Transactions of the Krylov Shipbuilding Research Institute

1, 2009
42(326)

SUMMARIES

V.M. Grekov and G.I. Efremova. **Calculation of in-plane shape equilibrium of circular stiffeners in cylindrical shell.** Pp. 5–18.

The paper offers a methods of calculating the critical pressure for side («out of plane») buckling of circular frames used to stiffen the circular cylindrical shell loaded with omnidirectional uniform external pressure.

To idealize the problem, the stiffener side buckling in combination with the local shell deformation in the spacing (caused by external pressure) is analyzed. It is assumed that stiffener side buckling will be the most pronounced effect because the bending shell deformation in spacing and the stiffener strain coincide in shape or have similarity shape.

The main assumptions: shell and stiffeners are of ideal shape, their material is ideally elastic, shell length is infinite, the stiffeners are at equal distances from each other, their cross-section shape is symmetrical with respect to the plane of their location before the buckling. The solution is found within the linear theory of circular bars (stiffener flange), thin plates (web) and shells (plating). The calculation considers such factors as variability of the stiffener cross-section shape under buckling, the presence of both tangential membrane stresses and radial stresses in web, contribution of initial stresses in stiffener web and flange to the reduction of web clamp by these elements.

Based on some of the assumptions mentioned above, the investigation of stiffener «out of plane» buckling is reduced to examining the behaviour of one isolated stiffener with the «plating flange» whose length is equal to the spacing. This buckling is examined using the integration of stiffener web neutral equilibrium equation, the web being regarded as a circular plate. The influence of deformation peculiarities of its boundary elements – flange and shell – is included in the formulation of the corresponding boundary conditions for the plate-shaped web.

In two cases of the plate side buckling – in axially symmetric $(n = 0)$ and one-wave form – the neutral equilibrium equation is integrated over the closed surface. Its general integral in both cases is expressed through cylindrical functions. The critical value of radial pressure on the plate is obtained through the solution of some transcendental equations including the specified functions and problem parameters.

In the general case of the plate-web wave buckling $(n \geq 2)$ the equation is integrated using Bubnov-Galerkin method, and critical loads are determined using a special procedure.

For implementing the above-mentioned algorithms some software was developed for computations in FORTRAN 90 language. As an illustration, some calculation results and their plots are presented. In particular, it is concluded that that internal shell stiffeners, as it should have been expected, are more likely to buckle than external ones.

Key words: *circular ribs, cylindrical shells, form stability.*

G.I. Efremova. **Defining stressed & strained state of stiffened cylindrical shells with initial bending of arbitrary shape.** Pp. 19–26.

The paper is dedicated to the solution of the problem regarding the definition of stressed & strained state of stiffened cylindrical shells with consideration of initial imperfections without bending shape limitation.

The problem is solved as linear, i.e., the solution considers extra loads – normal plane projections of products between initial (without consideration of bending) forces and the variations of its curvature caused by initial imperfections, corresponding projections from extra forces are not considered. Thus, specifying the bending of entire compartment by one value of the series we come to the traditional solution with complex bending factor, suggested by P.F. Papkovich, which is used practically.

In fact, the frame deviations from regular shape and plating deviations in relation to frames are registered. In this case, the number of points along the circle where the measurements are taken, is different for the frames and for the plating.

The present algorithm defines initial curvatures basing on measurement results, then we pass to the load which causes complex bending.

An important factor in the Fourier expansion of the function $f(x)$ specified by the points (in our case these are the values of frame and plating deviation) is approximation of this function. The study showed that to form a curve passing through a series of measurement points the best approximation is achieved by means of cubic splines with the segments connecting two points of each measurement interval.

The algorithm is realized in the software, which has been used in certification of real compartments. The software makes it possible to consider practically arbitrary bending shape (basing on actual geometry measurements of the shell with frames of various stiffness, with various spacings). Its application to a speific hull whose frame deviations exceed acceptable limits and on which, respectively, the stiffeners were installed using a traditional approach, showed that, taking into account rather chaotic actual distributions of deviations by various frames, it was possible not to use the reinforcements.

