THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
and
THE SHIP STRUCTURE COMMITTEE

Paper presented at the Ship Structures Symposium '93
Sheraton National Hotel, Arlington, Virginia, November 16-17, 1993

A Methodology for Reliability Assessment of Ship Structures

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Abstract

This paper presents a methodology to assess the reliability of an important and representative failure mode of a ship: buckling of the deck panels. This methodology uses tools for evaluation of the limit states, modeling of loads, geometry and material properties, reliability assessment and sensitivity analysis. The proposed methodology estimates the failure probabilities of the above failure modes, identifies the most important uncertainties and determines the most effective design modifications that result in the highest improvements in reliability. The methodology is illustrated by analyzing the reliability of a cruiser.

Introduction

Naval surface ship structures are still designed deterministically according to working stress formats. Structural safety is quantified by the margin between the applied load and the capacity of the structure, which is measured by the safety factor. Since these formats use only one safety factor, they lack the flexibility to adjust the prescribed safety margin in order to account for factors which are critical in design, such as variability in the strength, loads, likelihood of load combinations, and uncertainties in structural analysis. As a result, these deterministic methods may yield designs whose components have inconsistent reliability levels.

Moreover, current design criteria could become invalid or unrealistic as new materials and geometries are introduced. Indeed, these criteria are typically codified in the form of simple equations or charts that are suitable for a particular range of applications. Advanced designs usually fall outside this range and thus current design criteria are no longer applicable.

Consequently, improved design criteria and methods for assessing structural safety need to be introduced into ship structural design. These methods should be capable of handling both existing and new technologies and materials. They should also account for the uncertainties involved in the design process. The ultimate goal is to develop a reliability based design method for ship structures, which is both general (applicable to both conventional and advanced hull forms) and practical (affordable, timely, and in balance with other aspects of ship design).

Probabilistic methods are already used in civil and offshore structural design and they have matured enough to be used in design of ships. These methods are more effective than deterministic methods because they account for more information than their deterministic counterparts. Such information includes uncertainties in the strength of various structural elements, in loads, and in analysis and design procedures. Probabilistic methods can contribute to the effort for advancing and improving design procedures for ships by providing new design criteria that meet the requirements mentioned in the previous paragraphs. These design criteria are more flexible and consistent than deterministic ones and they yield safer and more economical designs. Moreover, as Moses ['85, '86] demonstrated, all structures designed according to these criteria have consistent safety levels.

This paper proposes a methodology for reliability assessment of a stiffened panel of a ship. The methodology is demonstrated by using it to assess the reliability of the deck panel of a cruiser that may fail due to beam column collapse. This panel is between the Vertical Launch Space (VLS) and the forward end of the superstructure. The deck panel of the particular cruiser that was analyzed has a knuckle that is equivalent to 1 in. eccentricity. In the failure mode considered the load effects are three-dimensional (because of the nearby VLS) and the limit values involve not only longitudinal stress but also transverse and shear stresses, lateral pressure due to green seas impact, and eccentricity in the strength deck due to the knuckle.

Reliability Assessment Methodology

The proposed methodology to assess the reliability of a deck panel consists of the following steps:

- Evaluate the limit state
- Model the uncertainties
- Evaluate the probability of failure
- Evaluate the sensitivity derivatives of the failure probability with respect to the random variables
- Identify the most effective design modifications to improve the reliability of the panel

In the following we describe each step.

Failure of Stiffened Panels Due to Beam Column Buckling

Beam column buckling of the deck panels between the superstructure and the VLS can occur due to the combined action of several load effects including wave bending and whipping moments, and green seas. The deck panels at this critical location are prone to beam-column failure due to the aforementioned knuckle. Buckling has occurred in one of the deck panels located between the superstructure and the VLS.

Due to their significance, these panels and the associated failure modes have been analyzed by several researchers. Sikora et al. (91) calculated the stresses in the deck plates by finite element analysis. They accounted for the wave bending moment by balancing the ship on a sinusoidal wave of height $1.1L^{1/2}$. The effects of whipping moments and of green seas were neglected. Sikora and his coworkers found that the calculated stresses were considerably lower than those required to cause buckling.

Evaluation of the limit state

A longitudinally stiffened panel may fail under two modes:

a) failure due to buckling of the stiffeners, and
b) failure due to buckling of the plate.

