrations maintained by resonance of these structures when the inertia generated by the general hull vibrations acts.

3. SOME REQUIREMENTS FOR CARRYING OUT CALCULATIONS AND PROVIDING LOCAL RESISTANCE TO VIBRATION OF HULL STRUCTURES

- *The forces generating local vibrations of the hull structures* are:

- the pulsatory hydrodynamic pressures transmitted to the body by the propellers, while they are in service;
- the inertia forces accompanying the general hull vibrations;
- the balanced forces generated by the main and auxiliary machinery.

■ *The construction structures that should be calculated* under the action of the inertia forces are:

- the bottom floors around the location of propellers (they come directly under the action of pulsatory pressures generated by the operation of propellers and inertia forces generated by the general hull vibrations);
- the extreme stern structure (which mainly supports the action of the inertia forces accompanying general hull vibrations);
- the structures of the hull existing in the area of unbalanced, or non-supported machinery;
- conspicuous hull structures (subject to the action of the pulsatory pressures, resulted from the propellers' motion or of the forces accompanying the general hull vibrations).

■ *Disruptive forces calculation frequencies* are:

- If they are generated by the propeller: the number of turns multiplied by the number of blades and double the number of blades (the first two orders) for non-cavitating propellers; the number of turns multiplied by one, two and three the number of blades (the first three orders) for cavitating propellers;
- If they are generated by loose (unsupported) machinery: orders one and two of frequencies of the loose machinery forces.

■ *Determination of forces producing local vibrations of the hull within the operation area of propellers* includes:

- For non-cavitating propellers - dimensionless amplitude blades pressure in a given point of the hull, which is calculated [3]:

$$K_{pv} = \frac{p_0}{\rho n_H^2 D^2} = (12{,}5 + q) \cdot \left(\frac{e_{0,7}}{D} \right)^{1,33} \cdot \frac{1}{Z^{1,53} \left(\frac{2a}{D} \right) k}, \tag{1}$$

where:

p_0 is the amplitude of the blade rate pressure in kN/m^2;
ρ - density of sea water in t/m3;
n_H – the turns of the propeller in rpm, at depth H;
H – the immersion depth of propeller center, in m;
Z - number of blades;
$e_{0,7}$ - thickness of propeller's blades at a relative section r / R = 0.7, in mm;
D - propeller diameter in mm; $a = \sqrt{y^2 + (Z - 0{,}45D)^2 + x^2}$ - the distance between the point on the hull with coordinates (x, y, z) and the given point on the propeller disc.

- for cavitating propellers, where the value of pulsatory pressure is the sum of the corresponding pressure produced by the non-cavitating propeller and the supplementary pressure created by closed spaces – the dimensionless amplitudes of blade pressure frequency and the double frequency of the blade dependent on cavitation is determined with the following formulae:

$$K_{pi} = \frac{\Delta P_i}{\rho n_H^2 D^2} = \mu_i \cdot I_v \left(W_{T\,max} - W_T \right) \cdot \frac{1}{\sqrt{T_s \left[1 + \frac{I_v^2 (1 - W_T)^2}{\pi^2} \right] \cdot 8{,}1}} \cdot \frac{1}{\frac{2a}{D}} k \tag{2}$$

where:

$i = 1,2$ - order number;
$I_V = v/n_H D$ – the relative advance, determined by the help of vessel's speed v;
W_T – the effective medium swirl coefficient on the propeller's disc, determined in accordance with the results of model tests or prototype;
W_{Tmax} – the maximum value of swirl coefficient.

4. RECOMMENDATIONS AND CONSTRUCTIVE MEASURES TO REDUCE VIBRATION LEVEL AND AVOID THE RESONANCE PHENOMENON

The general vibrations of the hull can appreciably affect the whole construction, as well as the component structures if they are generated either by consistent disruptive forces, or by coming disruptive forces frequencies that can interfere with on of own free frequencies.

In order to reduce the pulsatory pressures transmitted through water to the hull, while the propellers are operating involves the setting of an optimal distance between the propeller and the hull. There are also hydrodynamic measures that can create a uniform and equal flow of the current in water within the propeller zone.

If the frequency of the pulsatory pressures is close to one of the free vibration frequencies of the hull, then there will be a change in the disruptive force frequency, by changing the number of propeller blades, thus resulting into removing the resonance phenomenon.

The existing data in the technical literature [3, 4, 7] in what the level of marine vibrations is concerned, refer (80 % of it) to the negative effects of some local vibrations in different structures of the hull. In most cases, high value local vibrations are caused by large excitation forces, or the high elasticity of structures. If the situation requires, in some cases, to reduce local vibrations shock absorbers can be used; they should be adjusted to the concrete conditions of exposure of the respective structures and to the operating conditions mechanisms in the areas [1, 2].