Key words: *shell, complex bending, initial curvature, frame.*

B.V. Druzhilovsky, N.V. Burnasheva. **On the shell plating deformation of the external submarine hull in process of diving operations.** Pp. 27–40.

When a submarine is diving, the hydrostatic pressure load is applied directly to its pressure hull.

However, its external hull, which is not directly exposed to the outboard pressure, and the pressure hull are connected with rather stiff and densely placed radial stiffeners. These stiffeners ensure combined deformation of the hulls.

The most interesting is the combined deformation of the pressure hull and external hull when the ship has two-hull structure, i.e. when the external hull, with exception of stern and bow ends, completely covers the pressure hull in cross-sections, since the interactions of the hulls in this case is the most intensive. The paper is focused exactly on this variant of the hull architecture.

The substantial difference in the shell thicknesses of the external and pressure hull plating and the areas of frame cross-sections makes it possible (with certain correction) to conclude that the external hull is subject to the displacements caused by the pressure hull deformation.

Specifically, it should be noted that relative thickness of the external hull plating with the cross-section radius of $r_{external}$ is normally about $h_{external}/r_{external} = 1/600$ to 1/900 and less at relative radial displacements of hull frames being of the same order at the operation depth. It provides conditions for the occurrence of non-linear effects of plating deformation and buckling.

In this relation the paper considers the buckling of the submarine external hull plating in the diving process, i.e. under rather complicated stressed conditions when rather thin shells, apart from being subject to compressive stresses, have areas of high bending stresses. The analysis is performed taking into account the possibility of non-linear deformation, including the one in supercritical area.

It is shown that the plating with characteristic geometric and kinematic parameters in case of the transverse framing system is subject to non-linear deformation without buckling. This situation is confirmed by numerical and analytical evaluations. However, the plating with the framing of longitudinal system may be subject to buckling. This effect is rather stable and occurs in the shells without any initial bending as well as in the shells having initial deflections.

It is noted that all the effects of non-linear deformation involve limited displacements and stresses, so they do not normally lead to disastrous damage, however, they require thorough examination in hull design process.

The studies presented in this paper were carried out with participation of E. Novichkov.

Key words: *submarine, shell, external hull, strength, form stability.*

A.P. Fedorov, K.M. Parnov. **Numerical and experimental investigation of stress concentrations near corrosion caveties on the surface of marine structures.** Pp. 41–48.

The paper presents the of experimental and calculated data on stress concentrations near corrosion cavities under conditions of uniaxial tension of the plates simulating external surfaces of marine structures.

Two flat 8 mm thick plates sized 140×350 mm were manufactured and subjected to tensile tests. Stress concentration was defined for two cavity types: one with the ratio between cavity radius R and plate thickness $t(R/t) = 1.8$ and the other one with r/t ratio equal to 0.5. For both types of cavities their penetration depth h in the plate remained the same and equal to $h/t = 0.3$; 0.6 and 0.9, with respect to the plate thickness. Each cavity type was examined a separate plate simulating all penetration parameters. Each specific cavity variant was doubled on a model to make it possible to determine the concentration of stresses in the conditions of not only uniaxial but biaxial tension as well.

To obtain the data regarding stress concentrations near the cavities the «freezing» method was applied. The model material at «freezing» temperature was in the high-elasticity state and had Young's modulus $E = 25$ MPa and Poisson ratio $\mu = 0.5$ and optical constant $\sigma_0^{1,0}$ of 0.37 kN/m. The models were divided into 6 parts, and then the sections were cut to find the stresses near the cavities by means of photoelastic method. Two types of sections were cut: one served to define the stresses at the cavity bottom, and the second was used to define the stresses around the cavity edge. For the model with the cavity of $R/t = 1.8$ only the first section type was cut, and for the model with $r/t = 0.5$ – both types were made. In its turn, to define the stresses at the cavity bottom, the sections were cut along the plate (tension direction) and across it. The sections along the plate were intended to define the stress concentration under uniaxial tension. The sections across the plates served to introduce the correction in order to obtain stress concentration under biaxial tension. Similarly, the second type of section was cut along the plate and across it, but only for the model with $r/t = 0.5$.

