КНИЖНОЕ ОБОЗРЕНИЕ

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Shamil U. Galiev. Modeling of Extreme Waves in Technology and Nature. CRC Press (2020) 822 p.
Volume II. **Extreme Waves and Shock-Excited Processes in Structures and Space Objects**

Linear vibrations and waves were well studied already in the 19th century, which was reflected in Rayleigh's fundamental course [1]. However, this in no way can be said about nonlinear, especially extreme oscillations and waves. The realization that nonlinear equations contain qualitatively new information about the surrounding world came due to Poincaré who developed new methods for studying them [2]. Methods for integrating nonlinear equations created by him and other remarkable researchers have found wide application in radiophysics and solid mechanics [3, 4]. Nonlinear concepts and approaches entered the mechanics of fluids and solid deformable bodies later. It is significant that first monographs devoted to the nonlinear behavior of deformable systems were published at the turn of the first half of the 20th century [5–7]. At the same time, interest in linear waves propagating in various structures (plates and shells) and complex media has sharply increased [8]. Nonlinear waves in bounded bodies and structures have been studied to a much lesser extent. In the latter cases, the problems of the formation of extreme waves as a result of force, thermal, radiation, or shock loading of boundaries in bodies and structures are of great importance. The complexity of the problem is associated with the need to take into account physical phenomena that usually do not manifest themselves far from boundaries, such as destruction, melting and evaporation of media, as well as the mutual influence of these processes [9–12].

Volume II of the Galiev's book presents and generalizes the results given in [9–12]. The modeling problem of extreme waves is considered as a puzzle of studying the behaviour of wave systems with parameters, the distribution of which in time and space is unknown and is found in the problem solving process. Insufficient knowledge of this class of problems has caused the need to create non-standard algorithms that allow calculating the motion of cavitation waves in liquids, plastic zones and waves of destruction, melting and evaporation in bodies and structures.

Integration of corresponding equations is carried out by numerical methods. The so-called hybrid schemes are often used, which ensure high accuracy of calculations.

Such schemes are constructed from well-known schemes in such a way as to take the advantages of well-known schemes and have none of their disadvantages. Note that because of the development of computers and the standardization of numerical methods of calculations, interest in solving boundary value problems based on the use of widely known models of behavior of continuous media is weakening. At the same time the development of new models of the behavior of various media becomes more important for mechanics. Moreover, when solving problems based on approximate new models of media, the accuracy of which is not completely determined, there is no need to use numerical schemes and grids that provide high accuracy. The main thing is that the calculation error is within the accuracy of the models.

Of course, the issue of the accuracy of the calculation remains very important. The accuracy of the calculation must be guaranteed even if experimental data are not available. In this volume for checking the results, approaches are used based on different representations of the equations of motion or constitutive equations (models) of the media under consideration. Changing the original equations usually leads to the use of a different algorithm for solving the problem. The author believes that the agreement between the results of solving the same physical problems in the case of their different mathematical description and the use of different numerical schemes of the solution is a strong support of their objectivity.

We have considered above the main ideas on which volume II is built upon. Now let us look at the contents of the parts and chapters.

Part 1 sets out the theory on the basis of which the calculations are performed in the subsequent parts of the book.

The basic relations of the mechanics of continuous media, solid deformable body, fluid, as well as the theory of plates and shells are presented in Chapter 1. Equations of state are introduced that are valid in a wide range of changes in the thermodynamic parameters of various media. The next chapter is devoted to some issues of the destruction of continuous media in tension waves. It underlines both the proximity of some criteria for the destruction of liquid and solid media and some inconsistency of the existing approaches to the analysis of the dynamics of defects (gas bubbles, pores) in liquids and solids. The theory of destruction of these media is described and the equations of the mechanics of a destroyed medium are written taking into account both the interaction of defects and the inertia of their development. The theory of extreme waves propagating in loosely coupled media (granular materials, bubble media) is presented in Chapter 3. The theory is based on the equations given in Chapters 1 and 2.