The deck panel considered in this study may only fail in the second mode because the deck plate is always under compression due to the eccentricity and the pressure due to green seas.

The method for calculating the ultimate strength of longitudinally reinforced panels is described in [Hughes '88]. In the following we summarize this method.

The key idea in evaluating the ultimate strength of a longitudinally stiffened panel is to analyze each stiffener separately as a beam-column, assuming that the compressive load is uniformly distributed over the stiffeners. For each stiffener the corresponding portion of the attached plate is modeled as a flange of that stiffener. The secant modulus and other properties of the flange, which are different from those of the stiffener, are determined from the theory of ultimate strength of plates [Hughes '88, Chapter 12]. The Young's modulus of the plate, which varies with the strain when the plate is under compression, is then replaced by the equivalent secant modulus of that plate. Failure occurs when the stress in the compressive flange, which corresponds to the plate, reaches the ultimate stress of that plate. The algorithm for evaluating the ultimate strength of stiffened panels is summarized in [Hughes '88, Chapter 14]. The limit state function (performance function) is the difference between the ultimate stress, $\sigma_{a,u}$, and the applied axial stress, σ_{ax}. This algorithm accounts for the effect of the applied normal stress in the transverse direction, σ_{ay} and the shear stress, τ, by using the interaction formula that was proposed by Ohtsubo ['86]. The algorithm has been validated by comparing its results with experimental measurements in several cases [Hughes '88, Section 14.4, pp. 479-486].

Probabilistic Models for Loads, Geometry, and Materials

Loads

The normal stresses in the axial and transverse directions, the shear stress and the pressure due to green seas impact are the loads. The three stresses were obtained using finite element analysis of the full ship. The computer code MAESTRO [Hughes '88] was used for the finite element analysis. In modeling the loads, we broke down the load spectrum into two portions, one in which green seas impact occurs and one in which it does not occur. The reliability was assessed for each of the above portions of the spectrum separately. We established probabilistic models for the loads based on the following assumptions:

a) Only the effects of stillwater, vertical wave and vertical whipping bending moments are considered in evaluating the load models for the stresses. Thus, lateral wave bending and whipping bending moments are neglected.

b) The lifetime maximum wave and whipping bending moments are perfectly correlated.

c) The distribution of the combined sagging bending moment (stillwater, wave bending and whipping) along the ship is approximately the same as that of the bending moment due to the sinusoidal wave that is used in MAESTRO to analyze bending stresses due to sagging.

d) Green seas may occur only with the largest 15% of the load cycles of the combined bending moment (this corresponds to significant wave heights larger than approximately 5 meters). The relative frequency of occurrence of green seas, given that the conditions are favorable for the occurrence of green seas impact, is 5%. Consequently, the portion of the load spectrum that corresponds to green seas impact consists of 0.75% of the total number of load cycles during the lifetime of the ship.

e) The total number of load cycles of the wave bending moment over the lifetime of the ship is 3.3×10^7.

The following procedures were used to calculate the statistical properties of the maximum lifetime values of the bending moment amidships for the portion of the load spectrum with and without green seas.

a) Calculate the long term probability distributions of the wave and whipping bending moments.

The wave bending moment was assumed to follow the exponential distribution. We estimated the parameters of this distribution based on the results presented by Sikora et al. ['83] (ship number 2). The whipping bending moment was assumed to follow the truncated Weibull distribution. The parameters of this distribution were estimated based on results from at-sea measurements and model tests performed on the cruiser (Engle 92a).

b) Derive the probability distributions of the lifetime extreme wave and whipping bending moments.

We found that both bending moments follow the Extreme I distribution.

c) Combine the lifetime extreme wave and whipping bending moments by using the approach proposed by Sikora et al. ['83] (eq. 8). The phase angle of whipping (Figure 1) was assumed to be 220°. This value is based on results from at-sea measurements and model tests.

d) Calculate the lifetime extreme stresses in the panel.

We considered a sinusoidal wave and used MAESTRO finite element analysis of the full ship to calculate the scaling factors (influence coefficients) in the linear relations between the stresses and the bending moment amidships. We derived the probability distribution of the lifetime extreme stresses from the probability distribution of the bending moment amidships using the above scaling factors.

