Research Project 557
Suitability of Stability Criteria Applied to Small Fishing Vessels and Associated Survivability
Report No. 557

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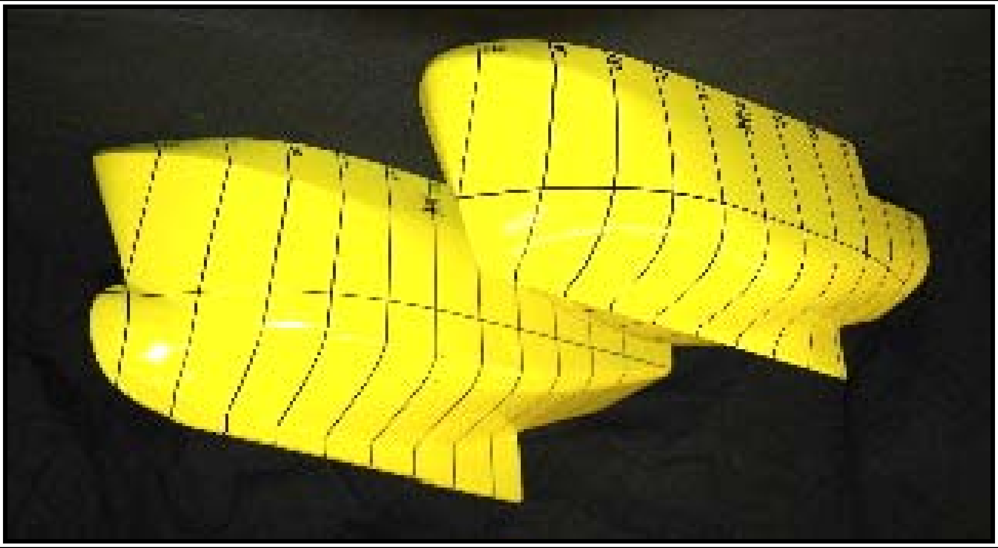

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EXECUTIVE SUMMARY

The remit of this study was to investigate whether the current trend in low length to breadth ratio fishing vessels are exposed to an increased risk of capsize when compared to a conventional length to breadth ratio fishing vessel of comparable fishing capability.

After an extensive survey of the existing fleet of vessels who are actively fishing, two vessels were identified that met the requirements for length to breadth ratio and fishing capability. Models of these vessels were constructed and tests conducted in regular waves for number of stability cases. The tests were conducted for the vessels when each just met the UK Fishing Vessel stability criteria and were repeated for two additional cases identified as potential risks to these vessels, fish room flooding and an additional load (typical of recovering nets). The tests qualify if the influence of L/B on the stability criteria imposed on the vessels in their most onerous condition presents a greater risk to the fishermen from capsize.

Around 500 test runs were conducted where the minimum wave heights to capsize the two vessels in the tested conditions were identified and the sensitivity to heading and wave frequency investigated.

When loaded so as to just comply with the stability criteria, the low length to breadth ratio vessel demonstrated a greater resistance to capsize when compared to the conventional length to breadth ratio vessel. However the low length to breadth ratio vessel was found to be at greater risk of capsize when an additional operational load was applied at shelter deck level. The low length to breadth ratio vessel also demonstrated greater sensitivity to fish room flooding with a significant reduction in the wave height at which capsize occurred.

The design of the low length to breadth ratio vessel, having very full sections along much of its length results in a large, broad fish room. Flooding of the fish room posed a significant threat to the ability of the vessel to resist capsize. It is seen as essential that flood water is prevented from entering and accumulating in internal spaces, especially those compartments which span the breadth a vessel, such as the fish room, as they pose such a risk to the safety of vessel's in waves. Early detection through functioning bilge alarms and effective removal through clear bilge strainers and adequate pumping can help to ensure future accidents related to flooding are prevented.

The results of this study highlight the deficiency of the current stability criteria as applied to larger fishing vessels in being able to distinguish between the capsize resistance of the two vessels. A sensitivity analysis was conducted to highlight the relationship between the exposure to capsize and various stability parameters. This indicated that assessment of the range of stability and maximum right moment would distinguish not only between the two vessels and their ability to survive in waves, but also the alternative loading cases tested for each vessel.

An alternative stability assessment method developed in a previous research project was extended to the results of these tests and the viability of its use as a method of defining the operational sea state in which a vessel might be able to operate safely has been investigated.

Recommendations are made for the alteration and application of stability criteria to low length to breadth ratio vessels below 12 metres in length in the light of the results of these tests. These are intended to ensure the safety of this type of so-called rule-beater designs for the operations and areas in which they carry out their fishing.

In order to prevent future accidents related to reduction in stability it is essential that crews become well informed of the risks their vessels are exposed to. Simple stability notices that can be posted in the wheel house and other high visibility areas are seen as a viable means of effectively relating the dangers various operations and situations pose to a vessel. It is hoped that by being constantly visible to the crew the messages these notices convey will taken onboard and acted on.

CONTENTS

1 INTRODUCTION

This report describes Research Project 557 aimed at investigating the capsize resistance of conventional length to breadth ratio vessels when compared to the current trend in low length to breadth ratio vessels. Models of two vessels were constructed and tested in their intact condition for a range of wave headings (head, stern, beam, bow-quartering and stern-quartering) to assess the influence of L/B on capsize. The tests were conducted for the vessels when each just met the IMO stability criteria and were repeated for two additional cases identified as potential risks to these vessels, fish room flooding and an additional load (typical of recovering nets). The tests qualify if the influence of L/B on the stability criteria imposed on the vessels in their most onerous condition presents a greater risk to the fishermen from capsize.

2 BACKGROUND

The general intact stability criteria recommended by the IMO for passenger and Cargo ships have been applied to fishing vessels of over 12m registered length in the UK since the Fishing Vessels (Safety Provisions) Regulations 1975 came into force.

Fishing vessels load cargo at sea and are subject to high loads from their gear and environment; a significant number of smaller vessels those over 12m registered length are also close to the stability criteria minima with weathertight shelters and deck structures often used to enable these vessels to meet requirements.

The ability of a fishing vessel to withstand transient loadings such as recovering fishing gear, lifting cod ends and the use of above deck hoppers to temporarily store a catch prior to processing at sea is unknown. Compliance with the stability criteria gives a measure of safety; however, research that has been conducted for the MCA by the Wolfson Unit into the survivability of large slender monohulls which, when just able to comply with the High Speed Craft stability criteria has shown that they could capsize in relatively small waves when an additional heeling moment is applied.

Concern has also been raised by the MAIB in their report the sinking of the MFV Solway Harvester regarding the trend to lower length to breadth ratios in newer fishing vessels and made the following recommendation "…to consider a research project too investigate whether the trend in modern fishing vessel design towards lower length to breadth ratios is exposing them to an increased risk of capsize in the event of fishing room flooding." This prompted by the vessel's integral arrangement and the small amount of flooding which occurred in this particular vessels fish hold, leading to capsize of the vessel and loss of the entire crew.

3 OBJECTIVES

The following objectives were detailed in the MCA specification:

- To investigate the ability of a conventional length to breadth ratio and low length to breadth ratio fishing vessel of similar fishing capability to resist capsize in head, stern, beam and quartering seas when meeting but not exceeding the stability requirement applied to UK fishing vessels.

- To investigate the effect of an additional heeling moment simulating a load applied by fishing operations applied in the above cases.

- To determine whether the low length to breadth ratio vessel examined is exposed to an increased risk of capsize in the event of fish room flooding when compared to the conventional length to breadth ratio vessel.

- To suggest how the stability criteria for fishing vessels can be modified to improve capsize resistance.

4 LITERATURE STUDY

The fishing industry is a global industry with an estimated 4.1 million vessels in service worldwide. Despite the best efforts of the fishing community to constantly improve working conditions and make fishing a safer environment the industry remains the most dangerous professions in most if not all, participating countries. Prevalent in the yearly statistical reports of fishing related accidents is the incidence of capsize. Whilst the occurrence of capsizes are few in number, the cost in human life per capsize is typically large; this gives each capsize event significant impact.

There are two simplistic causes of capsize, a badly loaded/operated boat and severe weather. The former is actively being addressed with loading guidance and awareness programmes whilst the latter is being compounded by the economic climate and competitive pursuit of fish, forcing fishermen to put to sea on bad weather days. There is little guidance for the skippers, an exert from the Seaman's manual[1] reads, " How best to handle a ship in extreme weather depends so much upon the type, size and capabilities of the particular ship that it would be unwise to lay down precise instructions as to how to act in various circumstances." Despite the knowledge that the best way to mitigate the effects of heavy weather is to avoid it, more vessels are exposed to the risk of capsize as more and more fishermen are chasing fewer fish.

To enable fishermen to effectively extract the fish in the current licensing climate, vessel designers are optimising vessels to extract maximum catch as their primary role, with seakeeping and crew comfort as secondary. This has been achieved by restricting the length of the vessels and increasing all other parameters particularly breadth and to a lesser extent depth. The adoption of the wider vessels now popular in the UK fleet has been ongoing for some time; the effect of these beamy designs on the ability to resist capsize is just being realised and has not been explored thoroughly.

This report studies the effect of Length / Breadth (L/B) ratio on two typical UK fishing vessels currently registered and actively fishing UK waters. The vessels are of comparative fishing effort under the current licensing system and have equivalent Vessel Capacity Units (VCUs). However, the length and tonnage of both vessels are different due to disparate driving factors in their designs. The first vessel (denoted Type I) is one of the new type of fishing vessels now finding popularity, built in 2001 with low L/B ratio, box like sections and below the 12 metre registered length category. The second vessel (denoted Type II) is a more traditional vessel designed and built in 1980 before the imposition of restrictive licensing schemes. This vessel is 4 metres longer than the Type I vessel, with fair lines and proportional geometry.

4.1 Safety Climate

In the UK the imposition of rules to control fishing effort to protect fish stocks has had an unwanted effect on the design and mission of fishing vessels in what had been a traditional and evolutionary industry. New designs are being developed with small length to breadth ratios and some are optimised for 'rulebeating' instead of safe operation on the very diverse waters of the UK coastline [2]. Deep beamy vessels are now appearing with high-sided shelter decks; many of these vessels go against the conventional wisdom of the Naval Architect. The adoption of the rulebeater design has been a fast one and offers (under the current system), lucrative benefits to the fishermen for extracting more resource usually at a reduced operating cost. The deviation from traditional designs has made wide working platforms with low L/B ratios and typically stiff motions with high accelerations. Little account has been made to investigate if the stability of these vessels once compromised leads to a more onerous case in terms of capsize, due to flooding or lifting weights high on derricks.

The evolution of the modern UK fishing fleet is being driven by influence of a wide range of interested parties, from national and international regulators, vessel owners, and the marine scientific community. Often these parties have conflicting interests, with arguably the safety of vessels not always being at the forefront of decisions affecting the fleet. The appearance of the rulebeater has changed forever the pedigree of the design of fishing vessels in the UK. The main influence on fishing vessel design has undoubtedly come from a regulatory need to control fish stock levels. This approach does not however tackle the problem head on but uses a second order approach to limit the fishermen's catching ability. There is no doubt that the impact of the modern rules on vessel design has been unexpected, the new rules have unwittingly led to the development of the modern low L/B ratio vessel.

Traditionally fishing vessels evolved to suit a particular fishing method, a particular coastline, or sea condition. Modern vessels are typically generic, designed abstract from the operating environment and usually offer several choices of superstructure for the one hull form, with little or no optimisation to suit the fishermen. The final product is vessels that are beamy and compact in design, with little option to position equipment in the most suitable place rather than available spaces. Their motions are very stiff with rapid responses due to high GM and typically with very high accelerations, which cause increased fatigue in the crew. Despite these design consequences rulebeaters are successful and popular, they represent a vessel optimised to work and be successful in the current economic and regulatory climate [2].

Design evolution is continuing for the fishing vessels but it is led by regulatory constraints and international governmental guidance such as the IMO. In the 1980's the use of fishing effort control using L_{PP} lead to large stern overhangs and associated broaching problems. The introduction of the VCU as a measure of fishing capacity resulted in an unanticipated optimisation of fishing vessel forms. Constrained by the deck area, vessels have been designed to maximise displacement and volume. Maximising displacement enables heavier equipment to be installed, and more fish or fuel to be carried, while maximising volume allows an increase in the accommodation and areas for working with the gear and catch. As a result the actual catching capability can be considerably greater than that indicated by the measured VCUs.

As neither depth nor draft are controlled, in the measurement of VCUs, displacement may be maximised by increasing draft and increasing the fullness of form, especially forward Volume is maximised by increasing freeboard and making the actual deck area fill as much of the measured deck area as possible, so wide transoms and exceptionally bluff bows are prevalent in the modern fleet. In some cases the entire deck, from transom to stern, is utilised as the working area, with no forecastle and with the wheelhouse located over the working deck, the nets being hauled beneath it. The adoption of short fat vessels, which maximise the volume onboard for fish hold and equipment enable a skilled fisher to take a disproportionate catch from the ocean. It should not be forgotten however that the economic environment that favours so called ‘rule-beater’ designs is entirely artificial, and could be turned on its head by the introduction of slight modifications to either the regulations for capacity measurement, or for quota allocation.

4.2 Modes and classification of capsize

The risk of capsize is inherent in every vessels mission profile, it is a risk that should be minimised at all times. For fishing boats, the risk of capsize is more so a concern on a daily basis, simple operations such as retrieving nets, loading cargo at sea and recovering cod ends all increase the risk of capsize. The type of fishing vessel can also influence the risk of capsize. An open deck small fishing boat will be at significantly more risk than a larger shelter deck trawler [3] due to the ability to resist heavy weather. However the causes need not be so obvious, the causes can also be as abstract as a recent capsize caused by a refrigerant leak in the engine room, starving the engine of air and shutting down all systems, leaving the vessel prone to the elements [4]. Even with this daily risk of capsize, poorly loaded vessels, dangerous handling of the vessel and unauthorised vessel modifications persist; lives continue to be claimed. The common understanding that safe operation dictates safe practice was highlighted by Deakin [5] as being a fallacy as the day they capsize the vessel becomes unsafe.

4.2.1 Capsize definition

In spite of the randomness of the operating environment there are relatively few ways in which a vessel will capsize, classification of capsize modes is therefore a useful tool in assessing the causes and hence proposing solutions to the problem of capsize. The definition of capsize is an ambiguous one and it has led to numerous authors proposing different definitions partly to comply with their tests. For example Dand [6] whilst testing capsize of Ro-Ro vessels defined capsize as “occurring when there was a rapid increase in roll rate accompanied by a large increase in static heel.” The maximum heel taken by the vessel before permanent buoyancy took effect was about 50 degrees. This would be beyond the panic level for the passengers and due to the complexities of the internal vessel layout and mustering and evacuation potentially lethal for those onboard. Further Van ‘t Veer [7] denotes capsize as a 90 degree roll angle from which the vessel cannot recover, but it is Johnson [8] provides probably the best definition of capsize in that “ Capsize is to heel to an angle from which it cannot return without assistance.” The conventional ethos of the vessel turning 180 degrees is therefore a little ambiguous as vessels can capsize and sink at 90 degrees like the M/S Helland-Hansen [9] without ever turning keel up. A further definition is also required when numerically modelling the capsize process. To remove any ambiguities the capsize definition by Taggart and De Kat [10] is given when the GM of a vessel is equal to zero. Whilst this may not hold true for all physical models this is a suitable definition for numerical methods.

4.2.2 Simplistic capsize mode

The capsize of a vessel is unique for each event, an dependent on numerous events (or chain of events), from sea state, loading, operation, vessel modifications and so on. To establish a basic rational to quantify the modes of capsize simplistic cases can be identified which quantify the basic phenomenon. There are clearly two types of vessel that are apparent in the most simplistic capsize causes and those are:

1. A vessel with a good initial GM and a healthy (and broad) stability curve. This vessel may capsize when operating extreme weather beyond its capabilities.
2. A vessel with initial GM and stability curve just meeting the IMO criteria. The range of stability for this vessel would typically be 50-60 degrees; the vessel is exposed to a risk capsize even on a calm day.

4.2.3 Primary capsize mechanisms

From the simplistic analogy of section 4.2.2 the author's deviate in their descriptions of the primary modes of capsize. Morrall for instance conducted a series of model tests to determine the modes of capsize. Two modes were identified both of which occurred very rapidly in 10-20 seconds [11] both are valid for zero or forward speed and are stated as:

1. The hull is balanced on a wave (without water on deck) and looses waterplane inertia and capsizes.
2. The wave overwhelms the bulwarks and floods the decks producing a roll moment greater than the restoring moment and the vessel capsizes.

The second mode was also studied by Yamakoshi [3] who found that Purse Seiners were susceptible to typical modes of capsize which occurred with the hydrodynamic wave forces combining with the effect of trapped water. When more protected pair trawlers were model tested this risk of capsize was reduced by several magnitudes.

Aall Dahle [12] in his study of risk analysis applied to fishing vessels added the following causes of capsize:

1. The vessel is hit by high steep waves, or near breaking from the side causing the vessel to heel over violently and capsize.
2. The vessel is hit by Synchronous waves causing progressively large roll angles leading to capsize.

Aall Dahle explained that the effectiveness of the breaking waves depends on characteristics of wave and ship. The wave can be thought of 2 phases impact and the heeling action proportional to the area under the GZ curve multiplied by the vessel mass. This analogy implies a vessel with good stability will have a large heeling angle.

De Kat [13] cites another cause of capsize as low cycle resonance. This mode is characterised by the frequency of the roll motion being close to natural frequency and different to the wave encounter frequency i.e. encounter frequency is twice the natural frequency. The wave amplitude does not need to be large to result in significant roll angles under proper conditions such as the roll angle in phase with the wave elevation. The restoring moment is therefore altered and can in some cases be reduced by a factor of three within two periods of encounter.

Umeda [14] cites three additional causes of capsize as parametric roll resonance, broaching and bow diving. Parametric roll resonance is due to the righting arm of a vessel varying with time. If the encounter period is a multiple of half the roll period, roll motion develops with a period equal to the natural roll period, similar to low cycle resonance it can easily lead to capsize. Broaching is caused when a vessel cannot maintain a constant course despite maximum heel angle being applied typically in following seas. The uncontrollable yaw velocity coupled with the sway velocity results in capsize. Finally Umeda cites bow diving as a cause of capsize. This is caused when the nominal ship speed is similar to the wave celerity and the bow height is relatively small.

In addition to the modes of capsize several parameters have been highlighted which contribute greatly to the capsize mechanism. Adee [15] found that vessel heading was important for determining capsize. Following and quartering seas were shown to be more dangerous and the models tested with low stability in head bow quartering or beam seas would quickly capsize in seas approaching from astern. Deakin [16] highlighted one of the most important parameters contributing to capsize in that the initial GM is less important that the range of stability of the vessel.

4.2.4 How a vessel responds during and after capsize

Once a vessel looses its ability to remain upright and capsize occurs, the way in which the vessel capsizes is clearly an important factor. The most terrible consequence of capsize is the large loss of life associated with each case. It is desirable that the way in which a vessel capsizes allows the maximum number of crew to escape before the vessel capsizes. This is not always possible as vessels typical of today's fishing fleet have high VCG's and once a poor stability condition is reached have a tendency to capsize very quickly. Deakin [16] found several methods of actual capsize once GM was lost when conducting model tests for high speed craft. Most are applicable to fishing vessels and give some indication as to the attitude of the vessel as things start to go wrong.

1. Beam seas induced a heel to windward, which gradually increased, sometimes with a small amount of rolling until the model capsized to windward.
2. Heel to leeward, down by the stern in bow seas gradually increased the heel and trim with some roll and pitch until the model capsized diagonally
3. Heel to leeward in beam or bow seas increasing the roll angles until the model capsized to Leeward
4. Water trapped inside the superstructure with gradually increasing heel as more water is trapped until the model capsized. When the damage was to leeward the model capsized to leeward, and windward capsized to windward.

Johnson and Borlase suggested in their analysis of the sinking of the Artic Rose; the fact that when a capsize has occurred a vessel does not simply invert 180 degrees a better understanding is needed of a vessels behaviour after capsizing until the vessel reaches equilibrium on the surface or comes to rest on the ocean floor [8]. Borlase [17] in post analysis of the Arctic Rose suggested further research into the dynamics of fishing vessels in the flooded condition. This is critical in understanding the possibility of escape for trapped fishermen inside the vessel and any measures that can be implemented to aid their escape will save lives.

4.2.5 Protection against capsize

One of the dominant features from the open literature for protection against capsize is that the vessel be ‘secure for sea’ by reducing the free surface effects, taking on water and avoiding shifting weights [18]. However before this occurs and the vessel leaves port, loading of the vessel should, where possible, produce a healthy GZ curve with good initial GM and a range of stability beyond 70 degrees. This requirement is stipulated by the Nordic countries, where as a result, capsize is relatively rare.