Stress concentration factors at the cavity bottom at $h/t = 0.30$; 0.60 and 0.90 for the model with $R/t = 1.8$ under condition of uniaxial tension were $K\sigma = 2.27$; 3.03; 3.80, respectively. For the model with $r/t = 0.5$ $K\sigma = 2.65$; 2.75; 2.90. Under condition of biaxial tension for the model with $R/t = 1.8$ $K\sigma = 2.57$; 3.42; 4.28. For the model with $r/t = 0.5$ $K\sigma = 3.12$; 3.32; 3.52. Stress concentration factors at the outer cavity contour for the model with $r/t = 0.5$ under condition of uniaxial tension $K\sigma = 1.78$; ; 2.40; 3.00; under biaxial tension $K\sigma = 1.76$; 2.22; 2.79.

The numerical calculations are performed using ANSYS software. In the calculations, Young's modulus is assumed to be $E = 25$ MPa and Poisson ratio $\mu = 0.48$. For example, it was found that for the uniaxial tension of the model with $R/t = 1.8$ $K\sigma = 2.04$; 2.63; 3.34 at the cavity bottom and $K\sigma = 2.36$; 2.65; 3.39 for the model with $r/t = 0.5$. At the outer contour for $r/t = 0.5$ $K\sigma = 1.92$; 2.51; 3.05. Without going into details, it should be noted that the difference between experimental and calculated data amounts to 10–15 %.

The investigations performed for the two types of cavities with various geometry showed that there is a rather high stress concentration in the vicinity of these cavities. It is recommended to take all possible measures to prevent cavity occurrence.

Key words: *corrosion, cavity, stress concentration, experiment, calculation.*

A.P. Fedorov, K.M. Parnov, Yu.A. Libov. **Buckling investigation on cylindrical and cylindrically – conical shells under various boundary conditions.** Pp. 49–58.

The buckling problem for cylindrical and cylindrically-conical shells is solved using photoelasticity and numerical calculation by means of sweep method with orthonormalization.

The shell sizes were selected to be equivalent, kinks being neglected. Working length of the shells was 147 mm, the mean diameter of the cylindrical shell was 88 mm, the mean diameter of the cylindrically-conical shell – 75 mm, the thickness was 3 mm, cone angle from the shell middle was equal to 0.375 radian.

Five models were tested with various bottom thicknesses to obtain different values of shell end supports (from free to fixed ends).

The models were made of hardened epoxide resin. To manufacture the models, the first step was to mould the blanks, which were then processed on a turning machine after that the model was glued together.

During the tests the model was placed in the thermostat with transparent windows. It was heated up to the temperature of 135°C, at which the model material was acquiring a high-elasticity state, Young modulus reducing from $E = 3000$ MPa to $E = 25$ MPa. To obtain the proper external pressure the vacuuming was performed. For this purpose the model was connected with a vacuum pump by a hose. The buckling was observed visually, the pressure value being defined by means of a pressure gage.

Visual model observation at the moment of buckling showed that two-wave buckling is characteristic for the models with thin bottoms $(S = 9\,\text{mm})$, which corresponds to the free support. Three-wave buckling appears when thick bottoms $(S = 37\,\text{mm})$ are installed and models a rigid support.

The calculated data were obtained using a sweep method with orthonormalization (Fortran 4 language), Young modulus being of $E = 25$ MPa and Poisson ratio $\mu = 0.48$.

The experimental and calculated data agree well for the shells with thin bottoms. In case of thick bottoms the experiment gives lower critical pressure values. Along with it, the trends predicted in the calculation were confirmed: in case of a free support the compound shell is 1.5 times more likely to buckle than the cylinder, but under conditions close to a rigid support it is somewhat less likely to buckle.

Key words: *shell form stability, buckling, experiment, calculation, boundary conditions.*

V.M. Ryabov. **Similarity criteria for the problems of cylindrical and spherical shells.** Pp. 59–76.