Actions of extreme waves and explosions on structural elements are considered in Part II. For example, these waves arising on the ocean surface or in containers of vessels can destroy the vessel hull, the oil platform or containers (Fig. 1).

Submarines and structures can experience displacement, deformation or destruction under the action of an underwater wave. Note that one of the first to start studying these processes mathematically was the Lenin Prize laureate, shipbuilder, academician V.V. Novozhilov (Fig. 2) [13].

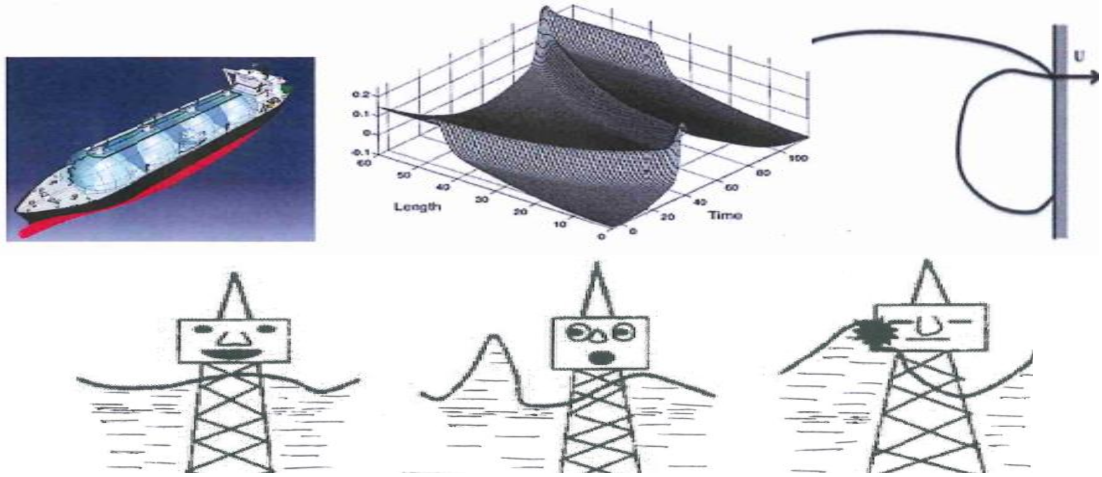

Fig. 1. (Top pictures) LNG carrier (left). Oscillating in the container internal extreme wave (center). Extremal wave shocking on vessel's hull or container wall (right). (Bottom picture) Diagram of the impact of an extreme resonant ocean wave on an oil platform (from left to right))

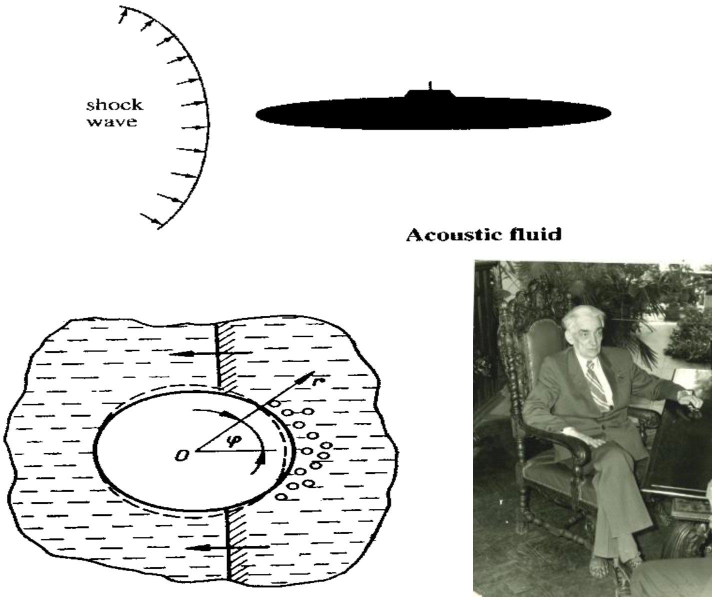

Fig. 2. Sketch of a shock wave, induced by an underwater explosion, impinging on a submarine (upper). A qualitative picture of the cavitation interaction of underwater shock waves with the hull of a submarine. V.V. Novozhilov’s photo (bottom)