This sensitivity to the GZ curve has been confirmed in several model tests such as Adee [15] who found that for a limited number of tests no capsizes were observed for models which were close to meeting the criteria, capsize only occurred when the models were grossly below the criteria. Morrall [11] notes that when the GZ curve is reduced the reduction in GM results in reduced roll stiffness, Morrall attributed this as the main cause of capsize.

Clearly the under 24 metre fleet is subject to many different interpretations of stability guidance in light of the absence of IMO criteria. France, Russia, New Zealand and the Nordic countries all have in place alternatives to the IMO rules and enforce them for this sector of the fleet. Whilst there are obvious differences in the interpretation of the rules, all restrict the working role of the small craft to reduce its exposure to risk. Typically all of the vessels are required to show a load line mark, possess a minimum range of stability, comply with minimum GM, have freeboard limits, heeling moment limits and follow specific working practices if the vessel is un-decked.

Yamakoshi [3] found that shipping of water on deck was significant cause of capsize during his model tests of Japanese fishing vessels. He recommended that shelterdecks should be employed (and kept watertight), however given the different methods of fishing this may not always be possible. The shelterdeck does also lead to the vessel presenting more lateral area to the wind/waves. This may be a trade off, lessening the water on deck but increasing the risk in beam seas or strong winds. Aall Dahl [12] found that prevention of capsize can be achieved by limiting broadside exposure in high steep waves, severe rolling, wind gusts, synchronous high waves and control heading to limit time with a wave at midship in following seas.

4.2.6 Conclusions on the modes of capsize

In conclusion the following modes of capsize have been reported in the open literature and are acknowledged as significant causes of capsize:

1. The hull is balanced on a wave (without water on deck) and looses waterplane inertia and capsizes.
2. The wave overwhelms the bulwarks and floods the decks producing a roll moment greater than the restoring moment and the vessel capsizes.
3. The vessel is hit by high steep waves, or near breaking from the side causing the vessel to heel over violently and capsize.
4. Synchronous waves
5. Low cycle resonance

The following parameters have been found by previous authors to influence the occurrence of capsize:

1. Compliance with IMO stability criteria
2. Range of stability of the GZ curve
3. Initial GM value
4. Vessel heading with respect to waves

4.3 Suitability of IMO criteria to the UK fishing fleet

The diversity of the UK fishing fleet ensures that there are few similarities in hull form, layout or superstructure, yet the stability guidance and regulations for the UK fishing fleet is a 'one size fits all approach' with little regard for vessel size, mission or sea state. Despite a multi-national effort to make fishing vessels safer there is still no universal guidance for vessels below 24 metres. The stability evaluation methods adopted worldwide for small fishing vessels, are not based on rigorous scientific basis merely their adequacy in the light of better guidance.

The development of the intact stability criteria is based on the work of Rahola [19] who, in 1939 studied 34 vessels which capsized sailing in the lakes and waterways of Iceland. From this small sample 13 vessels were selected for righting arm comparisons; only one of these was a fishing vessel. The data gathered by Rahola for adequate stability is fundamentally flawed, it varies greatly as it is based on the accident investigators interpretation of the capsize event.

The vessels fishing in UK waters have radically changed in the last 10 years and are almost unrecognisable from the pre-war designs. The pre-war vessel selected by Rahola for the stability study is therefore clearly not a meaningful example of a typical contemporary fishing vessel. This is evident in analysis of the maximum righting lever, which for Rahola occurred at the deck edge immersion point, with modern shelterdecks and watertight superstructure this is no longer a valid argument. Rahola does however conclude his work by noting that the stability guidance rules should not be applied to both large and small boats, and that the stability rules be reconsidered for special circumstances (e.g. trawling). Rahola in conclusion notes that a one rule fits all stability standard for vessels would be an '*insurmountable difficulty*', yet this is precisely what is in use today.

The current stability requirements for fishing vessels suffer from being over restrictive in some instances and under restrictive in others, both of which are leading to casualties. Womak [20] cites several factors that could be included to update these requirements, many of which were noted by Rahola. For instance no account is taken for weather conditions, critical for fishing vessels which are conducting loading operations at sea. Currently the amount of catch that is safe to load is dictated purely by the skippers feel for the vessel. However, the introduction of variable loading guidelines, dependant on weather conditions, would undoubtedly meet with hostility from the industry, as vessels would be forced to carry less fish at times than they have historically done so.

More importantly Womak addresses the issue of scalability of the stability criteria and poses the question that, are the same rules applied to a large tanker also valid for a small fishing vessel. Johnson [21] cites that wind and water heeling increases with the square of the dimensions whereas, the righting moment increases with the cube of the dimensions due to its relationship to the displacement. This implies that the righting energy for a vessel will increase significantly faster than the heeling moment as the size of the vessel increases, thus bigger is better. Francescutto [22] addressed a similar issue and noted that the scalability not only effects the righting moment but miss critical factors like water on deck or excessive rolling.

Erlingsson [23] reviewed the Icelandic rules for fishing boats (2004) and found them adequate for the purposes intended. He noted that whilst classification societies are harmonising many of the aspects in shipbuilding they have made little progress with the fishing industry; this is unfortunate given the daily risk these vessels face. It is also worth mentioning that the societies differ greatly on their definitions of fundamental parameters such as subdivision, stability and freeboard. The Icelandic rules require load lines to be fitted on vessels, in compliance with approved stability booklets. No or little account is taken for vessel size or sea state. Erlingsson also notes an interesting cause of most down flooding fatalities is that watertight doors are held open often because of poor ventilation. He notes that it is the ventilation that should be considered in regulations as this is the cause of weather tight doors being held open and at risk to down flood. It is appropriate therefore that ventilation be addressed and considered in any sub-division calculations.

4.4 Methods of predicting capsize

The solution to the capsize problem remains elusive. Capsize analysis is a highly non-linear problem often requiring complex and involved mathematical approaches to understand. The adoption of non-linear dynamics has enhanced the understanding of large angles of roll and capsize [24] however the fishing industry needs a simple approach which may be easily calculated by the fishermen themselves.

Two distinct approaches in the prediction of capsize are followed in the open literature; firstly basic naval architecture parameters are used to devise simple relationships that influence capsize; secondly complex time domain solutions are used in an attempt to predict added mass and damping terms. Whilst the two methods have their own merits it is the more simplistic first method, which is a desirable solution in this report.

4.4.1 Prediction using basic parameters

Perhaps one of the most basic formulas for assessing a vessels tendency to capsize is given in Eqn. 4.1.

$$Capsize = \frac{Beam}{\left(\frac{Displacement}{64}\right)^{\frac{1}{3}}} \tag{4.1}$$

Equation 4.1 was developed in the aftermath of the Fastnet disaster and is intended for application on Yachts. If the vessel has a value calculated below 2 it is less likely to capsize than those with higher values. This is attributed to beamy and heavy boats are harder to capsize.

Ferdinande [25] provides the classical moment equation to assess the energy transfer from a breaking wave to the side of a trawler. He assumes that in dynamic equilibrium for a breaking wave is reached when a reaction force of equal magnitude acts at a distance of half the draught below the waterline. The healing moment in the upright position is therefore the breaking wave force (F) multiplied by the lever between the centroid of application and half the draught. Ferdinande plotted Heeling Moment Coefficient (HMC) given by Fh/Δ plotted against length as given in Eqn. (4.2).

$$HMC = \frac{\left(\frac{Fh}{\Delta}\right)}{L_{wl}} \qquad (4.2)$$

Ferdinande showed that for both the Gaul [26] and Helland-Hansen [27], all casualties had high HMC's whilst Belgian Lady, a vessel which narrowly avoided capsize in an extreme breaking wave and associated roll period exhibited lower HMC values. Ferdinande felt that the lateral area available for a vessel and hence its risk of broadside wave impacts should be proportional to displacement. This is interesting as the shelterdeck and enclosed high superstructure are prevalent in today's fleet. Ferdinande's work however presented only a small amount of data from which further conclusions can be drawn.

4.4.2 Limiting GM

Another method to assess the likelihood of capsize is to study the hydrostatics of the vessel and in particular the GM. The value of GM needed to just pass the IMO stability requirements is known as the limiting GM. Renilson [28] found that as a rule of thumb the required limiting GM is roughly proportional to 20% of the significant wave height.

$$\text{Required GM} = 0.2Hw \qquad (4.3)$$

Further a good estimate for the limiting GM value for fishing vessels was given as:

$$\text{GM}_{\text{limit}} = 0.2H_w + 0.25\left[\left(\frac{B}{T}\right) - 4.6\right] - 0.1\left[\left(\frac{L}{B}\right) - 4.1\right] - 0.1\left[\left(\frac{D}{T}\right) - 2.4\right] \qquad (4.4)$$

Renilson found this gave good agreement for vessels in waves in excess of H_s=3.5m.

2.4.3 Maximum Wave Height

An alternative stability assessment method was proposed by Deakin in MCA Research Project 509 [16]. The analysis of extensive test results aimed at seeking a linear trend yielded several formulae relating stability parameters to the minimum wave height that might cause capsize. The analysis indicated the size, righting moment and range of positive stability of a vessel as being the dominant factors in determining capsize risk. Having taken into consideration the fact that wave heights greater than the significant might be expected the initial formulae proposed were adapted assuming a capsize wave of twice the significant. The following two formulae 4.5 and 4.6 were proposed as a means of assessing maximum permitted operational seastate. It was proposed that these two formulae could be used as a simple method to ensure vessels operating in protected waters have sufficient reserve stability to survive encounters with waves of a minimum specified height.

$$\text{WaveHeight} = \frac{\text{Range}\sqrt{\text{RMmax}}}{10\text{B}} \tag{4.5}$$

$$\text{WaveHeight} = \frac{\text{Range}\sqrt{\text{RMmax}}}{10\text{B}} - \frac{L}{100} \tag{4.6}$$

It was suggested that although these formulae were developed through tests on high speed craft the fact that these tests involved a diverse range of hullforms meant they could be applied to other vessel types, including fishing vessels. A number of fishing vessel casualties were presented to ascertain the appropriateness of these formulae to assessing fishing vessel capsize risk, with all the casualties lying above the boundary line provided by the formulae. A comparison of the results from the tests conducted in this study and the formulae proposed in Research Project 509 is presented in section 7 of this report.

4.4.3 Time domain analysis

Whilst time domain numerical methods present useful mathematical exercises they are not yet at a suitably refined stage of simplicity to apply to the UK fleet. One of the early useful attempts at predicting capsize reported in the open literature was by Greenhow et al [29] in the development of a wave energy device known as Salter's duck. Greenhow developed a useful 2D theory for capsize of the wave energy device which agreed well with the experiments and provided a basis for application in ship stability studies. Thompson [30] applied a more rigorous mathematical approach to the problem and used basin erosion by incursive fractals in a complex mathematical analysis of transient capsize.

Time domain assumptions for linear ship theory such as ship is floating freely, may or may not have forward speed cargo/consumables is fixed and does not move during motions. Fluid the vessel operates in is inviscid, irrotational and a velocity potential exists. A first generation numerical model was developed by Oakley et al [31] for slender ships demonstrating 6DOF in severe following seas using linear strip theory. De Kat developed a numerical model to predict capsize [13] who described exact potential theory solutions dealing with non-linear and unsteady motions. De Kat demonstrated an extensive use of linear theory for the calculation of ship motion, based on classical linear wave theory, permitting the linearization of the free surface and the addition of forces. De Kat included the Froude-Krilov, radiation, diffraction, hull damping and manoeuvring forces and showed that the Froude-Krilov and radiation forces were sufficient to predict capsize and therefore important in the equations.

Time domain solutions can be extended and plotted graphically as a polar plot for capsize susceptibility as a function of heading. McTaggart [10] developed polar plots for frigates based on heading and speed to give some indication of risk of capsize. Most models are limited however, in their application by the need for constraints or assumptions to become a valid model. Such as wave heading or harmonic motion. This has limited the amount of work performed on capsize although this balance is now being championed by many researchers. There is still a lack of first principle methods for calculation of roll damping at the design stage particularly if the extreme motions are due to resonance [32]. Molin [33] investigated the viscous roll damping for non separated flow for barge sections and confirmed small angles of frictional roll damping. Extending the work further to adopt a CFD approach does look promising such as those by Sarker et al [34], however more often than not roll damping coefficients are obtained from scaled model tests.

Possibly the most important and actively researched area is the development of a multi degree of freedom model. There are two current codes which are showing great promise those are FREYDIN and LAMP. FREYDIN was developed to simulate large amplitude motions of a steered ship in waves and wind. The model uses a non linear strip theory approach which has recently been updated to use a 3D panel method to compute the hydrodynamic radiation and Froude-Krilov forces. The numerical methods of the LAMP codes extend the 3D time-domain potential flow panel method approach to large amplitude motions by using the exact shape of the incoming wave when applying the free surface boundary conditions to the instantaneous submerged hull surface. LAMP has been extended to incorporate green water on deck by Kim [35] and also by Belenky [36, 37].

Several other approaches do exist such as Ayaz et al [38] who extended a manoeuvring (4DOF) model to a 6DOF motion prediction model capable of assessing the influence on heave, pitch and the memory effect on the tendency to capsize. However given all of the models mentioned a recent benchmark study by the 24th ITTC found that no code could consistently reproduce the required simulation scenarios with satisfactory conformance to the experimental data [32]. Progress is still being made with the various methods however reliance for progress in the understanding and prevention of capsize must still remain with rigorous model test programmes.

4.5 Analysis of published model test data

The scope of the capsize model test is enormous, it covers simplistic models such as prismatic barges such as those by Cotton [24] to fully down flooding complex models such as Dand [6]. As there is no common consensus on an approved numerical method to predict capsize, test facilities are heavily reliant on model tests to further the understanding of this highly complex phenomenon.

Cotton [24] provides the most simplistic approach for capsize model testing by modelling a simple prismatic barge in a narrow tank to simulate an infinite section. The object of the tests was to predict a capsize boundary and to validate a non-linear dynamic model of the barge. Despite reflected wave problems due to a very short testing tank the experiment proved a good starting point and provided useful data.

The results showed the appearance of a bias of the model to capsize towards the waves and also that the process was highly non linear with two solutions, known as bifurcations possible in the results. This bifurcation allowed a solution which resulted in a capsize at a given height and period to become safe again as the wave height (or period) changed and vice versa. Additionally Cotton noticed the importance of the first wave hitting the model, in a case where capsize was likely and a crest hit the model a steady state was likely to occur, if a trough was first to hit the model a capsize was more likely. This was also reported by Deakin [16] who noticed that how the first wave impacted the model could influence the outcome of the test.

Yamakoshi [3] tested a series of different Japanese fishing boats including Purse Seiners and pair trawlers. The tests focused on vessels underway shipping water on deck and the vessels ability to resist it or clear the water quickly whilst retaining stability. Once the models shipped water on deck capsizing was found to be dependent on the balance between the shape of the GZ curve and the capsizing moment due to water on deck. The water on deck increased rapidly and the model took a heel angle equal to that of the bulwark edge immersion. In this condition, if the GZ curve is negative or nearly equal the model capsized.

Yamakoshi found that for types of vessels studied they were most vulnerable to capsize when running in quartering seas. In following seas however capsize occurrences were closely related to the reduction in GZ due to the wave crest amidship. Yamakoshi's tests also demonstrated that the roll angle of the vessel needed for the bulwarks to become immersed in waves were lower than those for still water. This is an interesting conclusion as it is water on deck which is a significant factor in many of the capsize incidents reported in the UK.

One option in the light of these findings would be to provide guidance on safe wave headings to reduce exposure to vulnerable capsize situations. This guidance could be included in the stability notices proposed in Ref [43]. However, as noted in Ref [43] while operational hazards are under the direct control of the crew and can be avoided, they have only limited control over environmental hazards. It is already common seamanship practice to keep a vessel head to severe seas, and so may be unwise to issue additional guidance on wave headings when by its nature the sea and the waves a vessel experiences are highly irregular and uncontrollable.

A simple statement recommending keeping the vessel head to heavy weather, highlighting the danger of breaking waves and loss of stability on a wave at alternative headings would ensure the crew were aware of the risks. It should be noted that the Norwegian Stability Notice includes a statement to *avoid following seas*. This could be included in conjunction with advice to avoid areas of breaking waves, as recommended in Ref [43] for small vessels.

As there is little else the crew can do other than change heading or avoid heavy weather all together, any additional guidance should be focussed on risks which they are able to control through preventative action, such as closing watertight doors in heavy weather and ensuring catch is not free to move, and be focussed on the particular features of a vessel that pose a hazard to its stability.

As is discussed later in this report the ability of a vessel to clear water on deck had a large influence on the occurrence of a capsize. For the cases when vessel motions were violent, water was easily thrown from deck and so not allowed to accumulate and lead to a gradual reduction in stability and subsequent capsize. For cases where water was trapped on deck or within the superstructure there was a significant reduction in the wave height causing capsize, due to the reduction in range of stability and maximum GZ, caused by the presence of trapped water.

Dand [6] conducted flooding experiments with a Ro-Ro vessel to determine the risk of capsize when a free flooding model was placed broadside to irregular waves and performance was monitored. Useful conclusions were drawn from the work and the method of presentation of the model test data was adopted by Deakin, and has been reviewed in the current work. Interestingly Dand also found that in using a Froude relationship, the scale of the model had no detectable effect on the outflow of water from the flooded model providing scantlings are kept as thin as possible. This effect was to be expected since the viscous forces on the model are negligible.

Aall Dahl [9] reviewed the capsize of M/S Helland-Hansen caused by a breaking wave in Norway. It was not possible to reconstruct plunging waves exactly due to difficulties modelling shallow water waves. A higher wave therefore was generated and forced to plunge on the model by means of a false rise of floor in the model basin. The method worked well, one stroke of the wave generator resulted in two identical plunging waves breaking at the same position in the model basin. Due to the mode of capsize only the first wave was of interest, however during the test it was common for the second wave to right the intact vessel again.

Three factors in the model test were of interest, the maximum heeling angle achieved after the first wave, the geometry of the wave at impact and also the behaviour after the second wave impact. From the 500 experiments performed in the model test, it was shown that the steep breaking wave also exposes the vessel to a quasi static turning moment, which although smaller in magnitude than the breaking wave, acted over a longer wave period. Calisal in comments to de Kat’ s paper [13] found difficulty in capsizing models in beam seas that satisfied the IMO criteria (sufficient GZ) and needed special breaking waves to force a capsize. The GZ requirements for the vessel should therefore indicate a requirement for positive GZ up to 80-90 degrees, this would have eliminated the second phase of the stable capsize at 80 degrees.

Aall Dahl [9] argued that any increase in superstructure, such as the adoption of shelterdecks would be beneficial, however, a trade off is needed, as increasing superstructure has other implications such as wind and wave impacts. The research by Aall Dahl also suggested that the larger range of stability be extended to the positioning of openings for down flood to be set to the same 80-90 degree range.

Grochowalski [39] conducted an early series of capsize model tests for both captive and free running models for a variety of beam and quartering cases. The objective was to understand the dynamics of the capsize phenomenon and the research while confirming traditional rationale into the causes of capsize such as righting arm curve and wave parameters. The tests also highlighted additional influences such as bulwark and deck edge submergence and the influence it has on the longitudinal axis of rotation as well as the danger of quartering waves. This was due to the heeling moment exerted by the wave on the vessel, which although smaller than for the beam condition is nevertheless significant. The restoring capability of a vessel is much smaller in this condition and therefore exposes the vessel to greater risk.

The effect of principle parameters on a vessels performance is a significant factor in its design. Renilson [28] studied the likelihood of capsize of a small fishing vessel in steep breaking waves with respect to principle parameters. Six models were constructed with varying L/B, B/D and D/T ratios. The models were decked to prevent down flood and positioned in beam on waves using light lines. Each of the experimental runs had two outcomes, a capsize which was considered a success or if the model drifted a distance of 40 metres from the starting point which was considered a failure. Renilson demonstrated that the effect of variations in displacement alone had little influence on capsize. The effect of changes in beam however showed that when GM was held the same and breadth increased the time to capsize was reduced, a vessel therefore needs increased GM with increased breadth for the same level of stability. It also implies that the safer vessel will have a shorter roll period with stiffer more violent motions, something that is apparent in the new rulebeater vessels.

Renilson also studied the effect of freeboard for two depths at two displacements both with varying GM. The lower freeboard capsized first for the same GM at the lowest displacement. For the higher displacement the high freeboard always capsized at low GM first but with increased GM soon became very stable and did not capsize. With increased draught at given GM the vessel needed increased GM with increased draught for the same stability.

