SCHRIFTENREIHE SCHIFFBAU

LESEPROBE

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Stress Analysis of Stiffened Panels Subjected to Shock Loads

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Oktober 1997
1 INTRODUCTION

In stiffened panels made of composite materials, apart from cost, the strength of stiffener-to-plate joints is the main problem to be coped with, and more precisely, the strength when the interface is subjected to high tensile stresses. Local loads transferred to stiffeners by means of brackets can be the cause of large tensile stresses at the interface. In this case, a static analysis can be performed in order to estimate the state of stress. Also, when panels are subjected to shock loads, such as those due to underwater explosions or slamming loads, reflection of shock waves and differential inertia forces due to the overall dynamic response of stiffened panels are responsible for large through-thickness tensile stresses. Slamming loads are small in comparison to shock loads due to underwater explosions, even in severe sea states. Anyway, in both cases a dynamic analysis must be carried out to determine the state of stress.

A closed form solution for such an analysis is almost impossible at present due to the complexity of both the geometry and the physics of the system. Smith suggests the use of a modal analysis or the use of discrete element programs such as ELSHOK or USA. USA is a boundary element code which has been used to model the fluid surrounding the structure, and it has been coupled to different finite element codes which are used to model the structure, such as STAGS or VEC/DYNA3D. But these codes involve a great deal of computational effort.

The aim of this paper is to analyse a stiffened panel subjected to a shock load by means of a spectrum analysis with a power spectral density (psd) function. No validation of the method has been carried out since no data is available to the author and, to the knowledge of him, there is no closed form solution, as stated above. The purpose of this report is to show how to perform such an analysis, as well as to demonstrate the effect of various structural modifications. Further to composite panels also steel panels are analysed for comparison.

2 PANEL MODELS

Estimated panel and top hat stiffener scantlings taken from a ship of about 30 m overall length are used in this investigation (figs. 1, 2).
The first step is to perform a modal analysis, the results of which are used in a subsequent spectrum analysis. The code used for the analysis is ANSYS, release 5.2. While with ANSYS it is possible to model with finite elements the fluid surrounding a structure and to perform a modal analysis of such a model, the results of this analysis cannot be used in a following spectrum analysis\textsuperscript{12}. To circumvent this, instead of modelling the surrounding fluid by means of finite elements, a certain mass -called the added mass- is used to simulate the effect of the fluid. To that end, the density of the composite plate core material and that of the steel plate are increased to include the added mass. The results of the modal analysis using the added mass will be checked against those of the modal analysis using finite elements to model the fluid.

Whereas in a static analysis, the contribution of the stiffener core to the panel stiffness is negligible since the Young's modulus of the materials from which cores are usually made are rather small in comparison to those of the stiffener laminates, in a dynamic analysis stiffener cores must be modelled since they affect panel mode shapes and therefore the results of the spectrum analysis.

The first analysis (job 19) represents the baseline model. The surrounding fluid is modelled by means of finite elements and both the plate and stiffener cores are made of PVC.

The same panel has been analysed using an added mass (analyses job 21 to job 25). In these five analyses, the number of extracted modes used in the spectrum analysis has been varied -from 5 to 25 modes- in order to find out how many of them are required.

A similar panel without stiffener core (job 27 and job 28) and the same panel with a stiffener core made of balsa (job 29) have been analysed.

Also, a hat-stiffened panel made of steel has been analysed (job 31).

2.1 FINITE ELEMENT MODELS

Displays of the stiffened panel models are included in the appendix: job 19 (panel with surrounding fluid fig. 3), job 25 (panel with added mass and stiffener core, fig. 4), job 27 (panel with added mass and without stiffener core, fig. 5) and job 29 (panel with added mass and balsa core, fig. 6).
The plate and the stiffener are modelled by means of layered shell elements (shell91\textsuperscript{13}) with eight nodes and six degrees of freedom at each node -three translations and three rotations. The stiffener core is modelled with solid elements (solid95\textsuperscript{13}) with twenty nodes and three translations at each node. In those analyses in which the surrounding fluid has been modelled, this has been done by means of solid elements (fluid30\textsuperscript{13}) with eight nodes and four degrees of freedom per node -three translations and pressure. The steel panel has also been modelled by means of layered elements in order to be able to determine the through-thickness stresses.

2.2 BOUNDARY CONDITIONS

The panels are clamped on both ends and symmetry degrees of freedom constraints are applied on both sides of the panel.

2.3 MECHANICAL CHARACTERISTICS OF PANEL COMPONENTS

Composite panels are of sandwich structure. All stiffener and plate laminates are made of the same lamina, a layer of E-glass woven roving in a polyester matrix. The sandwich plate has a symmetric structure: both skins comprise four laminas and the PVC core has a thickness $t_c=32$ mm. Five laminas make up the stiffener laminate and the overlaminates consist of three laminas. Three laminas are laid up onto the inner skin of the plate under the stiffener as reinforcement.

The material properties used for the analyses are those given in the rules of Germanischer Lloyd (GL) for high speed craft\textsuperscript{11}. Polyester resin has a density $\rho_r=1200$ Kg.m$^{-3}$, a Young's modulus $E_r=3000$ MPa and a Poisson's ratio $\nu_r=0.316$. E-glass has a density $\rho_v=2540$ Kg.m$^{-3}$, a Young's modulus $E_v=73000$ MPa and a Poisson's ratio $\nu_v=0.25$. The mechanical properties of PVC and balsa are taken from reference 6(table A.5,346). It is assumed that a PVC foam with a density $\rho_c=130$ Kg.m$^{-3}$ is used; this has a Young's modulus $E_c=115$ MPa. As to balsa, it has a Young's modulus $E_c=1400$ MPa and a density $\rho_c=180$ Kg.m$^{-3}$. Since no datum for the Poisson's ratio is given in the aforementioned reference, a value $\nu_c=0.33$ is used in both cases.

A content in mass of reinforcement in the lamina $\psi=0.50$ is assumed, which is a common value\textsuperscript{2}. Following GL rules, a vacuum content $\mu_v=0$ is assumed. Also a fabric density $P_{vf}=919$ g.m$^{-2}$ is used.
With these values, the mechanical characteristics of the lamina can be estimated using the formulas given by GL\textsuperscript{11}. The content in volume \( \phi \) of reinforcement in the layer is\textsuperscript{11}:

\[
\phi = \frac{\psi(1 - \mu) \rho_{x}}{\psi + (1 - \psi) \rho_{r}} \tag{1}
\]

So \( \phi = 0.32 \).

In order to estimate the mechanical characteristics of a WR lamina, those of a unidirectional (UD) layer must be first determined.

The Young's modulus parallel to the fibres \( E_1 \) is\textsuperscript{11}:

\[
E_1 = \phi E_{y} + (1 - \phi) E_{r} \tag{2}
\]

Then \( E_1 = 25400 \text{ N.mm}^{-2} \).

The Young's modulus perpendicular to the fibres is\textsuperscript{11}:

\[
E_2 = \frac{E_{r}}{1 - \nu_{r}^2} \left[ \frac{1 + 0.85 \phi^2}{(1 - \phi) 1.25 + \phi} \right] \tag{3}
\]

The Poisson's ratios are\textsuperscript{11}:

\[
\nu_{12} = \phi \nu_{y} + (1 - \phi) \nu_{r}, \quad \nu_{21} = \nu_{12} \frac{E_2}{E_1} \tag{4}
\]

\( \nu_{12} = 0.295 \) and \( \nu_{21} = 0.067 \).