The pressure due to green seas impact was also assumed to follow the extreme I probability distribution. Its probable lifetime maximum value was assumed to be 3 meters of equivalent static water pressure. This includes the effect of dynamic water impact at the junction of the deck and the front of the deckhouse.

Table 1 presents the probability distributions of lifetime extreme values of the following quantities for the portion of the load spectrum without green seas:

- The wave induced stresses.
- The whipping stress that corresponds to the maximum sagging value of the wave bending stress (that is the amplitude of the whipping stress at time t_0 in Figure 1). This value is used in combining wave and whipping stresses.
- The stresses induced by the stillwater bending moment.

In deriving the statistics of the whipping stresses in Table 1, the exponent of the Weibull probability distribution of the long term whipping moment was assumed to be 1.

Table 2 presents the statistics of the lifetime extreme combined stresses for the portion of the spectrum without green seas. Table 3 presents the probability distributions of the combined stresses and the pressure for the portion of the spectrum of the load cycles with green seas. The results in Tables 2 and 3 are based on the assumption that the stresses acting on the panel are perfectly correlated. This is a reasonable assumption because the source of these stresses is the same set of waves and the reliability analysis is of a very localized region of the ship. It is observed that the mean value of the axial stress for the portion of the load spectrum with green seas (Table 3) is 17% lower than that for the portion of the spectrum without green seas (Table 2). This is true because the period of exposure to green seas is only about 1% of the total period of exposure.

The phase angle of the whipping bending moment is important in combining wave and whipping bending moments (this phase corresponds to the elapsed time between the beginning of a cycle of the wave bending moment and the occurrence of a slam, Fig. 1). Based on at-sea measurements on the cruiser that was analyzed in this study it was found that the phase is typically about 220° (Engle 92a). Sikora et al. used a value of 150° in combining wave and whipping moments. These two values are significantly different because the former [Engle '92a] corresponds to bow flare impact while the latter [Sikora '83] corresponds to bottom slamming. Ochi and Motter (73) based on measurements on the Wolverine State concluded that the phase angle corresponding to bottom slam impact ranges between 90° and 140°. Our results were similar; we found that the phase angle is 180° for bottom slamming and 250° for bow flare impact. These values are based on the results from Monte-Carlo simulation of the wave and whipping bending moments performed by Nikolaidis and Kaplan ['91] on a containership.

Table 4 shows the effect of the phase angle of the whipping on the lifetime extreme axial stress. The statistics of the stress for four cases where the phase ranges from 150° to 220° are presented in this table. The probability density function of the lifetime extreme combined axial stress is plotted in Fig. 2 for different values of the phase angle of whipping. It is observed that the mean value of the stress for 150° is smaller than that for 220°. The c.o.v. is insensitive to the value of the phase angle. The trend in the mean value of the combined bending moment is due to the hull damping. Specifically, when the difference between the phase angle of whipping and 270° (which corresponds to the occurrence of the maximum value of the wave bending moment) increases, the combined bending moment decreases because the amplitude of the whipping stress decays with time due to the damping of the hull.

We investigated the effect of the value of the exponent of the Weibull probability distribution of the long term whipping bending moment on the lifetime extreme combined bending moment amidships and on the resulting stresses. The probability distribution of the lifetime combined bending moment is plotted in Fig. 3 for different values of the exponent ranging from 0.5 to 1.5. Table 5 presents the mean values and the c.o.v.'s of the combined axial stresses for three values of the exponent; 0.5, 1.0 and 1.5. It is observed that the c.o.v. reduces with increasing exponent. Furthermore, the mean values are relatively insensitive to the value of the exponent.

Geometry and Material Properties

We believe that the eccentricity of the panel is the only important parameter associated with the geometry. We assumed that the eccentricity is Gaussian. This panel has a knuckle which is approximately equivalent to an eccentricity of 1.0 in. This eccentricity accentuates the effect of green seas because it is in the same direction as the induced pressure. We assumed that the standard deviation of the eccentricity is 0.048 in. This value is approximately equal to the span of the panel divided by 2,000. The dimensions of the panel are presented in Table 6.

The yield stresses and Young's moduli of both the plate and the stiffener were assumed to be Gaussian with c.o.v. 5%. The mean value of the yield stress was assumed to be 88,000 psi, and the mean value of the Young's modulus 3 x 10^7 psi.

