الأبحاث المنشورة (1974-1998)

فى مجال تصميم واقتصاديات السفن

للأستاذ الدكتور محمد عبد الفتاح شامة

Published Papers (1974-1998)

on Ship Design and Economics

by

Prof. Dr. M. A. Shama

1- "Structural and Economical Consequences of Ship Deflection", Seminar on the Application of Science & Technology in Marine Transport, A.M.T.A., J. Res. and Consultation Centre, July. (Egypt-1974), Shama, M. A.,

2- "Optimizing Hull Steel Weight for Overall Economic Transportation", Marine Week, May 2, (UK-1975), Shama, M. A.,

3- "The Cost of Irrationality in Ship Structural Design", PRADS. Int. Conference on Practical Design in Shipbuilding, SNAJ, Tokyo Oct. (Japan-1977), Shama, M. A.,

4- "Computer Design of Ships", Bull. Collage of Engineering, Basra University, (Iraq-1977), Shama, M. A.,

5- " Economical Consequences of Irrational Structural Design of Ships", Bull. Of Collage of Eng., Basra University, Vol.2, No.1, March, (Iraq-1977), Shama, M. A.,

6- "On the Rationalization of ship Structural Design", Schiff und Hafen, March, (Germany-1979), Shama, M. A.

7- "ON the Economics of Safety Assurance" Dept. of Naval Architecture and Ocean Engineering, Glasgow University, (UK-1979) Shama, M. A.,

8- "CADSUCS, the Creative CASD for the Concept Design of Container Ships", AEJ, Dec. (Egypt-1995), Shama, M. A., Eliraki, A. M. Leheta, H. W. and Hafez, K. A.,

9- "On the CASD of Container Ship; State of the Art", AEJ, Dec., (Egypt-1995) Shama, M. A., Eliraki, A. M. Leheta, H. W. and Hafez, K. A.,

10- "Assessment of Uncertainties of the Sea Margin", Maritime Research Journal, Sept., (Egypt-1998), Shama, M. A., Moniem, A. F. A. and Eweda, S.,

On the rationalization of ship structural design

Zur Rationalisierung der Schiffskonstruktion

M. A. Shama*)

Die Grundprinzipien eines rationellen Verfahrens für den Entwurf der Schiffsstrukturen unter besonderer Hervorhebung der Entwurfskriterien werden erläutert; deterministische ebenso wie probabilistische Verfahren werden analysiert.

Weiter wird ein Verfahren für die Bestimmung des Risikos von Strukturbeschädigungen der Schiffssektionen, verursacht durch Scherspannungen, erläutert und die Veränderlichkeit der Strukturfestigkeit untersucht mit besonderem Augenmerk auf den Einfluß der dimensionellen Fehler, der Dimensionstoleranzen und der Veränderlichkeit der Bruchspannungen. Das Risiko von Beschädigungen wird bestimmt und zur Illustrierung des Problems ein Rechenbeispiel gegeben. Es wird gezeigt, daß die Verbesserung der Zuverlässigkeit der Strukturen eher durch die Verminderung der Veränderlichkeit der Strukturfestigkeit als durch die Vergrößerung der Sicherheitsfaktoren erreicht werden kann.

Summary

The basic principles of a rational procedure for ship structural design are outlined. Particular emphasis has been placed on design criteria. Deterministic as well as probabilistic approaches are considered. The latter is based on the demand and capability concept. A procedure is then given for estimating the risk of structural failure of a ship section subjected to shear loading. The variability of structural capability is examined with particular emphasis on the effects of dimensional errors, tolerances on scantlings and variability of yield stress. The risk of failure is estimated on the assumption that both demand and capability have normal density functions. An illustrative numerical example is given for this purpose. It is shown that improving structural reliability would be better achieved by reducing the variance of structural capability rather than by increasing the factor of safety.