Renilson also found that the effect of heeling moment will vary with the cube of the length for a fixed wave height, in other words as the vessel size increases for a given wave height the required GM remains constant. Reductions therefore in freeboard, draft and an increase in beam all require increases in GM to retain the same level of stability.

4.6 Methods of presenting experimental results

The model test results are specific to each respective hull geometry, it would be useful to find a way of non-dimensionalising the results to generalise the findings. This would allow amongst other things critical GM_f for capsize at a particular freeboard to be related to significant wave height (sea state) and range of GZ_{max} in flooded condition [6]. The IMO suggested method [40] for passenger vessels is given in Eqn. (4.6)

$$H_s = f\left[\frac{GM_f \cdot F}{B}\right] \tag{4.6}$$

This relationship was modified by Dand [6] to acknowledge the important part played by B/T in determining GZ_{max} and its range. The greater the value of B/T the greater the intact GZ_{max} and the smaller the intact range. This resulted in Eqn. (4.7) where the wave height has been non-dimensionalised with respect to freeboard. The greater Hs the greater the risk of capsize.

$$\frac{H_s}{F} = GM_f \cdot C_B\left[\frac{T}{B^2}\right] \tag{4.7}$$

Dand found that the results collapsed onto non-dimensional plots capable of determining capsize and non-capsize.

4.7 Accidents related to capsize

It is unfortunate that data related to capsize events is more often than not taken from accident analysis where most if not all of the crew perished. This is often a subjective aspect to the interpretation of accidents as the exact weather, sea and vessel condition cannot be known, instead forensic type approaches are yielding the most likely scenario for these events. Vessels like the Gaul [26] and the Solway Harvester [41] have been extensively researched and the most likely chain of events leading up to the capsize identified.

One capsize that has been well documented in the open literature is that of M/S Helland-Hansen where most of the crew survived giving clear and consistent descriptions of the circumstances. Aall Dahl [9] reviewed the capsize which was caused by a 5 metre breaking wave hitting the vessel broadside resulting in a 60 degree list of the vessel in a mater of seconds.

As down flooding occurred and the vessel was hit by subsequent waves and it reached a stable position of 80 degrees before sinking sideways some 20 minutes later. The captain did not alter course and reduced the speed of the vessel, allowing the wave to roll the vessel. The wave had partial impact on the vessel due to openings and superstructure; it was dominated by gravitational forces. The vessel capsized despite its compliance with the Torremolinos convention and did not right itself in an irregular wave train of 3.5 metres significant wave height possibly due to the down flooding that had already occurred.

Adee [15] reviewed capsize case histories in America and found that most of the capsize incidents were proceeded by the skipper applying full power and turning the rudder hard over, positioning the vessel head on to the wave. Adee concluded from model test experiments that the correct course of action was indeed to hold course and kill the engine. The model rolled over to a large angle of heel but was likely to recover, however the models were not able to down flood like the Helland Hansen whose freeing ports with mid mounted hinges could (in extreme weather) flip over and remain closed thereby trapping the water onboard. The high bulwarks typically present on fishing vessels to protect the crew can then trap water on deck creating a trade off between manoverboard risk and capsize vulnerability.

Sailing vessels however contend with volumes of water on deck by using either removable bulwarks for bad weather sailing, or a partial bulwark with safety rail; the trade off for this approach when applied to fishing vessels is understandably complex. Due to large energy content of moderate waves Aall Dahl concluded that small fishing vessels should, where possible, be made to self-right by making their wheelhouses weather tight.

Johnson [8] reviewed the capsize of the Arctic Rose which sank due to flooding through an open watertight door in 24 foot (7.2 metres) significant wave height and a period of 8-12 seconds with a 45 knot wind. The Marine Investigation Board concluded that it was unlikely that the vessel sank in the intact stability condition. In depth study conducted to predict the flooding and time to capsize found that the most likely chain events leading to capsize would occur in a period less than 3 minutes, possibly without the knowledge of the crew.

5 EXPERIMENTAL DESIGN

To provide a meaningful comparison for fishing effort and vessel size two vessels were selected for the stability analysis. Two vessels were available for the low L/B ratio an under 12 metre and under 10 metre vessel (both registered dimensions). However it was felt that a useful study would be to study the implications of capsize in a piecewise fashion, starting with the under 12 metre vessel allowing recommendations to be made for the more problematic under 10 metre fleet. Once the sample vessels were decided upon each of the vessels was modelled using an in house hydrostatics and stability package and both vessels compared before testing began. The experiments provide a quantitative analysis in keeping with the experimental design of Grochowalski who used captive models in the determination of the physics of capsize.

5.1 Selection of sample vessels

One of the dominant factors in selecting two sample vessels for the study is that they should be comparable in fishing effort whilst the basic parameters such as length and breadth could vary a great deal. In selecting the vessels a basis ship was selected to represent contemporary fishing vessel design in light of the current regulatory constraints on fishing effort.

The benchmark length for the vessel was set at 12 metres, this allowed a representative study of this class of vessel, which do not currently have to comply with stability regulations.

The adoption of the rulebeater has meant that vessels are being designed to flout the spirit of the regulatory guidance laid down to protect fish stocks, it is one of these vessels an under 12 metre stern trawler, with full shelterdeck and forward wheelhouse which was selected as the basis ship and the subject of the test programme. The vessel has a typically low length to beam ratio and it is this design feature, which is to be studied in this research.

Fig. 1 shows a sample from the 2005 RSS database of the UK fleet. It can be seen that there is significant scatter in the under 10 metre fleet, this is partly due to the small workboat nature of the fleet which operate at very low speed and hence Froude number. Therefore L/B ratio is not a dominant factor in this sector as the vessels are typically inshore vessels with low wave making characteristics and low service speeds.

Closer to the boundaries the ‘snowdrift’ effect may be observed as the rulebeater vessels gather, the L/B ratio noticeably increases at 10 metres and also at 12 metres, this is a by product of the vessel designers restraining length and increasing breadth (and to some extent depth) to retain volume and hence fishing effort.

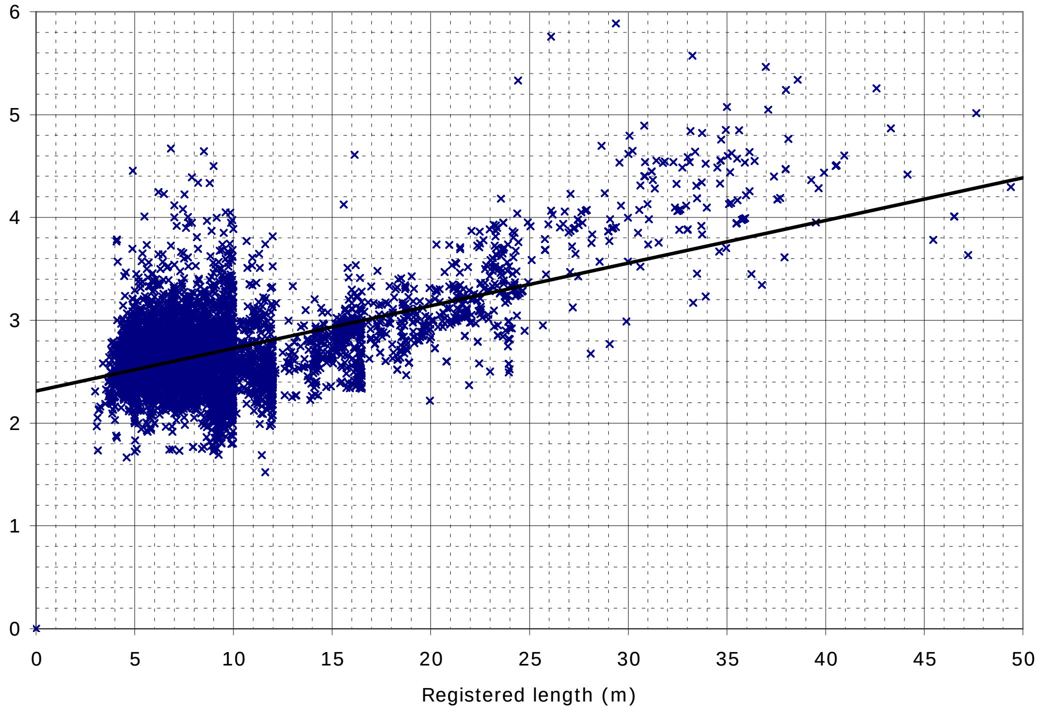


Fig. 1 – Length to breadth ratio of the UK fleet as a function of Registered length

Figures 2 – 5 show a sample from the data showing the under 10 fleet and the over 12 metre fleet respectively. A linear fit of the data reveals that for the under 10 fleet, despite a large scatter in the L/B ratio it is on average uniform for the fleet at approximately 2.65. Beyond 12metres the vessel length to breadth ratio increases gradually from 2.65 to 4.4 for the 35 metre vessels

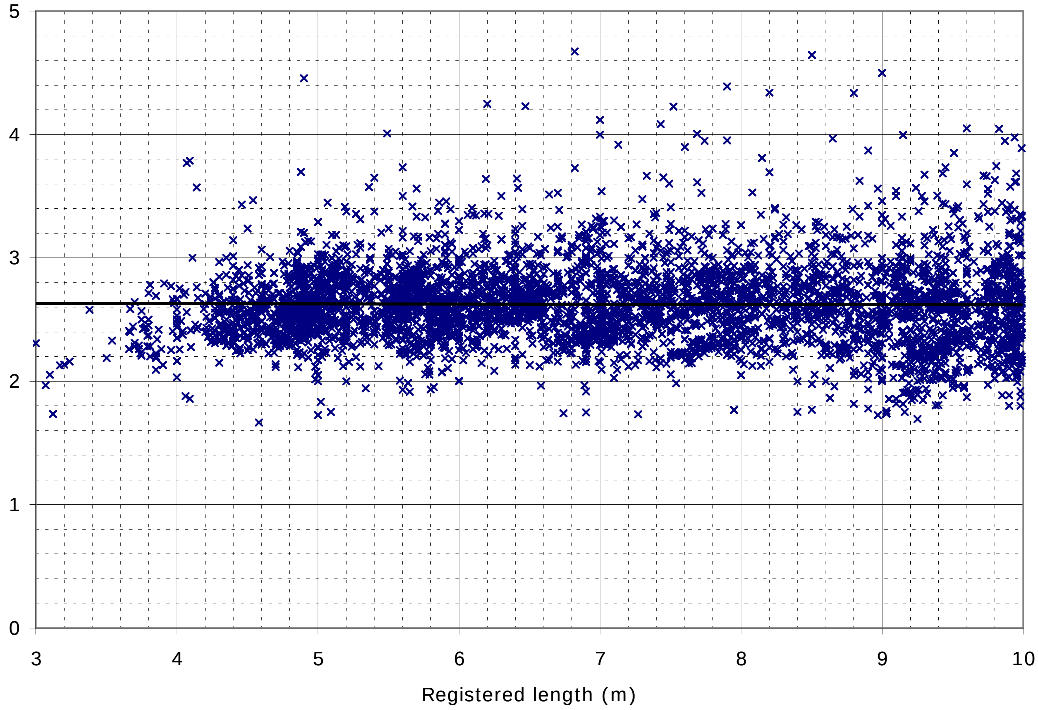


Fig. 2 – Length to breadth ratio for the under 10 metre UK fleet

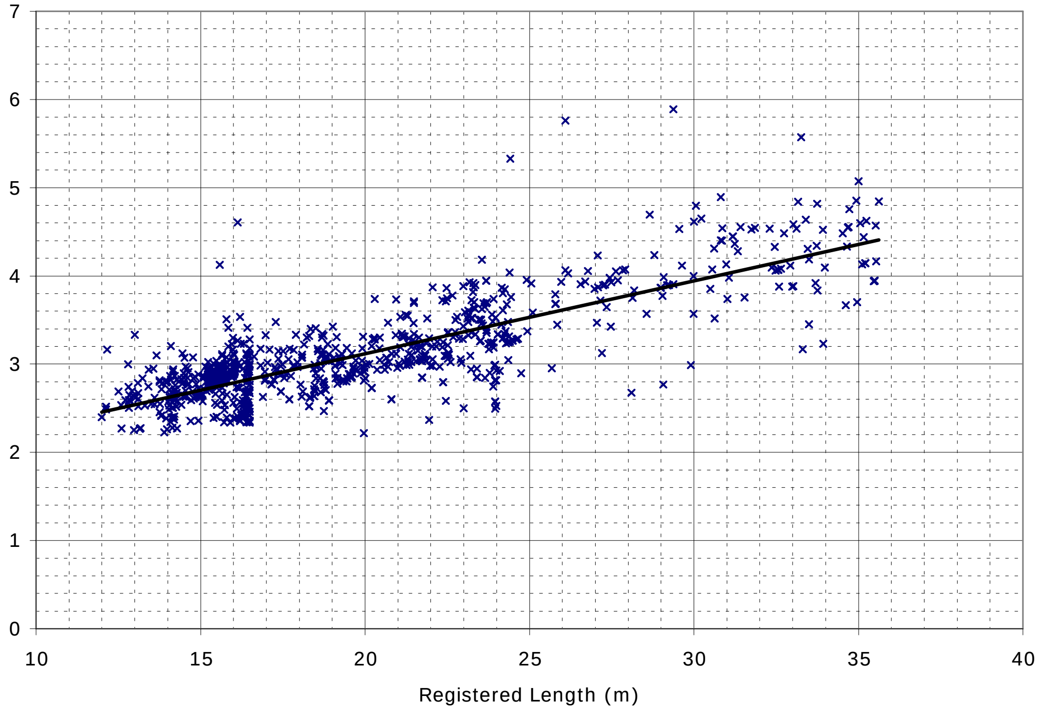


Fig. 3 – Length to breadth ratio for the over 12 metre UK fleet

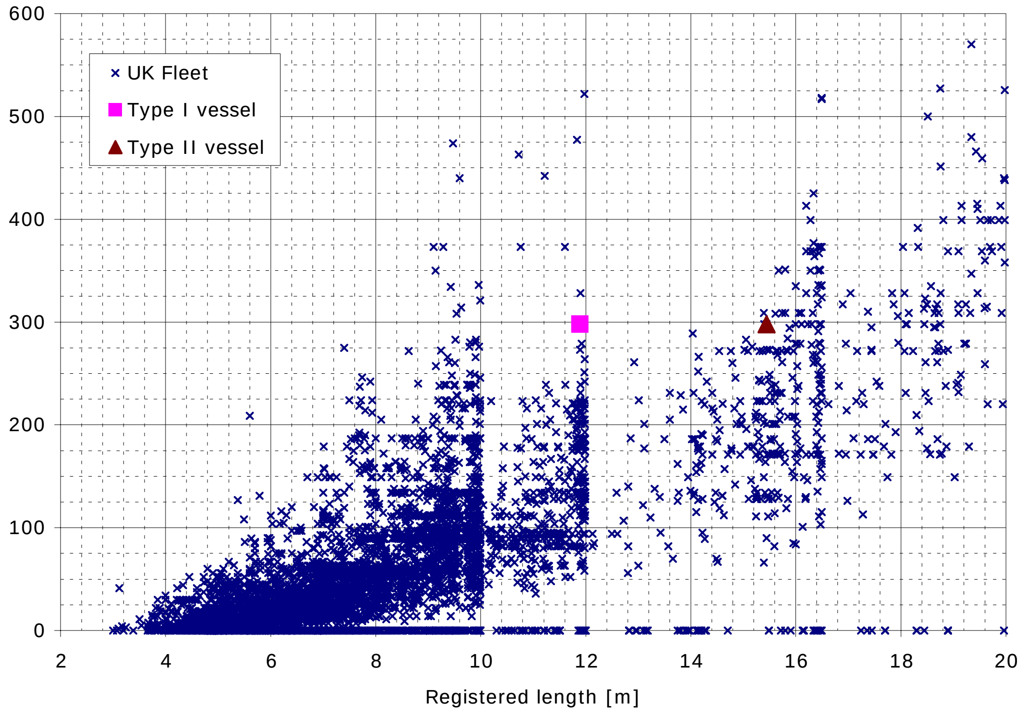


Fig. 4 – Engine power for the UK fleet up to 20m registered length

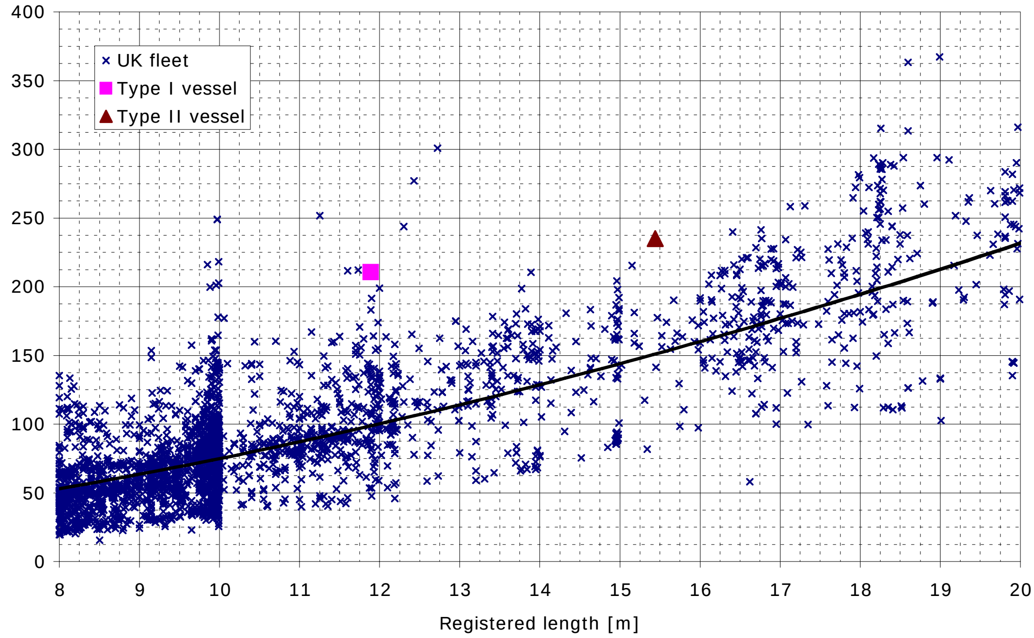


Fig. 5 – Vessel capacity units (VCU) for the UK fleet up to 20m registered length

5.2 Vessel particulars

The two selected fishing vessels for the capsize study are currently registered and fishing in the UK. The main hull form is a typical modern under 12m registered length trawler denoted Type I vessel. The second vessel is a more traditional design trawler of equal fishing capacity and effort, but with a greater length. This vessel is denoted Type II vessel. The profile and section view of both vessels is given in Fig. 6 and 7, the dimensions for model and full scale are given in Table I and II.

