A FIRST PRINCIPLE APPROACH FOR THE STRENGTH ANALYSIS OF A SEMI-SWATH VESSEL

SHAHARUDIN BIN AHMAD

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To my beloved father & mother

Tuan Haji Ahmad Bin Haji Kasbon

Hajah Ja'arah Uyob

To my lovely wives

Siti Markamah Haji Ali

Rohani Omar

And my Sons

Harith Fikri

Haziq Amirun

Hazlam Arsyad

Also my siblings

Dr. Azhana

Khairunnisa

Nurul Nazifah

And Mohd Bajuri family

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ABSTRACT

Structural strength is an important factor for a Semi-Small Water-plane Area Twin Hull (Semi-SWATH). A Semi-SWATH ship is a combination of the Small Water-plane Area Twin Hull (SWATH) ship in the forward half and conventional catamaran in the stern half. Due to the twin hull design, strength analysis is most important, especially in transverse direction to prevent structural failure in the cross deck between two hulls. In this research, a First Principle approach using modified formula for strength analysis of a semi-SWATH structure was developed. The approach focussed on evaluations of the longitudinal and transverse strengths of the Semi-SWATH bulkhead. Predictions using this First Principle approach are mostly catered for failures and high stress concentrations especially at the transverse structures that connect the twin hulls. To verify the results, a 1:10th scale model of the Semi-SWATH was tested in the National Hydraulic Research Institute of Malaysia (NAHRIM) tank facilities. Data Acquisition System (DAS) was also developed to capture the strength data of semi-SWATH vessel structure by using strain gauges. Data collected from DAS were customized by using LabView software through SCXI signal conditioning. The experiment results were used to verify the results of static and wave impact in head seas on the compartment's beam structures. It was found for the case of plating failure, the First Principle approach predicted stress values of 52.6% and 15.34% higher as compared to experiment and Finite Element Method (FEM) respectively. The results are significant on ship structure analysis as reported by Ship Structure Committee SSC, which was in the range of capacity design value of the bulkhead compartment structure.

ABSTRAK

Kekuatan struktur adalah faktor penting bagi kapal separa badan kembar berluas satah air kecil (Semi-SWATH). Semi-SWATH adalah kapal yang mempunyai bentuk badan yang menggabung bentuk kapal SWATH dibahagian depan dan bentuk *catamaran* di bahagian belakang. Rekabentuk kapal badan berkembar memerlukan analisa kekuatan terutamanya pada kedudukan ombak melintang bagi mengelakkan kegagalan struktur pada dek silang kapal. Penyelidikan ini membangunkan pendekatan Prinsip Pertama dengan formula yang di ubahsuai untuk menganalisis kekuatan struktur kapal Semi-SWATH. Kaedah ini memberi tumpuan kepada penilaian kekuatan sekatan melintang Semi-SWATH. Jangkaan pendekatan Prinsip Pertama ini berupaya mengesan kegagalan struktur dan konsentrasi tegangan yang tinggi terutamanya pada struktur melintang yang menyambung kedua-dua badan kapal. Verifikasi terhadap hasil ujikaji dijalankan terhadap model Semi-SWATH berskala 1:10 di Institut Penyelidikan Hidraulik Kebangsaan Malaysia (NAHRIM) menggunakan fasiliti kolam sedia ada. Sistem Data Perolehan (DAS) juga dibangunkan bagi tujuan ujikaji untuk merakam data kekuatan rasuk Semi-SWATH menggunakan tolok penapisan. Data yang diperolehi adalah ditempahsuai menggunakan perisian LabView melalui alat isyarat SCXI. Hasil ujikaji digunakan untuk verifikasi pada keadaan statik dan dinamik (kesan ombak) terhadap struktur rasuk ruang. Perbandingan dengan keputusan ujikaji dan analisa unsur terhingga bagi kegagalan plat menunjukkan pendekatan Prinsip Pertama memberi keputusan lebih tinggi sebanyak 52.6% berbanding ujikaji dan 15.34% berbanding analisa unsur terhingga. Hasil keputusan ini adalah sinifikan dalam analisa struktur kapal sepertimana laporan *Ship Structure Committee* SSC, dalam julat kapasiti rekabentuk untuk struktur ruang sekatan kapal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

