# Critical review of transverse stability criteria of fishing vessels

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A critical review of IMO' transverse intact stability criteria for fishing vessels stability is presented. The paper analyzes all possible risk and causes of loss of a fishing vessel. The analysis is based on investigating all hazards associated with the loss of transverse stability of fishing vessels. The analysis handles uncertainties associated with basic design variables that are involved in stability assessment and ship design. The fishing vessels stability criteria are discussed under dynamic conditions and under the combined effect of all probable factors affecting the heeling moments on ship such as that resulting from wind rolling, trapping of water on deck, towing of fishing gear, direction of towing force during trawling, structural damage due to steep waves, crew mistakes, etc. A rational approach for evaluating and accepting transverse stability based on considering uncertainty in stability parameters, operational environment, and measuring methods is presented. The transverse stability criteria are proposed to be based on an acceptable level of societal risk. Finally conclusions and recommendations for further work in this area are presented.

يقدم هذا البحث مراجعه نقديه لقواعد ومتطلبات الإتزان العرضى لسفن الصيد الصادره عن المنظمه البحريه الدوليه تحت كل العوامل المحتمل حدوثها مجتمعه مثل العزوم الناشئه عن هبوب الرياح بعرض السفينه وتراكم المياه على سطح السفينه والشد الناشىء عن سحب معدات الصيد واتجاه قوة جر الشباك اثناء اللإبحار و الإنهيارات الإنشائيه الناجمه عن ضرب الأمواج العاليه للسفينه و اخطاء طاقم السفينه... إلخ. تم استخدام نتائج تقصى الحقائق لفقدان الأتزان العرضى وغرق بعض سفن الصيد لتقديم الخطوط العامه لاقتراح طريقه لوضع أسس معايير الإتزان العرضى لسفن الصيد بحيث يؤخذ فى الإعتبار العشوائيه فى خصائص السفينه وفى قراءات نتائج تجربة الإماله و ظروف تشغيل السفينه كارتفاع الأمواج وشده الرياح. الطريقه المقترحه تتطلب الموافقه على حسابات الإتزان العرضى على أساس المقارنه بمستوى من المخاطرفى اعمال أخرى فى المجتمع. فى نهاية البحث تم تقديم الإستنتاجات والتوصيات للعمل المستقبلى فى هذا المجال.

**Keywords:** Reliability, Transverse stability, Fishing vessels, IMO, Intact stability criteria

## 1. Introduction

The commercial fishing industry is one of the most dangerous, and deadly, occupations in many countries. Fishermen in the United States in 2000 ranked second in deaths per 100,000 workers, right behind timber cutters and well above airline pilots, police, and construction workers. Within the first three weeks of 1999, 10 commercial fishermen were killed or remain missing following the sudden sinking of three large fishing vessels in the southern New England and New York/New Jersey areas. Initial reports [1] suggest that stability conditions on these vessels may have been a factor in their sudden loss. Fishermen in Maine have experienced concern about stability related sinking, where at least 10 Maine fishing vessels have been lost due to stability related incidents in recent years. For the 10 years period, 1983 to 1993, 41% of fatalities in marine accidents involved fishing vessels [2]. In 1994, 1597 fishing vessel accidents involving 1,642 vessels and 64 fishermen fatalities occurred. The Centers for Disease Control and Prevention (CDC) have estimated that the fatality rate for the Alaskan Commercial fishing industry for 1991 and 1992 was almost 7 times the mean fatality rate for all private sector Alaskan industry. Although there are no statistics for fatality rate in the fishing industry in Egypt, it is well known that fishermen experience a similar high risk in fishing vessels accident. The author expects the fatality rate to be even higher in Egypt compared to that in the US because the Egyptian fishing industry depends totally on tradition and family business for both building and operation of fishing vessels. The majority of the Egyptian fishing fleet consists mainly of vessels that are very poorly designed and equipped, badly maintained, and unscientifically operated by untrained crews.