The complexity of studying the response of submarines and structures is aggravated by the appearance of the so-called hull cavitation on their surface. This phenomenon has been thoroughly studied in the experiments conducted by M.A. Ilgamov and A.A. Pavlov [14] (Fig. 3). The hull was modeled by a plate.

These experiments determined the basic ideas of the theory and calculations presented in Part II. In particular, it studies the unsteady response of thin-walled structural elements containing or immersed in pure or bubbly, highly heated or cryogenic liquids to the action of extreme waves or explosions [9–16]. It is shown that the influence of various types of nonlinearities on the dynamics of a structure is not the same.

Cavitation affects non-stationary behavior of a thin wall system almost always even when the wall deflection is much smaller than the wall thickness (Fig. 4) (Chapter 4) [12].

The geometric nonlinearity of the systems occurs only when deflections exceed its thickness. This nonlinearity exerts less effect on the mathematical conditions in the interfaces between the media. Account taken for the plastic properties allows finding the residual change in the shape of a structural element (Chapter 5). Chapter 6 discusses, in particular, reinforced and thick-walled structural elements. The main attention is paid to comparing the results of calculations for various mathematical models of structures, the study of wave amplification on stiffeners and joints of structural elements.

The behavior of a tank wall and a vessel hull during the action of extreme waves may be very complex (Part III). Thin metal elements can demonstrate the so-called counterintuitive behavior (CIB). This is an occurrence of final deflections of the elements which are opposite to a direction of impulsive loading. Experiments (Fig. 5) testify that CIB is possible for different structural elements and under various impulse loads. The experimental results were simulated using numerical methods. Consideration is given to circular plates, cylindrical and spherical shells subjected to a uniformly distributed pressure pulse, or air or underwater explosion. These elements can sometimes lose stability of their deformed geometry by a reverse snap-buckling (see the experimental curves in Fig. 5). This CIB is a result of unloading of the structural material. For blast loading an influence of unloading wave moving behind the compression part of the loading wave may be important. An influence of the transient cavitation may be important for the underwater explosion.

The author following [16] believes that the counterintuitive results presented by him are an extension of the classical results of Poincaré and Edward Lorenz [16–19] to elastoplastic systems.

As is known, the action of very short but intense laser radiation on the surface of the material can form thermal waves, waves of fracture, melting and evaporation. These waves interact and complicate the study of the picture of extreme processes in the material. They are studied on the basis of both microscopic and macroscopic approaches in Volume II. The author suggests that it was precisely the actions of laser pulses on a surface of an asteroid that resulted in their destruction and saved life on Earth.

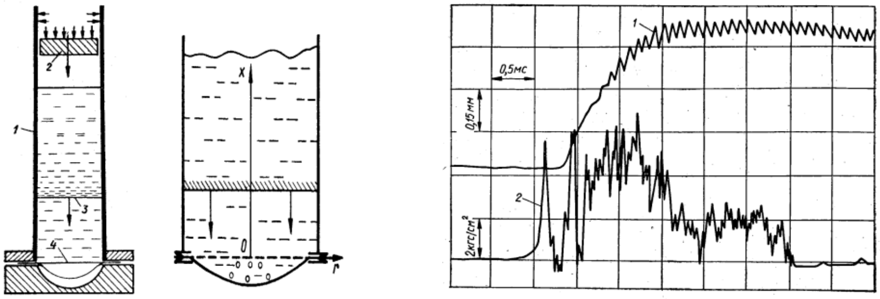

Fig. 3. Sketch of the experimental apparatus (left), a scheme of the plate-shock wave interaction (center) and displacement (curve 1) and pressure (curve 2) oscillograms near the center of a duraluminum plate (right)