The paper substantiates similarity criteria in the buckling problems within and beyond the limits of the material elasticity, which allow designing the models whose initial shell buckling parameters are equivalent. It also shows the possibility to replace the material without violating equivalence conditions. For the cylindrical shells stiffened with frames and loaded by external omnidirectional pressure, the criteria are obtained which concern various buckling forms:

– Local buckling between the frames;
– Global buckling from one shell edge to another;
– «Groove» buckling expanding to the frames if they are placed very frequently.

For all the forms specific similarity criteria are obtained and their compatibility criteria are examined.

For the global buckling three types of boundary conditions are examined:

– Classical free support on both edges;
– Closing of the shell from two sides with semi-elliptic (in the limit – semi-spherical) bottoms;
– One edge has free support, the other being closed with semi-elliptic bottom.

Joint similarity criteria are obtained for the whole structure and its bottoms.

Similarity criteria are also given for non-ideal shells having deviations from the regular shape.

In conclusions, after the numerical example, similarity criteria for the spherical shell are given.

Key words: *cylindrical shell, spherical shell, shell form stability, buckling, experiment, calculation, boundary conditions, similarity criteria.*

A.M. Puzyrev. **Complex application of solid modeling and finite-elements method as a verification tool in the design and structural tests of a prototype AK-SV compartment.** Pp. 77–86.

The paper examines the design and complex tests of a prototype compartment in the format of mathematical modeling. It suggests a simple configuration of CAD and CAE (SolidWorks, DesignSpace, ANSYS Structural) software family, which makes it possible not only efficiently solve the problems of prototype structure design, but also ensures an easy import of a geometric compartment module into ANSYS environment for the analytical verification and mathematical modeling at various stages of the compartment tests. It shows a practical realization of the generalized FE-models tree construction to solve particular problems concerning the calculation of the stressed-strained state basing on a generalized 3D solid model. The paper examines the interaction problems of the constructed mathematical models with normalizing analytical methods and with strain measurements performed directly during the tests. Basing on the comparison of the calculated and experimental data the accuracy assessments are obtained which concern the application of analytical calculation methods for a series of the main structure elements (up to 20%). It reveals the necessity of further steps to improve the interpretation of FEM-data for the structural joints made under existing rules. At the last stage of the structural strength tests the FEM was used to predict the critical state of structures which made a major contribution to successful completion of the whole project.

Key words: *FEM, finite element method, simulating, experimental model*

A.V. Alexandrov, I.V. Burnasheva. **Comparing the buckling computer modeling results for the reinforced built-up conical and cylindrical shells under external pressures using sweep, FE and reduced elements methods.** Pp. 87–92.

The paper presents the calculation results for the elastic buckling of cylindrical reinforced shells obtained by three different methods: sweep method, FEM and reduced elements method, using MPL ANSYS and RELEM software, respectively. The paper gives the buckling calculation results for three shells with identical frames and spacing, but with different length, under condition of omnidirectional uniform pressure. It examines the cases of freely supported and fixed ends. The critical pressure values obtained by means of different calculation methods agree well with each other and vary within 1%, which confirms the possibility of using different approaches to defining the critical loads on deep-water hulls.

Key words: *buckling, cylindrical reinforced shell, finite element method, critical load.*

V.I. Alferov. **Guidelines on calculation of welding deformations in hull structures using FEM in static formulation.** Pp. 93–116.

The existing calculation methods for residual welding deformations, stated in RD 5.9807-93 (Metallic ship hulls. Methods for defining and preventing residual welding deformations) are applicable to the calculations of welding deformations in case of relatively simple typical joints and flat sections. Further refinement of the calculation methods for residual deformations and stress assessment is suggested using an FE-method in static formulation, which makes it possible to consider heat effects of welding process on the deformations and perform a more detailed modeling of complex 3D hull structure geometries.

The main points of these guidelines are as follows:

The object under examination (sections, blocks, hull at berth, etc.) is approximated by means of plate-like and rod-like finite elements. In the areas where the connections are welded in the course of assembling, the finite-element mesh is made finer to ensure more accurate modeling of equivalent forces arising as a result of heat effects caused by welding and shrinkage in the welding seams.

