Monitoring System for Safety of Fishing Vessels Subjected to Waves

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Abstract
This paper describes and implements a monitoring and decision support system to evaluate the safety of fishing vessels subjected to waves. In order to develop the system, the Portuguese fleet and fishing methods had to be identified. As a result, it was concluded that although capsizing is the most serious hazard due to the loss of human lives, operational hazards are the most common ones. Thus, capsize mechanisms and environmental hazards were studied. The system architecture is described. The system is composed by a load monitoring module, a static stability analysis module and wave safety analysis module. The load monitoring module allows inputting the load conditions. The static stability analysis module computes the Torremolinos Convention Criteria for fishing vessels, the weather criteria and the IMO Severe Wind and Rolling Criteria. The wave safety analysis module implements the IMO-MSC(2007) guidelines and displays the critical speeds for environmental hazards on a polar diagram. The system was implements into the SM-SEPEO application which was tested for the load conditions defined by the Torremolinos convention Criteria. The application demonstrates that it is possible to implement the concept of monitoring and decision support to evaluate the safety of fishing vessels subjected to waves using low cost equipment.

Introduction
It is difficult to isolate engineering problems from the issue of safety since every human endeavor has an element of hazard or risk. Apparently the need for safety measures is influenced by the existence of such hazards or risks. In this respect fishing vessels are no exception in the sense that fishing vessels’ hazards are related with the environmental conditions and with the fishing methods employed. Portuguese fleet has continuously decreased in number of vessels and volume of catch since 20 years ago. It consists now of less than 1000 vessels of which over 9000 are smaller than 12 m in length. Most of the vessels larger than 12 m are netters and longliners, followed by purse seiners and trawlers. Most of these vessels operate in Portuguese waters next to mainland. Trawlers face hazards such as coming fast, which is dangerous in heavy seas if breaking out is attempted, and bag lifting, especially if the trawl is filled with stones and mud. Handling the trawl doors is more of a personal danger. Potting involves great personal dangers and may cause capsize of the vessel if the anchor or pots became fouled in the seabed or if an excessive number of gears are carried on deck. Netting is only a problem if an excessive number of nets are carried or if the net bins became filled with water. Purse seiners are vulnerable to capsize if an excessive weight of fish is in the net, if sea water in the hold causes the fish to become fluid and shift or excessive fish load is on deck. Longlining may involve the danger of water inside the shelterdeck in case of heavy seas. So, the operational hazards can be categorized and
include: handling the gear, boarding the catch, abnormal loads, coming fast, freeing fastened gear, overloading the boat, modifying the gear or the boat. Environmental hazards include wind heeling, stability on wave, breaking wave, rolling in waves, icing and flooding. Wolfson (2004) investigation of fishing vessels accidents shows that operational mistakes were the major factor in these accidents; however capsizing is the most serious hazard due to the loss of human lives, Antão and Guedes Soares (2004).

Experimental and theoretical calculations made by De Kat (1989), Umeda (1994) and Adee (1986) permitted divide capsizing modes into the following six categories: pure loss of stability, breaking wave, synchronous waves, low cycle resonance, broaching. Pure loss of stability occurs when the righting arm decreases to the point that there is not sufficient restoring energy in the vessel to upright itself. The essential prerequisite for this to occur is a ship speed nearly or equal to de wave speed so that the ship remains almost stationary relative to wave crest for a sufficient length of time to capsize. This usually occurs in a following sea at high speed. On breaking wave, two modes were identified: the hull is balanced on the wave, looses water plane inertia and capsizes, and the wave overwhelms the bulwarks and floods the decks producing a roll moment grater then the restoring moment leading the vessel to capsize. For the case of Synchronous waves the vessel is hit by synchronous waves causing progressively large roll angles leading to capsise. Low cycle resonance can be recognized by the frequency of roll motion and occurs when the encounter frequency is nearly equal to twice the roll nature frequency in following seas. Broaching implies the loss of directional control and occurs when the vessel speed is close to the phase of the wave. The ship is then forced to move along the wave so that it becomes directionally very unstable and may capsize. As seen from the above capsizing modes, there are three critical conditions for inducing ship instabilities: wave speed equal ship speed in following seas, encounter frequency equal to twice the roll natural frequency and encounter frequency equal to roll natural frequency.

Regarding guidance for safety in following and quartering seas, IMO issued MSC Circ 707 in 1995, which was superseded by Circ 1228 in 2007. The Guidance in this document can form the basis for a decision making system.

According to these guidance, Benedict et al. (2006) developed a simplified but robust method for the on board calculation, based on the comparison of the ships natural rolling period and the period of the wave encounter to prepare a polar diagram for synchronous and parametric resonance and other wave effects from basic data of the ship and the sea state, even by manual calculation. A computer program ARROW-Avoidance of Roll Resonance and Wave impact was developed to display the potential dangerous conditions of rolling resonance or other high wave impacts on ships due to specific wave encounter situations.