There have been many efforts to review the current criteria for transverse stability of fishing vessels. Most of these efforts emphasized that the current criteria ignores many causes of capsizing, the combined effect of these causes, and the uncertainties associated with the parameters affecting transverse stability of ships.

Shama [3] discussed the implementation of reliability-based approach on assessment of risk of loosing stability in criteria used in intact and damaged condition. The probability calculation in this study was based on assuming the following performance function:

$$D_R = D_S - D_H \,, \tag{1}$$

where $D_s$ is the dynamical stability of a ship, $D_H$ is the work done by the heeling moment on the ship, $D_R$ = performance or safety margin or the reserve dynamical stability. Also, he assumed that all relevant stability variables to be normally distribution to simplify the calculations and examined the impact of range of variation of $M_D$, & $M_H$. Based on these assumptions, it was concluded that both ship's initial stability and the shape of its static stability curve have a great influence on its capsizing probability.

Shama [4] discussed the impact of the combination of factors and accidents on the probability of capsizing of a floating hotel in the River Nile. It was recommended in this study that a minimum safety measure and an acceptable risk level should be considered when reviewing all stability calculations during design; it was also recommended that all external factors affecting ship's safety should be examined collectively as random variables.

In his assessment of risk of loosing stability, Shama [5] concluded that initial stability is not enough as the sole measure of stability; he also emphasized the need for more investigations on the variability of different heeling moment components. It was evident in this study that compliance with the current deterministic stability criteria does not ensure ship's safety against capsizing.

In all the above-mentioned studies, the uncertainty characteristics of stability design factors were not known and were all assumed to be of normal distribution and with assumed range of variation (Coefficient of Variation) for simplification.

Lockerby [6] discussed the development of a reliability analysis approach to damage stability criteria for naval ships to comply with the changes of weapons, environments, and requirements utilizing probabilistic analysis. The results of the analysis can enhance the stability of ships.

Atua and Ayyub [7] presented a demonstration of the computation of capsizing probability for a ship that meets stability criteria according to both the U.S. Coast Guard, and the Department of the Navy [8]. The capsizing probability computations were performed according to selected reliability methods. The stability performance function for the ship was kept to its simplest form in order to illustrate the presented concept. The function has two random variables that correspond to the dynamic stability and heeling for a ship as represented by the respective two areas. The probability of capsizing was found to be 9.7% although both the deterministic and the safety factor approaches show that the ship is safe and stable with a margin of 20% according to both design rules used in the analysis.

The objectives of this paper are (i) to investigate the most common causes of capsizing of fishing vessels; (ii) to review the current transverse stability criteria of fishing vessels in IMO's requirements; and (iii) to provide recommendations for future work for the development of reliability-based transverse stability criteria of fishing vessels.

## 3. Some possible causes of capsizing of fishing vessels

Thorough investigations of the loss of stability of fishing vessels in rough water and breaking waves were performed for two inshore fishing vessels having almost the same principal dimensions and displacement, but with different statical stability characteristics. Conclusions were drawn based on test results and calculations. Morrall [9] concluded that:

i. Insufficient roll stiffness leads to excessive roll even in modest sea conditions, which was considered to be the main cause of capsizing of one model although having the same GM value as the other model that survived the same sea condition due to greater dynamical stability under the stability curve. Low roll stiffness leads to rolling to larger angles.

ii. Capsizing due to sudden gust of wind can only be considered when the ship is balanced on the crest of a wave as the ship loses its waterplane inertia and hence stability.

iii. Characteristics of the stability curve such as maximum righting moment and its position and the angle of vanishing stability have more impact on greater dynamical stability than just providing the required GM value. In all cases where tested models capsized, the hull rolled to angles exceeded $50^o$, which was very close to the angle of vanishing stability.

iv. Increased sheer line and low stern trim showed a considerable increase in the magnitude and angle of the maximum righting moment, and the magnitude of angle of vanishing stability.

v. Stern design has no effect on ship's behavior as both transom and round stern-models tended to broach in following seas and ended up beam-on to the waves regardless of the rudder action.