Structure deformations will be defined with consideration of the assembling and welding sequence, including the increase of structure stiffness in the process of its assembling and its boundary conditions variation. The effect of each seam is regarded as independent of the adjoining seams and sequence of their application (for example, in separate areas, single-pass welding, step-back welding, etc.).Reduction of the weld seam area in longitudinal (along the seam axis) and transverse directions are examined separately and assumed to be independent of each other. The longitudinal reduction of weld seams are assumed to be uniform, end effect not considered. If the structure is bent, flat sections hypothesis is applied.

Basing on the welding deformations theory (S.A. Kuzminov. Welding deformations of ship hull structures. «Sudostroeniye», Leningrad, 1974) bulk reduction of welding seams are assessed in longitudinal and transverse directions, with the consideration of the material's thermophysical and mechanical properties and welding modes as well. The equivalent forces (or relative shortening) in longitudinal and transverse directions are used to represent the loads arising in the structure while the welding seam is being made.

The paper considers two study cases for the welding deformations of the beam and cylindrical shell, for which the experimental data are available in literature. It also presents a practical case: modeling of sequential installation and welding of three pairs of cylindrical pipes into a spherical shell. All the work was schematically divided into three technological stages, each of which comprised the assembly and welding of one pipe.

The calculated values of pipe displacements in the horizontal and vertical planes made it possible to develop technological measures designed to prevent or reduce deviations in the cylindrical pipe size to ensure the specified tolerances.

Methodically, FEM application has opened new opportunities to model the assembling and welding process for complicated 3D structures and made it possible to develop practical recommendations to the reduce welding deformations of ship structures.

Key words: *welding deformations, hull structures, finite element method.*

N.V. Burnasheva, I.A. Saraeva. **The influence of pressure chambers on the stresses and support reactions.** Pp. 117–126.

The paper is dedicated to the static strength problem of the divers' pressure chamber complex carried by a rescue vessel, the chambers being connected with each other by means of lock chambers and their supports being rigidly fixed.

The paper presents the calculation results for the stressed state of a system of pressure chambers connected with each other by lock chambers and supported by separate lower supports. Two ways of calculation are described – the first way giving an approximate calculation procedure with the fixation in assumed planes of symmetry and the other being purposed for the whole pressure chamber complex with fixation on lower supports. The results obtained were analysed. The paper shows the influence of pressure chambers interaction on the values of the obtained stresses and forces transferred through the supports. ANSYS software was used to develop computer models and perform calculations.

It is shown that in case when the object of calculations consists of separate blocks mutually influencing each other, stress calculation based on the local models constructed according to the «supports – symmetry planes» principle may lead to excessive stresses in the places of supports which, in its turn, will result in unnecessary reinforcing of these places and, consequently, in the waste of expensive materials used to build this object.

It is concluded that time-consuming development of electronic model to allow comprehensive consideration of all design feature provides wide opportunities for the investigation of stressed state under condition of various load combinations and installation techniques, and considerably increases the accuracy of calculations.

The work is done under the contract with Lazurit Design Bureau.

Key words: *pressure chamber, stress, electronic model.*

O.Ya. Timofeev, O.G. Rybakina, O.A. Strogonova. **Definition of in-service defects acceptability for subsea pipelines.** Pp. 127–146.

The paper describes the scientific background for the fault detection procedure in application to subsea pipelines to be performed periodically during the service life. The paper suggests a method for classification of defects, formulates defect acceptability criteria. The work was performed for the development of relevant regulations for the Russian Maritime Register.

Key words: *fault detection, defects, subsea pipelines, regulations.*

V.S. Dresvyankin. **Approximation of Nordheim equation through orthogonal Chebyshev polynomials.** Pp. 147–152.

Author of this paper has developed a simplified compact approximating formula for dependency of reactivity from power duplication period of the nuclear reactor that is based on application of the least-squares method and Chebyshev polynomial of the 6^{th} order that can be used instead of Nordheim equation, which is conventionally applied in studies of the nuclear reactor dynamics (that is also known in the scientific and technical literature as in-hour equation or formula). Application of the proposed formula will allow obtaining high accuracy of reactivity approximation directly from power duplication period without usage of delayed neutron characteristics with maximum relative deviations of the reactivity: +0.355 % and –0.435 % for power duplication period values (reactor periods) 178 s (256.32 s) and 900 s (1298.43 s), respectively.