Stress	Distribution	Mean (psi)	C.O.V.
Axial wave	Extreme I	-16571	0.0720
Axial whip	Extreme I	-8243	0.0827
Axial still	Constant	651	0.0000
Transv. wave	Extreme I	-867	0.0720
Transv. whip	Extreme I	-431	0.0827
Transv. still	Constant	36	0.0000
Shear wave	Extreme I	-413	0.0720
Shear whip	Extreme I	-205	0.0827
Shear still	Constant	17	0.0000

Table 1
Load Models of Wave, Whipping and Stillwater Bending Stresses (No Green Seas)

Stress	Distribution	Mean (psi)	C.O.V.
Axial	Extreme I	-24,164	0.0776
Transverse	Extreme I	-1,264	0.0776
Shear	Extreme I	-602	0.0776

Table 2
Load Models (No Green Seas)

Quantity	Distribution	Mean (psi)	C.O.V.
Axial stress	Extreme I	-19,791	0.095
Transverse stress	Extreme I	-1,035	0.095
Shear stress	Extreme I	-493	0.095
Pressure	Extreme I	4.56	0.095

Table 3
Load Models (Green Seas)

Phase (deg)	Mean of Axial Stress (psi)	C.O.V.
150	-22,279	0.0768
180	-23,012	0.0774
200	-23,548	0.0775
220	-24,164	0.0776

Table 4
Effect of Phase Angle of Whipping on Combined Loads

Exponent	Mean of Axial Stress (psi)	C.O.V. of Axial Stress
1	-24,164	0.0776
0.5	-24,380	0.101
1.5	-24,030	0.07

Table 5
Axial Stress in the Panel for Different Values of the Exponent of the Weibull Distribution of the Long Term Combined Bending Moment

Notes:

a) The number of cycles of combined stillwater, wave and whipping bending moment is 3.3×10^7 for Tables 1, 2, 4 and 5, and 2.5×10^5 for Table 3.

b) Tensile stress is positive and compressive stress is negative (Tables 1-5)

Parameter	Value
Width	71.0 in
Span	96.0 in
No. of Stiff.	3
Plate thick.	0.219 in
Web height	4.72 in
Web thickness	0.125 in
Flange width	4.2 in
Flange thick.	0.22 in

Table 6
Geometry Parameters of Deck Panel

Evaluation of Reliability

The reliability of the deck panel of the cruiser was evaluated using an advanced second-moment method [Ayyub and Haldar '84, White and Ayyub '85] for 3 cases. Each case represented a different set of possible loading assumptions and combinations. In each case some random variables might be either perfectly correlated or independent. In order to insure that the reader understands which random variables are correlated and which are independent we provide the following definition for the types of random variables used in the example cases. The three stresses in the panel are made up of load effects from each of the three load components. The load effects from each of the load sources can be combined as shown below to produce the three stresses.

$$\sigma_x = \sigma_{x,wave} + \sigma_{x,whipping} + \sigma_{x,stillwater} \tag{1}$$

$$\sigma_y = \sigma_{y,wave} + \sigma_{y,whipping} + \sigma_{y,stillwater} \tag{2}$$

$$\tau_{xy} = \tau_{xy,wave} + \tau_{xy,whipping} + \tau_{xy,stillwater} \tag{3}$$

In the above equations σ_x, σ_y, and σ_{xy} are the applied, combined axial, transverse and shear stress in the panel, respectively. Subscripts "wave," "whipping" and "stillwater," specify the load components that cause the stresses.

The above equations lead to nine independent random variables. However, the three stresses from the stillwater load are considered to be deterministic variables (constants). The statistical characteristics of each of the nine components are provided in Table 1.

The load components are stillwater, wave and whipping. The stress types are the axial, transverse and shear stresses, σ_x, σ_y, and σ_{xy}, respectively. The hydrostatic lateral load induces a pressure that is also a random variable. This will be identified as the pressure random variable.

In each of the cases discussed in this section the eccentricity was assumed to be normally distributed random variable with a mean value of 1.0 inch and a coefficient of variation of 0.048. The phase angle of whipping was assumed to be 220°.