Introduction

Because of the rapid expansion of world trade, cargo movement by sea has become a strategic industry, especially for the transport of bulk cargoes such as oil, grain, etc. Ships, therefore, should be designed and operated on a techno-economic basis. A ship hull girder should not only have adequate strength to sustain the hostile sea environment, but should also have a low weight/strength ratio, so as not to have adverse economical consequences. The design process, therefore, should be based on realistic estimates of loading, powerfull methods for computing hull girder and local stresses, rational design criteria for ensuring structural safety and a sound criterion for evaluating the economy of transportation.

Since sea loads and ship responses are both stochastic phenomena, structural safety should be based on the variabilities of both loading and strength. The estimation of the risk of structural failure should therefore represent an essential part of the design process. This paper outlines the basic principles of ship structural design, with particular emphasis on design criteria. A procedure based on the demand and capability concept is given for estimating the risk of failure. An illustrative numerical example is given for this purpose.

1. Main items of ship structural design

The design process could be divided into, see fig. (1):

a) establishment of a realistic structural configuration,
b) selection of a suitable material,
c) determination of local and general loading likely to act on a ship over her expected service life,
d) establishment of structural design criteria,
e) design of individual structural elements, without due regard to their mutual interaction. This step could be based on the published rules of Classification Societies,
f) generation of a realistic mathematical model suitable for the type of loading, structural configuration and method of analysis,
g) calculation of stresses and deformations,
h) optimization of structural configuration and scantlings.

The importance of each item of the above procedure depends on ship type and size. For certain types of ships, such as bulk carriers, shear loading and stresses may be rather significant (1, 2). For other types, torsional loading, local loading, etc. may require special attention. However, much work has been done in recent years on load predictions (3), mathematical modelling of ship structures, improved methods of stress analysis (4) and on structure optimization (5). The latter normally aims at improving weight/strength ratio of ship hull girder without due regard to its impact on the economy of transportation (6). Therefore, in order to improve ship economical efficiency, structural safety and optimization should be examined simultaneously. Structural safety is ensured by using appropriate design criteria (7).

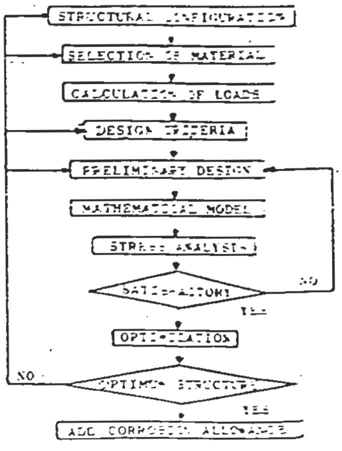


Fig. 1: Flow diagram of design procedure

*) Assoc. Prof., Faculty of Eng., Alexandria University, Egypt. Visiting Prof., Faculty of Eng., Basrah University, Iraq.

2. Structural design criteria

A design criterion represents the limiting performance of a structure under the particular loading system, and therefore should represent an integral part of the structural design process.

The simplest form of a design criterion may be a limiting stress, deflection, instability, ultimate load, etc. Structural safety is ensured by the conventional factor of safety (deterministic approach) or by an acceptable degree of risk of failure (probabilistic approach).

However, it is generally accepted that any member should not be stressed beyond the yield stress of the material. Therefore, for one-dimensional members, the design criterion is given by:

$$x \leqslant x_y, \quad (x = \sigma, \tau) \tag{2.1}$$

where: σ_y, τ_y = yield stress in tension and shear, respectively.

For two-dimensional members, the equivalent stress of von-Mises Hencky (8) is used as the limiting stress, i. e.

$$\sigma_e \leqslant \sigma_y \tag{2.2}$$

where: $\sigma_e = \sqrt{\sigma_X^2 + \sigma_Y^2 - \sigma_X \cdot \sigma_Y + 3\,\tau_{XY}^2}$

$\sigma_X, \sigma_Y, \tau_{XY}$ = normal and shear stresses at the point under consideration.