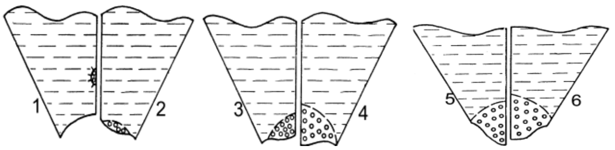

Fig. 4. Dynamics of the development of cavitation zones in liquid during the elastic deformation of the shell over time: a) $t = 0$; b) $t = 12{\cdot}10^{-4}$ sec; c) $t = 15{\cdot}10^{-4}$ sec; d) $t = 18{\cdot}10^{-4}$ sec; e) $t = 20{\cdot}10^{-4}$ sec; f) $t = 26{\cdot}10^{-4}$ sec

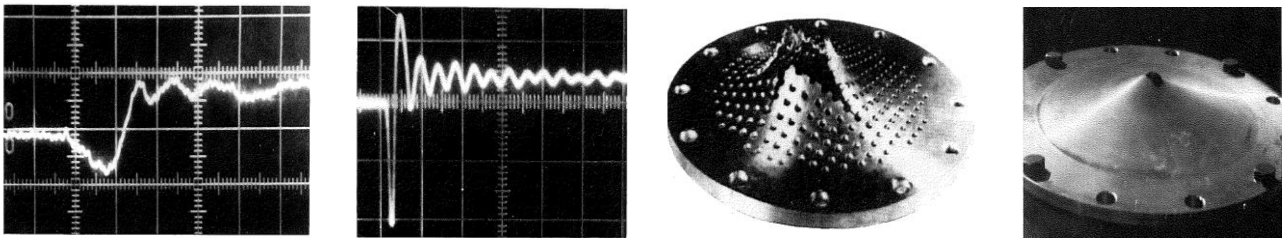

Fig. 5. Typical oscillograms showing counterintuitive displacement at the center of specimens. A failed perforated round plate and a failure cap after the blast loading and CIB

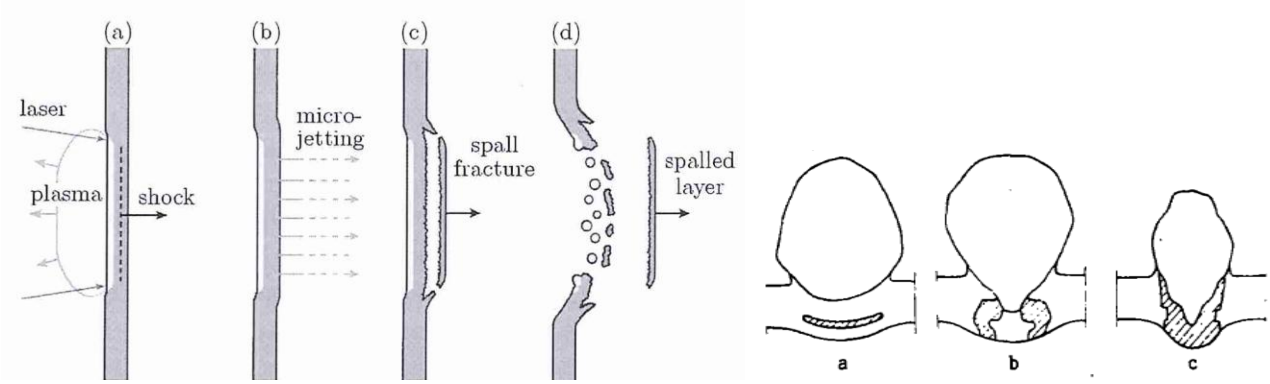

Fig. 6. Scheme of laser shock-induced fragmentation of an aluminum target ((left, see from left to right). Examples of the zones of vaporization and fracture during the laser beam action on a metal target (right, see from left to right)