Case 1 - Without Green Seas, Perfectly Correlated Stress Types and Load Components

This case is for the portion of the load spectrum where there are no green seas on the deck of the ship. As a result the lateral pressure on the panel was taken to be zero. The presence of lateral pressure tends to induce positive bending in the panel and a Mode II collapse mechanism (initiated by plate buckling in the direction of the stiffeners). The lack of lateral pressure means that the collapse mode will likely be determined by the presence of any initial eccentricity. If the eccentricity is positive (in the direction of the stiffeners) the failure mode will likely be Mode II. If the eccentricity is negative (away from the stiffeners) the failure mode will usually be Mode I (initiated by stiffener buckling in the direction of the plating).

The stresses in the panel were assumed to be perfectly correlated. Moreover, the three principal load components (stillwater, wave-induced, and whipping) were also assumed to be perfectly correlated. The statistics of the combined stresses are presented in Table 2. The probability of failure was determined by using an advanced, first order, second moment method. For the load effects specified in Table 2, the probability of failure was determined to be 0.051. This corresponds to a safety index of 1.64. To verify the results of the reliability assessment program, a direct Monte Carlo simulation of the same problem was conducted. Using 10,000 simulation cycles, a probability of failure of 0.056 was found. The coefficient of variation of this estimate was 0.04. The failure mode was determined to be Mode II.

Case 2 - Without Green Seas, Independent Load Components and Stresses

The probability of failure for this loading condition was determined to be 0.013. This was the lowest probability of failure and corresponds to a Mode II collapse mechanism. When using 10,000 simulation cycles in a direct Monte Carlo simulation, the probability of failure was estimated to be 0.018 with a coefficient of variation of 0.072.

Case 3 - With Green Seas, Perfectly Correlated Stresses, Load Components, and Pressure

Case 3 is for the portion of the load spectrum where green seas were experienced on the deck. Because the area under investigation is only 18 inches forward of the deckhouse, there will be an amplification of the pressure felt by the deck panel. The amplification is due to the dynamic effects of the seas that impact the deckhouse and rise up on the front of the structure. To account for this effect, the pressure loading was modeled as an extreme value distribution with a probable extreme value equivalent to 3 meters of hydrostatic pressure (4.37 psi).

For this case, the pressure due to the green seas and the axial in-plane stress were assumed to be perfectly correlated. The relationship between applied axial stress and lateral pressure is given by:

$$p = 0.0002304\ \sigma_x$$

In addition, the wave-induced and whipping stresses are assumed to also be perfectly correlated. The statistics of the load effects for this case are provided in Table 3.

We found that the collapse mechanism was again a Mode II type and the probability of failure was 0.051. This corresponds to a safety index of 1.63. The Mode II failure mechanism was expected due to the presence of the lateral load. Notice that the probability of failure was nearly the same as in Case 1, however the mean value of the axial in-plane stress for this case was about 17% lower than in Case 1. This confirms the expected result that the presence of the lateral load significantly reduces the in-plane load capacity of the panel.

A summary of the results for all the above cases is presented in Table 7. It is clear from these results that the effect of allowing the loads to be independent decreases the probability of failure.

Case No.	Description	Failure Probab.	Safety Index
1	No green seas, perfectly correlated load components and stresses	0.051	1.64
2	No green seas, independent load components and stresses	0.013	2.23
3	Green seas, perfectly correlated load components and stresses, mean pressure 4.56 psi	0.051	1.64

Table 7
Summary of Test Cases for Deck Panel

Sensitivity analysis

Second moment methods yield the sensitivity factors of the random variables. The sensitivity factor of a random variable is a measure of the importance of the uncertainty associated with the random variable. Moreover, we can use the sensitivity factors to assess the effect of design modifications on the reliability of a structure. In subsection a) we define the sensitivity factors and explain their importance in identifying the most significant uncertainties. We also provide the sensitivity factors of the most important random variables for the cases 1 and 2 analyzed in the previous section. In subsection b) we assess the effect of design improvements on the reliability of the panel using sensitivity analysis.

Sensitivity factors

The sensitivity factors are the direction cosines of the vector corresponding to the probable point (design point) in the reduced space. The sensitivity factors are measures of the importance of the random variables. If the standard deviation of a random variable reduces to zero then the safety index is scaled up by $1/\sqrt{(1-\alpha_i^2)}$, where α_i is the sensitivity factor of the random variable. Consequently, the higher the sensitivity factor of a random variable the more important is this variable. In the following we provide the sensitivity factors and identify the most important uncertainties.