In the majority of cases, there is no difficulty in calculating σ_X and σ_Y whereas τ_{XY} may require a separate analysis using shear flow methods (9). However, if the finite element method is used, the normal as well as shear stresses are readily obtained at the desired location. It is evident that the former approach is generally more economical, regarding time and cost of analysis. It is also very practical when the loading on the structure is not fully identified, when approximate values of stresses are required or when qualitative results are needed for comparing alternative designs.

Since local and general hull girder loading and strength are not in general deterministic quantities, structural safety should be based on the estimation of the risk of failure, i. e. the probability that the loading exceeds the available strength for the particular mode of failure (10). Failure, in this context, implies either structural damage or collapse (7). Therefore, the risk of failure depends entirely on the variabilities of both loading (demand) and strength (capability).

3. Variabilities of loading and strength

The demand, D, normally refers to the maximum value of loading likely to occur over the expected service life of a ship. It is influenced by ship parameters, configuration, mass distribution along ship length, speed, heading, sea state, etc. Under a specified demand, the capability, C, represents a limiting state beyond which the structure is expected to fail, to be damaged or collapse. The mode of failure depends entirely on the type of loading and structural configuration.

The variability of C results from the variabilities of the mechanical properties of the material, dimensional tolerances (11), fabrication and residual stresses (12, 13), accuracy of stress analysis, errors in mathematical modelling, etc. Practically, the variability of C is rather limited and certainly does not extend from $-\infty$ to $+\infty$. Therefore, the probability density function, p.d.f., of C should be represented by a truncated density function whose lower and upper limits give the feasible range of variation. The lower limit represents the critical value und therefore should be controlled so as to give adequate strength capable of resisting the estimated maximum value of D at an acceptable degree of risk of failure. The upper limit represents the unnecessary extra strength and hence extra steel weight which may have adverse economical consequences (6). Therefore, it is necessary to have a narrow capability density function.

The variability of loading, however, may have a wider spectrum, but for practical and economical reasons, D could be represented by a truncated density function whose lower limit is of no importance and could be assumed zero. The upper limit, however, should be carefully estimated so as not to unduly exceed the lower limit of C.

The truncated density functions of both C and D could be determined from their corresponding p.d.f.'s as follows (14):

$$f_X(x) = p_X(x) \,/\, K_X \tag{3.1}$$

where: $p_X(x)$ = p.d.f. of X, (X = C, D)
$f_X(x)$ = truncated density function of X,

$$K_X = \int_{-\infty}^{x_U} p_X(x) \cdot dx - \int_{-\infty}^{x_L} p_X(x) \cdot dx \tag{3.2}$$

U and L stand for upper and lower respectively.

4. Calculation of the risk of failure, R

When the p.d.f.'s of both C and D are given, the risk of failure, R, could be calculated as follows (10), see fig. (2):

$$R = \int_{-\infty}^{0} p_M(m) \cdot dm \tag{4.1}$$

where: M = C – D
$p_M(m)$ = p.d.f. of M and is given by (15):

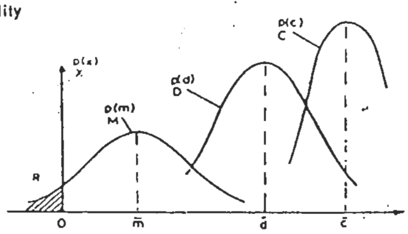
$$p_M(m) = \int_{-\infty}^{\infty} p_{CD}\{c, (m-c)\} \cdot dc \tag{4.2}$$

Since C and D are in general statistically independent, the p.d.f. of M is given by (15):

$$p_M(m) = \int_{-\infty}^{\infty} p_C(c) \cdot p_D(m-c) \cdot dc \tag{4.3}$$

It is evident from fig. (2) that R depends on:
i) mean values of C and D, i.e. $\bar{c}$ and $\bar{d}$,
ii) variances of C and D, i.e. σ_C^2 and σ_D^2.