Usually, strong local vibrations appear when the frequency of disruptive forces coincides with the first free vibration frequency of structural elements. Therefore, one of the most effective ways to reduce local vibrations consists in the increase of free vibrations frequency, thus increasing the overall rigidity of the construction, i.e. its component structures. To increase the rigidity of the construction, we recommend the introduction of additional supports or bearers, for example, the mounting of stanchions for consolidating the floors.

It should be noted that additional supports are not to be located on the nodal lines or on the bends of vibrations resonance forms, as with such rigidity the free frequency is not changed. Therefore, the setting of supports for rigidity is efficient in places where the amplitude of maintained vibrations reaches maximum value.

If the shape of vibration can not be described theoretically, to reduce their level and avoiding the resonance phenomenon, it is recommended that experimental methods.

Adding the observations and tests performed for a large number of real or simulated cases with the experience compiled in naval records, some useful recommendations have resulted referring to elements and nodes (bends) of ship hulls, so as to prevent and limit the destructive effects of vibrations. Of these, we will present only those which refer to *the structures around ship hull extremities*.

The structures situated at the stern are the one which are the most affected by the excitations generated the propellers in operation, and by the hydrodynamic field of the ship. The negative effects of vibrations in this area (which can create flaws or cracks in the structural components of the hull) are caused by the following factors:

- the level and frequency of pressure in the aft part of the ship;
- the dynamic features of the structures (resonance);
- the quality of the execution , the fixing and rigidity features of the structures;
- the damping effectively realized through special devices, or through distribution of ballast tanks i.e.

Obviously, the most important steps to be taken into account in order to reduce the level of vibration and to avoid the resonance phenomenon aims at avoiding the decrease of pulsatory pressure in the aft extremity of the ship and at the changing of the dynamic properties of structures near the resonance area. Also, in addition to such measures, it is recommended that appropriate structural solutions are adopted, such as:

- accurate transmission of tasks to the end of the frame elements, as illustrated in figure 4;

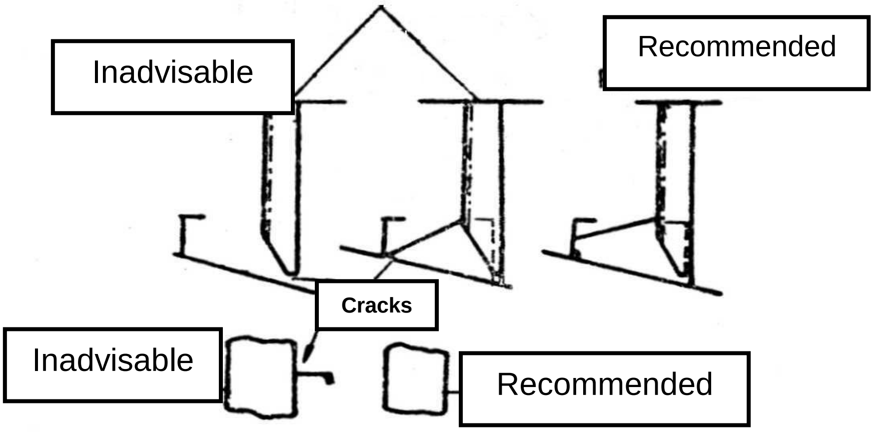

Figure 4.

- the brackets at the end of the frame elements will be extended up to the transverse frame elements, as seen in figure 5.

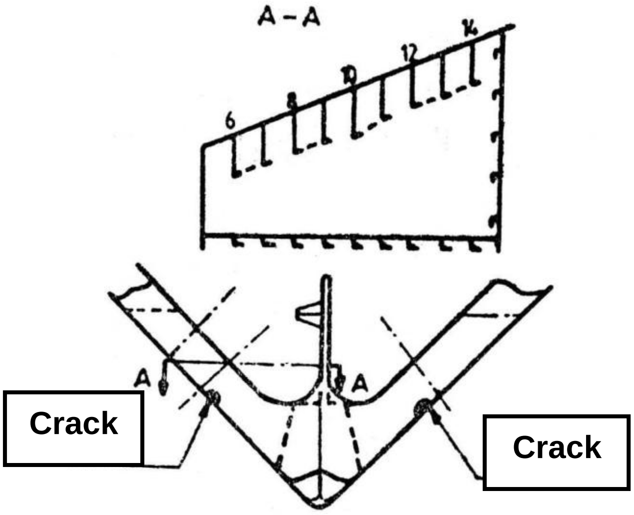

Figure 5.