a	-	spacing of transverse frame, plate length
A	-	length of panel
A_A	-	cross-sectional area
A_B	-	area of the bottom including stiffeners
A_D	-	cross-section area of the deck including stiffeners
A_e	-	effective cross section area
A_s	-	effective shear (web) area
A_{SR}	-	area of one hull side including stiffeners
A_T	-	cross sectional area of longitudinal
A_v	-	volume of electrode metal melted off per unit length
b	-	spacing between longitudinal stiffeners, plate width
b_{wt}	-	spacing between transverse stiffeners/frame, plate width
B	-	width of panel
C	-	spring stiffness of plate
D	-	depth of the midship section
D_f	-	flexural rigidity
D_x	-	longitudinal flexural rigidity
D_y	-	transverse flexural rigidity
E	-	modulus of elasticity
f_D	-	stress deck
F	-	factor gage
g	-	gravity = 9.81 m/s^2 or 32.185 ft/s^2 or 385.92 inch/s^2
g_S	-	distance from the center of the deck area to the plastic neutral axis
G	-	modulus of elasticity

h	-	wave height
I_c	-	current
I	-	moment of inertia
I_a	-	moment of inertia (longitudinal)
I_{et}	-	effective second moment of areas panel section
I_e	-	effective second moment of areas panel section
I_{pc}	-	polar moment of inertia
I_{px}	-	moment of inertia of the effective plate associated with the stiffeners extending in the x directions
I_{py}	-	moment of inertia of the effective plate associated with the stiffeners extending in the y directions
I_s	-	second moment of area of panel
I_x	-	moment of inertia of stiffeners with effective plate extending in the x-direction
I_y	-	moment of inertia of stiffeners with effective plate extending in the y-direction
I_z	-	moment of inertia about vertical axis through CE
k, K_c	-	buckling coefficient
K	-	St. Venant torsion constant
K_i	-	constant coefficient – initial distortions
L	-	length of wire
l	-	length of stiffener
L_T	-	length of stiffeners between tripping brackets
m	-	number of half-waves plate in x direction
M_o	-	maximum bending moment
M_p	-	Caldwell fully plastic moment
M_{uc}	-	Caldwell ultimate bending moment
M_{uh}	-	Hughes ultimate bending moment
M_{uho}	-	ultimate bending moment in hogging condition

M_{usa}	-	ultimate bending moment in sagging condition
n	-	number of half-waves plate in y direction
P	-	pressure
P_{cr}	-	critical load
R	-	resistance
R_m	-	plate coefficient MIT
r	-	radius of gyration
r_e	-	effective radius of gyration
s	-	spacing between stiffeners
S	-	spacing of primary members
S_x	-	spacing of stiffeners extending in the x direction
S_y	-	spacing of stiffeners extending in the y direction
t	-	thickness of plate
t_p , t_{pt}	-	built thickness of plating (longitudinal)
t_{tt}	-	built thickness of plating (transverse)
t_w	-	thickness of stiffener web
ν	-	possion ratio
w	-	equivalent fillet $\sqrt{\frac{A_v}{0.6}}$
y_e	-	distance from the centroid axis to the transverse cross section
y_f	-	distance from the centroid axis to the mid-thickness of the stiffener flange
y_p	-	distance from midthickness of the plate to centroid axis effective cross section of panels
V	-	voltage
Z_p	-	plastic section modulus
σ	-	stress
σ_{cr}	-	critical stress
σ_e	-	transverse stress

σ_{ecr}	-	elastic critical stress
σ_f	-	total stress in stiffener flange
σ_m	-	average compressive stress
σ_{necr}	-	elastic critical after correction
σ_o	-	average yield stress
σ_p	-	proportional limit gradual stress; may be taken as 60 % of σ_o
σ_r	-	residual stress
σ_y , f_y	-	yield stress of material
σ_{uf}	-	axial compression-stiffener flange
σ_{ul}	-	ultimate stress plate
σ_{ult}	-	ultimate Strength
σ_{up}	-	axial compression-plate flange
σ_{ue}	-	loss of plate stiffness due to compression
β	-	slenderness ratio
α	-	aspect ratio a/b
α_B	-	keel hull aspect ratio
α_D	-	deck hull aspect ratio
α_S	-	side hull aspect ratio
γ	-	equal area axis
Γ	-	warping constant
δ_a	-	element of area
δ_o	-	initial deflection
Φ	-	strength factor
Φ_{cp}	-	strength factor critical panel
ϕ_D	-	deck strength factor
ϕ_S	-	side hull strength factor
Δ	-	displacement in tones
Δ_e	-	initial eccentricity

ΔP	-	eccentricity caused by the loss of plate stiffeners
ΔL	-	change in length of wire
η	-	torsion coefficient
λ	-	column slenderness ratio $\frac{l}{r\pi}\sqrt{\frac{\sigma_y}{E}}$
ε	-	strain
ρ_m	-	receptivity of wire material
Ω	-	ohm
ε_1	-	strain for 1st reading
ε_2	-	strain for 2nd reading
ρ	-	density of water (1000 kg/m^2)
ABS	-	American Bureau of Shipping Classification
SWATH	-	Small Water-plane Area Twin Hull
DAS	-	Data Acquisition System
NAHRIM	-	National Hydraulic Research Institute of Malaysia
FEM	-	Finite Element Method
DNV	-	Det Norske Veritas Classification