Case 1 - Without Green Seas, Perfectly Correlated Stress Types and Load Components

In this case the uncertainties in the loads were represented by one random variable because all load components and load types were perfectly correlated.

The most important random variables were the axial in-plane stress and the yield stress of the plating. Their sensitivity factors were -0.94 and -0.32 respectively. The yield stress of the plating was important because, for Mode II, failure collapse was driven by the plating reaching the compressive yield limit. The uncertainty in the eccentricity was not important. Its sensitivity factor was 0.1. It was also observed that all the sensitivity factors except for that of the eccentricity were negative. This means that, at the most probable failure point, the values of all the random variables, except for the eccentricity, are in the left tail of their probability density.

Case 2 - Without Green Seas, Independent Load Components and Stress Types

In this case the three load components and the three stress types were independent. Therefore, we needed nine random variables to represent the uncertainties in the stresses. However, the stresses induced by the stillwater load were assumed to be deterministic (constants). Therefore, the random variables reduced to six; the axial, transverse and shear stresses due to wave and whipping loads.

The sensitivity factors of the most important random variables are plotted in Figure 4. The wave stress, the yield stress of the plating and the whipping stress were the most important random variables. Their sensitivity factors were -0.78, -0.47 and -0.37, respectively. The stress due to wave bending was found to be more important than that due to whipping.

In conclusion, the wave and the whipping stress were the most important load effects. The yield stress of the plate was the most important uncertainty associated with the material properties. This was expected because the failure of the panel is driven by plastic plate buckling in all cases.

Identification of the Most Effective Design Improvements

From the results of the previous section we concluded that the most effective design modifications are the reduction of the mean value of the eccentricity and the increase in the mean value of the yield stress of the plating.

We felt that the easiest way to increase reliability was to replace the deck panel with a panel without a knuckle. In order to quantify the improvement in the reliability that can be achieved by this modification, we evaluated the failure probability of a modified panel that has no knuckle. The eccentricity of this panel was represented by a Gaussian random variable with zero mean and standard deviation equal to 0.048. The failure probability of the modified panel was found to 0.21×10^{-3}. This value was approximately 250 times smaller than the failure probability of the original panel with the knuckle. The safety index of the panel without the knuckle was found to be 3.52 (the safety index of the original panel was 1.64). We believe that the above results validate the conclusion that the replacement of the panel with a modified one without knuckle is an effective way to increase the reliability of the panel.

Conclusions

We tested reliability assessment methods in a real-life problem; the evaluation of the probability of failure of a deck panel of a cruiser. This panel, which has a knuckle, has failed due to buckling in one cruiser. Reliability assessment methods explained why the panel failed. Previous efforts, which employed deterministic analysis, failed to explain why the panel buckled. Reliability assessment methods also allowed us to identify and rank the most important uncertainties and the most effective design improvements.

The following are the most important conclusions from the study of the reliability of the deck panel:

- The probability of failure is approximately 5%.

- The most important uncertainties are associated with the following random variables (ranked in terms of the importance of the associated uncertainties):

1. wave induced axial stress in the panel,
2. yield stress of the plating,
3. axial stress in the panel due to whipping.

- The lateral pressure due to green seas impact significantly reduces the in-plane capacity of the panel.

- The phase angle of whipping and the value of the exponent of the long term probability distribution of the whipping stress (which is Weibull) affect the probability distribution of the extreme lifetime combined wave and whipping bending moment.

- The most effective way to improve the safety of the panel is by eliminating the knuckle. The probability of failure of a panel without a knuckle is 200 times smaller than that of the original panel with the knuckle. The second most effective modification is to increase the mean value of the yield stress of the plating.

Based on the above we believe that methods for reliability assessment have high potential and they have matured enough to be applied to the design of ships. We can use them to develop powerful and efficient design tools which yield designs that are economical and have consistent safety levels.

Acknowledgments

The work presented in this paper has been supported by the Small Business Innovation Program, Topic Number N91-100, Contract Number N00024-92-C-4056. Dr. Robert Sielski has been the chairman of the project technical committee.