Fig. 2: Demand and capability distributions



Therefore, if D is specified, then it would be possible to control R either by ensuring sufficient margin between $\bar{c}$ and $\bar{d}$, i.e. by increasing the factor of safety F ($F = \bar{c}/\bar{d}$), or by reducing σ_C. Increasing F, by increasing $\bar{c}$ may have adverse economical consequences (6). Therefore, R should be controlled by reducing σ_C.

In order to examine the effect on R of the variabilities of both C and D, it is assumed that they are statistically independent random variables having normal density functions. These assumptions may not always be valid and are used here only to simplify the analysis and subsequent calculations.

Thus, $X = N(\bar{x}, \sigma_X)$, $(X = C, D, M)$ (4.4)

where: $\bar{m} = \bar{c} - \bar{d}$
$\sigma_M^2 = \sigma_C^2 + \sigma_D^2$
σ_X = standard deviation of X (X = C, D, M)

The calculation of R could be further simplified by using the coefficients of variation of C and D as follows:

$$R = 0.5 - \int_0^{w} \frac{1}{\sqrt{2\pi}} \cdot \exp \cdot \left(-\frac{t^2}{2}\right) \cdot dt \tag{4.5}$$

where: $t = \frac{m - \bar{m}}{\sigma_M}$, $w = \frac{\bar{m}}{\sigma_M} = \frac{F-1}{\sqrt{F^2 \cdot u^2 + v^2}}$

$u = \sigma_C/\bar{c}$, $v = \sigma_D/\bar{d}$ and $F = \bar{c}/\bar{d}$

R has been calculated for a series of values of u, v and F, as shown in fig. (3).

However, when either C or D, or both, do not have a normal p.d.f., R could be calculated using transform methods (16) as follows, see fig. (4.a):

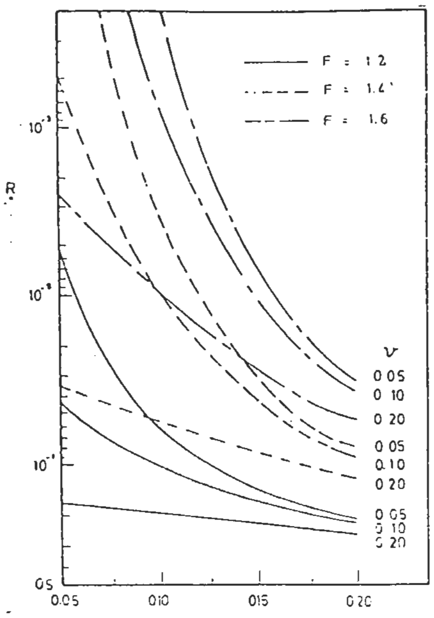


Fig. 3: Risk of failure

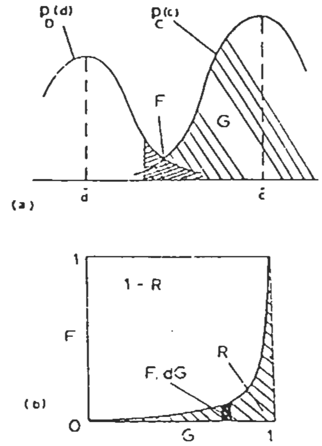


Fig. 4

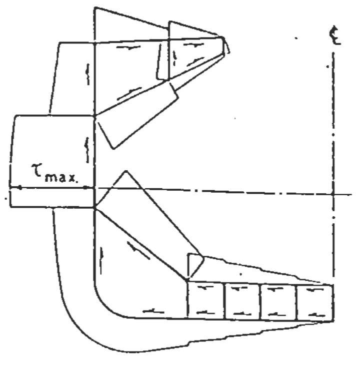


Fig. 5: Shear stress distribution

$$R = \int_{-\infty}^{\infty} p_C(c)\,[\int_{c}^{\infty} p_D(d)\cdot dd]\cdot dc = \int_{0}^{1} F\cdot dG \qquad (4.6)$$

where: $F = \int_{c}^{\infty} p_D(d)\cdot dd$ and $dG = p_C(c)\cdot dc$

It is evident from fig. (4.b) that R is equal to the shaded area and could be calculated using numerical integration.