Unit Converter

N	-	Newton
		x 0.102 = kgf
N/m^2	-	Newton/Square Meter
		x 0.00145 = Pound/Square Inch (psi)
tsi	-	Tonne/Square Inch
		x 2000 = Pound/Square Inch (psi)
psi	-	Pound/Square Inch
		x 6.894757 = kilopascal (Kpa)
		x 0.689476 = N/m^2
kg/m^2	-	Kilogram/Square Meter
		x 9.81 = Newton/Square meter N/m^2
		x 0.00142233 = Pound/Square Inch (psi)
kg/m^3	-	Kilogram/Cubic Meter
		x 0.0624279 Pound/Cubic Foot

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Research

A Semi-Small Water-plane Area Twin Hull (Semi-SWATH) is a high performance speed ship which is combination of a Small Water-plane Area Twin Hull (SWATH) ship and a conventional catamaran in the forward half and in the stern half respectively (Shack, 1995). The SWATH hull configuration has better stability characteristics than a conventional mono hull of similar displacement. Most SWATH family (Figure 1.1) has the capability of sustain for various load due to the twin hull stability, but the tendency failure in transverse section are very high.

Catamarans compartment concepts are more suitable for machinery arrangement and especially for integrating water jet propulsion. The integration of combination of SWATH and catamaran results in Semi-SWATH vehicles with greater speed performance and offer a great deal of arrange able deck space. Due to that, Semi-SWATH are required a good structure design due to longitudinal and transverse strength.

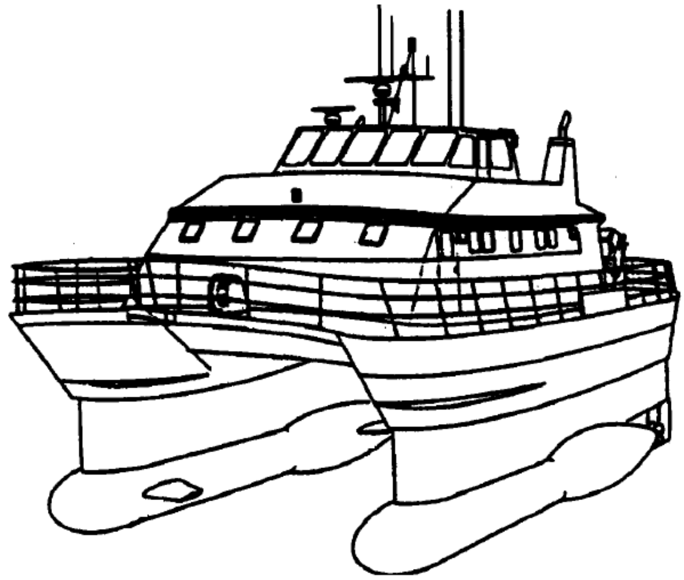

Figure 1.1 : SWATH Ship (Pegg at el, 1995)

Therefore the difference design combination at the middle between hulls of Semi-SWATH can cause a multi pressure (torsion moment, bending moment, shear force) and greatest strain in transverse direction when the load is applied. For these reasons, the first principle approach is introduced and involves a thorough analysis on the factors affecting the safety and performance of the structure of Semi-SWATH. Thus first principle approach is necessarily tactical formulation which is a design focus on evaluation of the strength of longitudinal and transverse Semi-SWATH bulkhead compartment structure under static loading and control dynamic wave. A synthesis of this information, together with the objective, which the structure is intended to produce a design which best, covers the objectives and provides enough safety.

1.2 Problem Statement

Structural strength is an important factor for a Semi-Small Water-plane Area Twin Hull (Semi-SWATH). Due to twin hull design, the strength analysis is most important especially in transverse direction to prevent structural failure in the middle (Gupta and Schmidt, 1986). The general loading case for a marine structural is a combination of longitudinal stress and transverse stress. The transverse strength between the hulls must be increased to adequate mid transverse stability to resist heeling over moments as a result of wind or head sea wave.

The interaction of bending moment and axial force including effect due to wave induced load, buoyancy, structural weight, will come into focus on mid bulkhead as a result of the tendency on failure by transverse strength. Full scale Semi-SWATH development can be most costly and not effective. Until now further research on structure comparing due to sea keeping and manoeuvring analysis of Semi-SWATH are small. Therefore, the study on a first principle approach is very important in first step of accessing the longitudinal and transverse strength capability of Semi-SWATH.