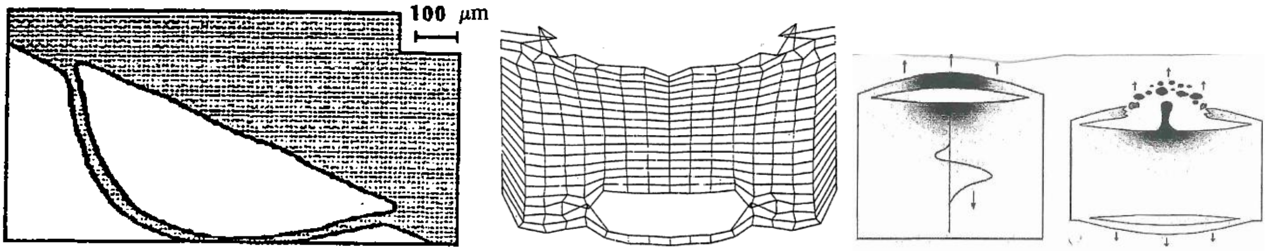

Fig. 7. Form of the cupola on the rear (free) surface of the plate loaded with laser radiation (left). Schemes of the processes occurring during irradiation of the target by a laser radiation (center and right)

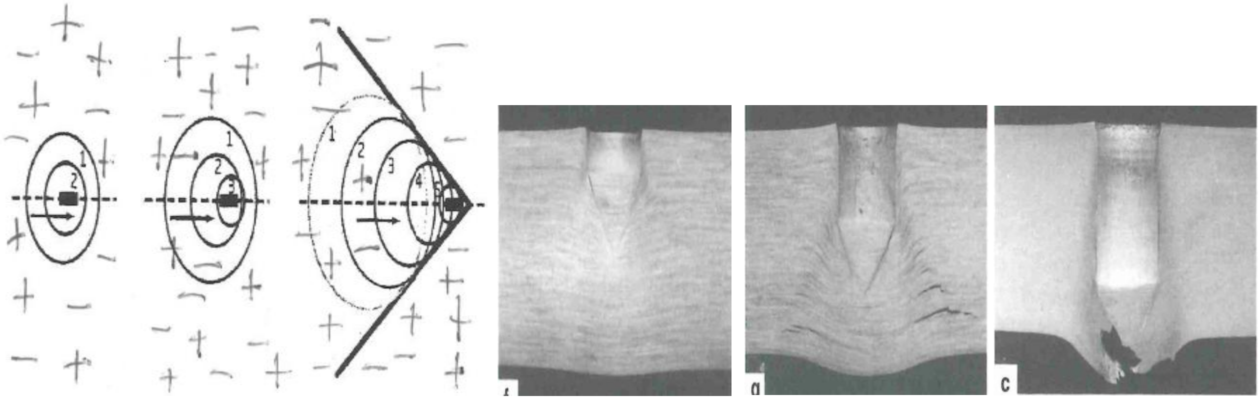

Fig. 8. The Mach cone arising when the speed of a body exceeds some critical speed (left)

The formation of cupola-like shapes on the rear surface of the irradiated plates is the phenomenon which is often used as a test. On the other hand, it presents a special subject for theoretical examination (Fig. 6). Analysis of the formation of cupola-shaped convex areas on the rear surface of the irradiated plate indicates that the process consists of two stages. At the first short-time stage (the wave stage) a disk-shaped crack forms in the vicinity of the rear surface of the plate. The crack partly separates the sheet of the material from the main volume. The thickness of this sheet is considerably smaller than the thickness of the plate. The second long-time stage (conventionally referred to as the deformation) consists of the inertia movement of the sheet with its deceleration as a result of energy losses for plastic deformation. It should be mentioned that during the development of dynamic fracture in the plate there is a time period characterized by the simultaneous rapid occurrence of both extreme wave processes and plastic deformations (Fig. 7).

