# DAMAGE STABILITY OF SMALL VESSEL

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**DEDICATION**

I dedicate this work of mine to:

My beloved Wife and My beloved "QueeN"
My Father, My Late Mother and My Aunty "AS"
My father and My Mother in Law
My Brother and My Sister
My Sister in Law

Whom I always remember for the help they have given me throughout my studies, emotionally, prayers, support, loves, understanding, and assistance.

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# ABSTRACT

The survivability of a vessel is related to intact and damage stability requirements. However, intact ship survivability has received more attention than damage ship survivability. This study seeks to emphasise in damage stability for the reason, the safety of passenger vessels has always been the prime concern of regulatory bodies. There are various ways of assessing the damage stability such as deterministic, probabilistic and real time simulation approaches. The purpose of this study is to further develop a ship stability program using MATLAB based on real time simulation of the dynamic behaviour of the damaged vessel in wave conditions. The mathematical model comprises six degrees of freedom motions in beam seas whilst taking into consideration progressive flooding as well as water accumulation. The 'Sarawak Fast Ferry' was chosen for parametric study for the application of the developed Damage Stability Program. Damage stability experiment was carried out to validate the simulation program. The experiment was conducted using image processing technique. Experimental results have shown good correlation to the results of simulation. The result of the study also indicated that wave height and loading conditions are the main parameters influencing ship's stability in damage condition. The critical KG for Sarawak Fast Ferry was found to be 1.3 m and the vessel only can survive with wave height until 0.2 m. The safety KG was found to be 1.1 m since the vessel can survive with wave height 0.5m. On the basis of the results, suggestions are made to improve the damage survivability of the vessel.

# ABSTRAK

Ketahanan suatu kapal berkait dengan syarat kestabilan bocor dan juga kestabilan tanpa bocor. Walaupun begitu, ketahanan kapal tanpa bocor lebih mendapat perhatian daripada ketahanan kapal bocor. Kajian ini memberi penekanan kepada kestabilan bocor atas sebab keselamatan penumpang yang merupakan aspek yang diberi keutamaan oleh badan penyeragamaan. Terdapat beberapa kaedah untuk menilai kestabilan bocor seperti kaedah penentuan, kaedah kemungkinann dan pendekatan simulasi masa sebenar. Tujuan kajian ini adalah memperkembangkan lagi pembangunan suatu perisian kestabilan kapal berasaskan simulasi masa sebenar dengan menggunakan MATLAB bagi perlakuan dinamik kapal bocor dalam keadaan laut berombak. Model matematik yang terdiri dari pergerakan enam darjah kebebasan pada keadaan ombak dari samping kapal dengan mengambil kira bocor yang berketerusan dan keadaan semasa pengumpulan air. ‘Feri Cepat Sarawak’ dijadikan kajian kes bagi aplikasi perisian kestabilan bocor. Sebagai pengesahan kesahihan perisian tersebut, uji kaji kestabilan bocor telah dilakukan. Uji kaji ini dijalankan dengan menggunakan teknik pemprosesan imej. Keputusan uji kaji menunjukkan hasil yang sesuai dengan keputusan perisian simulasi. Keputusan dari kajian ini menunjukkan terdapat dua parameter utama yang memberi pengaruh kepada kestabilan kapal bocor iaitu ketinggian ombak dan kondisi pembebanan kapal. Keputusan memberikan KG kritikal bagi Feri Cepat Sarawak adalah 1.3 m kerana kapal hanya mampu bertahan dengan tinggi ombak sampai 0.2 m. Adapun keadaan KG yang selamat adalah 1.1 m kerana kerana kapal mampu bertahan dengan tingi ombak sampai 0.5 m. Berdasarkan keputusan tersebut, sebarang cadangan diperbuat untuk memperbaiki ketahanan bocor dari kapal tersebut.

