CHAPTER 3

STABILITY ASSESSMENT

3.1 Introduction

By now it should be appreciate that stability is a balance between forces acting on the hull, trying on the one hand on overturn it and on the other to return it to the upright position.

The stability characteristics of a fishing vessel can be derived with considerable precision and some authorities fall into the trap of quoting parameters such as initial metacentric height with great arithmetic accuracy. This shows a lack of appreciation of the true concept of stability and the uncertainties surrounding the ship in the real world.

The above remarks will have made to be more aware of the true natur of the problem of stability at sea, and the limitations of the current static approach. However, there is, as yet, no agreed method of dealing with the true dynamic situation.

The problem of how to establish criteria for stability of specific vessel has been studied by specialists of many countries [25,36,45].

It remains, however, to make use of the experience of designers builders and fishermen throughout the world to establish a common criterion for all fishing vessels.

Among the most fundamental considerations facing a vessel designer is the requirement for a successful integration of vessel utility and vessel safety and nowhere is this need more acutely felt than in the area of stability assessment(28). Unfortunately, this is also the area in which the least amount of quantitative guidance is readily available. The need to quantify not only the stability characteristics of the vessel but the impact of its operating environment as well has often left the engineer with little more than untenable mess.

In 1939, the study of vessel stability effectively entered a new era with the introduction by Jaako Rahola [58] of a numerical based on Baltic sea casualty reviews. Rahola incorporated a principle that the work done by an inclining force tending to right the vessel this criterion indicated not one, but several limiting parameters. The relative importance of each parameters, as well as what safety factors are inherent in each and there by in the whole, must be questioned.

Cleary [13] suggests that vessel form is the fundamental consideration for development of a stability criterion with vessel type and service providing the necessary supplementary information.

Much of rational development has been lost in the evaluation of the various stability criteria in use today. Since the tendency has commonly been to add onto existing, successful criteria and to stretch their limits to cover additional vessel types or new forms. Unfortunately the method has led to applications of statistically derived standards such as Rohola's to vessels well outside their intended range.

Two forms of stability criteria can be defined :-

a) General Criteria

The criteria which compare the vessel to other, statistically safe vessels operating under similar conditions.

b) Specific Criteria

The criteria which assess the response of the vessel under the influence of a specific upsetting force.

Table [3.1] shows the advantages and disadvantages of each. Summary of existing intact stability criteria are also shown in

Table [3.2] for USCG (U.S. Coast Guard Criteria) and International Maritime Consultative Organisation* is clearly seen from the table that the Coast Guard currently applies specific criteria to cover some external forces acting on vessel. Typically a specific criterion sets a

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* IMCO, at present, is IMO (International Maritime Organisation)

limit on a chosen vessel parameter, based on an analysis of the fundamental mechanism of instability concerned rather than on statistical data about successful designs. No specific criteria exists for fishing vessels at the moment.

Three main methods used to assess stability are :-

1) Initial GM as a criteria
2) Moment-Balance criteria
3) Work/Energy-Balance criteria

Table (3.1) Comparison of specific and general-type criteria

General Criteria

Advantages	Disadvantages
. The criteria include all possible types of hazards the exposure of the vessel sample.	• The statistical base use maynot ve valid.
. They are based on actual experience.	• A correct measure of stability may not have been use.
. Detailed knowledge of the types of hazards or the vessel dynamics is not required to formulate the criteria.	• No information on the influence of environmental conditions in the criteria is available. • Vessels with unusual features may not be properly evaluated.

Specific Criteria

Advantages	Disadvantages
• The types of hazards faced and specific design features which influence the degree of hazard.	• To be complete, the set of specific criteria must include the proper hazards to which the vessel will be exposed. If only one is omitted, resulting set is unsatisfactory.

- The environmental condition to which the criteria apply is defined.

- There is a better chance that vessels with new features, size or proportions will be properly evaluated.

- A good analysis and understanding the mechanisms of capsize hazards are required.

Table (3.2) Summary of existing intact stability criteria

Type of Vessel	U.S.Coast Guard Criteria	IMCO Criteria
Passenger	$GM = f$(wind force) $GM = f$(passenger heeling moment)	Area under righting arm curve >16.9 ft-deg (0.09 m-rad) Initial GM at least 0.5 ft (0.15 m) Passenger heeling moment not exceed 10 deg
General cargo	$GM = f$(wind force)	Area under righting arm curve >16.9 ft-deg initial GM at least 0.5 ft
Tugboats	$GM = f$(wind force) $GM = f$(bollard pull) Area under righting arm curve>16.9 ft-deg (0.09 m-rad)	same as above
Offshore supply	$GM = f$(wind force) Area under righting arm curve 15 ft-deg (0.08 m-rad)	same as above
Drilling rigs	Area under righting arm curve $= f$(wind force)	none

Deck cargo	GM = f (wind force) Area under righting arm curve > 15 ft-deg	none
Sailing vessels	Area under righting curve = f (wind heeling moment)	none
Fishing	none	area under righting arm curve >16.9 ft-deg Initial GM at least 1.15 ft (0.35 m)

3.2 Initial GM as a criterion[2]

The first third of this century soly used specific criterion based on GM alone, In fact, it is still in uses today, throughout the world since it is easy to calculate and simple to understand, Unfortunately GM tells surprisingly little about the character of the vessel at other than very small angles of heel.

