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A.I. Doulnev, V.I. Fedorov. **Statistic Evaluation Methodology for Ballistic Impact Resistance of Marine Protective Barrier Specimens.** Pp. 5–30.

The paper discusses the stochastic nature of protective barrier resistance to high-velocity impacts and considers methods of experiment planning and statistic analysis of test results for more unbiased, accurate and valid evaluations.

Based on processed and analysed actual barrier ballistic impact resistance data, the authors demonstrate that the outcomes of high-velocity interactions are random and assess the scatter observed in protective characteristics of structures made of different kinds of materials. They review the major result interpretation and statistic analysis methods presently applied for specimen tests. It is shown that there is still no single common approach to these tasks and the existing procedures have certain deficiencies.

The suggested statistic analysis model is based on interpreting the ballistic limit as a random internal parameter of the barrier+projectile system. The authors offer techniques for finding numerical characteristics of this random value using the maximum likelihood method and the Bayes formula.

The authors outline principles of verification tests performed with specimens of protective barriers to confirm their compliance with design requirements. They also formulate guidelines on improvements in the methods of ballistic impact tests for armoured structures. The suggested philosophy anticipates planning the impact velocity for each subsequent test in such a way as to minimize the expected scatter in the new assessment of the mean ultimate penetration velocity.

The accuracy of the suggested testing and analysis approach has been compared against other ballistic test result evaluation techniques using the Monte Carlo method. It is demonstrated that the new procedure improves the accuracy of establishing ballistic impact protection characteristics by some 15~30% on the average and even by over 1.5 times in some particular cases.

G.L. Nikiforov, L.B. Polozhentseva. **Interactions of an Elongated Rigid Projectile with Metallic Barriers.** Pp. 31–39.

There is no analytical insight into the issue of barrier penetration by elongated projectiles associated with the formation of debris, i.e. the so-called «plug knocking-out» because this task involves jointly considering several processes, including barrier cracking, heating and deflection rate effects, as well as the projectile deflection and fragmentation. Simultaneously investigating all these phenomena is for any practical purpose impossible, and therefore adequate analytical models have to be based on various assumptions.

The authors assume that the projectile material is stronger than that of the barrier and hence its deformations are minor. Besides, they ignore barrier deflections in planes that are perpendicular to the impact direction and assume that all points of the barrier resting on circular cylindrical surfaces with axes coinciding with the axis of the axis-symmetric projectile simultaneously suffer identical dislocations. Thus, in this model the moving projectile gradually pushes some of the material out of the barrier. After the ogive enters the front face of the barrier and a certain ultimate shear angle is achieved, there appears a knocked-out fragment of the same diameter as the maximum diameter of the projectile.

The obtained analytical solution enables to find minimum barrier penetration velocities for specified impact velocities. In case the projectile penetrates through, the model allows finding its velocity behind the barrier. Besides, it is possible to assess projectile ogive length and front-end diameter effects upon the barrier resistance and to determine the effects of physical and mechanical properties of the barrier upon its resistance.

A.I. Doulnev, M.B. Lavrenov, V.I. Fedorov. **Experimental Research on the Resistance of Advanced Protective Material Specimens to High-velocity Impacts.** Pp. 40–58.

The paper discusses some experimental results of fragmentation resistance investigations carried out with the help of a light-gas gun at the Krylov Shipbuilding Research Institute. The offered data are related to one of the most promising kinds of protective barriers: ceramic composites that include polycrystalline ceramics based on aluminium oxide, silicium carbide and nitride, and a titanium-carbide cermet.

It was experimentally established that depending on the highly rigid material incorporated in the barrier formula, the ballistic limit velocities are related approximately in proportion to the following ballistic efficiency coefficients. Assuming the silicium-nitride ceramic material coefficient for 1, the sintered silicium-carbide has 0.98~1.02, the self-bonded silicon carbide has 0.92~0.96, the glassceramic has 0.84~0.88, the alumina ceramic has 0.81~0.85 and the cermet has 0.68~0.76. A limited number of tests with boron-carbide ceramic materials indicated that their coefficient would be within 1.02~1.10.