Morrall [9] recommended that great emphasis should be placed on magnitude and position of the maximum righting moment together with the value of the angle of vanishing stability in any fishing vessels stability criteria.

In his investigation of the loss of the GAUL, Morrall [10] concluded that some of the following could have caused that disaster:

i. Asymmetry of deck house and openings on the trawl deck would allow water to accumulate on one side on both trawl deck and lower decks, in addition to the blockage of the freeing ports by fishing gear.

ii. Progressive flooding of trawl deck and factory deck through access doors on the starboard increased by an initial list due to excessive rolling and reasons mentioned in 0. Heel angle during sudden turning, which is almost twice the steady heel angle during steady turning when turning the helm from amidships to either side and four times the steady heel angle when turning the helm from portside to starboard and vice versa.

iv. Structural damage to the bridge front due to large steep waves that led to a total loss of steering control and radio contact.

v. Crew mistakes: A common fishing vessel's watertight integrity is watertight doors or hatches being left open. Several fishing vessels were lost from flooding through a fish hold hatch that was not fully closed or due to a watertight door being left open. The investigations [1] showed that when sank, the F/V Arctic Rose's watertight door in question became submerged at about 24 degrees of heel, significantly less than 30 degree breakpoint in the Torremolinos Convention criteria. The door opened into a large main deck processing space, which if flooded with as little as 6 inches (150 mm) of water created such a large free surface effect the a significant loll angle developed. This lolling angle would submerge the door at ever-smaller heel angles, likely leading to progressive downflooding and eventual loss of the vessel.

## 4. Review of current design criteria for transverse stability

In this section, the IMO's transverse stability criteria for fishing vessels are summarized in terms of requirements for adequate stability for different operational conditions. Also, shortcomings in the IMO's criteria are highlighted in the light of the uncertainty involved in basic stability parameters; main causes of capsizing from real cases investigations, and results from test models.

### *4.1. Shortcomings in IMO's criteria*

1. The IMO's transverse stability requirements considered all design parameters to be of deterministic values, this assumption is invalid due to the uncertainties involved in errors in measured parameters, measuring methods, calculation methods, etc.

2. Uncertainties associated with basic stability parameter that will affect the judgment on

stability adequacy in the righting arm curve are not considered. The area under the curve is mainly affected by the values of displacement, D and vertical center of gravity, *KG*. Hansen [11] analyzed accuracy in measuring ships displacement and vertical center of gravity resulting from inclining experiment by analyzing random errors in measured objects (hull geometry and draft mark locations) and random errors due to measuring methods (measuring ship's heel, reading the draft, and estimating weights to complete and deduct. The resulting Coefficients Of Variations (COV) are shown in table 1 below. The distribution type of all errors was assumed to be Gaussian.

3. Other ship stability parameters should be analyzed probabilistically as well; KM, LCB, $MCT_{1cm}$, and Trim. These parameters are subjected to human errors such as reading, errors due to measuring methods, and errors due to calculations models used to determine these values. The uncertainty and variability in these parameters should be statistically analyzed to assign the distribution type, bias, and coefficient of variation.

4. All stability requirements on the righting arm curve are indicated in still water condition, whereas the ship is operating mostly among waves. GZ curve is significantly reduced at waves, especially when the ship is balanced on a wave crest amidships as shown in fig. 1 [12] in following seas.

5. Also, there is a significant loss of stability due to wave making that could amount to 12% at a corresponding $V/\sqrt{L}$ equal to 0.9 according to Nutku [13] as shown in fig. 2.

6. Icing is another natural phenomenon that is not considered in the IMO's requirements. Icing has an adverse effect on transverse stability as it is usually asymmetrical which causes an additional heeling moment. Also, the added weight on deck causes a reduction in $GM_o$ [12].