GM - based criteria have at least one major shortcoming in that they are valid only for small angles of heel, generally in the range of 0 to 7 deg (0-0.1 Rad.) since at larger angles the metacentre begins to "wander" and the $\sin \Theta = O$ linearity is lost. For a specified heeling moment descriptions, equilibrium heel angles can be predicted. Hence GM has been widely used to establish a maximum heel angle under the influence of external forces such as : lateral wind loading, towline pull, lifting heavy weights over the side, passenger movements etc.

Wind heel U.S. Coast Guard gives weather criterion at present, as

$$GM_R = \frac{PAh}{\Delta \tan\Theta} \quad , \text{ft}$$

where GM_R = Required GM , ft

P = is in the form $x+(LBP/14200)^2$ and represents pressure on the projected lateral surface of the vessel due to a steady beam wind. The value of x varies depending on the area of vessel operation, tons/ft^2

A = Projected lateral area of vessel above WL, ft^2

Δ = Displacement, long tons.

h = Vertical distance from centroid of A to half-draft point, ft

ϕ = Angle to 1/2 freeboard or 14 deg. (0.24 Rad.) whichever is less

The heeling moment being resisted is the couple created by the force due to beam wind pressure districted over the exposed lateral arm of the vessel and the resisting drag force of the submerged hull, assumed to be acting at the half - draft point. The limitation of max. hell as one - half the freeboard is intended to allow. The upper limit of 14 degrees in the relation is normally allowed for.

Towing forces When a vessel is undertowed, there is a tendency of a towing vessel to trip when the towline causes a heeling moment to be introduced. Two types of towing related stability hazards are

- Self - tripping ; relates to the tendency of a towing vessel to overturn itself under the influence of the heeling couple created by the opposing towline pull and propeller fores.

- Tow - tripping ; relates to the tendency for the tow to veer off and and create an unexpectedly large transverse component of forces on the vessel with a large upsetting moment resulting.

Self - tripping case has been more thoroughly examined and simple relationships can be found.

The basic form of tow - tripping relationships is exemplified by the Argyriadis formula

$$GM_R = \frac{SHP.h}{100\Delta(f/B)} \quad , \quad ft$$

The above formula assumes that the towline is directly athworthships and that rudder is put hard over with full power applied.

where

SHP = Shaft horsepower
Δ = vessel's displacement, long tons.
f/B = Ratio of freeboard and breadth
h = distance between the centre of underwater resistance and the towing bit.

Fishing Vessels

General-type criteria which establish the required amount of GM for fishing vessels based on analysis of the hull form parameters of successful vessels are in use by Japan, Poland, and the Soviet Union. Since these criteria deal with only one specific group of vessels, it has been assumed that the form of the vessels does not vary radically within the group. A GM based criterion is used to indicate the initial stability statistically required to provide for safe operation within the environmental conditions to which the vessels in the data base were exposed (70). As in all general-type criteria, however, it is imperative that the data base be properly evaluated to insure that all reasonable hazards to which the vessel might be exposed are included. In addition, the controlling parameters assumed in the criterion must be properly selected and their coefficients must accurately reflect their relative influences. Each vessel must be of the same form and size as those in the sample population. In short, the technique of statistical analysis used must be done carefully and properly. The IMCO Simplified Criterion for Fishing Vessels under 98 ft (30 m) in length is typical of this form and is expressed as follows :

$$
\begin{aligned}
GM_R \quad = \quad & 1.7388 + 2B\,(0.075 - 0.37\ f/B \\
& + 0.82(f/B)^2 - 0.014B/D - 0.032\ l/L),\ \text{ft}
\end{aligned}
$$

where

B = beam at waterline

f = minimum freeboard along length

D = minimum depth

l = length of superstructure

L = waterline length

3.3 Moment - balance criteria

In this case it is normally assumed that action of upsetting forces on the vessel effect only static considerations of equilibrium since their rates of application and variation with time are much slower than frequency of response of the vessel in roll. As a result, time - dependent dynamic effects due to the inertia of the vessel and the entrained water and the momentum of roll motion can be neglected.

The principal problem in developing specific-type criteria to address equilibrium at large angles of heel is in quantifying the heeling moment and its variation with heel angle [56].