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# NOMENCLATURES

## Vessel/Environment Parameters

| | | |
|---|---|---|
| B | : | Breadth of vessel |
| Cb | : | Block coefficient |
| $C_m$ | : | Midship area coefficient |
| $C_{PL}$ | : | Longitudinal prismatic coefficient |
| D | : | Depth of vessel |
| $D_W$ | : | Water depth |
| $F_{bd}$ | : | Freeboard of vessel |
| GM | : | Metacentric height |
| GZ | : | Righting lever |
| $H_W$ | : | Wave height |
| T | : | Draught of vessel |
| KG | : | Vertical height of centre of gravity from the Keel |
| L | : | Length of vessel |
| $V_S$ | : | Forward speed of vessel |
| $V_W$ | : | Wave celerity |
| $\Delta$ | : | Displacement |
| $\lambda_W$ | : | Wave length |
| $\zeta_W$ | : | Wave profile |
| $\gamma$ | : | Wave number |
| $\eta$ | : | Wave elevation |

**Co-ordinate Systems**

| | | |
|---|---|---|
| oxyz | : | Vessel co-ordinate system |
| OeXeYeZe | : | Earth co-ordinate system |
| OgeXgeYgeZge | : | Co-ordinate system at the centre of gravity G and the directions are parallel to the earth system, is used to measure vessel motions. |

**Equations of Motion**

| | | |
|---|---|---|
| $a_n$ | : | Added mass |
| b | : | Damping moment coefficient |
| $b_c$ | : | Critical damping |
| $F_{i\ wave}$, $M_{i\ wave}$ | : | Wave excitation force and moment |
| $F_{i\ wod}$, $M_{i\ wod}$ | : | Excitation force and moments due to water on deck |
| i, j | : | Mode of motion, 1 for surge, 2 for Sway, 3 for Heave, 4 for Roll, 5 for pitch and 6 for yaw |
| $I_{ij}$ | : | Mass moment of inertia |
| $I_v$ | : | Virtual mass moment of inertia |
| M | : | Mass of vessel |
| u, v, w | : | Velocity of linear motion : surge, sway and heave respectively |
| $\dot{u}$, $\dot{v}$, $\dot{w}$ | : | Acceleration of linear motion : surge, sway and heave respectively |
| p, q, r | : | Velocity of angular motion : roll, pitch and yaw respectively |
| $\dot{p}$, $\dot{q}$, $\dot{r}$ | : | Acceleration of angular motion : roll, pitch and yaw respectively |
| $RES_i$ | : | Restoring force and moments |
| x,y,z | : | Displacement of linear motion : surge, sway and heave respectively |
| $\phi,\theta,\psi$ | : | Angle of angular motion : roll, pitch and yaw respectively |
| $\phi_{max}$ | : | Roll response |
| $\phi_3$ | : | Roll amplitude at time $t_3$ |
| $\phi_1$ | : | Roll amplitude at time $t_1$ |
| $\gamma$ | : | Damping ratio |

$\kappa$ : Non-dimensional damping factor

$\Lambda$ : Tuning factor

$\mu_{\phi}$ : Magnification factor

**Water Ingress and Flooding**

Aop : Area of the damaged hole or opening

DC : Distance between the centre of volume of the flooded water and the centre of rotation

H : The head between the water level and the center of damage hole

K : Flow coefficient

$M_f$ : Mass of flooded water

$Mt_R(t,\phi,\theta)$ : Instantaneous static heeling moment due to water on deck

$Mt_T(t,\phi,\theta)$ : Instantaneous static trimming moment due to water on deck