Evaluations of the test data enabled to identify qualitative features typical of the behaviour of different ceramic materials under high-velocity impact conditions and to suggest possible explanations for their differences in ballistic-impact properties.

Using a set of calibrated screens, the authors have separated different fragmented highly rigid materials into fractions. The performed analysis of that information has demonstrated significant differences in fragmentation patterns of ceramic, glassceramic and cermet materials.

Yu.B. Borisov, N.S. Karateev, G.L. Nikiforov, L.B. Polozhentseva, V.P. Solenov. **Fractures of Ship Hull Structures under External Explosions.** Pp. 59–72.

Research and design experiences suggest that medium-size and small ships need certain structural provisions for restricting and localizing hull damages in case of external explosions. The existing formulae for hull damage estimations have been derived from generalized experimental results but they can provide only a rough assessment for a particular ship since they ignore specific architectural and structural features.

The suggested model of computations for ship hull fractures due to internal explosions is based on considering demolition effects of the explosion. Computations for grillages that surround the involved compartment are made assuming direct and reflected pressure wave pulses. Adjacent-compartment grillages are subjected to impacts of the broken grillages or their fragments and the procedure also allows accounting for the equipment inside the affected compartments. The grillage strength analysis is performed on the grounds of the potential displacement principle and the plastic hinge theory. The procedure was validated by test results obtained from internal explosions in experimental compartments. A dedicated PC software package for fracture-affected zone computations was designed and the paper offers such numerical prediction results.

This computation model enables to assess damage predictions assuming different internal architecture arrangements in order to establish the significance of particular structural details in the hull fracture scenario and to elaborate general design guidelines on localizing the effects of internal explosions (cofferdams, additional bays, platforms, etc.).

V.V. Khokhryakov. **A Comparison of Various Approaches and Numerical Solution Methods for Acoustic Pressure Wave Diffraction Problems.** Pp. 73–83.

Problems of the acoustic pressure wave diffraction on bodies of various shapes are usually reduced to a wave equation solution in terms of velocity potentials. Numerical methods allow solving wave diffraction problems for arbitrary-shape bodies for which any analytical solution is hardly feasible.

However, solutions that are found for separated-flow problems display significant fluctuations in the results. Besides, both analytical and numerical methods require the transparent-body assumption, i.e. finding the wave arrival time at each point of the considered body assuming that this body is transparent for the waves.

The authors compare results achievable with different numerical approaches and methods using an example of a single plane pressure wave diffraction on a rigid circular cylinder. Based on the obtained results, they suggest recommendations for selecting numerical solution approaches and methods for wave diffraction problems.

A.I. Doulnev. **Strength and Shocks of Ship Structures Associated with Helicopter Crash-landing on the Deck.** Pp. 84–102.

Design estimations for the scenario of helicopter crash-landing on a ship deck are derived from evaluations of statistical data. It is demonstrated that the probability of such a flight accident is not negligibly small and therefore should be considered in environmentally critical marine designs that involve helipads.

The paper describes computation models that allow estimating helicopter crash-landing consequences for ship hull structures and equipment, and if necessary determining parameters of structural protections preventing the penetration of damaging effects (helicopter debris, spilt fuel, fire) into internal spaces. The model used for the impact effects upon the ship structures is based on considering the airframe as a plastically deforming in crushing shell with piece-linear length-wise distribution of running weights, support cross-section areas and crushing stresses. The author offers numerical estimations of forces on rigid structures (barriers) due to type «Ka-32c» helicopter crashes with different impact velocities. The paper also formulates basic postulates for load-bearing capacity assessments and for the selection of structural protection parameters under the criterion of ultimate loads or ultimate sags.