7. IMO's transverse stability requirements ignore another factor that is very common in fishing vessels, which is shipping green water on deck. Water on deck leads to rising in center of gravity and creating a heeling moment if accumulated on one side only or when rolling. Design of freeing ports and height of bulwark are major factors in mitigating this effect as it provides more righting moment in case of ship with insufficient stability. However, high bulwark may have bad effect on stability if the ship has sufficient stability as it retains more water on deck, hence inducing greater heeling moment. Fig. 3 below shows the resultant heeling moment due to water on deck. IMO has advised precautions against water trapping on deck (see. 9.3.3. below), but without any specified criteria or guidance to follow in the early design stage.

Table 1
Uncertainty characteristics of KG and D in inclining experiment

| Stability parametr | Distrbution type | COV |
|---|---|---|
| Displacement D | Normal | .005 |
| Vertical center of gravity KG | Normal | .0029 to .0073 |

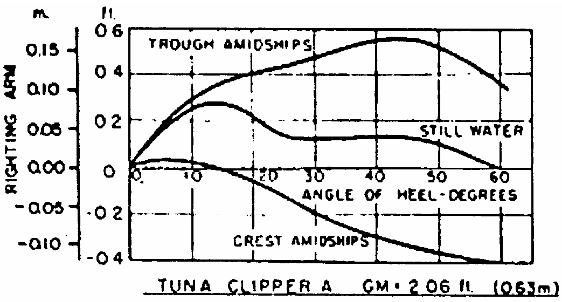


Fig. 1. Transverse stability in following waves.

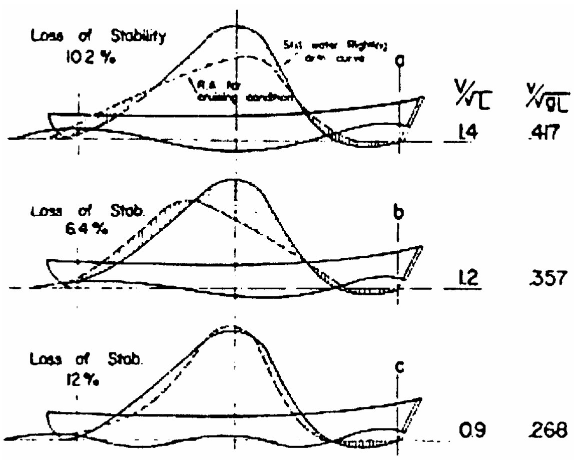


Fig. 2. Transverse stability loss due to wave making.

8. IMO's requirements advised precautions against capsizing due to heeling moment during fishing resulting from forces such as pull of warp ($M_{pull}$), and jamming of gear net if trawl is fastened on one side causing a heel angle, $\theta_{pull} = M_{pull}/GM.\Delta$.

Also, there is a reduction in *GM* if trawl is fastened on both sides,

$$GG' = \frac{f}{4}(h_1 + 3h_2)/\Delta\,, \qquad (2)$$

where: $f$ = stalling force of winch on one side, and $h_1$, $h_2$ = height of application of stalling force, $f$, above water line.

9. IMO's stability criteria assume the crews operate their vessel correctly; watertight closures secured and good seamanship. In the real world, however, people make honest mistakes, which are not addressed by the current criteria. If the crew are aware of the current risk of capsize, they will better evaluate current sea conditions, then the crew may elect to increase their stability levels, hence lower the risk of capsize. Given the small size of many fishing vessels, it is critical that the risk of capsize analysis should reflect both static and dynamic methods

10. Another common fault with the current stability criteria for small commercial fishing vessels is the lack of any risk assessment. The criteria are strictly safe/unsafe, which is not representative of how fishermen consider the real world. Small fishing vessels generally do not suddenly lose their stability. A fishing vessel's stability is often lost when an unusual combination of capsizing forces such as wind, waves, or fishing loads occurs.