1.3 Objective of Research

The main objectives of this research are

a) To develop a first principle approach uses a modified formula for the longitudinal and transverse strength analysis of a Semi-SWATH vessel under static loading and control dynamic wave.
b) To use a scale down model Semi-SWATH for finite element analysis and tank experimental.
c) To determine the strength of Semi-SWATH on compartment structure using tank experiment and finite element analysis.

1.4 Scope of Research

The scopes of this research are:

a) Literature review of various strength analyses formulation and twin-hull technologies.
b) Use the modified empirical formula of longitudinal and transverse strength evaluation for a Semi-SWATH vessel, aided by computer programming.
c) To use a scale down model of Semi-SWATH consist of compartment beam structure and analyse using finite element analysis program and tank experimental.
d) To develop Data Acquisition System (DAS) for measurement the strength of longitudinal and transverse bulkhead and the result of FEM analysis and experimental.

1.5 Importance of Research

This study mainly focuses on the transverse strength structure of Semi-SWATH vessel. The significance of this study includes the following:

a) To obtain a better understanding of structural analysis of Semi-Swath ship.
b) To have the ability in predicting in preliminary and very basic stages the structure strength where can cause damage to Semi-SWATH. Thus better designs are proposed.
c) To provide the information that would identify the easy steps required to achieve the structural calculations of the structure analysis of longitudinal and transverse strength of Semi-SWATH vessel.

1.6 Visit to Kay Marine Sdn. Bhd.

Visiting to company Kay Marine Sdn. Bhd. (KSMB) are indeed aims to get latest information on ship structure especially catamaran. This company is located in Kuala Terengganu and produced more than 100 types of boats and vessels. KMSB provides industry with engineering solutions in structures incorporating welding and associated technologies in boatbuilding. The production plants of current catamaran project are the faster way to collect information regarding the ship structure failure comparing to SWATH vessels. Figures 1.2 and Figure 1.3 showed the catamaran boat under construction, while Figures 1.4 and Figure 1.5 showed the grillage structure, bulkhead and frame of catamaran completed assembled.

Figure 1.2 : Catamaran Boat at Kay Marine Sdn. Bhd.

Figure 1.3 : Catamaran Boat Under Construction

Figure 1.4 : Grillage Deck Structure

Figure 1.5 : Bulkhead & Frame Structure

1.7 General Outline of the Thesis

As the initial aim of the study is to develop principle approach on the strength evaluation of Semi-SWATH longitudinal and transverse beam structure, Chapter One, *Introduction*, introduces the significance and importance of Semi-SWATH structure design. A visit to the practical local shipyard on producing catamaran was also mentioned.

Chapter Two, *Literature Review*, discusses the history of the structure strength of Semi-SWATH and the concept of principle approach. It can be analysed by finite element program and experimental. It also discusses the components of Semi-SWATH structure like longitudinal frame, stiffeners and compartment beam. The form of common failure of Semi-SWATH is also mentioned in this chapter.

Chapter Three, *Research Methodology*, the approach method is proposed as a research design and procedure concept to solve this research problem. A flow chart of methodology is presented to ensure the capability of development and function of first principle approach. Also discusses the development of scale down model of Semi-SWATH including the processes of fabrication. This also consider the classification use on developing the main structure

Chapter Four, *Development of First Principle Approach*, discusses the development of a principle approach for Semi-SWATH structure analysis. Most predication for this approach is covered towards form failure and high stress concentration in grillage between the twin hull section. Calculation for ultimate strength which is compounded to ultimate bending moment after plastic region mode on critical panel is also considered.

Chapter Five, *Finite Element Analysis and Computational Analysis of Beam Wave*, discusses a finite element analysis for bulkhead compartment of Semi-SWATH. This chapter also discusses the structure modelling and boundary condition used. The validation of finite element and experimental results are included.

Chapter Six, *Development of Data Acquisition System DAS and Experimental Setup*, discusses the concept of development of DAS system including the LabView software on analyse the signal from strain gauges with it attached to compartment of scale down model.

Chapter Seven, *Result and Discussions*, discusses the verification of the scale down model by comparing it with the experimental results, finite element analysis and principle approach. The discussions also cover the results which have been obtained from the analysis of CATIA, experiment-strain gauge measurement and principle approach of longitudinal and transverse strength of Semi-SWATH. Early application of first principle approach on several vessels is also discussed as evaluation initial design on steel and composite structure strength.

Chapter Eight, *Conclusion*, the conclusion of the present work and recommendation for the future research are discussed.

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