Statistical Characteristics of Strength and Load Random Variables of Ship Structures

Khaled Atua[1], Ibrahim Assakkaf[2] and Bilal M. Ayyub[3]

Abstract

Data on strength and load random variables of ship structures were collected from different studies and sources. Statistical analyses of these data were performed. Recommendations for the statistical characteristics of these random variables are provided for use in reliability studies of ship structures.

Introduction

The statistical characteristics of basic random variables used in strength and load models of ship structures need to be defined for the purpose of reliability assessment, reliability-based design, and the evaluation of strength and load partial safety factors in reliability-based design formats. The definition of these random variables requires the investigation of their uncertainties and variability. In this paper, data on strength and load random variables of ship structures were collected, statistical analyses were performed, and recommendations are provided.

Strength Random Variables

Material Properties

The material properties include the yield strength F_y, ultimate strength F_u, modulus of elasticity E, and Poisson's ratio ν. Statistical information on these variables for shipbuilding steel was summarized from different sources as detailed by Ayyub et al (1996). Distribution types, mean to nominal ratios, and coefficients of variations (*COV*) were recommended as shown in Table 1.

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[1] Graduate Student, Reliability Engineering, Nuclear and Material Engineering Department, University of Maryland at College Park.
[2] Graduate Student, Civil Engineering, University of Maryland at College Park.
[3] Professor of Civil Engineering, University of Maryland at College Park, MD 20742.

Fabricated Dimensions of Shipbuilding Steel

Statistical information on plate thickness t of shipbuilding steel (Daidola and Basar 1980) was based on tolerances of plate dimensions. Recommended statistical charateristics are provided in Table 1.

Fabricated Dimensions of Ships

It can be assumed that the length variability in the form of a standard deviation does not exceed one or two inches with a normal probability distribution. Statistical information on ship depth D (Daidola and Basar 1980) was based on average tolerances resulting in the recommended values in Table 1.

Hull-Girder Strength

The ultimate bending capacity of a hull girder can be determined based on other basic random variables as follows:

$$M_u = cF_yZ \tag{1}$$

where Z = elastic section modulus, and c = a buckling knock-down factor. Mansour et al (1993) used a *COV* of M_y of 0.15. The computed mean value and *COV* of Z were found to be 1.04 and 0.05, respectively (Guedes Soares and Moan 1988), and 1.0 and 0.04, respectively (Mansour et al 1993) with lognormal distribution. The mean value and *COV* of c were calculated for both sagging and hogging conditions over the entire length of a ship and also over the length of the parallel middle body (*0.4LBP*) amidship of the ship as shown in Table 1.

Load Random Variables

Stillwater Bending Moment

Data were collected based on different operational conditions of ships from 15 countries by Soares and Moan (1988). Mansour et al (1995) assumed a normal distribution with *COV* of 0.15 for cruisers and 0.25 for tankers and fine form ships (such as SL-7 ships). Kaplan et al (1984) provides statistical information on stillwater bending stress for a group of 10 containerships.

Wave-induced Bending Moment

Type I extreme value distribution was used to model life-time extreme wave bending moment with mean to nominal ratio of 1.0 and a *COV* value of 0.2 (Mansour et al 1995). In a previous study, a *COV* value of 0.09 was set for extreme wave-induced bending moment for cruisers, tankers, and SL-7 type (Mansour et al 1995).

Slamming and Whipping Bending Moments

Kaplan et al (1984) recommended a *COV* of 0.21 for short term probability representation and the exponential distribution to model whipping moment. An extreme value distribution with mean to nominal ratio of 1.0 and a *COV* of 0.3 for both tankers and cruisers was used by Mansour et al (1995)

Summary of Statistical Characteristics of Strength and Load Variables

Table 1 provides a summary of the recommended statistical characteristics of strength random variables. Table 2 shows recommended statistical characteristics of load components for ship structures. The statistical characteristics consist of mean to nominal ratio or mean value, coefficient of variation (*COV*), distribution type, and bias or error information if any.

Table 5-1. Recommended Statistical Characteristics of Strength Random Variables

Random Variable	Nominal Value	Statistical Information			(Bias) or Error Information		
		Mean	*COV*	Distribution Type	Mean	Standard Deviation	Distribution Type
Thickness t (in)	t				0	0.02	normal
Plate size a (in)	a				0	0.11	normal
Plate size b (in)	b				0	0.09	normal
Ship length L (ft)	L				0	0.08	normal
Ship depth D (ft)	D				0	0.01	normal
Ship breadth B (ft)	B				0	0.01	normal
Ordinary strength F_y (ksi)	F_y	1.11 F_y	0.07	lognormal	(1.11)		
High strength F_y (ksi)	F_y	1.22 F_y	0.09	lognormal	(1.22)		
F_u (ksi)	F_u	1.05 F_u	0.05	normal	(1.05)		
E (ksi)	E	1.024 E	0.02	normal	(1.03)		
Poisson ratio ν	0.3	0.3	0		(1.)		
Section modulus Z	Z_r	1.04 Z_r	0.05	lognormal	(1.04)		
M_y	F_yZ	$\bar{F}_y \bar{Z}$	0.15	lognormal	(1.0)		
M_p	F_yZ_p	$\bar{F}_y \bar{Z}$	0.18	lognormal	(1.0)		
c	na	0.74	0.2	Normal	(na)		

na = not available, M_P = plastic moment, Z_P = plastic Z, Z_r = rules Z

Table 5-3. Recommended Statistical Characteristics of Load Random Variables

Random Variable		Bias Information	
	Distribution Type	Mean to Nominal Ratio	*COV*
Stillwater Bending Moment M_{SW}	normal	0.4 to 0.6 for commercial ships, and 0.7 for naval vessels	0.3 to 0.9 for commercial ships, and 0.15 for naval vessels
Wave-induced Bending Moment M_W	extreme value (type I)	1.0	0.1 to 0.2
Whipping (or Slamming) Bending Moment M_{wh}	extreme value (type I) exponential	mean value is given by $0.00075\ \rho g_o L^3 B$ for 10^{-8} exceedance probability	0.2 to 0.3
Springing Bending Moment M_{SP}	extreme value (type I)	1.0	0.3

ρ = unit mass of water, g_o = gravitational acceleration

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