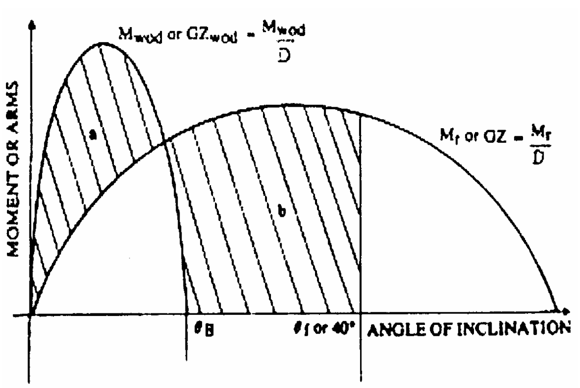


Fig. 3. Resultant heeling moment due to water on deck.

11. The artificial 30 degree breakpoint in the Torremolinos Convention criteria [14] should be changed to 30 degrees or the angle at which a watertight closure, if advertently left open, would become submerged, whichever is less. This will help to minimize situations [1] like that on the F/V Arctic Rise.

## 5. Rationalization of transverse stability criteria of fishing vessels

Fig. 4 outlines the proposed probabilistic approach for assigning, assessing, and accepting transverse stability for fishing vessels. The process considers the combined effect of all parameters causing capsizing, uncertainties in stability parameters, probability of occurrence of extreme conditions, national and international stability criteria, and acceptable risk level. As shown in fig. 4, all causes of fishing vessels are highly probable due to the nature of fishing operations and the operation environment in which the vessel is working.

Probabilistic analysis is needed to determine the extreme value of the environmental factors in the operational profile (speed, heading, and wave height). The environmental factor combined with crew mistakes result in different possible causes of losing stability and capsizing (Structural damage, broaching, flooding, excessive rolling, excessive heeling moment due to gust of wind, etc). The probability of occurrence of each scenario is determined using probabilistic analysis

Risk of losing stability due to fishing operation (towing force when fastened on one or/and both sides, jamming of the gear not, etc.) is probabilistically assessed.

The effects of the above mentioned factors are normalized in terms of reduction in righting arm, or reduction in the stability range and combined together as random variables.

Stability parameters in terms of the righting arm curve are probabilistically determined taking into consideration the uncertainty inherited in hull capabilities and