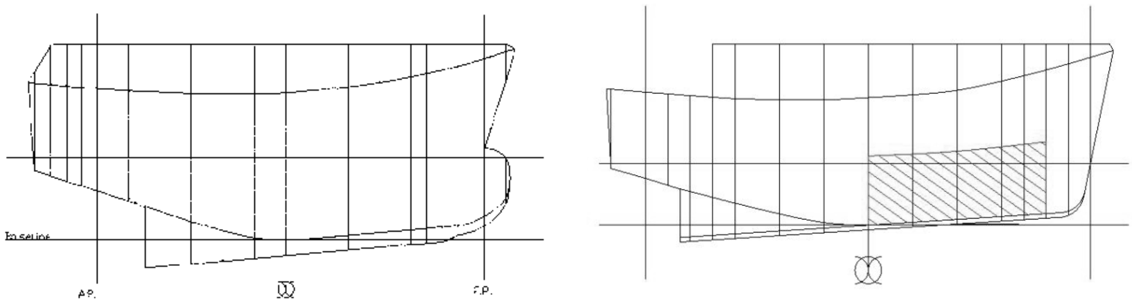


Fig. 6 – Profile view of the 2 trawlers, Type I – under 12m (Left) and the Type II - 16.7m vessel (Right)

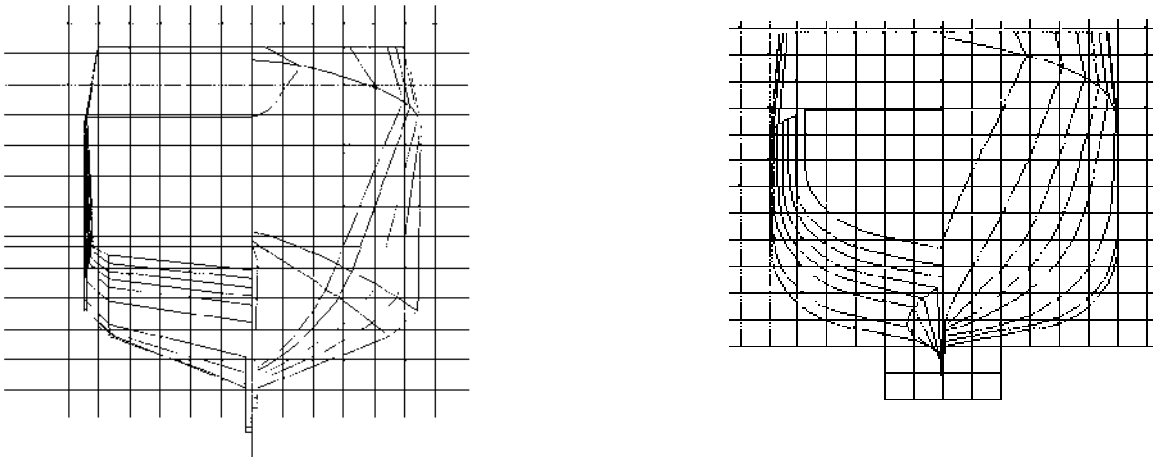


Fig. 7 – Section view of the 2 trawlers, Type I – under 12m (Left) and the Type II - 16.7m vessel (Right)

.Table I – Main particulars for the Type I vessel, the modern trawler design

Type I vessel	**Full Scale**	**Model Scale**
Scale Factor	1:30	
Length (Loa)	14.00m	0.47m
Length (BP)	11.10m	0.37m
Breadth	5.50m	0.18m
Draft (design)	2.50m	0.084
Wetted surface area	97.64m^2	0.11m^2
Block Coefficient	0.59	0.59
Prismatic coefficient	0.77	0.77
L/B	2.55	

.Table II – Main particulars for the Type II vessel, the traditional trawler design

Type II vessel	**Full Scale**	**Model Scale**
Scale Factor	1:40	
Length (Loa)	16.75m	0.42m
Length (BP)	14.70m	0.37m
Breadth	6.00m	0.15m
Draft	2.33	0.058m
Wetted surface area	117.18m^2	0.073m^2
Displacement	116.5 Tonnes	1.82kg
Block Coefficient	0.55	0.55
Prismatic coefficient	0.67	0.67
L/B	2.79	

The two vessels reflect the dynamic changes occurring in the UK fleet. The Type I vessel is a modern design with hard chines and U shaped sections together with a characteristic full shelter deck with a forward mounted wheelhouse. The factory deck is aft of the wheelhouse and extends full width and nearly 2/3 length of the vessel. Any entrapment of water in this space would generate a large free surface and drastically reduce stability.

The net drums and trawl are all enclosed in the shelter deck; downflooding is prevented by a forward water tight bulkhead leading to the wheelhouse

The Type II vessel is a more traditional design of trawler; it has smooth curving V sections giving a sea kind and predictable ride. The fish hold and factory deck is located forward and protected by shelter deck. The working area is much reduced compared to the Type I vessel. This also implies that any flooding incident will not generate a similar free surface to the Type I vessel. The aft net drums are protected by bulwarks and down flooding is prevented by the after water tight bulkhead leading to the 2/3 aft wheelhouse.

5.3 Sectional area curves

The sectional area curves for both of the vessels are given in Fig. 8. Despite the differences in registered length between the vessels, both vessels exhibit similar sectional area characteristics especially towards the midship region. The fundamental rational for the adoption of the newer rule-beater vessels is to design similar volumetric vessels which provide equal fishing effort yet are significantly shorter that the more traditional designs. Figure 8 clearly demonstrates this trend with comparable sectional area curves between stations 0-10. The Type II vessel does not however, have a bulbous bow or a stem overhang and this can be seen in the fore region of the graph.

The centroid of the graph which is the LCF for the Type II vessel is located close to midship with a near symmetric sectional area curve. The Type I vessel has more area distributed aft maximising its displacement with a wide transom. This will stiffen the pitch response of the vessel which could lead to violent motions should the natural pitch period be encountered. The transom of both vessels is given as reference in Fig. 8 clearly showing the adoption of fuller sections with more structure distributed further aft in the Type I vessel.

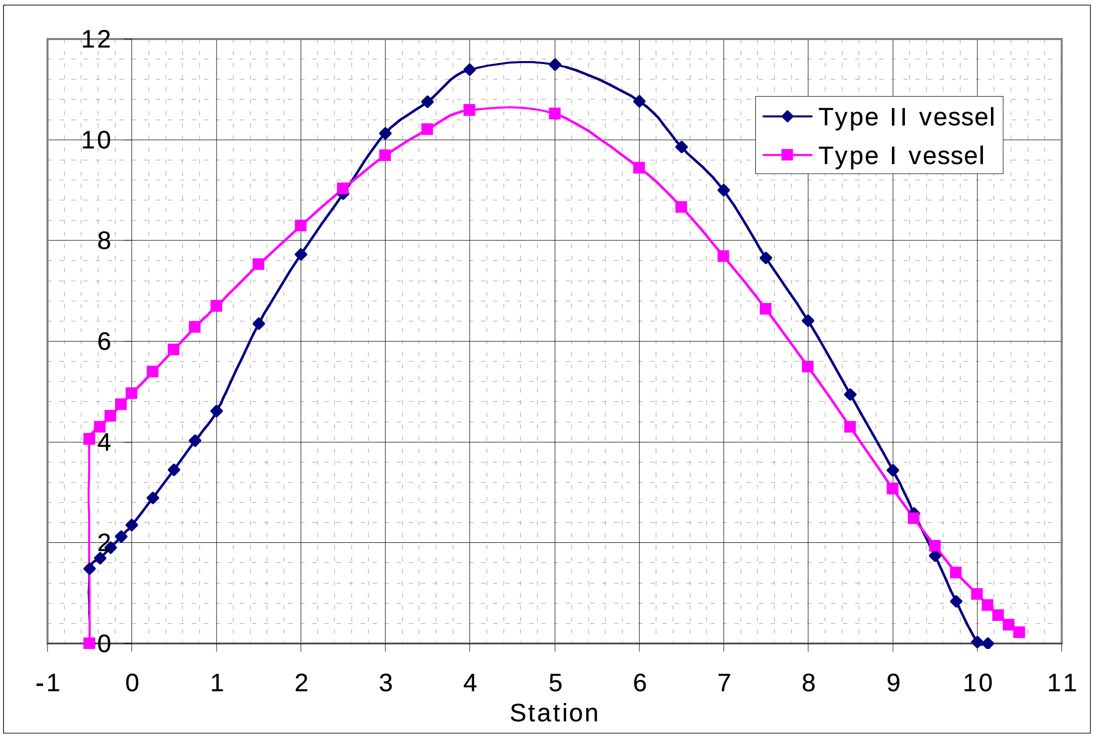


Fig. 8 - Sectional area curve for Type I (modern) and Type II (traditional) vessels

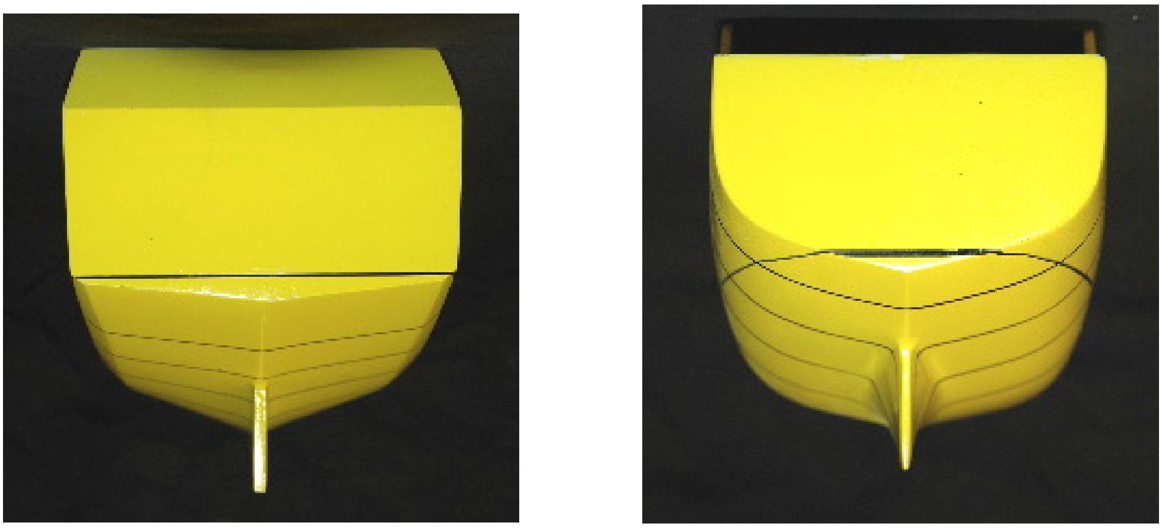


Fig. 9 – Stern arrangement showing Type I vessel (Left) and Type II vessel (Right)

5.4 Stability analysis

Both of the selected hull forms were modelled using an in-house hydrostatics and stability analysis package. The models were initially modelled using the entire superstructure and wheelhouses to study the effect of variable superstructure on the results. However results for the GZ curves for this method did not correlate with the Trim and Stability Booklets provided and therefore a further model was constructed with only the superstructure contributing to buoyancy in place. This is a valid assumption and in keeping with IMO criteria and was adopted for the tests. Representations of the 2 superstructure options for both vessels are given in Fig. 10 and Fig. 11.

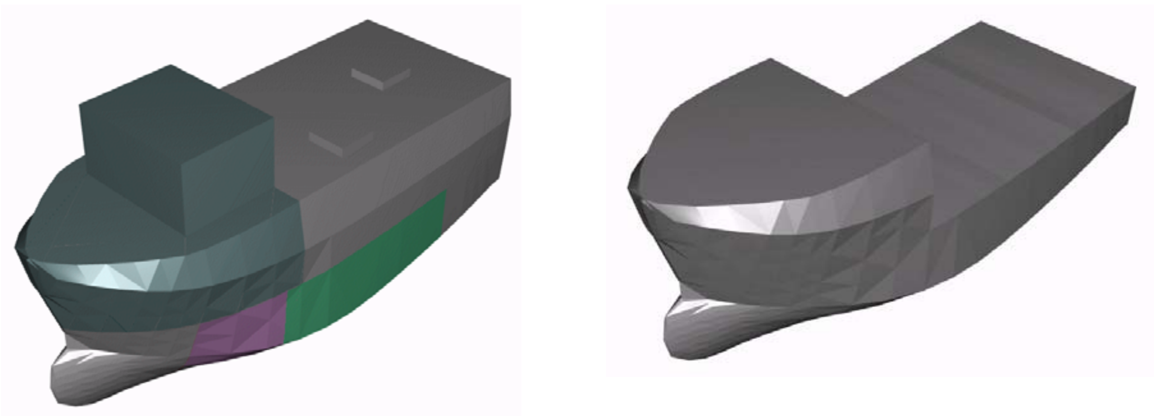


Fig. 10 – Graphical representation of the differences in superstructure between the two stability cases for low L/B Type I vessel

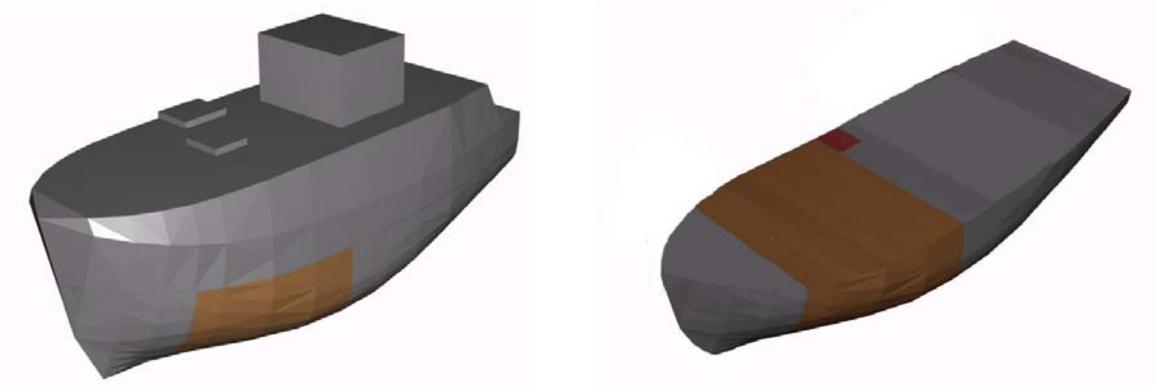
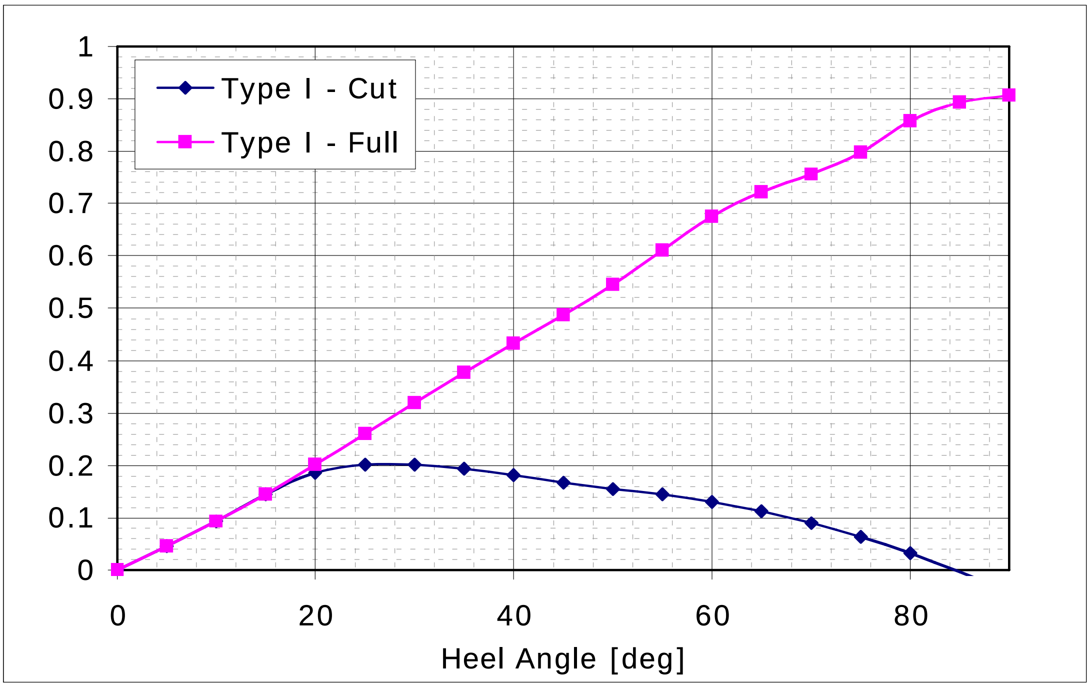


Fig. 11 – Graphical representation of the differences in superstructure between the 2 stability cases for the Type II vessel

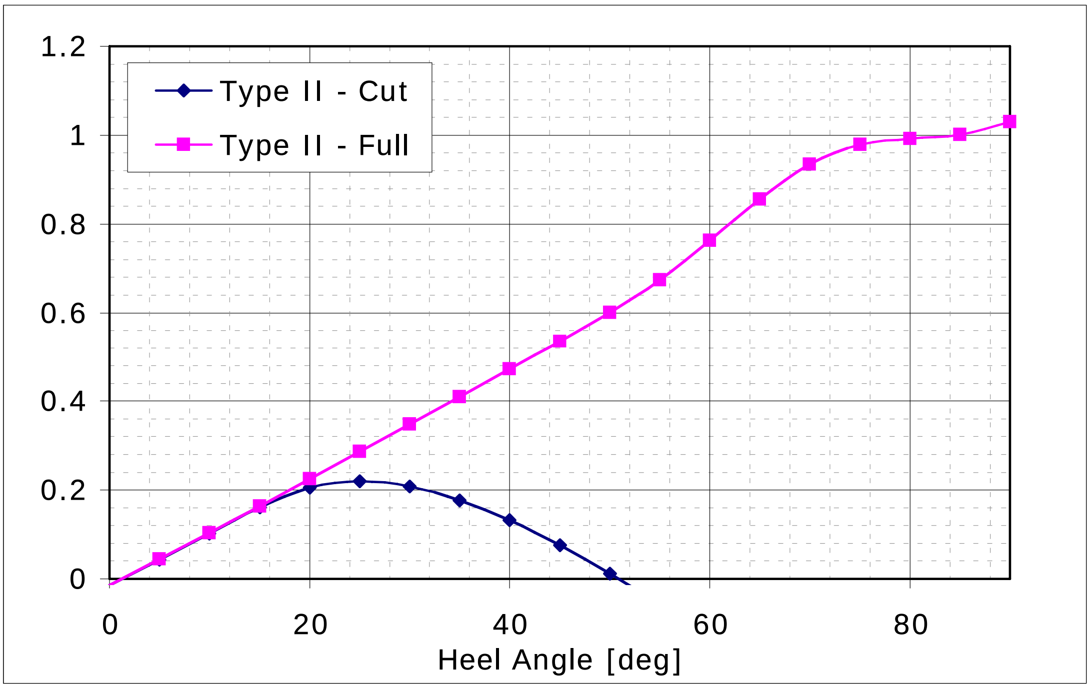
A comparison of the GZ curves for the two vessels is shown in Figs. 12-13. The Type I vessel shown in Fig. 12 has a stability range of 85 degrees with the effect of the aft shelter deck removed. This range increases dramatically with the inclusion of the shelter deck and must be seen as a good argument for retaining watertight integrity of the vessel. The curve plotted is for the most onerous case for the vessel typically when it is low on fuel and working with the catch on the factory deck. The maximum GZ value occurs at 27 degrees and the requirements to comply with the criteria are the minimum to satisfy the rule. There is a noticeable step in the curve past 40 degrees this is attributed to the vessel heeling over and receiving buoyancy from the large forward superstructure and wheelhouse.

The Type II vessel stability curve is given in Fig. 13. With the removal of the superstructure the GZ curve is significantly foreshortened with a range of positive stability of only 50 degrees; with the inclusion of a watertight superstructure this is increased dramatically.

In both of the above cases the addition of superstructure is without question beneficial, providing it is not allowed to flood, this oversight would put the vessel at severe risk. The shelterdeck therefore is increasing the vessels capsize resistance to that of a much larger vessel, giving unusually high freeboard which provides a large righting moment at large roll angles [42]. The addition of shelterdeck also increases the wind heeling moment and presents a greater surface area for a beam on wave to impact and roll the vessel. This has been shown to be a risk in terms of capsize such as M/S Helland Hansen and must be considered as a risk in an otherwise remedial solution.



|Fig. 12 – GZ curve for Type I vessel in the full superstructure and superstructure contributing to buoyancy case



|Fig. 13 – GZ curve for Type II vessel in the full superstructure and superstructure contributing to buoyancy case

In comparing the selected GZ curves it can be seen from Fig. 14 that the Type I vessel with its lower L/B ratio and greater enclosed superstructure has a greater range of stability than the Type II vessel with 85 degrees and 50 degrees respectively. The Type II vessel has a greater maximum GZ which occurs at a similar angle to the Type I vessel however it is the range of positive GZ which has shown to be important in previous studies. Therefore based on the initial stability analysis it would appear that the Type I vessel would be more capable at returning from large angles of heel. The curves in Fig. 14 however give no indication as to the recovery of water on deck when the larger deck area of the Type I vessel without any assistance from subdivision would be at a far greater risk than the Type II vessel.