The discussion covers task formulations for and basic approaches to the assessment of global and local shocks due to the helicopter impact. These shocks present a kinematic load for the equipment. To estimate the potential equipment damage, i.e. the critical level of structural shocks, it is suggested to apply an approach based on comparing the impact acceleration load spectrum, which describes the equipment shock resistance, with the kinematic load spectrum produced at the equipment station.

The paper presents numerical estimations of shocks transmitted to the ship equipment due to the helicopter impact. It is shown that the considered accident scenario poses the greatest risks to equipment items mounted rigidly on comparatively low-frequency deck grillages, which is associated with the resonance of global shocks with the deck oscillations.

A.B. Nesterov. **Computation Model Improvements for the Analysis of Anti-ramming Sidewall Protective Grillages.** Pp. 103–110.

Regulating safety issues under ship collision scenarios requires correct estimations of the energy absorbed in the deformation of hull structures. One of the most effective energy sinks involved in collision-induced deformations is

the sidewall grillage of the rammed vessel, and therefore correct estimations of its energy absorption capacities are most important. Traditionally, Russian engineering routines rely on a model of a rigid-plastic string resting on a rigid-plastic foundation that has been introduced by Yu.F. Lepp. However, that model is true only for vertical fore stems and therefore the author has earlier suggested considering slant-bow cases with an approximate linearised formula. The present paper offers a further refinement of the practical applicability of Lepp's function and demonstrates that it may be significantly simplified, which allows achieving closed analytical solutions for slant-bow ramming scenarios without any linearisation. The author also suggests a refined regulation technique for the sagging associated with the sidewall shell rupture.

V.S. Bojanovsky, I.M. Belov, A.M. Romantsev. **Vibration Performance Predictions for Hull Structures of Advanced Vessels Considering Requirements of New Methodological Documents.** Pp. 111–117.

Today, there is a need for certain corrections in methodological documents on ship vibrations. Therefore, the Krylov Shipbuilding Research Institute has carried out a comprehensive revision of the existing methodology and formulated amendments and additions to the relevant Rules of the Russian Maritime Register of Shipping and a new edition of Guidelines on Vibration Level Estimations for Manned Spaces on Marine Vessels.

These new document versions significantly expand the applicability of methods in respect of subject ship types and dimensions, vibration sources and design frequency ranges. Besides the traditional compact design models, they recommend more sophisticated three-dimensional schematizations of hull structures consistent with modern requirements, particularly those outlined in the documents of the major foreign Classification Societies.

The suggested approach is demonstrated using an example of a Project 20070 tanker constructed at the Admiralty Yards. Computations have indicated that under certain draught conditions the tanker would suffer resonant vibrations. In order to mitigate those excessive vibrations, it was suggested to apply measures for reducing the excitation forces and tuning away from the resonance.

O.N. Lychev, Yu.A. Nikolsky, Yu.N. Shavrov. **Fatigue Strength of Welded Joints between Grade 3V Titanium Alloy Rolled Plates.** Pp. 118–125.

The introduction of titanium alloys into the marine industry has called for comprehensive studies on their behaviour in ship structures. Many experimental investigations have been directed towards finding out fatigue performances of titanium weldments and the most effective ways to enhance their serviceability.

The paper generalizes results of studies showing that titanium alloys offer sufficiently high fatigue performances allowing their successful applications as shipbuilding structural materials.

The authors present experimental data about the efficiency of some local vibration strength enhancement techniques (shot-hardening, annealing, etc.) that may be when necessary applied to improve welded joint fatigue performances up to the levels dictated by practical service experiences of naval and commercial ships.

The paper also provides information about additional investigations, which have confirmed it could be feasible to achieve proper endurance of some kinds of welded joints used in the fabrication of closed structures like ducts, foils, etc. only through accurate observance of assembly and welding processes.

G.V. Egorov. **Specific Features of Hull Structures for New-generation Restricted-service Vessels.** Pp. 126–143.