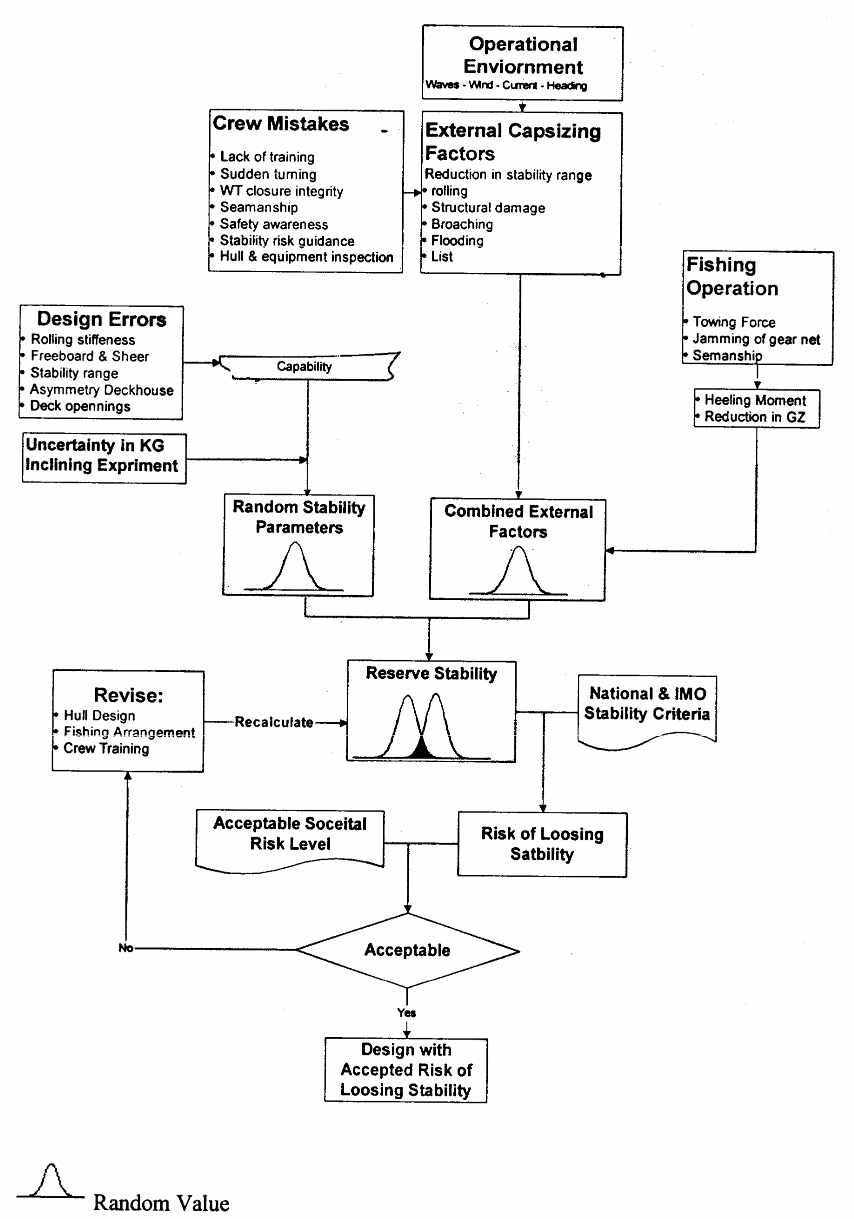


Fig. 4. Rationalized roadmap for risk-based transverse stability of fishing vessels.

uncertainties resulting from errors in the measured values during the inclining experiment as shown in item 2 in 4.1 above. The random stability parameters are compared to the stability criteria, and the risk of loosing stability is determined. The total risk of capsizing is calculated by:

$$R = \sum_{i} P_i \times C_i \ , \qquad (3)$$

where: $P_i$ = probability of occurrence of each capsizing scenario, and $C_i$ = consequence of each scenario (death rate or economical losses).

The total risk is compared to the acceptable risk level and a decision of acceptance or rejection made. The typical guideline for establishing risk-acceptance criteria is that the fatality rates from the activity of interest should never exceed average individual fatality rates from natural causes (about 0.07 per 100,000 population, from all natural causes) or should be less than risk of death from other related occupations.

## 6. Conclusions and recommendations

1. The IMO's requirements for transverse stability address some causes of capsizing of fishing vessels in terms of precautions without assigning measured criteria for each of these causes.
2. IMO's requirements ignore the probability of combined effect of more than one cause, if not all of them.
3. IMO's requirements disregard uncertainty and variability in transverse stability parameters, which may lead to a lower safety margin, hence to capsizing.
4. Transverse stability criteria need to adopt the proper level of societal risk into its acceptance process. The acceptable societal risk is that level of risk that should not exceed the economical losses and death rate associated with involuntary activities in the same society where fishing operations is taking place.
5. Further work need to be done on investigating uncertainties in stability parameters; the needed investigations should be based on statistical analysis on bias of each parameter and other characteristics such as distribution types and coefficients of variation.
6. Probabilistic risk assessment approach should be adopted to assess the safety margin associated with transverse stability of fishing vessels and to investigate all losses scenarios.
7. Fishing vessel crews should be provided with risk based stability guidance to increase their ability to safely operate their vessels. By adding risk assessment, the means for creating a risk based loading matrixes would be developed.
8. Finally, There is a need for a comprehensive project to implement this approach in order to verify the proposed probabilistic model to establish national transverse stability criteria for domestic fishing vessels. This will require analysis of statistical data on operation environment in the national waters and establishing a national societal risk acceptance in terms of fatality rate and economical losses.