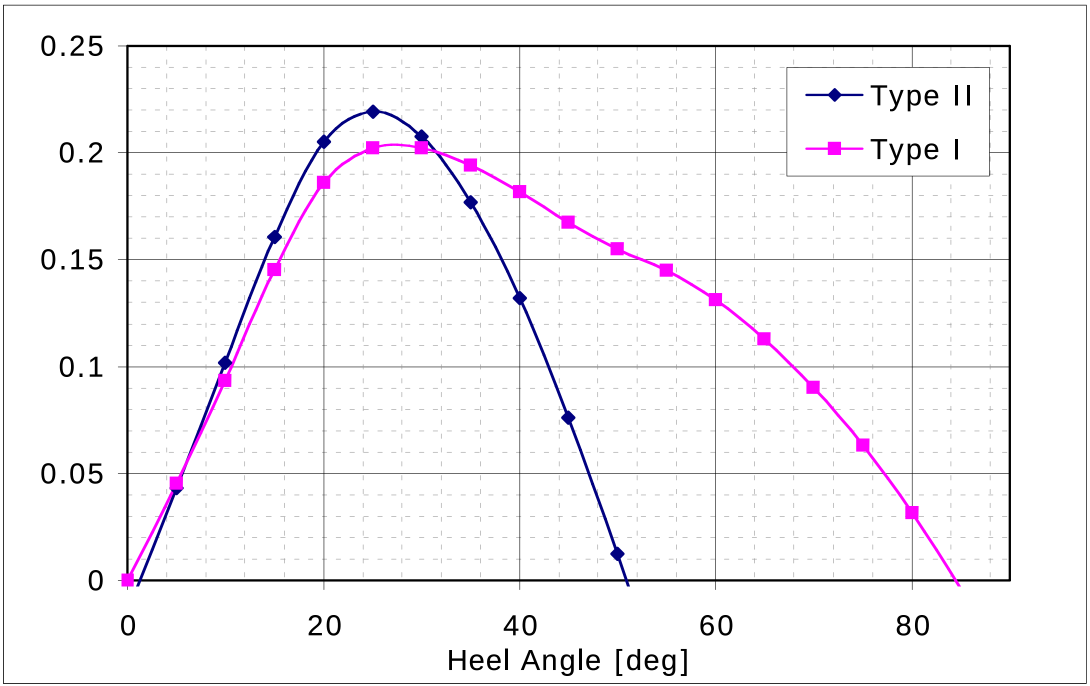


Fig. 14 – Comparison of the GZ curve for the Type I and the Type II vessels in the 'as tested' condition with only the superstructure contributing to buoyancy in place

6 EXPERIMENTAL SETUP

The capsize experiments were performed in the School of Marine Science and Technology's departmental towing tank, Newcastle upon Tyne in November & December 2005, using scale models of typical trawlers actively fishing in the UK fleet. To allow the models to capsize over a reasonable range of wave heights and periods the model scale was selected to give a typical model length of 0.4m; this scale was necessary due to the limitations of the wave makers.

6.1 Towing Tank

The towing tank is 35 metres long, 4 metres wide with a maximum water depth of 1.25 metres. The tank is capable of generating wave heights of 0.2 metres in regular or irregular form using 12 rolling seal wave paddles, which can be operated independently or in unison. Wave absorption is achieved via two parabolic wave absorbers arranged as a beach either side of the dock. During the experiment the water depth was held constant at 1.2m. A wave probe was situated 4.0m from the wave makers and was used as confirmation for the waves produced by the system. A photo of the tank facility is shown in Fig. 15.

Fig. 15 – Test Facility

6.2 Model Construction

The hulls were constructed using plank on frame technique, coated inside and out with a fibreglass skin to give a fair, smooth and accurate finish needed for such small models. The weight of the models was kept to a minimum by adopting lightweight materials where possible and removing any non-essential structure, this allowed for accurate ballasting of the models whilst retaining their rigidity and durability.

The Rule-beater model was constructed to a scale of 1/30 giving a LOA of 0.47m, the central skeg was included however appendages and propellers were not modelled as the test was intended to be at zero speed.

The Type II vessel was constructed to a scale of 1/40 with a LOA of 0.42m and again constructed without appendages. Both models were made waterproof both inside and out and fitted with shelter decks where appropriate and internal structure to allow for flooding of the fish hold to be simulated.

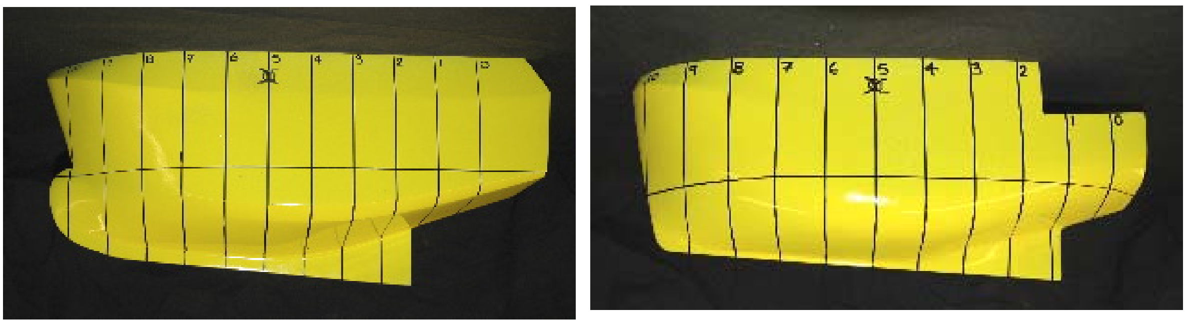


Fig. 16 – Profile of the 2 vessels showing Type I Vessel (Left) and Type II Vessel (Right)

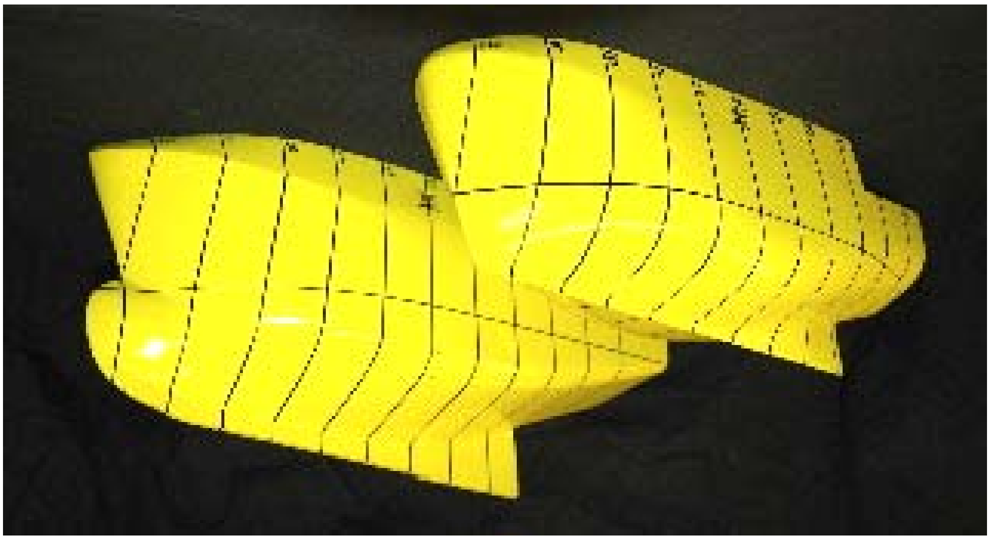


Fig. 17 – Comparison of the 2 hull forms together, Type I Vessel (1/30th scale) to the rear and Type II Vessel (1/40th scale) at the front.

6.3 Model setup - Ballasting

The models were ballasted for their most onerous case that complied with the IMO A167 criteria. An in-house hydrostatics package was used to model the vessels and determine a condition that would just meet these requirements. Lead ballast was added to the vessels and glued in place so as not to move during the experiment or in the recovery and resetting of the models. The correct lateral and vertical position of the ballast ensured that the same operational KG was adopted for the models, giving representative results and indication of capsize.

6.4 Determination of longitudinal centre of gravity (LCG)

The LCG for the models was determined by balancing the models on knife edges, one being held rigid whilst the other is placed on a scale. A simple moment calculation can therefore determine the centre of gravity in the longitudinal direction and it can be adjusted accordingly to give the required value; equation 6.1 below gives the simple moment equation.

$$x = \frac{w}{\Delta} \times l \qquad (6.1)$$

Where;

x	longitudinal centre of gravity
w	weight recorded on the scale
Δ	displacement of the model
l	distance between the knife edges

The LCG for the Type I and Type II models were set at 149mm and 175mm respectively which is in keeping with the trim and stability condition of just meeting the IMO stability criteria.

6.5 Determination of vertical centre of gravity (VCG)

The VCG for the models was determined using an inclining experiment; the small size of the models negated the use of an inclinometer. Instead the models were ballasted in a small tank situated on a marking off table allowing the use of a Vernier height gauge to pick known points along the deck edges and thereby determine the heel angle of the vessel. Once the vessel was upright a small weight was then applied and the angle of loll recorded, the KG was determined from the standard method. The GM of the models were calculated and adjusted by raising the ballast weights up along a vertical axis about the LCG until the required GM was achieved. Equation 6.2 gives the relationship.

$$GM = \frac{w \times d}{\Delta \ \tan\phi} \tag{6.2}$$

Where;

GM	vertical distance from the centre of gravity to the metacentre
w	inclining weight
d	transverse distance inclining weight is shifted
Δ	displacement of the model
ϕ	angle of loll of the model

The VCG for the Type I and Type II models were set at 87.7mm and 63.3mm above their respective baselines in keeping with their trim and stability booklets.

6.6 Experimental procedure

Following the calibration of the two models to simulate the vertical and lateral centre of gravity the models were tested in the departmental towing tank over a range of waves and periods. The models were initially tested in three configurations namely:

1. Most onerous case that just complies with IMO criteria
2. Most onerous case with an additional operational load applied
3. Most onerous case with fish processing room flooded at main deck level

An additional case was tested for the Type I vessel to investigate the effect of flooding the accommodation on the vessel’s capsize resistance, to better understand the importance of ensuring watertight integrity of shelter decks if they are included in the calculation of a vessel’s stability against criteria.

4. Type I vessel with main deck and accommodation flooded
5. Most onerous case with fish hold flooded

For case 1 the models were tested in the stability conditions described in section 5.4. For case 2 a load representing 5 tonnes of fish landed at shelter deck height was added to each model. For case 3, 5 tonnes of flood water was added to the main deck of each model. For case 4 for the Type I vessel an additional 5 tonnes of flood water was added to the accommodation compartment. For case 5, 5 tonnes of water was added to the fish hold of each vessel. The details of the loading conditions for these cases are included in the appendix.

Both models were ballasted and sealed to prevent down flooding, the ballast was bonded in place to prevent and shifting of weights during the test or resetting the experiment. The models were tethered fore and aft too the tank wall using lightweight chord and a spring mechanism. This configuration allowed the models to be restricted to the following heading conditions for a range of wave heights and periods with the assumption of symmetry only one side of the model was tested. The tests were conducted for the following headings at a range of periods and wave heights in regular waves.

- Head seas
- Bow quartering seas
- Beam seas
- Stern quartering seas
- Following seas

The methodology adopted for the tests was as follows. A capsize was deemed to occur when the vessel achieved an angle of roll from which it could not recover. The test was considered a capsize if this occurred before the reflected waves travelled down the tank and returned, thereby corrupting the regular waves. Given the length of the tank this interval was typically 2-3 minutes equivalent to 15 minutes exposure in full scale. Table III below gives the range of wave height and periods used in the test program at model scale. The results for each run had then two possible outcomes a capsize or no capsize, the results were tabulated and the capsize boundaries for a range of wave heights and periods were calculated. For each run video and still images were recorded

Table III – Wave height and Periods used in the test programme at model scale

Wave Height (m)	Wave Period (s)					
	0.5	0.6	0.7	0.8	0.9	1.0
0.03	X	X	X	X	X	X
0.04	X	X	X	X	X	X
0.05	X	X	X	X	X	X
0.06	X	X	X	X	X	X
0.07	X	X	X	X	X	X
0.08		X	X	X	X	X
0.09			X	X	X	X
0.10				X	X	X

7 PRESENTATION OF RESULTS

Around 600 test runs were conducted over the range of wave heights and periods described in the previous section. The following modes of capsize were observed across the range of configurations. The following discussion summarises the results for each model for the configurations tested. Fig 18 shows the results for all the capsize occurrences observed during the tests.

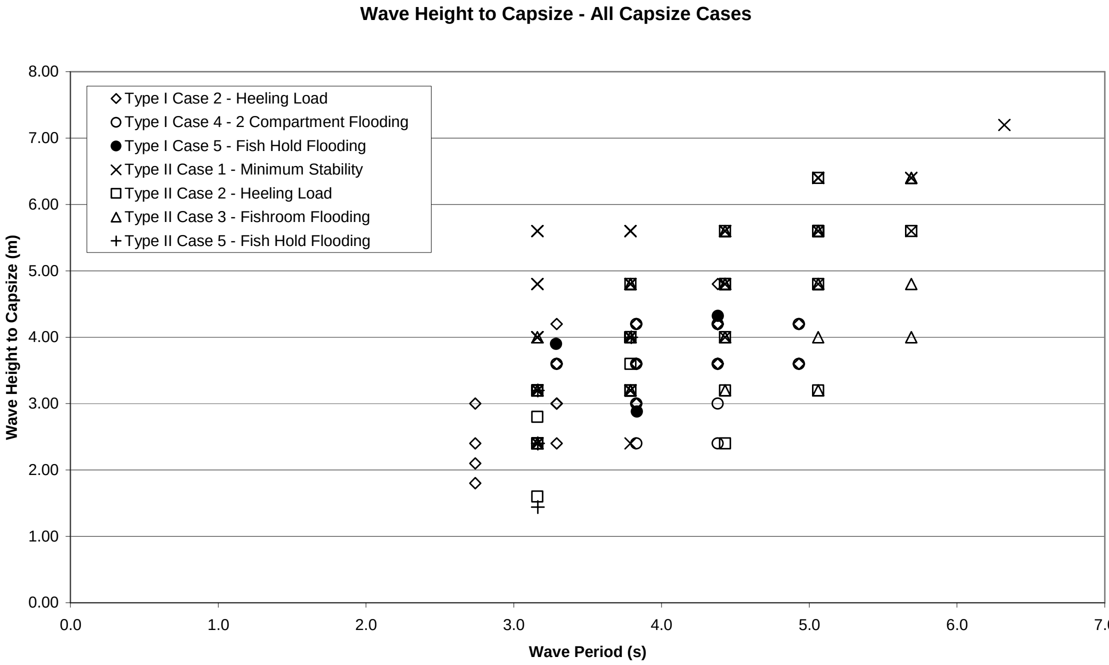


Fig 18 – All capsize occurrences observed

Although a large number of capsizes took place what is of critical interest is the minimum wave conditions for each configuration at which capsize occurred. For a number of configurations capsize took place for the same wave height at various periods. In figure 18 no account of the sensitivity to wave heading is taken into consideration. Table IV shows the minimum wave conditions that caused capsize for each loading case for the Type I vessel and Table V shows the results for the Type II vessel.

For those cases where capsize did occur the results are shown in the following figures. Fig. 19 shows the minimum wave height to cause capsize for both vessels at all headings. Fig. 20 shows the minimum wave height to capsize for the Type I vessel at all headings, and Fig. 21 shows the results for the Type II vessel at all headings.

Table IV – Minimum wave conditions causing capsize for Type I vessel

Minimum wave Conditions to Capsize at Each Heading				
Vessel	**Testing Condition**	**Wave Heading**	**Wave Height (m)**	**Wave Period (s)**
Type I	Case 1 - Minimum Stability	0.0	-	-
Type I	Case 1 - Minimum Stability	45.0	-	-
Type I	Case 1 - Minimum Stability	90.0	-	-
Type I	Case 1 - Minimum Stability	135.0	-	-
Type I	Case 1 - Minimum Stability	180.0	-	-
Type I	Case 2 - Operational Load	0.0	4.20	3.29
Type I	Case 2 - Operational Load	0.0	4.20	3.83
Type I	Case 2 - Operational Load	0.0	4.20	4.38
Type I	Case 2 - Operational Load	45.0	3.00	3.29
Type I	Case 2 - Operational Load	45.0	3.00	3.83
Type I	Case 2 - Operational Load	90.0	2.10	2.74
Type I	Case 2 - Operational Load	135.0	3.00	2.74
Type I	Case 2 - Operational Load	135.0	3.00	3.83
Type I	Case 2 - Operational Load	180.0	1.80	2.74
Type I	Case 3 - Main Deck Flooding	0.0	-	-
Type I	Case 3 - Main Deck Flooding	45.0	-	-
Type I	Case 3 - Main Deck Flooding	90.0	-	-
Type I	Case 3 - Main Deck Flooding	135.0	-	-
Type I	Case 3 - Main Deck Flooding	180.0	-	-
Type I	Case 4 - 2 Compartment Flooding	0.0	4.20	4.38
Type I	Case 4 - 2 Compartment Flooding	45.0	3.60	3.29
Type I	Case 4 - 2 Compartment Flooding	90.0	-	-
Type I	Case 4 - 2 Compartment Flooding	135.0	2.40	3.83
Type I	Case 4 - 2 Compartment Flooding	180.0	-	-
Type I	Case 5 - Fish Hold Flooding	0.0	4.32	4.38
Type I	Case 5 - Fish Hold Flooding	45.0	3.90	3.29
Type I	Case 5 - Fish Hold Flooding	90.0		-
Type I	Case 5 - Fish Hold Flooding	135.0	2.88	3.83
Type I	Case 5 - Fish Hold Flooding	180.0		-

Table V – Minimum wave conditions causing capsize for Type II vessel

Minimum wave Conditions to Capsize at Each Heading				
Vessel	**Testing Condition**	**Wave Heading**	**Wave Height (m)**	**Wave Period (s)**
Type II	Case 1 - Minimum Stability	0.0	3.20	3.79
Type II	Case 1 - Minimum Stability	45.0	5.60	4.43
Type II	Case 1 - Minimum Stability	90.0	2.40	3.16
Type II	Case 1 - Minimum Stability	135.0	2.40	3.16
Type II	Case 1 - Minimum Stability	180.0	2.40	3.16
Type II	Case 2 - Operational Load	0.0	3.20	3.16
Type II	Case 2 - Operational Load	45.0	2.40	3.16
Type II	Case 2 - Operational Load	90.0	1.60	3.16
Type II	Case 2 - Operational Load	135.0	2.40	3.16
Type II	Case 2 - Operational Load	135.0	2.40	4.43
Type II	Case 2 - Operational Load	180.0	2.80	3.16
Type II	Case 3 - Main Deck Flooding	0.0	3.20	3.79
Type II	Case 3 - Main Deck Flooding	45.0	4.80	4.43
Type II	Case 3 - Main Deck Flooding	90.0	-	-
Type II	Case 3 - Main Deck Flooding	135.0	2.40	3.16
Type II	Case 3 - Main Deck Flooding	180.0	2.40	3.16
Type II	Case 5 – Fish Hold Flooding	0	4.00	3.79
Type II	Case 5 – Fish Hold Flooding	45	3.20	3.16
Type II	Case 5 – Fish Hold Flooding	90	1.44	3.16
Type II	Case 5 – Fish Hold Flooding	135	2.40	3.16
Type II	Case 5 – Fish Hold Flooding	180	2.40	3.16