5. Numerical example

In order to illustrate the application of this probabilistic approach to ship design, the risk of failure of a ship section of a bulk carrier subjected to shear loading is examined.

i) Structural capability

The structural capability, C, of a ship section of a bulk carrier subjected to shear loading could be determined from the maximum shear stress induced in the side shell plating between the hopper and top wing tanks (2,9), as shown in fig. (5). Since a panel of plating subjected to high shear stresses may fail by either shear buckling or yielding (9), the structural capability is given by (2):

$$C \leqslant \tau_i/\Phi,\ (i = y, o) \qquad (5.1)$$

where: $$\Phi = (\sum_{o}^{N.A.} A.\bar{Y}.)/I\cdot t \qquad (5.2)$$

t = thickness of side shell plating,
I = second moment of area of ship section,
N.A. = neutral axis of ship section,
$A.\bar{Y}.$ = first moment of area about N.A. of ship section above, or below, N.A.,
τ_0 = critical buckling stress,
τ_y = yield stress in shear.

For a panel of plating subjected to pure shear loading, τ_0 is given by (17):

$$\tau_0 = K\cdot\frac{E\cdot\pi^2}{12(1-\nu^2)}\cdot(\frac{t}{b})^2 \qquad (5.3)$$

where: E = modulus of elasticity,
ν = Poisson's ratio,
b = frame, or longitudinal, spacing,
K = a coefficient depending on plate aspect ratio and support conditions.

ii) Probability density function of C

The p.d.f. of C could be determined from the density functions of both τ and Φ. Since the variations of "b" and "t" have a negligible effect on Φ and a significant effect on τ_0 (2), it could be assumed that τ_0 and Φ are statistically independent. Similarly, τ_y and Φ are also statistically independent. Therefore, the p.d.f. of C could be determined as follows (15):

$$p_C(c) = \int_{-\infty}^{\infty} p_\Phi(\phi)\cdot p_\tau(c\phi)\cdot|\phi|\cdot d\phi \qquad (5.4)$$

where: $p_X(x)$ = p.d.f. of X, $(X = \tau, \Phi, C)$

In the absence of sufficient statistical data to establish the mathematical models of both τ and Φ, it is assumed that they both have normal density functions. By virtue of statistical independence, C also has a normal density function (16).

Thus,

$$X = N(\bar{x}, c_X),\ (X = \tau, \Phi, C) \qquad (5.5)$$

where: $\bar{c} = \bar{\tau}_i/\bar{\Phi}$, $(i = y, o)$

$$(\sigma_C)_i = \frac{1}{\bar{\Phi}}\left(\frac{\bar{\Phi}^2\cdot\sigma^2_{\tau_i} + \bar{\tau}_i^2\cdot\sigma^2_\Phi}{\bar{\Phi}^2 + \sigma^2_\Phi}\right)^{\frac{1}{2}},\ (i = y, o) \qquad (5.6)$$

The calculation of σ_C could be simplified by using coefficients of variation as follows:

$$u_i = (\sigma_C/\bar{c})_i = \left(\frac{U_i^2 + V^2}{1 + V^2}\right)^{\frac{1}{2}},\ (i = y, o) \qquad (5.7)$$

where: $U_i = \sigma_{\tau_i}/\bar{\tau}_i$, $(i = y, o)$ and $V = \sigma_\Phi/\bar{\Phi}$

U_i, (i = y, o), and V could be estimated as given in Appendix (1). The effect on u of variation of U and V is shown in fig. (6). It is evident that:

$u > (\sigma_X/\bar{x})$, $(X = \tau, \Phi)$.

iii) Estimation of the coefficient of variation of C

In order to estimate u, the variabilities of τ_y, τ_0 and Φ should be examined. The variability of τ_y results from the variabilities of mechanical properties, residual stresses, etc. and could be determined from the analysis of tensile test results. Data obtained from several sources indicate that U_y may reach 0.08.