With the rapid increase in river-port cargo traffic, recent years have made it an important task to design new multipurpose bulk carriers and tankers that would be cost-efficient in Russian inland waters and limited depths of the Azov and the Caspian Seas. Besides, these ships should operate with minimum transit time losses along European costs, including crossing the Bay of Biscay in winter, and should have sufficient ice strengthening.

These designs feature full utilization of lock clearances on the Volga Waterway for high block coefficients, increased payloads through using extensive deck structures with the least possible draught, improved manoeuvring (azimuthing podded propulsors) in restricted passages, locks and shallow waters, and justifiably reliable hull structures with the optimised material consumption.

Material input optimization ways include using longitudinal framing for the deck, sides and the middlebody bottom with increased transverse spacings and reduced longitudinal ones, keeping flooring and shell thickness down to minimum acceptable levels, meeting local strength and buckling requirements through a rationalistic mix of common and deep frames, assigning equal web thickness for deep and plain frames to get equal wear endurance, designing side and bottom structures for service loads that are usually regarded as off-design conditions (bumping against water-lock structures, grounding, etc.), and so on.

G.B. Kryzhevich. **A Solution Method for Statistic Dynamics Problems of Ship Structures.** Pp. 144–159.

The paper suggests a solution method for non-linear statistic dynamics problems of ship structures based on an unconventional expansion of the steady sea wave history as a sum of several harmonics that have random amplitudes, frequencies and phases (with random input values). At first, these random inputs are fixed at several levels. With a fixed set of these random inputs, the non-linear dynamics problem of the ship and her structures is solved numerically and provides a value of the output history energy parameter, which is found as the mean sum of squared amplitudes of individual frequency components. A family of such energy parameters for a multitude of potential random inputs offers valuable statistic information for resolving probability dynamics problems in non-

linear formulations. Based on this family, it is possible to establish functional relations between energy parameters of input and output histories. Output energy parameter and amplitude probability distributions are found using the random-value generation method.

The suggested method is based on the frequency-domain probability analysis of wave-induced motions and forces applied to the hull. Unlike the time-domain methods, this technique is very economic in terms of the involved computation time and is very well adapted to existing methods of finding hydrodynamic forces due to wave motions that correspond to respective hydrodynamic coefficients in motion equations, which are largely functions of the wave frequency. The new method enables to improve the accuracy of design load estimations, which dictate the strength of ship structures, and hence to optimize the design, to perfect the weights and to enhance ship service reliability and safety.

It may be expected that thanks to its universal nature this method will find extensive applications in statistic dynamics problems of high-speed marine vehicles, as well as in environmental load problems of ship structural mechanics.

G.B. Kryzhevich. **Hydroelastic Oscillations of a Stub Foil.** Pp. 160–167.

The paper discusses the oscillation problem for a stub foil (with a span less than the chord length) placed in incompressible inviscid fluid flow. The hydrodynamic part of the problem is solved with the help of the boundary-value Green function. The suggested mathematical model describes hydroelastic oscillations of the foil and is suitable for the analysis of induced vibrations and investigations into hydrodynamic instability effects. The qualitative nature of motions of the hydroelastic system is considered through examining its main modes. Simplified divergence and flutter criteria are formulated. As a practical application, the author uses vibrations of a roll-stabilizing bilge fin.

V.F. Souslov. **A Comparative Efficiency Study on Alongside Transfer at Sea Systems.** Pp. 168–176.

The paper offers a comparative efficiency analysis of conventional transfer at sea systems and less conventional options like skin-to-skin replenishment with a multipurpose deck crane. Quantitative evaluations of the compared alternatives are made assuming the systems are installed on a particular cargo vessel.

V.F. Souslov, A.G. Danilevsky. **Marine Machinery Material Demands Can be Reduced.** Pp. 177–184.

Using a practical example of a deck crane, the paper discusses theoretical approaches that account for marine machinery weight effects upon service performance and show particular ways to reducing material expenses for marine machinery construction.