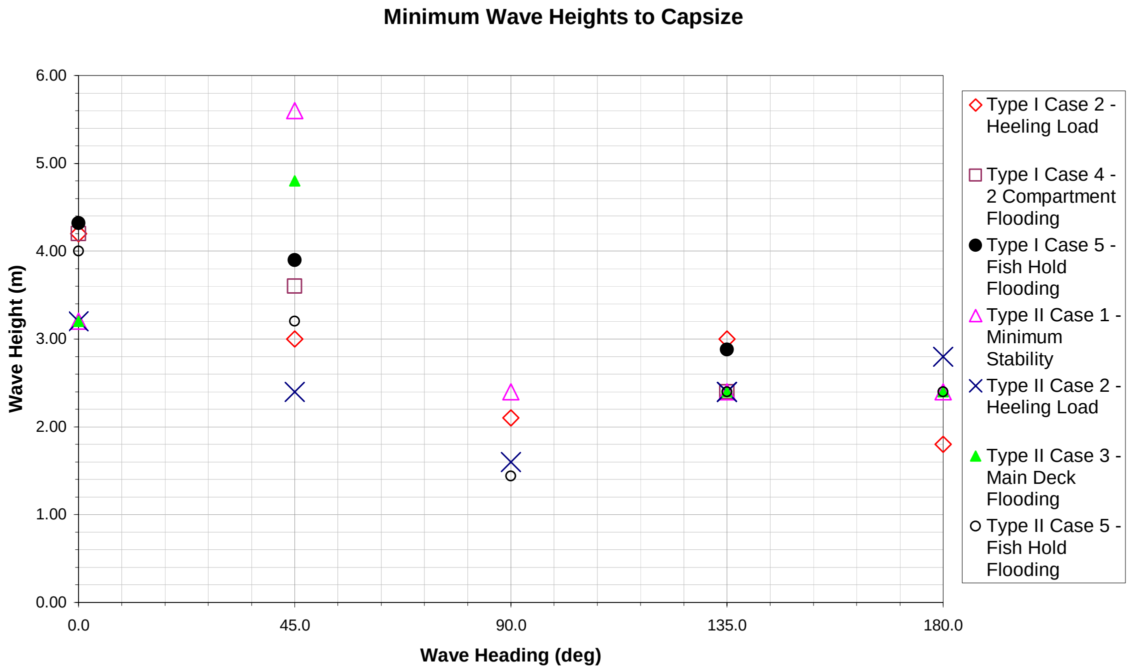


Fig 19 – Minimum wave heights to cause capsize both vessels at all headings

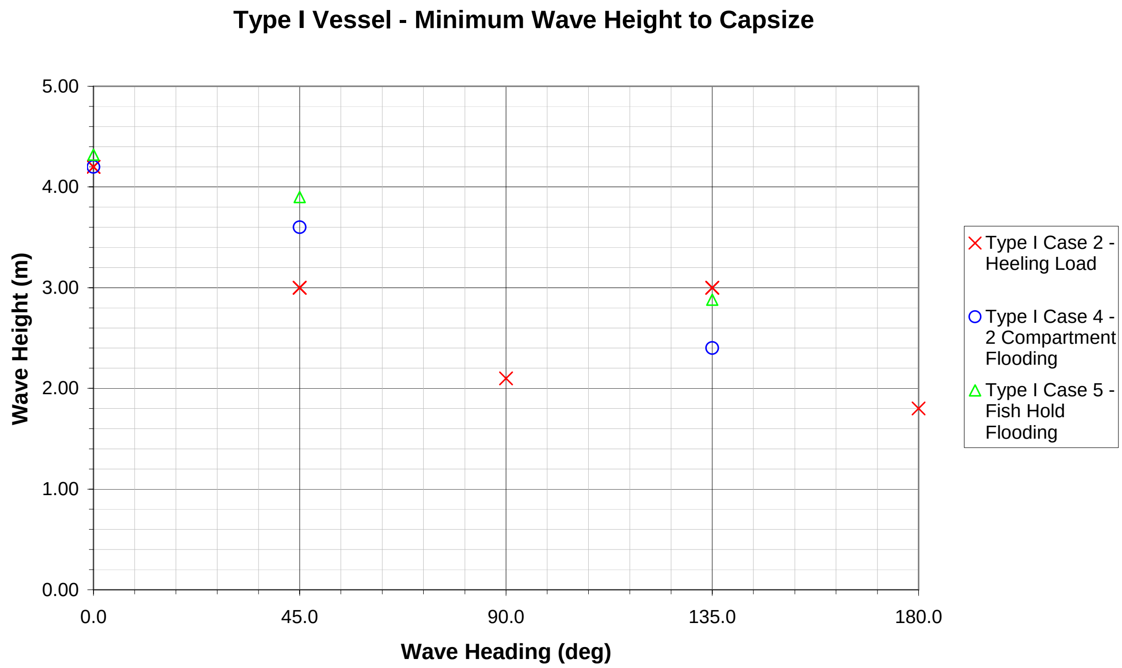


Fig 20 – Type I Vessel – Minimum wave heights to capsize all headings

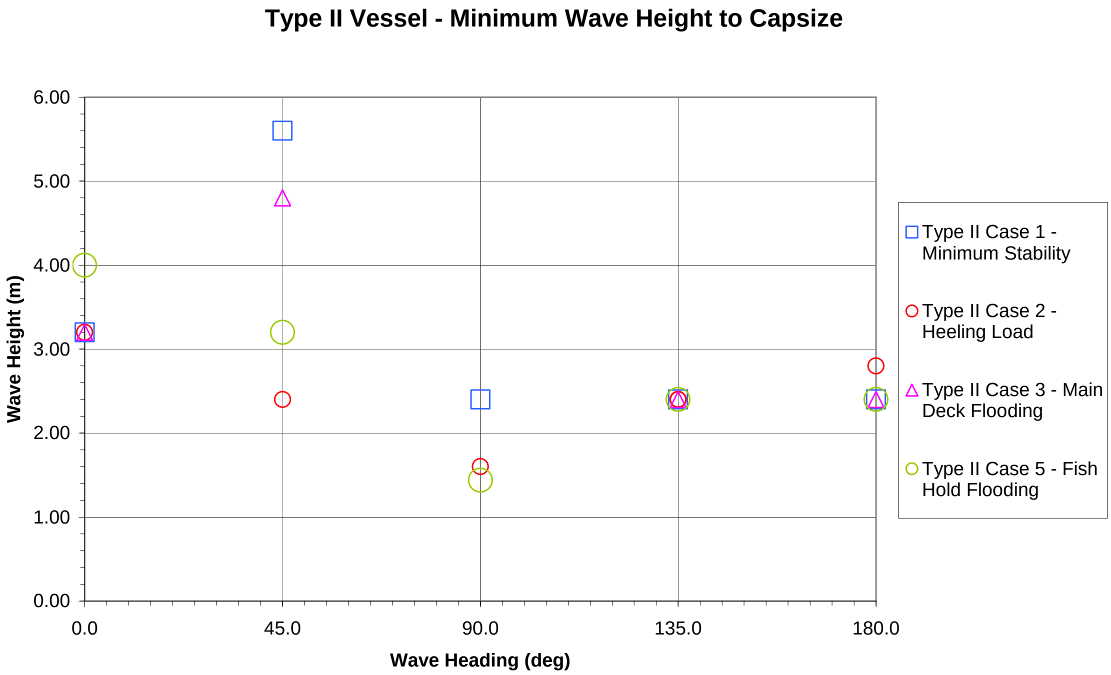


Fig 21 – Type II Vessel - Minimum wave heights to capsize all headings

7.1 Summary of Results for Each Case

7.1.1 Type I Vessel

Case 1 – Loaded to just meet IMO stability criteria

For this configuration the Type I vessel did not capsize within the range of wave heights and wave periods tested; this was attributed to the strong response characteristics of the vessel. The vessel response to the waves was in many cases a violent one, with large angles of roll, particularly in beam seas for periods of 0.6 seconds, but none which lead to capsize.

There were also cases in which parametric rolling was instigated in head seas but at no point did the model loose enough waterplane inertia to cause it to capsize. This is primarily attributed to the large range of stability present in the model for this configuration (85 degrees), and also the large area under the GZ curve, as will be expanded on in section 7.2.1. However it was also observed that due to violent motion observed for this case any water that was shipped onto the deck due to near breaking waves or deck edge immersion, was immediately thrown off due to violent rolling when the next wave impacted.

Thus there was little accumulation of water on deck at any of the headings tested and so no degradation of the vessel's stability due to progressive flooding. It is the author's opinion that this vessel in this condition would capsize only in very steep near breaking or breaking waves, and so has adequate stability to survive in normal working conditions. This does not however account for the human factor onboard vessels of this type. The motions observed were very violent and it is undoubtedly uncomfortable and hazardous to work on these rule-beating vessels in heavy weather.

Case 2 – Application of an additional operational load

Unlike the previous case this configuration showed significantly reduced resistance to capsize, additionally being vulnerable at a number of wave headings. The results shown in Table IV indicate that for a given heading it is the wave height that is the critical factor in producing a capsize event and not the wave period. It should be noted that the resistance to capsize varies significantly across the range of wave headings, with the vessel being able to withstand waves of 4.2m in head seas but only 1.8m in stern seas.

In the case of stern seas it is the combination of water being shipped onto deck and the loss of stability on the wave crest that lead to a very quick capsize. The speed of capsize is attributed to the vessel having a significantly reduced range of stability due to the presence of the additional load. The capsize of this configuration in head seas was brought about through the same mechanism of water on deck and then loss of stability on a wave crest, however this occurs at a much greater wave height than alternative headings, as water is only shipped onto deck over the transom as it immersed in the trough of a wave.

In beam seas the capsize was attributed to the roll moment generated by the force of the wave as it impacted the side of the vessel, over coming the restoring moment, as capsize occurred after only a few waves once the critical height was reached, with little or no water being shipped onto the deck.

Case 3 – Main Deck flooded

As for Case 1 it was not possible to capsize the Type I vessel in this configuration. Although the vessel has an initial heel angle in this condition the subsequent violent roll motion allowed the water on deck to be quickly washed off. This was due to the absence of the aft shelter deck structure as this was not included in the stability calculations and so could not be included on the model during testing as no arrangements were made for downflooding.

The ability of the vessel to survive capsize in the conditions tested is again attributed to the range of stability and the reserve buoyancy present in the watertight accommodation superstructure. Therefore from these tests this vessel does not have an increased risk of capsize if a small degree of flood water is present in the fish room, provided that water can clear the deck when the vessel rolls. The fact that the vessel responds to waves with a violent roll motion aids this process and therefore although as mentioned previously this motion is undoubtedly counter productive for the crew it is actually contributing to the safety of the vessel by allowing flood water to clear the deck.

Case 4 – Main deck and accommodation flooding

As it was not possible to capsize the Type I vessel in either the intact or when the main deck was flooded, it was decided to investigate the effect of additionally flooding the accommodation area, where the flood water present would not be able to escape as the vessel rolled. This portion of the tests highlights the importance of the ensuring watertight integrity of superstructures contributing to the intact stability of the vessel.

The results clearly show a reduction in the capsize resistance of the vessel in this configuration as compared to Cases 1 and 3. For head seas capsize was caused by the onset of parametric rolling due to the loss of stability on wave crests. Increasingly large roll angles were observed leading to the capsize occurring when the vessel reached its angle of vanishing stability, this being significantly reduced from 85 degrees in the intact case to 67.5 degrees when the accommodation is additionally flooded.

Interestingly the vessel did not capsize in beam or stern seas. For the case of stern seas this could be due to the vessel having more buoyancy in its fuller aft sections than in the bow area. Therefore it is able to pick up buoyancy more quickly as a wave passes from the stern than it can achieve, due to finer forward sections, when the vessel has its head into the waves.

It should noted that only one instance of capsize was observed for head seas this being at a large wave height of 4.2m, compared to those that caused capsize in stern quartering and bow quartering waves 3.6 and 2.4m respectively, and so relatively the vessel is safer in head seas than bow or stern quartering.

The lower wave heights leading to capsize for quartering seas are attributed to the coupling of the roll motion in these conditions with pitch, leading to increased rolling and eventually capsize. The coupling of roll and pitch was particularly evident for the Type I vessel due to its low length to breadth ratio, as compared to the Type II vessel with a more conventional length to breadth ratio.

Case 5 – Fish Hold Flooding

In light of the loss of the Solway Harvester both vessels were tested with 5 tonnes of flood water present in the fish hold. As can be seen from the results in Table IV and Fig. 20 the Type I vessel when loaded in this condition did have a reduced ability to withstand capsize when compared to the intact condition of Case 1. The vessel's motion was dominated by large roll angles at all headings except beam seas. For the case of beam seas it appeared to be that the presence of the flood water was acting as a roll damper and so dangerous roll angles that might lead to capsize were not observed. The minimum wave height at which capsize occurred was 2.88 metres in stern quartering seas. The vessel was also able to survive in stern seas, as was the case in Case 4, again this is attributed to the fullness of form allowing the vessel to pick up buoyancy as a wave passed from the stern forward.

When compared to Case 4 it can be seen that the presence of flood water low down in the fish hold did not have such a detrimental effect on the vessel's ability to withstand capsize as it did for the case when the accommodation was flooded in Case 4, where the flood water was located at main deck height in the forward superstructure. As can be seen from the GZ curves for Cases 4 and 5 in the appendix, the detrimental effect on the vessel's stability is much more pronounced when the flood water is located higher up in the vessel. This underlines the case for ensuring water tight superstructures remain water tight at sea to prevent any ingress of water. Any flood water either in a hold, low down in a vessel, or worse at main deck level or above should not be allowed to accumulate through ensuring scuppers and freeing ports remain clear at all times from obstructions, and bilge suction strainers are kept clear to allow the fish room to remain dry.

7.1.2 Type II Vessel

Case 1 – Loaded to just meet IMO stability criteria

The Type II vessel exhibits relatively little resistance to capsize when loaded to just meet the IMO Stability criteria. As can be seen from the Table IV and Fig. 21 the vessel capsizes at a height of 2.4m for beam, stern quartering and stern seas. In all cases it was the fact that the deck edge immersed and water quickly accumulated on deck. With no superstructure present on the model, no additional buoyancy can be picked up as the vessel rolls at ever increasingly large roll angles. The vessel was frequently swamped within the first few waves, due to a low freeboard not preventing the shipment of water on deck.

In the case of stern quartering waves the vessel capsizes very quickly as the water is shipped over the deck edge and transom. For head seas the vessel survived slightly larger waves, however again it was the immersion of the deck edge at the transom leading to progressive flooding that dominated the capsize response.

For bow quartering waves capsize only occurred in large near breaking waves when the vessel was swamped. Although water was shipped on deck at this wave heading the violent coupled roll and pitch motion of the vessel meant this was easily cleared over the transom. One point of interest is that the vessel often capsized after the wave makers were turned off and the waves were subsiding (these results have not been taken as legitimate capsize occurrences). This is attributed to the heeling moment caused by the large amount of water on deck. The vessel often capsized stern first towards the waves in this configuration as often it was the effect of the transom dipping leading to progressive flooding at the stern.

Case 2 – Application of an additional operational load

The effect of the additional operational load was less pronounced for the Type II vessel than the Type I vessel. As will be discussed in the next section the effect on the vessel's range of stability is less severe for the Type II vessel as opposed to the Type I vessel. In the case of head, bow quartering and beam seas the minimum wave height is reduced. Particularly in the case of beam seas this being due to the vessel more tender response due to it having a lower GM resulting in more tender motions with the associated lack of restoring moment.

Case 3 – Main deck flooded

The results for main deck flooding showed little change on the minimum wave height to capsize the vessel when compared to those of the intact condition of Case 1, with the only differences being for bow quartering and beam seas. This can be explained by the fact that the vessel reached the same flooded condition in Case 1 once sufficient water had accumulated on deck, as has been tested in Case 3.

It should be noted that the scenario of main deck flooding conducted in these tests is a simplistic one due to the simple nature of the models tested. When following ITTC model testing criteria no superstructure other than that which contributes to buoyancy should be present. Bounding the flow of water from the main deck with additional superstructure would contravene this assumption and so it was decided to analyse the main deck flooding as a water on deck situation.

To effectively model this case a more complex down flooding model would have to be used which despite imposing a time domain solution to the problem, would give a clearer picture as to the impact on the vessels stability of main deck flooding and the scenarios related to this event.

Case 5 – Fish Hold Flooding

The Type II vessel did not display the same violent motion as the Type I vessel in previous cases. Capsize occurrences were dominated by the point of deck edge immersion either on the starboard side or at the transom. Due to the presence of an initial heel angle of 7.16 degrees the wave height at which the deck edge immersed in beam seas was reduced from 2.40 metres for Case 1 to 1.44 metres for this case. Once this point had been reached the vessel progressively flooded until the vessel's stability was eroded to such an extent that capsize occurred. As in previous cases the vessel's motion was not of a violent nature, therefore water was allowed to accumulate on deck leading to progressive erosion of stability and eventual capsize.

7.2 Analysis of Critical Minimum Wave Heights

Having considered the effect of heading in the previous section the results here show the minimum wave height to cause capsize for each condition regardless of heading, as shown in Fig 22. Although the Type I vessel (rule-beater) did not capsize for Cases 1 and 3 one cannot simply say that the vessel survived a wave height of X metres as the maximum wave height before breaking waves are generated varies with wave period. In Fig 22 a line showing the maximum wave height for which the Type I vessel was tested in for the cases where capsize was not achieved.

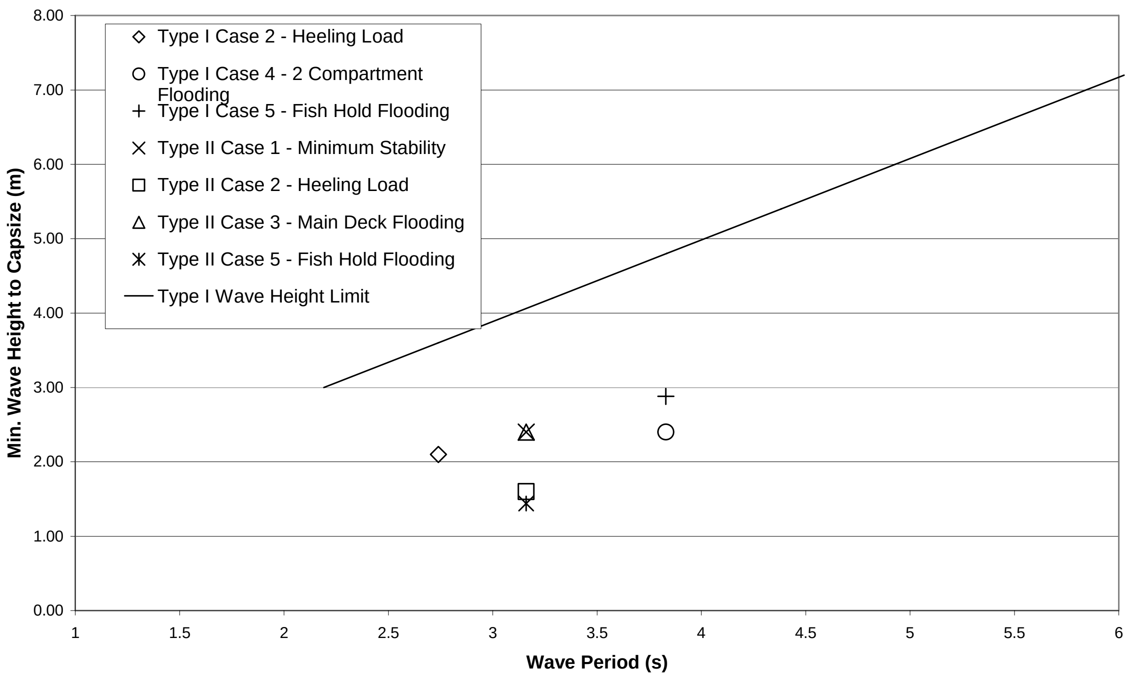


Fig 22 – Minimum wave height to capsize for each condition

7.2.1 Comparison of Results for Vessel Type

Case 1 – Loaded to just meet IMO stability criteria

From the Fig. 22 it is clear that the Type I vessel was able to withstand significantly larger waves than the Type II vessel for the case when the vessels were loaded so their stability just confirmed to the IMO criteria (Case 1). For the wave period at which the Type II vessel capsized in this condition the Type I vessel survived in waves of 4.0 metres whereas the Type II vessel capsized in waves of 2.4 metres.

Although rule-beater designs have received criticism from the industry that they provide a lower level of safety than conventional designs; from these results, when just complying with the IMO stability criteria ,the rule-beater type design tested here exhibits a greater ability to resist capsize in waves, and as such is not at an increased risk of capsize.

As both vessels were loaded to just comply with the stability criteria, this result highlights that fact that the IMO criteria do not effectively, directly assess a vessel's ability to resist capsize in their current form.

As discussed in Research Project 509 conventional stability criteria tend to relate GZmax and GZ area, and do not include limits on the range of positive stability. The following analysis highlights the fact that although the two vessels have similar GZ curves up to the point at which the GZ area is assessed (40 degrees or the angle of downflooding) they vary a great deal after this, something which is not currently taken account of by the existing criteria.

Vessel	**Disp.**	**GZmax**	**GZ area**	**Range**	**GZmax/L**	**GZarea/L**	**Range x GZmax / L**	**RMmax / L^4 x10^3**	**Wave Height / L**
	tonnes	metres	metre.radians	degrees					
Type I	91.7	0.204	0.102	85.54	0.0146	0.0073	1.245	0.486	No Capsize
Type II	116.5	0.219	0.103	49.65	0.0131	0.0061	0.649	0.324	0.143

The results in the above example concur with the conclusions drawn in research project 509 that it is not GZ area that governs the vulnerability to capsize but the combination of range and GZmax.

Despite having very similar values of GZarea/L, for the Type I vessel capsize did not occur, however the Type II vessel capsized in a wave height of 14% of its length. From the above non-dimensional parameters it is the *Range* and *Range x GZmax/L* of the Type I vessel that stands out as being significantly larger than that of the Type II vessel, by a factor of 2. This indicates it was the range of positive stability that provided the protection from capsize and not the GZarea.

When considering the above parameters as assessed by current criteria, if no account is taken of the length of the vessel, one could be fooled into believing the Type II vessel has a greater resistance to capsize than the Type I vessel as it has larger values of both GZmax and GZarea.

This further supports the conclusions of previous studies that GZmax and GZarea are not good indicators of capsize resistance, therefore the criteria in their current form cannot be expected to provide an indication of the relative resistance of a vessel to capsize.

Case 2 – Application of an additional operational load

The effect on an additional operational load on the vessels (in the case of these tests 5 tonnes located at shelter deck height) varies between the vessel types. For the Type I vessel capsize occurred at a wave height of 2.10m and for the Type II vessel at a wave height of 1.60m. For the Type II vessel this corresponds to a reduction in wave height of 0.80m or 33 % of that for Case 1.

As no wave height is known for capsizing the Type I vessel for Case I, conclusions cannot be readily drawn as to the degree of the increased risk of capsize when operational loads are applied. However it is clear for both vessels that the application of an additional load high up on the vessel reduces the minimum wave heights at which capsize occurs.

Consideration of these additional operational loads should therefore be taken when assessing the stability of a vessel for it to be fit to carry out its intended operations at sea. Without considering the effect of additional loads due to fishing operations the safety of a vessel cannot be assured at sea.