The variabilities of τ_0 and Φ result mainly from tolerances on scantlings and errors in geometrical dimensions and could be determined as given in Appendix (1). It is shown that:

$U_0 \cong 0.042$ and $V \cong 0.057$

Substituting these values in (5.7), we get:

$u_0 \cong 0.07$ and $u_y \cong 0.0984$

iv) Estimation of R

Assuming that v = 0.1 and F = 1.4 and using fig. (3), the probability of shear buckling of side shell plating of a ship section of a bulk carrier subjected to shear loading is approximately 1/400 and the probability of yielding is approximately 1/100. It is evident that the assumed values of v and F are not necessarily valid under all conditions. However, they are used here only to illustrate the procedure of calculating R.

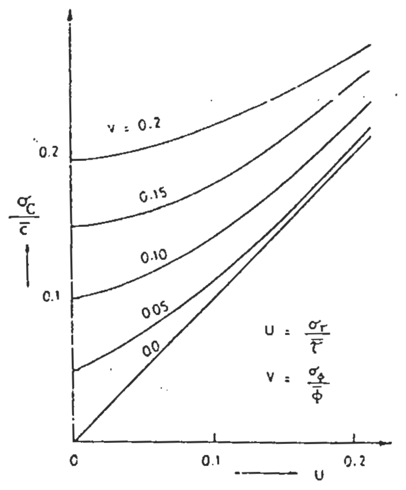


Fig. 6: Variation of $\frac{\sigma_C}{\bar{C}}$ with U and V

In order to reduce R, it is necessary to either reduce σ_C or increase F. Since the latter solution may have adverse economical consequences resulting from the unnecessary increase in hull steel weight (6), R should be reduced by reducing σ_C. This could be achieved by reducing either U or V or both.

Assuming that u has been reduced to 0.05 while F = 1.4, the probability of failure ≅ 1/2000.

The introduction of this probabilistic approach to the design process could be illustrated by fig. (7).

6. Concluding remarks

The following are the main conclusions drawn up from this investigation:

a) The rationalization of ship structural design should be based on structural safety as well as economy. This could be achieved by using an acceptable degree of risk of structural failure. The risk of failure could be estimated by using the demand and capability concept.

b) Improving structural reliability would be better achieved by reducing the variance of structural capability rather than by increasing the factor of safety.

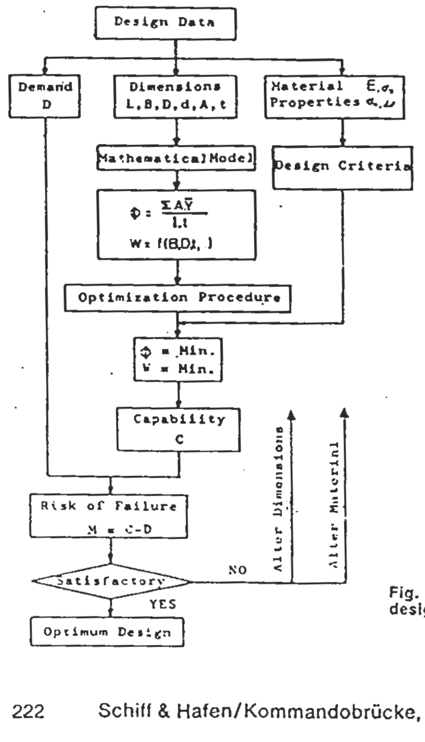


Fig. 7: Rational design procedure

c) Much work is needed to determine the p.d.f.'s of both demand and capability for various types of local and hull girder structural configurations.