LCB (t, z, θ, φ) : Longitudinal centre of buoyancy of the vessel

LCG : Longitudinal centre of gravity of the vessel

lcg(t,φ,θ) : Longitudinal centre of gravity of water on deck

Sf(t) : Instantaneous static sinkage force due to water on deck

TCB (t, z, θ, φ) : Transverse centre of buoyancy of the vessel

TCG : Transverse centre of gravity of the vessel

tcg(t,φ,θ) : Transverse centre of gravity of water on deck

U : Velocity of the water

Wd(t) : Instantaneous amount of water on deck

Δ (t, z, θ, φ) : Instantaneous displacement

$\Delta (t_0)$ : Initial displacement at time $t = t_0$

**Forces and Moments**

| | | |
|---|---|---|
| a | : | Maximum amplitude of the incident wave |
| cos(n,j) | : | Cosines directions |
| G | : | Pulsating source potential of unit strength at a point $(\zeta,\eta)$ in the strip contour |
| g | : | Gravitational acceleration |
| $n^{(i)}$ | : | Direction cosines of the outward normal vector for each mode of motion |
| $p^{(i)}$ | : | Hydrodynamic sectional pressure |
| $Q_d$ | : | Unknown source strength |
| S | : | Wetted surface area of vessel |
| s | : | Wetted contour of the strip section |
| $V_n$ | : | the normal velocity component of a point on the section contour. |
| $\rho$ | : | Density of water |
| $\nabla$ | : | Under water volume of vessel |
| $\mu$ | : | Heading angle (0.0:following, 180:head, 90 and 270:beam seas) |
| $\omega$ | : | Frequency of excitation |
| $\omega_e$ | : | Frequency of encounter |
| $n^{(i)}$ | : | Directional cosines of the outward normal vector and changes depending on the mode of motion (i) |
| $\phi_D(y,z)$ | : | Sectional diffracted wave potential |
| $\phi_I(y,z)$ | : | Sectional incident wave potential |
| $\Phi_{RR}$ | : | Real part of radiated velocity potential |
| $\Phi_{RI}$ | : | Imaginary part of radiated velocity potential |
| $\Phi_I$ | : | The incident wave potential (Froude-Krylov potential) representing the incoming waves |
| $\Phi_D$ | : | The diffracted wave potential representing the disturbance waves diffracted by the section |
| $\Phi_R$ | : | The radiation potential representing the motion induced disturbance of the initially calm water |

**Hydrodynamic Coefficients**

$A_{ij}$ : Hydrodynamic reaction in phase with acceleration (added mass) in the $i^{th}$ and $j^{th}$ direction (i,j = 1,2,…,6)

$B_{ij}$ : Hydrodynamic reaction in phase with velocity (damping) in the $i^{th}$ and $j^{th}$ direction (i,j = 1,2,…,6)

$C_{ij}$ : Hydrostatic stiffness of body in the $i^{th}$ and $j^{th}$ direction (i,j = 1,2,…,6)

$M_i$ : Mass or mass moment of inertia of body in the $i^{th}$ direction (i = 1,2,…,6)

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The safety of any vessel is of paramount importance to vessel designers and operators and to the regulatory bodies. For this reason, it is mandatory requirement for the vessel designers to submit stability booklet to the regulatory bodies such as classification society and marine department before the construction begins. Stability is generally defined as the ability of the vessel to return to the upright position whenever it heels to one side either by internal or external forces.

The consideration of safety is a complex matter as it has to be considered together with a number of conflicting factors such as the vessel's mission, performance, comfort, appearance, cost and profit. The type of vessel and function influence its safety standard. Vessels built for a specific duty such as research or defense has safety as their prime concern, while for commercial vehicles it is the economic viability (Turan, 1993).

The safety standard of commercial vessel at times conflict with their economical viability and their operational efficiency. A compromise has to be achieved between safety and economic viability. The main concern changes on design and regulations, results in extra cost or low operational efficiency.  It is obvious that this conflict increases the potential risk of vessels loss. Therefore, improvement in the safety of vessel must be practical but at the same time offer a substantially improved standard.