Previous studies were made. Köse et al. (1995) describes an intelligent monitoring and advisory system for vessel safety. This system uses environmental information obtained from a number of sensors and proposes corrective action based on a rule-base derived from human expertise, experiments, and theoretical research. The architecture of the monitoring and advisory system is based on the fuzzy logic using capsize modes of a ship. The results of the simulations of
various sea conditions leading to capsize and the vessel response to the corrective action suggested by the advisory system shows the feasibility of such system. In 1982, a microcomputer based capsize alarm system was developed by Koyama et al. (1982). In this system a pendulum was used to measure ship motions. Mean period and root mean square roll angle were used to assess safety of the vessel. As a result of an inadequate pendulum system, the results were not very reliable at high speeds.

Today, improvements in computer technology and the low prices of measurements equipments facilitate the integration of a safety monitoring system in fishing vessels. The monitoring and decision support system to evaluate the safety of fishing vessels subjected to waves was implemented on the computer application, SM-SEPEO, based on the following requirements: the system should measure minimum amount of data, the system should not interfere with the operation of the ship.

Description of effects and methods considered

As basis for implementing the monitoring and decision support system to evaluate the safety of fishing vessels subjected to waves, the guidance for safety in following and quartering seas, IMO issued MSC Circ 707 in 1995, which was superseded by Circ 1228 in 2007, the 1977 Torremolinos Convention and its 1993 protocol, were taken into consideration.

From the IMO(1995) and IMO(2007), the principal dangers were considered: surf-riding and broaching, synchronous rolling motion, parametric rolling motion, reduction of stability riding on the crest in the wave groups. The **Surf-riding and broaching** occurs when a vessel is situated on a steep forefront of high wave in following and quartering sea condition. As consequence, the vessel can be accelerated to ride on the wave; this is known as surf-riding. When the vessel is surf-riding, the so called broaching phenomenon may occur, which endangers the vessel to capsize as the result of sudden change of vessel's heading and unexpected large heeling.

The **synchronous rolling motion** occurs when the natural rolling period of a vessel coincides with the encounter wave period leading to large rolling motions. In case of navigation in following and quartering seas this may happen when the transverse stability of the vessel is marginal and therefore the natural roll period becomes longer.

The **Parametric rolling motion** is an unstable and large amplitude roll motion that takes place if the encounter wave period is approximately equal to half of the natural roll period of the vessel. This type of rolling can occur in head and bow seas where the encounter wave period becomes short. In following and quartering seas, this can occur particularly when the initial metacentric height is small and the natural period is very long.

**Reduction of stability riding on the crest in the wave groups** occurs when the vessel speed component in the wave direction is nearly equal to the wave group velocity, which is half of the phase velocity of the dominant wave components. If such situation occurs, the vessel is attacked successively by high waves. The expectable maximum wave height of the successive waves can reach almost twice the observed wave height of the sea state concerned.
For the analysis of intact stability of the ship, the following criteria represented in Figure 1 were considered: Torremolinos convention criteria for fishing vessels, IMO severe wind and rolling criteria and lifting criteria.

The Torremolinos Convention Criterion requires that the area under the righting arm curve should not be less than 0.055 meter-radians up to an angle of heel of 30 degrees; the area under the righting arm curve between the angles of heel of 30 degrees and 40 degrees or between 30 degrees and 40 degrees, should not be less than 0.030 m.rad; the area under the righting arm curve should not be less than 0.090 m.rad to an angle of heel of 40 degrees; the righting arm should be at least 0.66 at an angle of heel greater than 30 degrees; the maximum righting arm should occur at an angle of heel preferably exceeding 30 degrees but not less than 25 degrees; initial GM should not be less than 0.35 meters.

The IMO Severe Wind and Rolling Criteria in conjunction with the Torremolinos Convention Criteria and the Coast Guard also recommend that designers and naval architects should apply the IMO Severe Wind and Rolling Criteria. This criterion measures the ability of the vessel to withstand the effect of beam winds and rolling. The vessel is assumed to be subjected to a steady wind pressure acting perpendicular to the vessel’s centerline which results in a steady wind heeling arm $L_{w1}$. The vessel heels to an angle of equilibrium, $\theta_0$, which should not exceed 14 degrees. From the resultant angle of equilibrium $\theta_0$, the ship is assumed to roll due to wave action to an angle of roll ($\theta_1$) to windward. The ship is then subjected to a gust wind pressure which results in a gust wind heeling arm $L_{w2}$. Under these circumstances, area “b” should be equal to or greater than area “a” according to Figure 1.

Figure 1 - Torremolinos convention criteria for fishing vessels, IMO severe wind and rolling criteria and lifting criteria.