7. References

(1) M. A. Shama, "On the Optimization of Shear Carrying Material of Large Tankers", Journal of Ship Research, SNAME, March, 1971.

(2) M. A. Shama, "Shear Stresses in Bulk Carriers Due to Shear Loading", Journal of Ship Research, SNAME, Sept., 1975.

(3) International Ship Structure Congress (ISSC), Tokyo, 1970.

(4) I. Holland and K. Bell, "Finite Element Methods in Stress Analysis", Tapir, Trondheim, Norway, 1969.

(5) R. H. Gallagher and O. C. Zienkiewicz, "Optimum Structural Design, Theory and Applications", John Wiley and Sons, 1973.

(6) M. A. Shama, "Optimizing Hull Steel Weight for Overall Economic Transportation", Marine Week, May 2, 1975.

(7) International Ship Structure Congress (ISSC), Oslo, 1967.

(8) S. Timoshenko, "Strength of Materials", D. Van Nostrand Co., Part II, 1956.

(9) M. A. Shama, "Analysis of Shear Stresses in Bulk Carriers" Computers and Structures, Vol. 6, Pergamon Press, 1976.

(10) J. B. Caldwell, "Some Thoughts on Ship Structural Design", De Ingenieur, JRG, 80, NR 24, 14 June, 1968.

(11) V. E. Braid, "Dimensional Control of Steel Work in Merchant Shipbuilding", The Naval Architect, RINA, July, 1973.

(12) M. A. Shama, "Cold Forming Residual Stresses and Their Effects on the Accuracy of Post-forming Operations", European Shipbuilding, Vol. XIX, No. 2 and 3, 1970.

(13) M. A. Shama, "On the Calculation of Cold Forming Residual Stresses", Schiff & Hafen, 12, 1974.

(14) P. L. Meyer, "Introductory Probability and Statistical Applications", Addison-Wesley, Reading, Mass., USA, 1965.

(15) A. Papoulis, "Probability, Random Variables and Stochastic Processes", McGraw-Hill Book Co., 1961.

(16) E. Haugen, "Probabilistic Approaches to Design", John Wiley & Sons, 1968.

(17) S. T. Timoshenko and J. Gere, "Theory of Elastic Stability", McGraw-Hill Book Co., 1961.

(18) N. Piskunov, "Differential and Integral Calculus", Peace Publishers, Moscow.

(19) A. E. Mansour and D. Faulkner, "On Applying the Statistical Approach to Extreme Sea Loads and Ship Hull Strength", RINA, 1972.

Appendix (1)

Estimation of the variabilities of τ_0 and Φ

Using expressions (5.2) and (5.3) of the text, the relative errors of Φ and τ_0 are given by (18):

$$|\delta\Phi| = |\delta I| + |\delta t| + |\sum_{0}^{N.A.} \delta(A.\bar{Y})| \quad \text{(i)}$$

$$|\delta\tau_0| = |\delta E| + 2|\delta t| + 2|\delta b| \quad \text{(ii)}$$

The variability of E seldom exceeds 2.5 % and that of "t" depends on plate thickness, being higher for thinner plates. However, a mean value of 4 % could be used (19). No published data are available for δb and δI. The former may be assumed not to exceed 1 % and the latter could be determined from the variabilities of local plate thicknesses, overall dimensions of ship section and sectional areas of longitudinal material as follows:

$$I = \sum_{i=1}^{n} A_i \cdot \bar{Y}_i^2 \quad \text{(iii)}$$

where: n = number of elements.

Thus, $|\delta I| = |\delta A| + 2|\delta \bar{Y}| \cong 0.07$

Substituting the estimated variabilities in (i) and (ii), we get:

$|\delta\Phi| \cong 0.17$ and $|\delta\tau_0| \cong 0.125$

The coefficients of variation of τ_0 and Φ are therefore given by:

$U_0 = |\delta\tau_0|/3 \cong 0.042$

$V = |\delta\Phi|/3 \cong 0.057$