Key words: *nuclear reactor, Nordheim equation, reactivity, Tchebyshev polynomial, least-squares method.*

V.S. Dresvyanki. **Engineering evaluation of heat-transfer surface area for direct-flow steam generator of ship-borne nuclear steam-raising plant.** Pp. 153–158.

This paper suggests simplified compact approximating formula of ratio between heat-transfer area of the direct-flow steam generator of the ship-borne nuclear steam-raising plant and a number of arguments (such as purpose parameters, operational and design parameters of the steam generator). Suggested formula is based on application of the least-squares method and multifactor regression method with Efraimson's procedure to the selection of the characteristics for the designed and operated coiled-type steam generators. Suggested formula is recommended to application in the computer-aided design systems (CAD, ASPRO) used in designing ship-borne nuclear steam-raising plants and allow determining main characteristic of the steam-generator design with (15..20-tuple) reduction of the time consumption instead of labour-consuming and conventionally applied thermofluid dynamic design of the steam generator. The formula will provide acceptable accuracy of approximation $\pm 5\%$ at large variations of the argument values given in the paper.

Key words: *steam generator, least-squares method, design parameters, approximation.*

V.B. Stepanov, A.V. Gladilin. **Calculation of vibration level distribution over complex ship structure using static – energetic method.** Pp. 159–168.

This paper presents calculation of the vibration level distribution over multi-sectional cylindrical shell with stiffening rings that are excited by vibration power sources located at arbitrary sections. The calculation is based on statistic – energetic method, which core consists in assumption of homogenous distribution of the section vibration energy between resonating modes of their oscillations that is possible for multiconnected multi-component structures under strip excitation. Authors provide grounds for valid application of this method within examined frequency range of 50–1500 Hz, which demonstrates that even at lower range limit not less than 5–7 modes of vibration are resonating at each shell section in the standard measurement strips. Therefore, condition of their effective power interchange is provided. Modified equation of the statistic – energetic method is applied to describe distribution of the vibration energy over the shell sections, where concept of the mean-power input impedances that demonstrate ratio of the resonating mode number both in the section shells and in separators dividing the sections is introduced to calculate coefficients of the vibration energy passage between sections. Quasi-bending, quasi-longitudinal and quasi-shear modes are accounted. This way allows calculating not only levels of the shell total vibration, but also dividing them basing on the wave flow types and spatial components. Knowing the latter is required, for example, to solve tasks of optimal vibration damping and radiation of the hull structures. Vibration levels at cylindrical coaxial smooth shell that is located outside of the stiffened one and connected to the latter only via medium are determined. It is demonstrated that even in this case when there are no rigid connections between shells, their vibration levels within entire examined frequency range are different for not more than 10 dB. Obtained results could be useful, for example, in estimations of the self-generated vibration interferences, when solving tasks related to radiation and reception of the hydroacoustic signals.
Key words: *vibration, hull structure, statistical energy analysis, hydroacoustics.*

A.V. Gladilin. **Generalised uncertainty function relative to power/angle curve of multipath signals in solutions to detection tasks.** Pp. 169–180.

This paper presents methodology for calculating efficiency of the multi-channel systems that allow approximate solutions for detection, localisation and classification in the Gaussian observation model, when expected models are deviating from «true» ones.

This analysis is based on application of the generalised uncertainty function. An option, when signal has a multipath structure, is examined in details. This is required to be considered in developing the processing algorithms for the hydroacoustic observation systems.

Effect of correct accounting of such characteristics as characteristic width of the signal angular spectrum and correlation level between individual rays is investigated basing on examined examples. It is demonstrated that additional processing is required, which considers the above-mentioned factors, since in some cases failure to account these factors will lead to significant losses in efficiency.
Key words: *multipath signals, hydroacoustics, angular spectrum, correlation.*

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