- assembly of brackets between the ribs and stringers, or between the longitudinal elements and the outer shell of the hull, should be roughly flat as illustrated in figure 6;

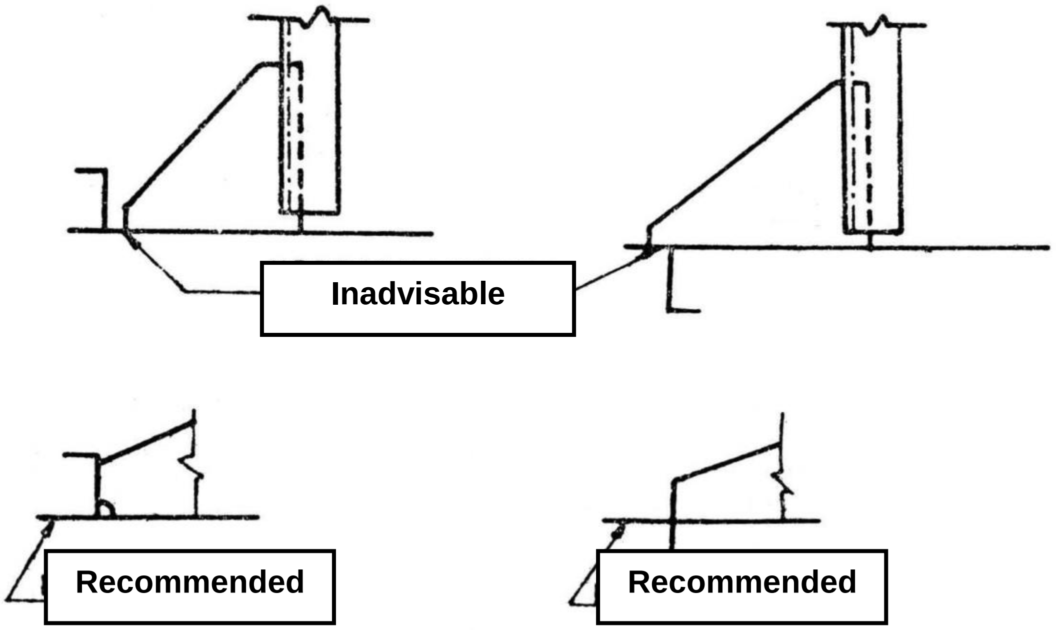

Figure 6.

- panel mounting (floors, walls) in the aft extremity, to increase the stability of the ribs;
- reducing elasticity of high floors by welding additional reinforcements, as shown in figre 7;