Wind - heel criteria

U.S. Navy criterion for wind heel approximates the variation of the lateral wind pressure loading on conventional vessels as

$$\text{Helling arm} = \frac{0.004\ V^2 . A . h \cos^2\phi}{2240\Delta}\ ,\ \text{ft}$$

where

V = Wind velocity , Knots

A = lateral surface area, ft^2

h = distance from centroid of A to half - draft centre of underwater resistance, ft

ϕ = heel angle, deg.

Δ = displacement, long tons.

The moment balance of this criterion requires that the angle of equilibrium must be less than 60 percent of the angle at which the righting arm is maximum [64].

It should be apparent that the moment - balance method discussed in this section is applicable only in the form of specific criteria.

3.4 Work or energy - balance criteria

If righting moment function is integrated from zero heel up to some specific heel angle o_2 work done to heel the vessel up to that angle is yielded. See Fig. (3.1). If the vessel is then released it will tend back toward the equilibrium position, zero heel in this case. The potential righting energy stored by the vessel, equal in magnitude but opposite in sense to the heeling work will produce a righting moment to accelerate the mass of the vessel and its entained water back toward equilibrium. By the time the equilibrium point is reached, all potential righting energy has been converted to the kinetic energy of roll motion, and the vessel continue to roll past the equilibrium point. The roll motion will continue to go on until energy is dissipated through viscous damping.

Fig. (3.2) shows the plots by integrating the righting moment and heeling moment functions. The resulting intersection of the two curves should be the point of dynamic equilibrium. The problems remain on the facts that input heeling work from external forces and moments can not be quantified in term of heeling angles. Many organisations are working on this topics.

The IMCO Criteria for Passengers and Cargo ships under 100 m (328 ft.) in length requires the following "dynamic" stability conditions to be met [27].

(1) The area under the righting arm curve (GZ curve) should not be less than 0.555 m-rad (10.34 ft-deg.) up to θ = 30 deg. (0.52 rad.) angle of heel and not less than 0.09 m-rad. (16.9 ft. -deg.) up to θ = 40 deg. (0.7 rad.) or the angle of downflooding whichever is less.

(2) The area under the righting arm curve between the angles of 30 and 40 deg. or between 30 deg. and the downflooding angle should not be less than 0.03 m-rad. (5.6 ft. -deg.)

The consideration of righting energy and heeling work balance requires insight into not only the individual heeling influences, but their ability to combine and be augmented by vessel roll.

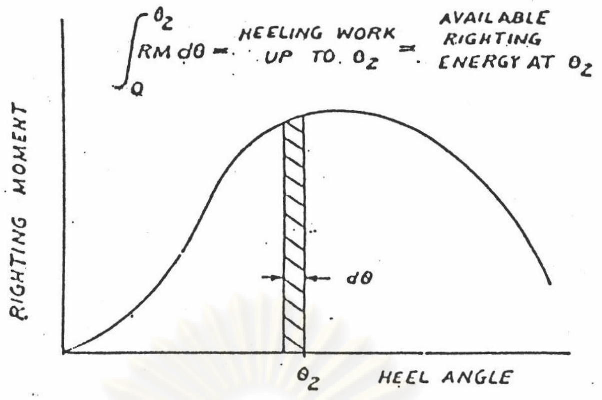

Fig. (3.1) Relationship of righting function to energy considerations

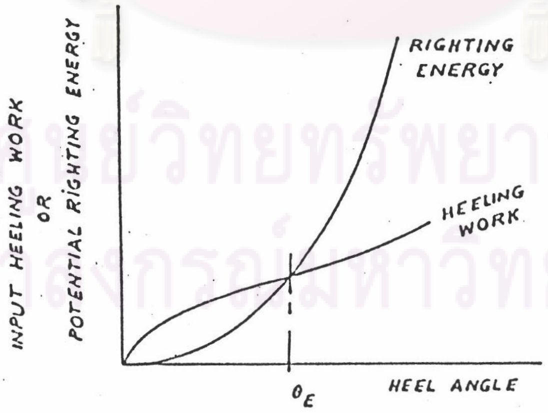

Fig. (3.2) Dynamic equilibrium

3.5 Conclusions

Since the forces of a sea state that affect the intact stability of a vessel are extremely difficult to define and quantify, there are a lot of areas not covered by criteria ie. lost of stability in longitudinal seaway; effects of water on deck.

The science of assessing intact stability must continue to grow with the expanding variety of hull forms and service conditions in existence today. Criteria must reflect accurately the known influences of specific heeling forces and provide adequate margin of safety for unknowns must be provided to the designer in such a form that they are usable without unrealistically sophisticated testing or analytic procedures. With continued study of the complex phenomena contributing to a vessel's intact stability, the criteria we use as tools to quantify the word "adequate" will grow increasingly more precise.