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## Appendices

*IMO recommended general stability criteria*

i. The righting lever should be at least 0.2 m at an angle of heel equal to or greater than $30^o$
ii. The initial metacentric height should not be less than 0.35 m for single deck vessels. In vessels with complete superstructure or vessels of 70 m in length and over the metacentric height may be reduced to the satisfaction of the Administration but in no case shall be less than 0.15 m.
iii. The maximum righting lever should occur at an angle of heel preferably exceeding $30^o$, but not less than $25^o$.
iv. $Area(0^o - 30^o) \geq 0.055$ m-rad, (4)
v. $Area(30^o - \theta_u{}^o) \geq 0.03$ m-rad, (5)
vi. $Area(0^o - \theta_u^o) \geq 0.09$ m-rad. (6)

Where:
Area ($0^o$-$30^o$) is the area under the righting lever curve between the angle of heel of $0^o$ and $30^o$, and
$\theta_u$ is the angle of heel of $40^o$ or the downflooding angle, whichever is less.

The following two requirements are recommended for fishing vessels to assure safety of lives.
vii. Where arrangements other than bilge keels are provided to limit the angle of roll, the Administration shall be satisfied that the stability criteria referred to in i to vi above are maintained in all operating conditions.

*Severe wind and rolling criterion (weather criterion) for fishing vessels*

Fishing vessels of 45 m, in length and over having large windage area should comply with the provisions shown in fig. 5.

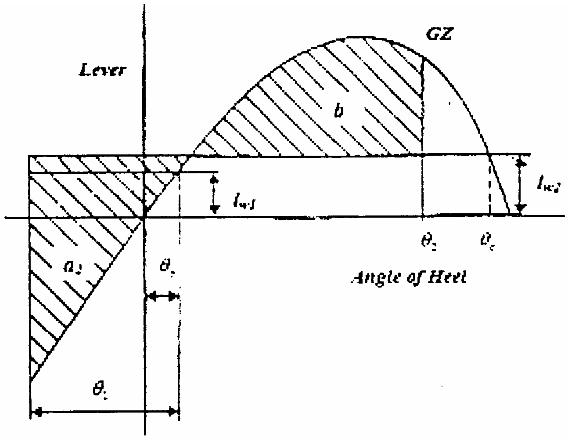


Fig. 5. Loss in range of stability and righting arm due to wind and rolling.

Where: $\theta_o$ = Angle of heel under action of steady wind, $\theta_1$ = Angle of roll to windward due to wave action, $\theta_f$ = Angle at which, openings in deckhouses or superstructures which cannot be closed immerse, $\theta_c$ = Angle of second intercept between wind heeling lever lw2 and GZ curve, $l_{w1}$ = Steady wind lever, and $l_{w2}$ = Gust wind lever.

*General precautions against capsizing*

(i) All fishing gear and other large weights should be properly stowed and placed as low as possible.
(ii) Gear for releasing deck load in fishing vessels carrying catch on deck, e.g., herring, should be kept in good working condition for use when necessary.
(iii) When the main deck is prepared for the carriage of deck load by division with pound boards, there should be slots between them of suitable size to allow easy flow of water to freeing ports to prevent trapping of water.
(iv) Fish should never be carried in bulk without first being sure that the portable divisions in the holds are properly installed;
(v) Reliance on automatic steering may be dangerous as this prevents changes to course which may be needed in bad weather.
(vi) In all conditions of loading necessary care should be taken to maintain a seaworthy freeboard.
(vii) Particular care should be taken when the pull from fishing gear results in dangerous heel angles. This may occur when fishing gear fastens onto an underwater obstacle or when handling fishing gear, particularly on purse seiners, or when one of the trawl wires tears off.

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