Guidance in the form of stability notices, alerting the crew to the increased capsize vulnerability caused by lifting or loading catch high up on the vessel, would ensure the crew were aware of the risks involved in carrying out these operations.

Case 3 – Main Deck Flooded

The results of the tests carried out with main deck flooding condition show no increased risk of capsize due to the presence of 5 tonnes of flood water on each model. In the case of the Type I vessel capsize was not achieved, and for the Type II vessel the minimum wave conditions to capsize occurred at the same values as in Case 1, 2.40 metres.

This result can be explained by the fact that the flood water was located in an unclosed compartment (on deck) and so did not contribute to a reduction in stability once the point of deck edge immersion was reached. The water was not constrained on the deck and so although the vessel was initially in a more vulnerable condition, once the point of deck edge immersion was reached the vessel was effectively in the same condition as Case 1.

From this finding we can conclude that if flood water is able to leave the deck as the vessel heels over, it does present an increased threat to the vessel’s survivability in waves.

Case 4 – Main deck and accommodation flooding

This case highlights the importance of maintaining watertight integrity of structures contributing to the buoyancy of the vessel. As can be seen from the results in Fig 22 the vessel capsized at a minimum wave height of 2.40 metres, well below the limit for which the vessel did not capsize in Case 1. The fact that the water contained in the accommodation cannot escape causes it to continue to have a detrimental effect of the stability of the vessel past the point of deck edge immersion.

When the results of Cases 2 and 4 are compared for the Type I vessel in the same manner as that conducted for Case 1, the same trend in range of stability being a distinguishing factor in determining the capsize safety of a vessel is highlighted.

Vessel	Disp.	GZmax	GZ area	Range	GZmax/L	GZarea/L	Range x GZmax / L	RMmax / L^4 x10^3	Wave Height / L
	tonnes	metres	metre.radians	degrees					
Type I Case 2	96.7	0.0992	0.041	41.25	0.0071	0.0029	0.292	0.250	0.150
Type I Case 4	96.7	0.0887	0.040	67.27	0.0063	0.0029	0.426	0.223	0.171

The vessel has a lower value of GZmax/L and the same value of GZarea/L yet capsizes in a wave 30% larger than that for Case 2. The GZ area would indicate that the vessel is not exposed to an increased risk of capsize with both Cases having very similar values. The values of Range x GZmax/L however, show a clear distinction between the two cases that follows the trend of increased wave height causing capsize for Case 4.

The analysis conducted in this section supports the findings from previous studies that the existing criteria by considering only GZmax and GZ area to not provide an adequate assessment of a vessel's ability to survive capsize in differing loading conditions.

Case 5 – Fish Hold Flooding

The effect of flooding on the Type I vessel has significant impact on the minimum wave height causing capsize. In the flooded condition the vessel capsized in waves of 2.88 metres in height and 3.83 seconds period. The vessel had previously survived in waves of 4.80 metres at the same period when loaded in the same condition but without the flood water present (Case 1).

The following analysis of the results for the Type I vessel comparing cases 1, 5 and 4 highlights again the trend in Range*GZmax in predicting the likely magnitude of the wave height to capsize. As can be seen for Case 5, when the fish hold was flooded the vessel still has a large range of stability up to 86 degrees. However the GZmax and Area under the GZ curve have been significantly reduced, hence the vessel readily rolled to large angles and eventually capsized in moderately sized waves (2.88 m).

As can be seen from the following table the non-dimensional maximum righting moment follows the trend in minimum wave height causing capsize, but range of stability does not. These results support the case of a method of assessment based not only on the existing stability criteria but also but incorporating those measures which seem to indicate the level of capsize resistance, namely maximum righting moment and range of stability.

Vessel	L	Disp.	GZmax	GZ area	Range	GZmax/L	GZarea/L	Range x GZmax / L	RMmax / L^4 x10^3	Wave Height / L
	metres	tonnes	metres	metre.radians	degrees					
Type I Case 1	14.00	91.7	0.204	0.102	85.54	0.0146	0.0073	1.245	0.486	No Capsize
Type I Case 5	14.00	96.7	0.1229	0.058	86.187	0.0088	0.0041	0.757	0.309	0.206
Type I Case 4	14.00	96.7	0.0887	0.040	67.27	0.0063	0.0029	0.426	0.223	0.171

The effect on the Type II vessel of flooding is less pronounced. There is a reduction in minimum wave height causing capsize but this is primarily due to the vessel having an initial angle of heel and therefore reduced freeboard. Although this vessel capsizes in smaller waves than the Type I vessel the relative change in minimum wave height is less pronounced. For Case 1 the vessel capsizes in wave of 2.40 metres height and for Case 5 in waves of 1.44 metres in height.

The effect on the stability of the vessels of the flooding seems to be more pronounced for the Type I vessel. This having a free surface correction of 0.437 m derived from free surface moment of 42.1 tm when its fish hold is flooded with 5 tonnes of water. In contrast the Type I vessel has a free-surface correction of 0.244 metres and a free-surface moment of 29.6 tm when its fish hold is flooded with 5 tonnes of water.

The fish holds of the two vessels are notably different in nature as shown in the following figures. For the Type I vessel the fish hold is located between frames 2 and 16, running from 0.90 metres forward of the AP to 7.20 metres forward of the AP. The fullness of form of the vessel means the fish hold is essentially box like in shape, and so a large free-surface is present when the hold is flooded. The Type II vessel however has its fish hold located forward, between frames and 14 and 29. The presence of the finer forward sections in the vessel reduced the area of the fish hold at lower levels, leading the resultant free-surface to have a lesser effect on the stability of the vessel than for the Type I vessel.

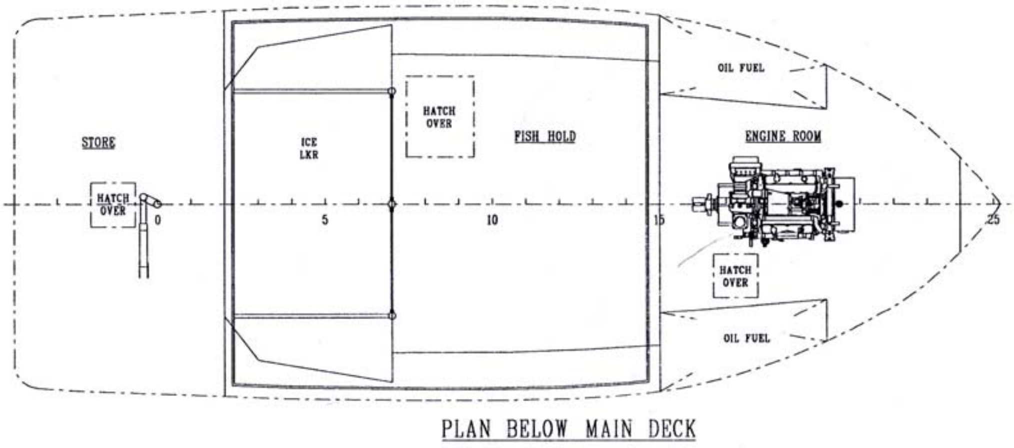


Figure 23: Plan of Type I vessel showing fish hold

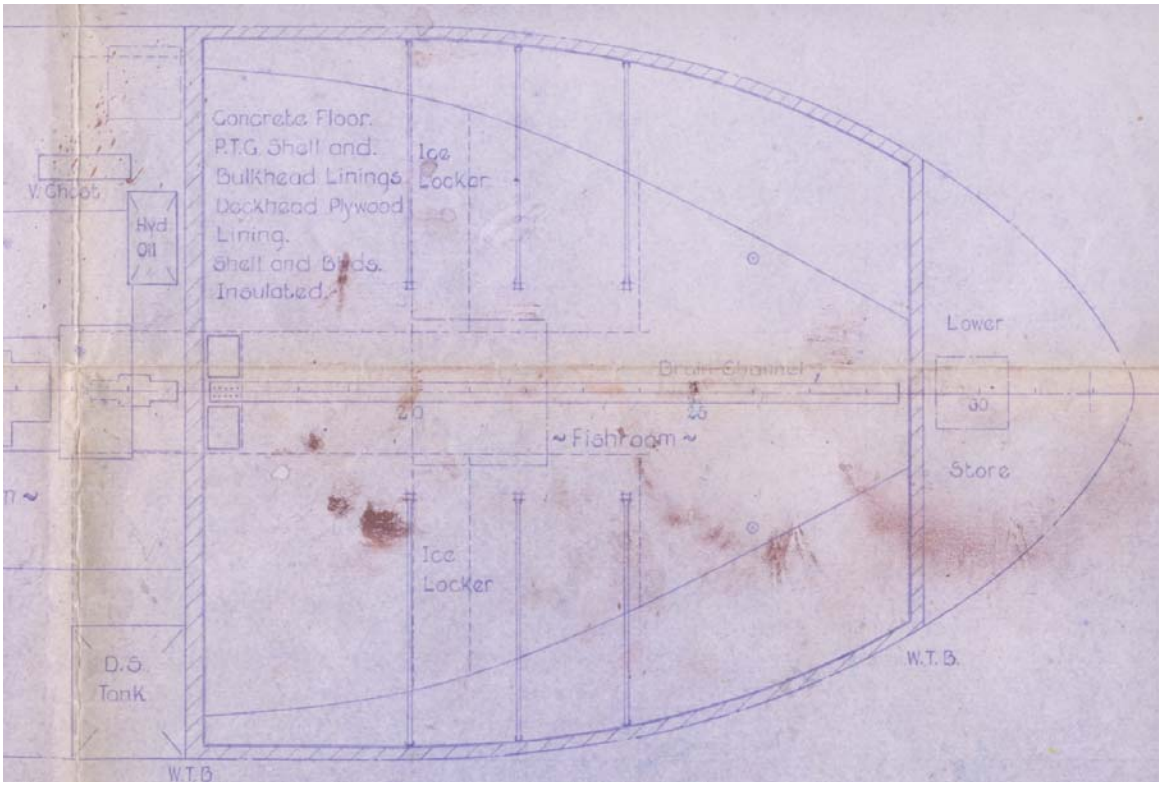


Figure 24: Plan of Type II vessel showing fish hold

8 CAPSIZE ASSESSMENT METHOD

Section 6 of this report has indicated that the range of stability and the maximum righting moment are useful indicators in the assessment of capsize safety. The previous analysis also indicates that the current stability criteria do not provide an adequate assessment of the risk of capsize being based on GZmax and areas under the GZ curve, which have been shown to be misleading in assessing the relative safety of different vessels and different loading conditions on the same vessel.

Research Project 509 investigated the relative levels of safety provided by the intact and damage stability criteria in the 2000 High Speed Craft Code, one of the outcomes of this project was a series of formulae, developed as an alternative assessment method was suggested that takes into account the size vessels and the seastates in which they operate.

The formulae were based on regression of plots of numerous combinations of stability parameters and the resulting minimum wave heights from the tests conducted on a large range of high speed craft models. Extensive analysis indicated the importance of size, righting moment and range of positive stability in assessing capsize safety.

When results of capsize tests normalised with respect to length were plotted against the product of the range of positive stability in degrees and the square root of maximum righting moment in tonne metres, normalised by the product of length and beam a linear trend was found that showed a good collapse of data. In plotting the results in this manner several types of model configuration were represented on the lower boundary of the data set indicating that a common safe boundary could be applied to all types of vessel.

Two formulae were presented as methods of assessing the minimum wave height that might cause capsize. The first being a fit through the lower boundary of the data, but where some points lay below the line represented the formula; and a second formula, providing a more conservative estimate, by forming a boundary to all the data points. The formulae were designated Formula 1 and 2 respectively.

$$\text{WaveHeight} = \frac{\text{Range}\sqrt{\text{RMmax}}}{10\text{B}} \qquad \text{Formula 1}$$

$$\text{WaveHeight} = \frac{\text{Range}\sqrt{\text{RMmax}}}{10\text{B}} - \frac{L}{100} \qquad \text{Formula 2}$$

Where:

Wave Height is the maximum wave height that might result in capsize
Range is the residual range of positive stability in degrees
RMmax is the maximum residual righting moment in tonne.metres
B is the overall beam of the vessel
L is the overall length of the vessel

Fig 25 shows the minimum wave results of the capsize tests conducted in this study normalised with respect to length plotted against the combined stability parameter described above. As can be seen from Fig 25 the line representing Formula 1 and 2 do not form the lower boundary of all the data points, providing an under estimate of the wave height at which capsize might occur. An alternative set of lines encompassing all the data points from the tests conducted in this study has also been plotted on Fig 25, defined as Formulae 3 and 4. These are defined as follows.

$$\text{WaveHeight} = \frac{\text{Range}\sqrt{\text{RMmax}}}{19\text{B}} \qquad \text{Formula 3}$$

$$\text{WaveHeight} = \frac{\text{Range}\sqrt{\text{RMmax}}}{19\text{B}} - \frac{L}{190} \qquad \text{Formula 4}$$

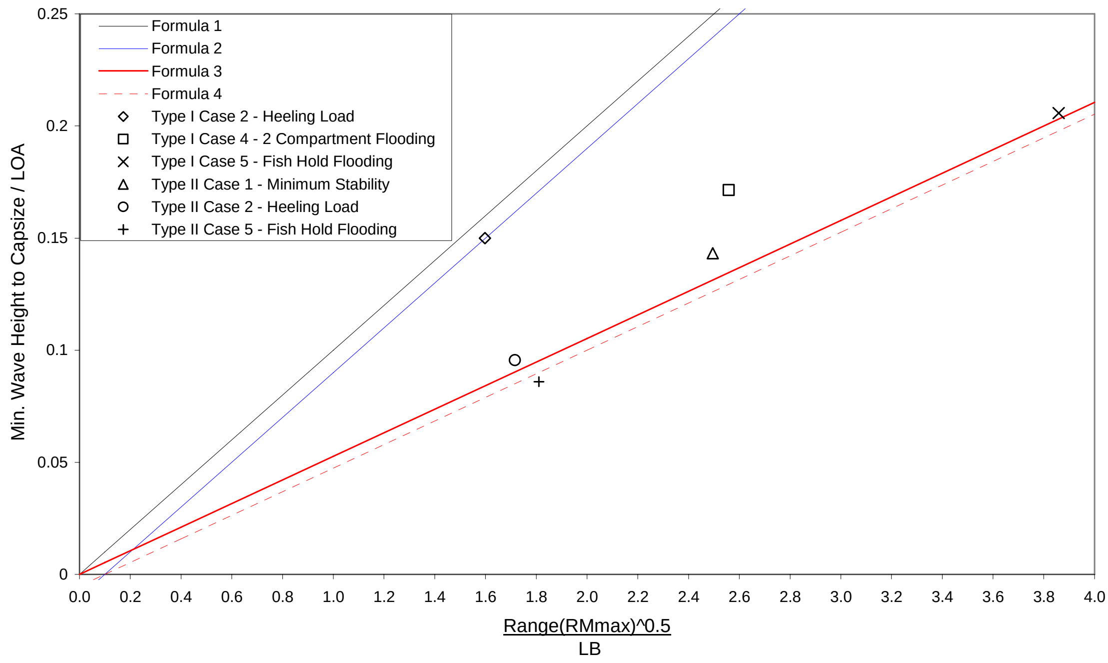


Fig 25 – Boundaries provided by variation of non-dimensional wave height with stability parameters

It should be noted the wave height as calculated by formulae 3 and 4 provide a conservative estimate of the results for the Type I vessel except in the case of fish hold flooding.

It is important to stress that the application of formulae of this type to the assessment of the safety of the UK fishing fleet should not be made on the basis of these test results alone as they do not provide a sufficiently large data set from which to set definite limits. This task would require more in depth study of capsize model tests and well documented capsize accidents to develop a database of capsize statistics on which to decide the appropriate safety level provided by the formulae.

8.1 Application of Capsize Formula to Sample of the Fleet

The minimum wave heights as calculated by Formula 4 are shown in Fig 26 based on a sample of small vessels from the under 12m and under 10m UK fleet, ranging in size from 5.9 to 14.2 metres length overall. The stability data for the sample of vessels has been based on the most onerous loading case for each vessel. For some of the vessels the range of stability has been truncated to 90 degrees as their GZ curves were only presented up to this angle. Length overall and maximum beam have been used to calculate the values in Formula 4. As can be seen from Fig 26 there is significant scatter in the data and the across the range of lengths of vessels.

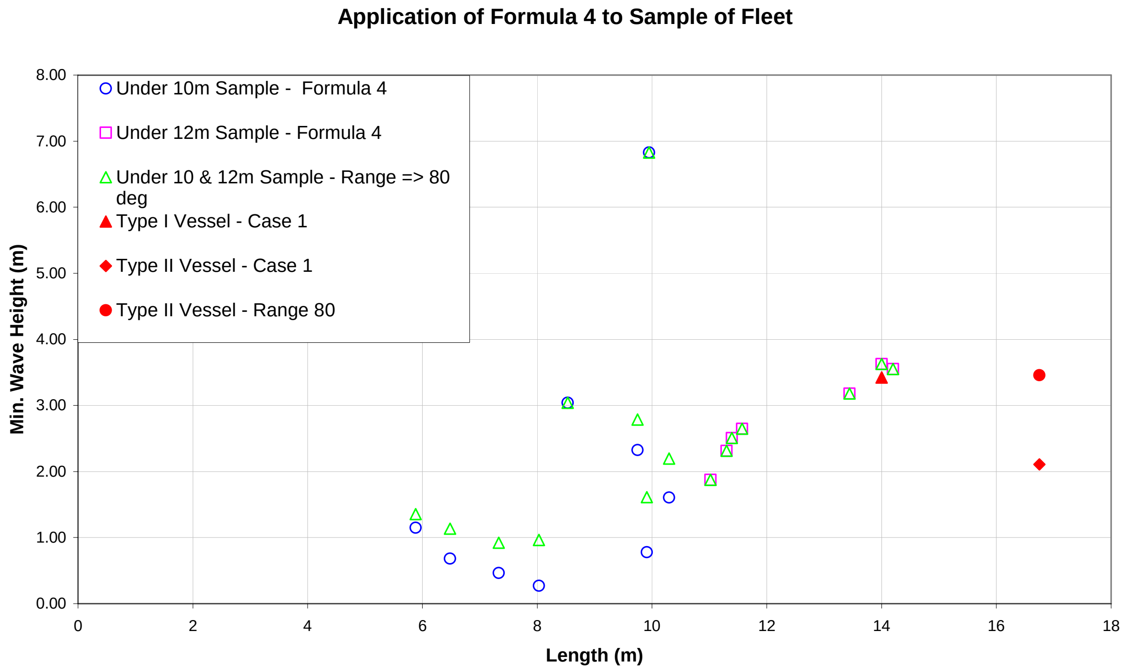


Fig 26 – Application of Formula 4 to existing fishing vessels

The minimum wave height for the vessels is also shown having fixed the range of stability to 80 degrees. This is a somewhat academic exercise, but it clearly demonstrates the effect that increasing the range of stability has on the wave height to capsize.

For the over 10 metres vessels when the range is fixed at 80 degrees or above the vessels all have a minimum wave height over 1.50m. Fig 26 highlights the safety level of current trend in vessel design of lower L/B ratio vessels similar to the Type I vessel investigated in this study. There are two clusters of points where the vessels had a range of stability over 80 degrees. For these cases the range was kept at its higher value when recalculating the minimum wave height.

Fig. 26 shows a cluster of points around the point representing the Type I vessel. These are all vessels under 12 metre registered length, with low length to breadth ratios typical of the current trend in so called rule-beaters. They have similar dimensions and stability characteristics, with a only slight variation in the range of stability between the vessels. The similarity in the minimum wave height to capsize as predicted by formula 4 would seem indicate that these vessels have similar resistances to capsize and therefore the results of this study could be extended to low length to breadth ratios vessels in the fleet with characteristics similar to the Type I vessel examined in this study.

An additional point has been added to demonstrate the effect of raising the range of stability of the Type II vessel to 80 degrees. With a range of 80 degrees the Type II vessel has a similar level of safety as the Type I vessel.

There is an obvious problem with setting limits on the range of positive stability for the existing fleet. Due to the diverse nature of the fleet there will be many cases where vessels cannot be to meet this requirement. It is proposed that the inclusion of a limit of between 70 and 80 degrees, in line with Norwegian regulations, be made to new vessels would ensure the safety of the fleet is improved in the future.

This could be used in combination with the proposed formulae for minimum wave heights to set operational guidelines for vessels which are not covered by the application of stability criteria. The use of guidance and not prescriptive regulation is seen as one of the only methods of improving the safety of the existing fleet without being at the detriment of livelihoods.