The damage that might occur to any compartment of a vessel can cause the loss of its cargo, crew and the vessel itself. Compartment damage can cause the vessel to sink, trim, heel, reduction of GM and GZ or combination of two or more of them, which could eventually lead to capsize. Therefore it is incumbent to the designer to provide all necessary documentation to the classification society or other related/concerned authorities to prove that the vessel still has adequate minimum buoyancy and stability. Unlike intact stability, where the concern over transverse stability always outweigh the longitudinal stability, during the damage situation, both transverse and longitudinal stability need to be assessed. This is due to high possibility of forward or aft end compartment being flooded which results of excessive trim and if the damage is unsymmetrical, it also can cause the vessel to heel.

The damage stability assessment for large vessel is not adequate for small vessel. The main reason is due to the smaller reserve buoyancy and the length of compartment is relatively smaller as compared to large vessel. The reason leads the small vessel to be more sensitive to damage. As a result, a small vessel can capsize in the damaged situation even it has satisfied the damage stability criteria requirement (Samian and Maimun, 2000).

The aim of this research is to concentrate on the assessment of damage stability of small vessel. Time Domain Simulation approach is used to examine the vessel motions during and after flooding in order to understand the physical problems behind the capsizing phenomena. By using the results of the analysis, an approach for more realistic residual and intermediate damage stability criteria can be developed. For such an investigation the most important thing has to be studied is motion. It is common knowledge that Roll motion, which is the most important motion for the dynamic stability of vessels is normally taken into consideration when researching the capsizing especially for Beam Seas. The rolling motion become bigger due to asymmetry leads the vessel to heel and capsize rapidly. Parametric studies are conducted to develop a damage stability simulation program for small vessel.

It should be noted that the present study does not attempt to develop a new damage stability criteria for small vessel, but this study is to develop a methodology for assessing damage stability of small vessel using Time Domain Simulation. However, with the developed methodology for assessing damage stability of small vessel, it is believed to be very useful as a reference for future development of damage stability criteria.

## 1.2 Research Objectives

The objectives of this research are given as follow:

i. To develop mathematical model to describe the water ingress and motions of small vessel in damaged condition.
ii. To develop a technique using Time Domain Simulation for the stability assessment of damaged vessel.
iii. To validate the output of simulation program with the experiment result.

## 1.3 Scopes of Research

i. The research is to modify an existing Time Domain Simulation program for damage stability.
ii. This research covers progressive flooding and method of calculation being used is added weight method.
iii. The research is limited to regular wave in Beam Sea condition and includes 6 degrees-of-freedom motions.
iv. The simulation program will be applied to the parametric study of “Sarawak Fast Ferry”
v. The experiment will be run to verify the output of the simulation program.

## 1.4 Research Outline

This study starts by critical review of the existing damage stability criteria. The summary of the background and basis of the existing damage stability criteria are provided. Then, it concentrates on the limitation of the existing damage stability criteria and the problem of damage vessel stability. This is followed by the use of Time Domain Simulation approach to analyze the vessel motion.

In the modelling part, a six-degrees-of-freedom mathematical model is adopted to the simulation program. The main effort of this model is based on the accurate computation of the water ingress acting on the vessel at each instant of time. Whilst, the dynamic term in the equation of motion is estimated by using the frequency independent coefficient, which can be obtained through the published literatures.

In the analysis, parametric studies are carried out to find the behaviour of the vessel in damage condition. The vessel is chosen for analysis is Sarawak Fast Ferry. In parametric studies, the boundary of safe region is determined by changing the environment and vessel design parameters. The experimental results will be used to validate the simulation output.

Finally, the safe and unsafe region determined by studying the results obtained from the parametric studies. These results are then discussed and conclusions are drawn. For future work, suggestions and steps to improve the present study are recommended.

vessel in other wave direction situation has to be done. Since the relevant hydrodynamic coefficients must be determined as accurately as possible, more experiments may have to be carried out to improve the mathematical model. Experiments also must be carried out as realistically as possible by continuously flooding the compartment of the vessel oscillating in the presence of waves to improve the mathematical modelling of water accumulation.

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