Thus, in volume II much attention is paid to extreme waves arising during extreme actions on various structures and solid materials. In particular, we have experimentally and numerically investigated the waves of fracture and melting arising at the high-speed action of the projectile on the target. The influence of the impact velocity upon the penetration depth and the process of deformation and perforation were investigated. Particular attention was given to the formation of a cone of the extreme melting wave in the targets due to temperature rising and material melting at the sites of intensive plastic shear deformations (Fig. 8).

Different moments of the intrusion of a steel projectile into an aluminum alloy target and the formation of a cone of the extreme melting wave (from left to right).

One can see that the volume is supplied with a huge amount of calculations, experimental data and observations considered together. It is devoted to a very relevant and rapidly developing field of science, in which the problems of mechanics and physics of high energies and pressures are closely related. The field is so vast that its full consideration in one book is impossible. By virtue of this, only some problems from their vast spectrum are considered which the author was directly interested with.

The considered tasks have had certain important areas of the applications (see, for example, [20–22]). To emphasize this, I, with the permission of the author of the volume, add to the review a letter from Department of the Navy (Arlington, Virginia 22217, USA), as well as a link to his latest publication [23].

Remark of the editorial board of the journal: With the material presented above, we have finished the cosideration of a series of books of Sh.U. Galiev. They were published in the time between 2011 and 2020 and were devoted to the analysis of extreme waves in the technology and Nature [23–26]. The reviews were written by Corresponding Member of the Russian Academy of Sciences, Professor M.A. Ilgamov.

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Reviewed by M.A. Ilgamov

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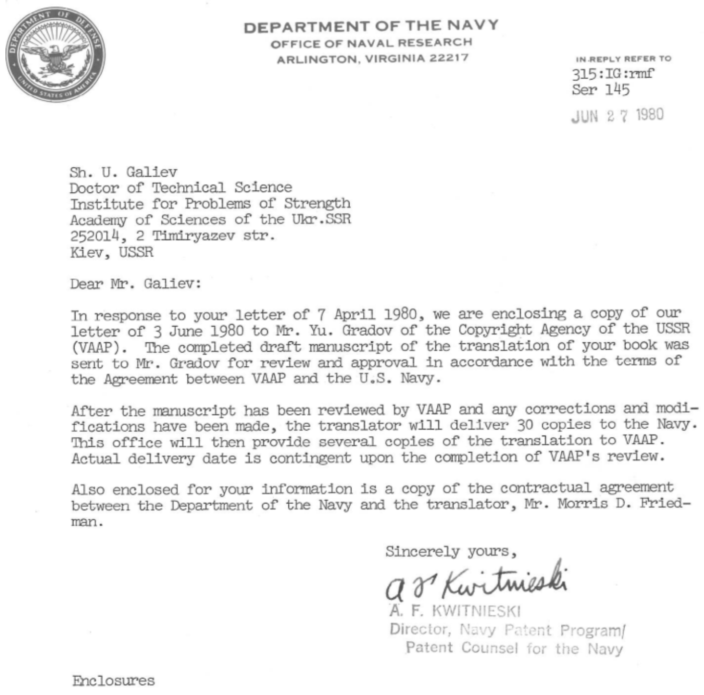

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Dear Mr. Galiev:

In response to your letter of 7 April 1980, we are enclosing a copy of our letter of 3 June 1980 to Mr. Yu. Gradov of the Copyright Agency of the USSR (VAAP). The completed draft manuscript of the translation of your book was sent to Mr. Gradov for review and approval in accordance with the terms of the Agreement between VAAP and the U.S. Navy.

After the manuscript has been reviewed by VAAP and any corrections and modifications have been made, the translator will deliver 30 copies to the Navy. This office will then provide several copies of the translation to VAAP. Actual delivery date is contingent upon the completion of VAAP's review.

Also enclosed for your information is a copy of the contractual agreement between the Department of the Navy and the translator, Mr. Morris D. Friedman.

Sincerely yours,

A F Kwitnieski
A. F. KWITNIESKI
Director, Navy Patent Program/
Patent Counsel for the Navy

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