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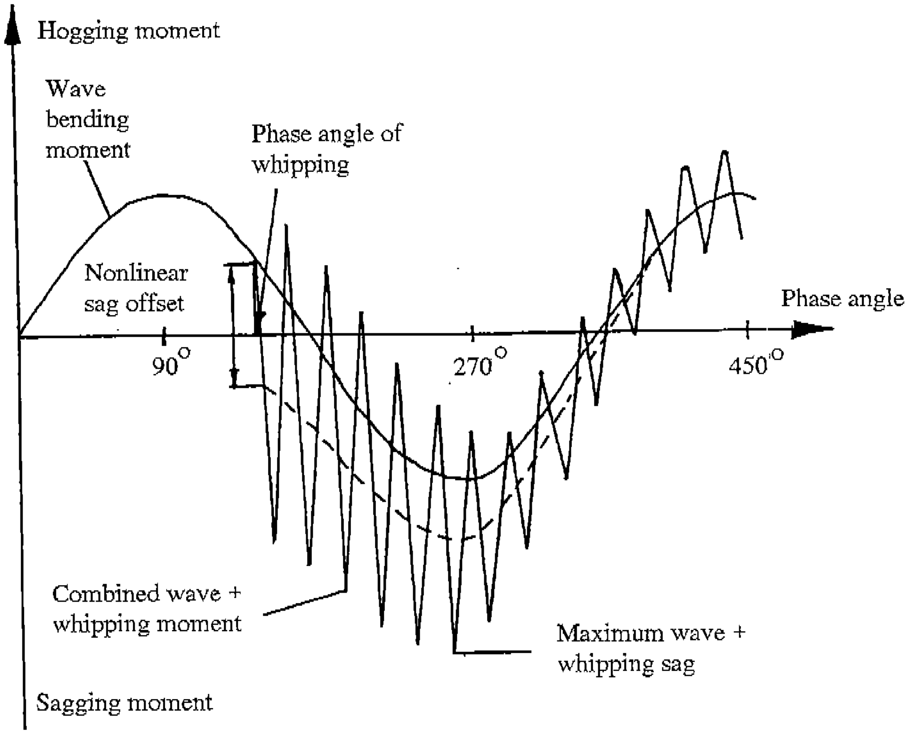

Figure 1
Combination of Wave and Whipping Loads

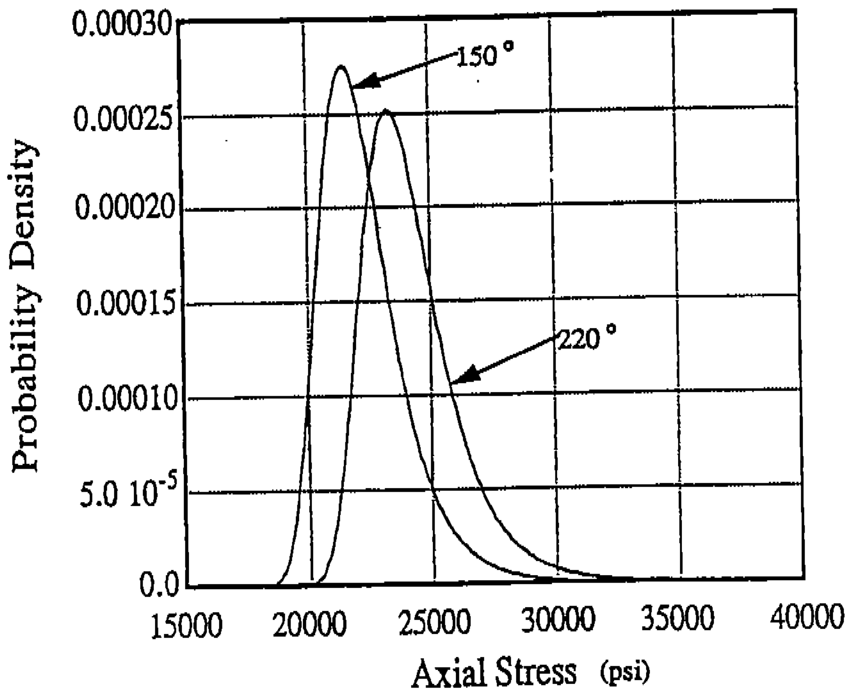

Figure 2
Probability Density Function of Lifetime Extreme Combined Axial Stress
for Different Values of the Phase Angle of Whipping