Heeling Moments Due To Fishing Gear occur because fishing gear can impose extremely high loads on a vessel, particularly when things go wrong. This is another of those areas in which the designers’ knowledge of the fisherman’s operating practices is crucial. The normal heeling moments imposed by trawling or seining for instance, should be evaluated by the designer and included when doing the stability analysis. Recent IMO papers addressed the moments which would be experienced by a side trawler in common trawling as well as when the vessel was attempting to clear a trawl which was snagged or fastened to the bottom. The moment caused by a common trawl is reasonably small, given a trawl wire length of 2.5 to 3 times the water depth. It is recommended that a residual righting area between the heeling arm curve and the
righting arm curve should be at least 15 foot-degrees to the angle of maximum righting arm. In addition, the static angle of heel should not exceed 10 degrees. The heeling moment is the maximum generated based on the allowed combinations of hook load and radius. The heeling arm curve is defined by $HA = \frac{\text{Maximum heeling moment} \times \cos \theta}{\Delta}$. In calculating the righting arm curve, the designer must remember to account for the increase in VCG due to the lifting of the weight.

**Outline the System**

The system SM-SEPEO was developed using a modular dependent architecture, composed by a load monitoring module, a static stability analysis module and wave safety analysis module. The load monitoring module allows inputting the load conditions. The static stability analysis module computes the Torremolinos Convention Criteria for fishing vessels, the weather criteria and the IMO Severe Wind and Rolling Criteria. The wave safety analysis module implements the IMO-MSC (2007) guidelines and displays the critical speeds for environmental hazards on a polar diagram.

![Figure 2 – Layout for monitoring and decision support system to evaluate the safety of fishing vessels subjected to waves – application SM-SEPEO.](image)

**Development of Monitoring Load Condition Module**

The load monitoring module allows inputting the load conditions. The data input and storage into the monitoring load condition module is done through ASCII text files, as shown in Figure 3. For this purpose, four different files are considered containing the following information: file with characteristics of fishing vessel, file with weight distribution, file with loading percentage on tanks, file with historic of sensor measurements. The second and the third type of files are simultaneously input and output files in the sense that the system saves the changes made by the user in these files. The fields corresponding to the identification of the vessel are not
editable by the user since this data is read from the file with the characteristics of fishing vessel. Only by changing this file is possible to update the ship characteristics.

Figure 3 – Layout of the monitoring load condition module and respective screen.

The user is allowed to change the weights and their corresponding locations, the tanks loading percentage, and to indicate if water on deck exists or if lifting operations are running. The longitudinal and transversal inclinometer measurement values, the free board and winch lifting weight are computed randomly by an internal function. Only the maximum winch lifting weight is validated by this module. However this validation only alerts for the situation, allowing the system to continue with the calculations.

Development of Static Stability Analysis Module

The static stability analysis module computes the Torremolinos Convention Criteria for fishing vessels, the weather criteria and the IMO Severe Wind and Rolling Criteria. According to the requirements specification this module displays the parameters computed by the system, which define the stability of the ship. The ship is graphically represented as well as trim and heeling lines, the tanks loading percentage as shown in Figure 4.

Figure 4 - Layout of the static stability analysis module and respective screen.
When the mentioned criteria are not full field with the inputted loading condition, visual alerts are immediately displayed in order to call user attention for this situation (Figure 4).

**Development of Wave Safety Analysis Module**

The wave safety analysis module implements the IMO-MSC(1995) and MSC(2007) guidelines displaying the critical speeds for environmental hazards on a polar diagram. The interface is contains three different frames: the input data area, the dangerous phenomena analysis area, and the polar diagram representation area.

The input data area allows the user to define the ship navigational parameters namely the forward speed, the heading and the rolling period. The sea state, which in this scope is characterized by the main propagation direction, the significant wave height and by the wave period, is also inputted by the user in this area. These values are used to compute the encounter period and angle, and the relation between the rolling and the encounter periods, both displayed in non-editable fields.

The dangerous hazards are displayed separately in a second frame. For each phenomenon, the critical values of the forward speed, encounter angle and relation between rolling and encounter periods, are displayed. These values indicate the limits in which the phenomenon occurs. The polar diagram displays graphically the heading and wave main direction of propagation angles, and the forward speed of the ship. The following values are displayed: wave main direction of propagation represented by an arrow at the diagram border, ship heading represented by a sketch of the ship at the origin of the diagram, the forward speed vector also located at the origin of the diagram, hatched areas where dangerous phenomena occur. The representation of these phenomena in the polar diagram allows the user to be aware if ship is near or inside a dangerous zone. For the last case a message with corrective measures is displayed.