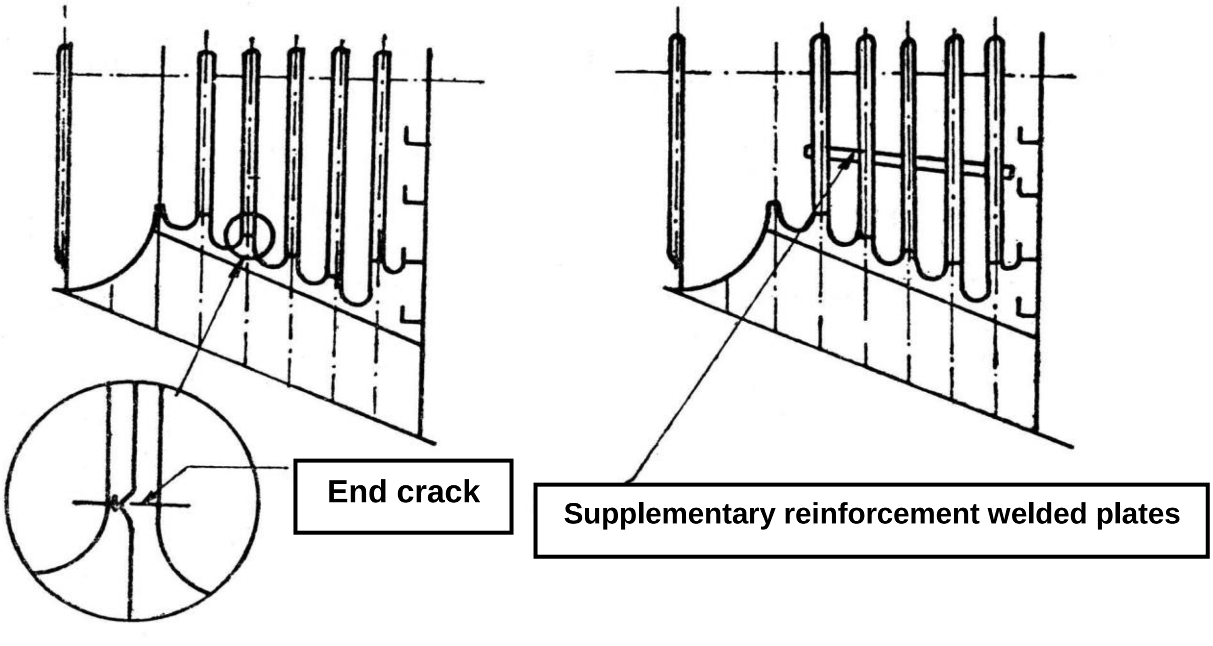

Figure 7.

- further strengthening of the central wall and of the rolling diaphragm, at aft end, as shown in figure 8;
- providing additional longitudinal ribs for deck and intermediary ribs for skins (processed at the joints to cover the walls of the hull).

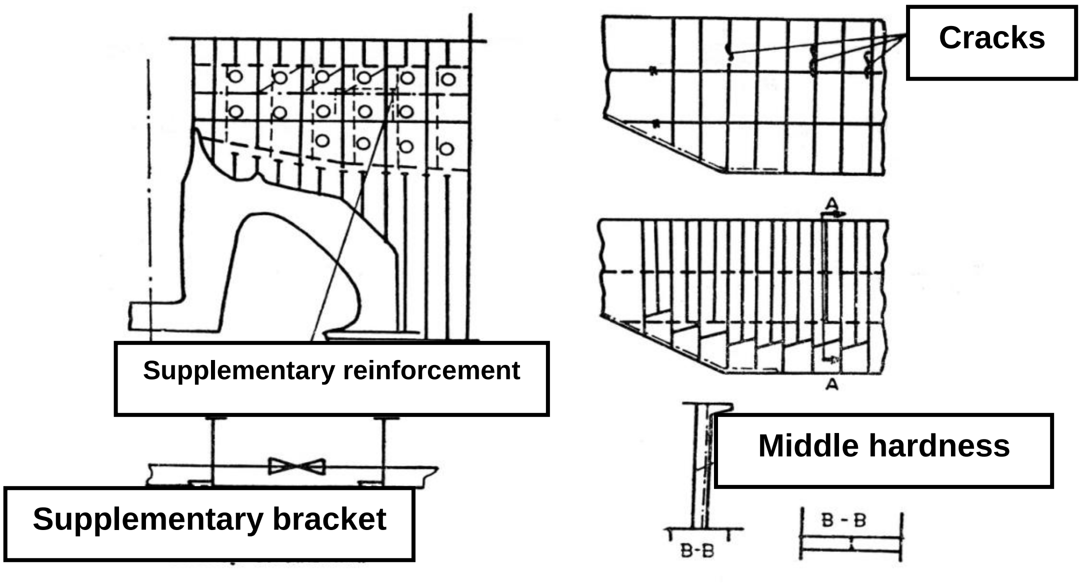

Figure 8.

Today's research raises new questions regarding the calculation of high frequency vibrations of the hull, which involves shearing and rotational inertia of its cross section. It is , therefore, necessary to reconsider the non-linear vibration, especially in the resonance field , since the amplitude limitation of vibrations , and various other phenomena can not always be explained only by energy diffusion.

5. CONCLUSIONS

Naval classification records, in their technical survey work, have shown that they frequently face some problems regarding the negative effects of vibrations on ships. These effects should be linked to new current trends in the shipping industry, while they are a major concern of specialists in research, design and operation, in the naval field.

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References:

1. Kurdiumov A.A., Vibraţia korablia, Editura Sudostroenie, Leningrad, 1961;
2. Posea N., Calculul dinamic al structurilor, Editura Tehnică, Bucureşti, 1979;
3. Pricop M., Cercetări privind statica şi dinamica structurii corpurilor navelor vrachiere, teză de doctorat, Universitatea Petrol şi Gaze, Ploieşti, 1999;
4. Theodor P., Contribuţii relative la metodele de analiză şi diagnoză a vibraţiilor maşinilor şi agregatelor, teză de doctorat, Universitatea din Timişoara, 1996;
5. Timoşenko, S.P., Kolebania v injenernom dele, Editura Fizmatghiz, Leningrad, 1979;
6. Tood, F.H., Ship Hull Vibration, Edward Arnold Ltd., London, 1991;
7. Voinea P. R., Voculescu D. S., Florian-Paul, Introducere în mecanica solidului rigid cu aplicaţii în inginerie, Editura Academiei, Bucureşti.