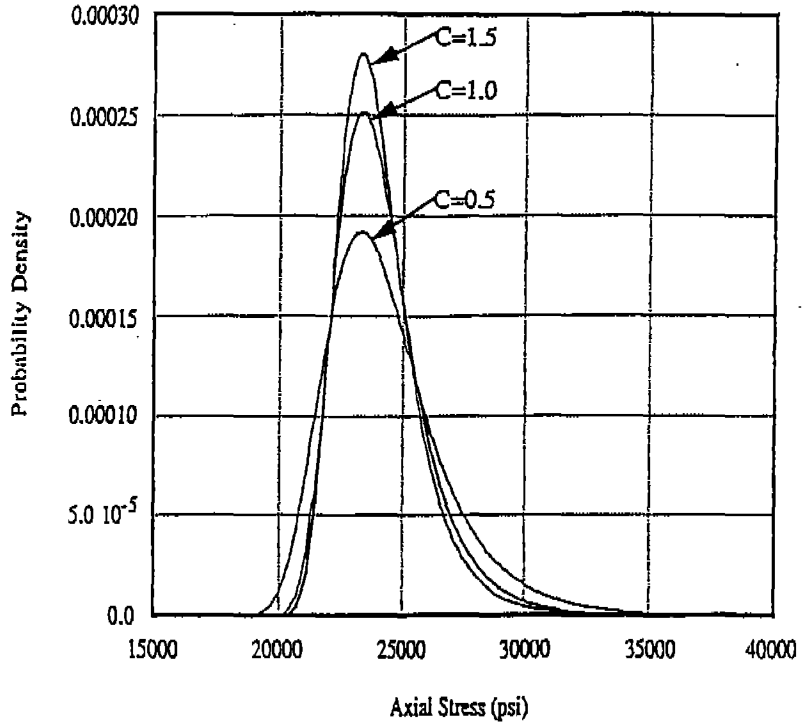

Figure 3
Probability Density Function of Lifetime Extreme Combined Axial Stress for Different Values of the Exponent of the Weibull Distribution of the Long Term Whipping Bending Moment

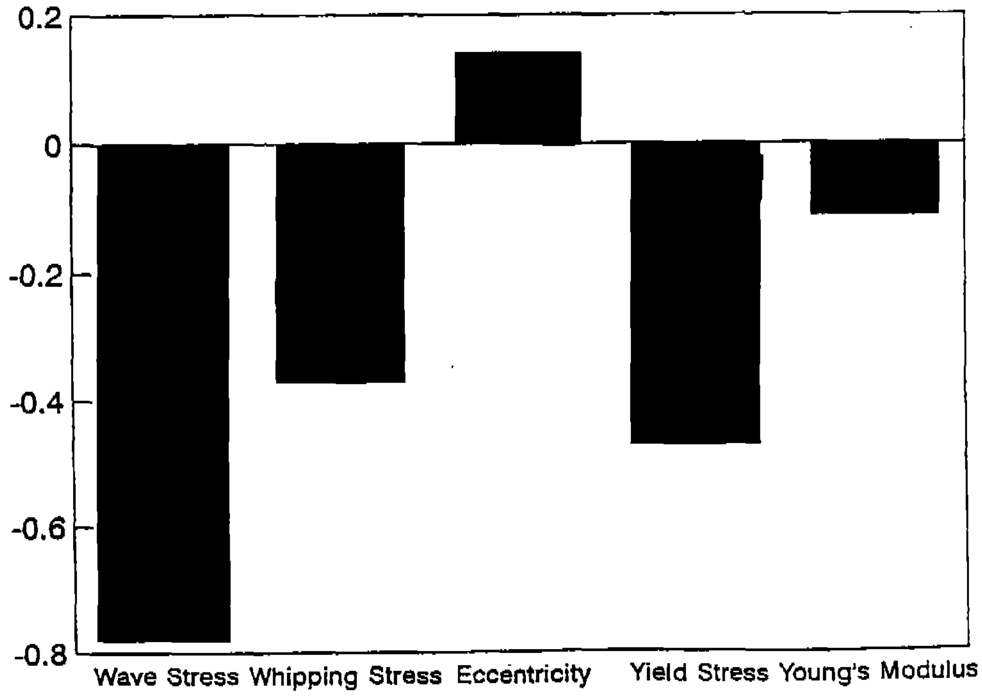

Figure 4
Reliability Assessment of Deck Panel, Case 2: Sensitivity Factors
(Note: Yield stress and Young's modulus are for the plate)