The rolling period is given by the following expression:

\[
Tr = 2\pi \sqrt{\frac{A_{44}^2 + A_{44}}{\rho g \sqrt{GMT}}}
\]

(Eq. 1)
where \( r_{44} \) is the rolling rotation radius measured in a parallel axis to a longitudinal axis that crosses the ship’s centre of gravity and for the present case \( r_{44}=0.35B \); \( A_{44} \) is the roll added moment and is equal to \( a_{44}L \), where \( a_{44} \) is the roll added mass \( a_{44}=0.04A_{MS}B^2 \); \( A_{MS} \) is the mid ship section area, where \( A_{MS}=0.97BT \); \( \rho \) is density of sea water (\( \rho=1.025 \)); \( g \) is the acceleration of gravity (\( g=9.81 \text{ m/s}^2 \)); \( GMt \) is the transverse metacentric height and \( \nabla \) is the displaced volume of the ship.

Encounter period is calculated by the expression:

\[
Te = \frac{Tw}{1 + (2\pi \cos \beta / g Tw)} \quad \text{(Eq. 2)}
\]

where \( T_w \) is the wave period, \( T_w=0.8 \sqrt{\lambda} \) where \( \lambda \) is wave length; \( V \) is de ship speed; \( \beta \) is the encounter angle where: \( \beta = |\psi - \psi_0 - 180^\circ| \) Where \( \psi \) is the ships course and \( \psi_0 \) is the wave heading angle.

Table 1 summarizes the effects and formulas for calculation of a basic polar diagram values.

<table>
<thead>
<tr>
<th>Phenomena</th>
<th>Direction/Sector/Area</th>
<th>Equations to calculate the speed values as basis for the diagram elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Synchronous rolling motion</td>
<td>stripe segments over diagram; All directions possible</td>
<td>1. for ( Te = Tr/0.8 ): ( V_{1,8} = \frac{g Tw}{2\pi} \left( \frac{Tw}{Tr/0.8} - 1 \right) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. for ( Te = Tr/1.1 ): ( V_{1,1} = \frac{g Tw}{2\pi} \left( \frac{Tw}{Tr/1.1} - 1 \right) )</td>
</tr>
<tr>
<td>2. Parametric rolling motion</td>
<td>Segment for direct head and stern waves conditions +/- 30º</td>
<td>1. for ( Te = Tr/0.8 ): ( V_{1,8} = \frac{g Tw}{2\pi} \left( \frac{Tw}{Tr/0.8} - 1 \right) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. for ( Te = Tr/2.1 ): ( V_{1,1} = \frac{g Tw}{2\pi} \left( \frac{Tw}{Tr/2.1} - 1 \right) )</td>
</tr>
<tr>
<td>3. Reduction of stability</td>
<td>Segment for direct following and quartering seas +/- 45º</td>
<td>( V_{\text{wave group,0.8}} = 0.8Tw )</td>
</tr>
<tr>
<td>riding on the crest of wave groups</td>
<td></td>
<td>( V_{\text{wave group,2.0}} = 2.0Tw )</td>
</tr>
<tr>
<td>4. Surf-riding and Broaching</td>
<td>Segment for direct following and quartering seas +/- 45º</td>
<td>( V_{\text{surf,1.4}} = 1.4 \sqrt{\lambda} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{\text{surf,1.8}} = 1.8 \sqrt{\lambda} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{\text{surf,3.0}} = 3.0 \sqrt{\lambda} )</td>
</tr>
</tbody>
</table>

Table 1 – Summary of effects and formulas for calculation of a basic polar diagram values.

Results

The tests performed to demonstrate the main functionalities of the system were based on the cargo conditions stated by the Torremolinos convention. The following recommendations for the cargo conditions were applied: leaving the fishing zone with fuel tanks, food and ice completely loaded, and fishing gear; leaving the fishing zone with maximum fishing cargo; port arrival with maximum fishing cargo and 10% of food and fuel; port arrival with 10% of food and fuel, and with 20% of fishing maximum cargo (the minimum cargo considered).
The following parameters were constant for all the tests in the wave safety analysis: wave direction of propagation (10 degrees), wave height (3 m), wave period (12 s), forward speed (20 knots), heading (120 degrees). As a result, the influence of the load variation in the safety of the ship on the wave can be evaluated as shown in Figure 6.

**Figure 6 – Results of 2nd and 4th load conditions of the Torremolinos convention.**

**Conclusion**

The presented study describes and implements a monitoring and decision support system to evaluate the safety of fishing vessels subjected to waves. The static stability analysis module computes the Torremolinos Convention Criteria for fishing vessels, the weather criteria and the IMO Severe Wind and Rolling Criteria. The wave safety analysis module implements the IMO-MSC (2007) guidelines and displays the critical speeds for environmental hazards on a polar diagram. The application demonstrates that it is possible to implement the concept of monitoring and decision support to evaluate the safety of fishing vessels subjected to waves using low cost equipment.

**Reference**


IMO-MSC (2007), “MSC Circ. 1228 – Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions”.