9 CONCLUSIONS

1. The Type I vessel, being representative of the current trend in low length over breadth ratio vessels was shown to have a higher resistance to capsize when compared to a conventional length over breadth ratio vessel of comparable fishing capability. This resistance is attributed to violent motions ensuring water on deck was not allowed to accumulate, and the presence of a watertight superstructure ensuring a large range of positive stability for the vessel.

2. Both vessels were shown to be at increased risk of capsize with the presence of 5 tonnes of flood water located in their respective fish holds. The Type I, low L/B ratio, vessel shows a greater reduction in capsize resistance when compared to the Type II vessel. However the Type I vessel survived in larger waves than the Type II vessel for all conditions tested.

3. The addition of a small amount of main deck flooding was shown to have little effect on the wave conditions at which both the Type I and Type II vessels capsized or survived in. This has been attributed to the flood water being unconstrained and free to flow over the bulwark. Comparison of this scenario (Case 3) and Case 4 and Case 5 for the Type I vessel demonstrated that when flood water was constrained the detrimental effect on the stability of the vessel was severe.

4. Both vessels showed a reduced resistance to capsize in the presence of an additional operational load. Indicating that stability assessment should be made in the light of foreseeable operational loads that will be applied to a vessel when conducting its operations at sea.

5. The effect of flooding the watertight superstructure of the Type I vessel showed a marked reduction in the wave height at which it capsized. If watertight superstructures are to be included on the assessment of a vessel's stability strong guidance should be given to the crew of the vessel indicating the importance of ensuring watertight doors and other openings remain closed while at sea.

   To keep doors shut at all times is obviously unrealistic, but none the less the importance of maintaining the integrity of watertight superstructures could be made very clear through the use of stability notices, indicating the adverse effects of flooding of spaces contributing to the stability of the vessel.

6. The current stability criteria when applied to the vessels examined in this study do not highlight their differences in capsize resistance. This was shown to be due to the lack of reference in the criteria to the range of positive stability and maximum righting moment of the vessels and their role in ensuring survival in larger waves.

It is proposed that a higher level of safety would be ensured if account is taken of the range of positive stability when applying criteria to fishing vessels. A realistic value for this limit would be in the region of 80 degrees.

7. A previously proposed alternative assessment technique was extended to the results of the tests conducted in this study and shown to provide a conservative estimate of the minimum wave heights that might cause capsize.

   It is proposed that the formulae applied to the results of these tests can only be applied to the fishing fleet after the production of an extensive capsize database either through model testing or thorough analysis of known capsize casualties. Through this the formulae could be refined to form a basis of an assessment of vessel safety based on vessel size, beam, range of residual stability and the maximum residual righting moment relative to operational seastate.

10 RECOMMENDATIONS

1. The current trend in rule-beater designs of low length to breadth ratio vessels at both the 10 and 12 metre registered length mark is as a result of owners gaining advantage from current licensing and safety regulations. These tests have shown that these vessels have the ability to survive in larger waves than a vessel of greater length but comparable fishing capability.

   These vessels often have large engines and are operating far offshore with similar fishing gear to vessels above 12 metres in length; as such it is proposed that their safety should be assessed in a similar manner to the larger vessels they are operating in competition with, through that application of stability criteria and the production of a stability booklet. This should be supplemented by guidance to the skipper and crew of the vessel so that they can readily understand the situations leading to a reduction in their vessels stability and the resulting exposure to risk of capsize.

2. The detrimental effect on a vessels stability caused by water *trapped* within a compartment should be made clear in any guidance given to crews.

   The importance of ensuring scuppers and freeing ports are open and clear of obstructions to allow water to drain from the deck, should be included in any guidance provided to crews.

   The presence of flood water in a fish hold has been shown to have severe consequences on a vessel’s ability to withstand capsize in waves. Early detection of any flooding is seen as essential in ensuring future accidents are prevented. Bilge alarms should be fitted to fish rooms and well maintained. Bilge suction strainers should be readily accessible. Alternatively vessels should be equipped with portable salvage pumps.

3. All vessels should be provided with a simple stability notices to highlight the dangers to a vessel’s stability. These notices should reflect the specific dangers relevant to the vessel type and fishing method employed, for example for vessels with high lifting blocks where stability may be reduced by boarding a large catch, the notice should

reflect this danger, for example by defining a maximum safe lift. Similarly for vessels where over loading is a danger that may cause a vessel to be loaded beyond its minimum freeboard the notice should highlight these dangers.

The overall intention of the notices should be to indicate that the stability of a vessel is variable, and actions can be taken to ensure that dangerous situations are avoided. For stability notices to be effective an appropriate training package should be developed to inform crews of the dangers these notices highlight. An example of a stability notice for the Type I vessel examined in this study is shown in Appendix 2. This notice highlights the vulnerability of the vessel when gear or catch is loaded high up on the shelter deck.

An extensive amount of work has been done in this area by the *SNAME Small Working Vessel Operations and Safety Panel*. An extensive guide to fishing vessel stability has been produced by the panel [44] which utilises simple diagrams to convey the stability dangers a vessel is exposed to and their effect on the vessel. The guide was developed to educate the commercial fishing community on how a fishing vessel's stability works and the effect of common fishing operations on a fishing vessel's stability levels. The topics covered and the illustrations used are generic examples of situations that fishing vessel crews may encounter and as such were intended to be used as a reference guide.

The production of a similar guide or some alternative form of training material such as a series of fact sheets would greatly increase the effectiveness of the safety provision provided by the stability notices.

4. It is suggested that a further study be conducted to derive standard formats for stability notices based on vessel types and fishing methods. This study would benefit from consultations with industry in order to agree a universal approach to the production of stability notices, in particular where colours are to be used to indicate the transition from a safe to an unsafe operating condition these boundaries need to be clearly defined and guidance given as to their determination by consultants preparing the notices.

5. Stability criteria if they are to be applied to over 10 metre and under 12 metre registered length vessels should include reference to the range of positive stability by setting a minimum of say 80 degrees. This would ensure when these small vessels are heeled due to either the action of weather of lifting weights during operations, they have sufficient reserve stability up to large angles of heel to reduce the likelihood of capsize occurring.

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APPENDIX 1 – STABILITY CONDITIONS

Type I Vessel - Case 1 - Minimum Stability Condition

Title	**Cargo**	**% full**	**SG** (t/m3)	**Weight** (t)	**LCG** (m)	**TCG** (m)	**VCG** (m)	**FSM** (t-m)
Fuel								
FO_P: Port fuel oil	FO	28.00	0.90	1.00	7.50	-1.74	1.48	0.10
FO_S: Stbd fuel oil	FO	28.00	0.90	1.00	7.50	1.74	1.48	0.10
Total Fuel				**2.00**	**7.50**	**0.00**	**1.48**	**0.20**
Fish								
Hold: Fish Hold - Cargo	CARGO	19.40	0.30	2.20	4.85	0.00	1.22	0.00
Total Fish				**2.20**	**4.85**	**0.00**	**1.22**	**0.00**
Condition 6								
fishing gear				6.00	1.83	0.00	4.60	0.00
Fresh water				0.10	10.90	0.00	3.46	0.00
Crew				0.80	8.50	0.00	4.30	0.00
Prov.				0.10	9.50	0.00	4.00	0.00
Ice				1.40	2.00	0.00	2.25	0.00
Total Condition 6				**8.30**	**2.66**	**0.00**	**4.16**	**0.00**
Lightweight				**79.20**	**4.57**	**0.00**	**2.54**	**0.00**
Total Displacement				**91.70**	**4.47**	**0.00**	**2.63**	**0.20**

Drafts at equilibrium angle

Draft at LCF	2.500	metres
Draft at AP	2.581	metres
Draft at FP	2.351	metres
Mean draft at midships	2.466	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	No heel	degrees
Trim by the stern	0.229	metres
KG	2.629	metres
FSC	0.003	metres
KGf	2.632	metres
GMt	0.516	metres
BMt	1.484	metres
BMl	7.723	metres
Waterplane area	60.872	sq.metres
LCF	3.865	metres
TCF	0.000	metres
TPI	0.624	tonnes/cm
MCT	0.638	tonnes-m/cm
Range postive GZ	84.536	degrees
Max GZ	0.2038	metres
Shell thickness	0.015	mm

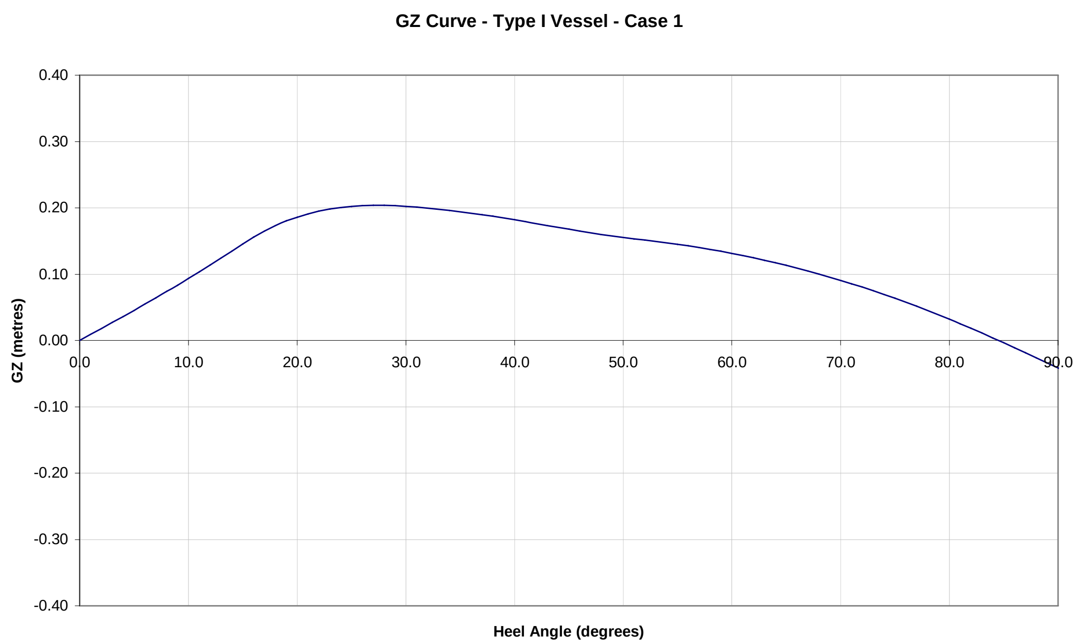
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.068	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.034	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.102	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.202	0.200
5	Initial GM to be at least 0.35 metres	0.516	0.350
6	Maximum GZ to be at an angle of => 25 degrees	27.0	25.0

Immersion Particulars

Deck Edge

Point #	X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
0	5.40	2.75	4.175	1.706	31.508
1	5.40	-2.75	4.175	1.706	99.000



Type I Vessel - Case 2 - Additional Operational Load

Title	Cargo	% full	SG (t/m3)	Weight (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t-m)
Fuel								
FO_P: Port fuel oil	FO	29.90	0.90	1.00	7.50	-1.74	1.48	0.10
FO_S: Stbd fuel oil	FO	29.90	0.90	1.00	7.50	1.74	1.48	0.10
Total Fuel				**2.00**	**7.50**	**0.00**	**1.48**	**0.20**
Fish								
Hold: Fish Hold - Cargo	CARGO	19.40	0.30	2.20	4.85	0.00	1.22	0.00
Total Fish				**2.20**	**4.85**	**0.00**	**1.22**	**0.00**
Fixed Subset 0								
Catch Landed				5.00	0.00	0.00	5.96	0.00
Total Fixed Subset 0				**5.00**	**0.00**	**0.00**	**5.96**	**0.00**
Condition 6								
fishing gear				6.00	1.83	0.00	4.60	0.00
Fresh water				0.10	10.90	0.00	3.46	0.00
Crew				0.80	8.50	0.00	4.30	0.00
Prov.				0.10	9.50	0.00	4.00	0.00
Ice				1.40	2.00	0.00	2.25	0.00
Total Condition 6				**8.30**	**2.66**	**0.00**	**4.16**	**0.00**
Lightweight				**79.20**	**4.57**	**0.00**	**2.54**	**0.00**
Total Displacement				**96.70**	**4.24**	**0.00**	**2.80**	**0.20**

Drafts at equilibrium angle

Draft at LCF	2.580	metres
Draft at AP	2.790	metres
Draft at FP	2.195	metres
Mean draft at midships	2.492	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	No heel	degrees
Trim by the stern	0.595	metres
KG	2.802	metres
FSC	0.002	metres
KGf	2.804	metres
GMt	0.324	metres
BMt	1.409	metres
BMl	7.378	metres
Waterplane area	60.965	sq.metres
LCF	3.775	metres
TCF	0.000	metres
TPI	0.625	tonnes/cm
MCT	0.643	tonnes-m/cm
Range postive GZ	41.248	degrees
Max GZ	0.0992	metres
Shell thickness	0.015	mm

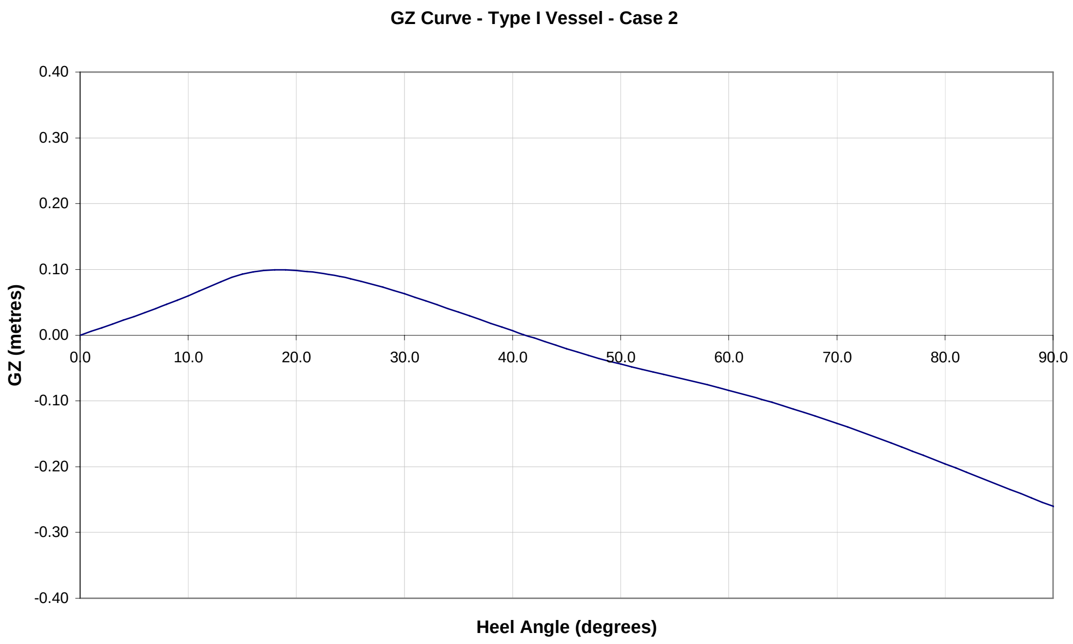
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.035	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.006	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.041	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.063	0.200
5	Initial GM to be at least 0.35 metres	0.324	0.350
6	Maximum GZ to be at an angle of => 25 degrees	19.0	25.0

Immersion Particulars

Deck Edge

Point #	X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
0	5.4	2.75	4.175	1.672	30.426
1	5.4	-2.75	4.175	1.672	99



Type I Vessel - Case 4 - Accommodation Flooded

Title	**Cargo**	**% full**	**SG** (t/m3)	**Weight** (t)	**LCG** (m)	**TCG** (m)	**VCG** (m)	**FSM** (t-m)
Fuel								
FO_P: Port fuel oil	FO	28.00	0.90	1.00	7.50	-1.74	1.48	0.10
FO_S: Stbd fuel oil	FO	28.00	0.90	1.00	7.50	1.74	1.48	0.10
Total Fuel				**2.00**	**7.50**	**0.00**	**1.48**	**0.20**
Fish								
Hold: Fish Hold - Cargo	CARGO	19.40	0.30	2.20	4.85	0.00	1.22	0.00
Total Fish				**2.20**	**4.85**	**0.00**	**1.22**	**0.00**
Acc. Flooded								
Acc. Water	WB	11.90	1.025	**5.00**	**8.33**	**0.00**	**3.38**	**36.10**
Total Acc. Flooded				**5.00**	**8.33**	**0.00**	**3.38**	**36.10**
Fixed								
fishing gear				6.00	1.83	0.00	4.60	0.00
Fresh water				0.10	10.90	0.00	3.46	0.00
Crew				0.80	8.50	0.00	4.30	0.00
Prov.				0.10	9.50	0.00	4.00	0.00
Ice				1.40	2.00	0.00	2.25	0.00
Total Fixed				**8.30**	**2.66**	**0.00**	**4.16**	**0.00**
Lightweight				**79.20**	**4.57**	**0.00**	**2.54**	**0.00**
Total Displacement				**96.70**	**4.67**	**0.00**	**2.67**	**36.30**

Drafts at equilibrium angle

Draft at LCF	2.580	metres
Draft at AP	2.517	metres
Draft at FP	2.694	metres
Mean draft at midships	2.606	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	No heel	degrees
Trim by the bow	0.177	metres
KG	2.668	metres
FSC	0.375	metres
KGf	3.043	metres
GMt	0.092	metres
BMt	1.054	metres
BMl	7.386	metres
Waterplane area	61.292	sq.metres
LCF	3.989	metres
TCF	0.000	metres
TPI	0.628	tonnes/cm
MCT	0.644	tonnes-m/cm
Range postive GZ	67.268	degrees
Max GZ	0.0887	metres
Shell thickness	0.015	mm

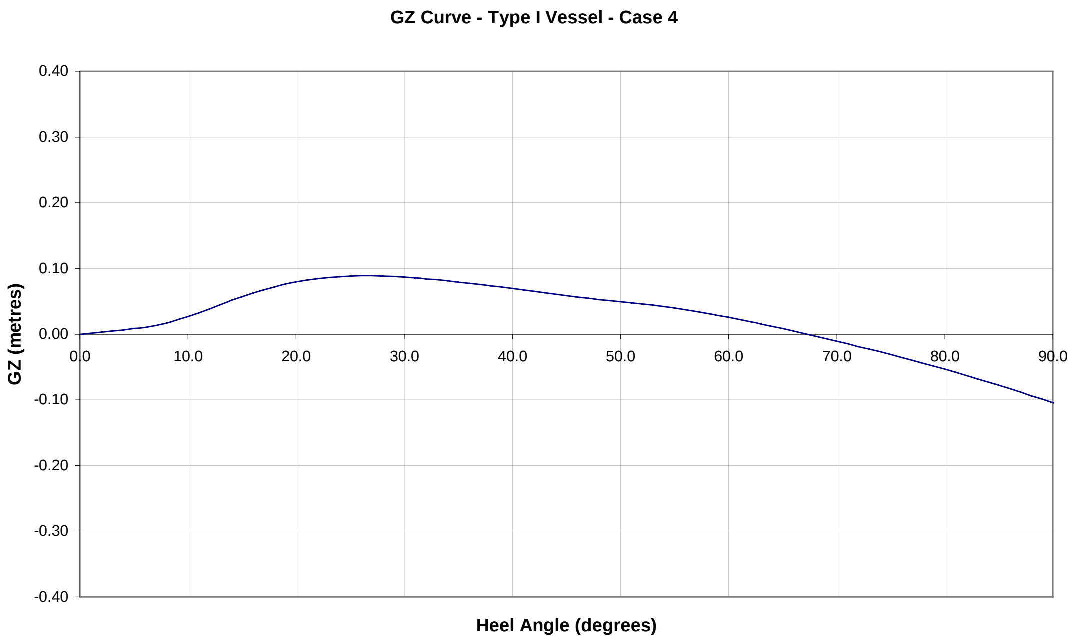
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.027	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.014	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.040	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.087	0.200
5	Initial GM to be at least 0.35 metres	0.092	0.350
6	Maximum GZ to be at an angle of => 25 degrees	26.5	25.0

Immersion Particulars

Deck Edge

Point #	X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
0	5.40	2.75	4.175	1.571	29.504
1	5.40	-2.75	4.175	1.571	99.000



Type I Vessel - Case 5 - Fish Hold Flooding

Title	Cargo	% full	SG (t/m3)	Weight (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t-m)
Fuel								
FO_P: Port fuel oil	FO	28.00	0.90	1.00	7.50	-1.74	1.48	0.10
FO_S: Stbd fuel oil	FO	28.00	0.90	1.00	7.50	1.74	1.48	0.10
Total Fuel				**2.00**	**7.50**	**0.00**	**1.48**	**0.20**
Flood Water								
Hold: Fish Hold	WB	12.90	1.025	5.00	4.80	0.00	1.15	42.10
Total Flood Water				**5.00**	**4.80**	**0.00**	**1.15**	**42.10**
Fixed								
Cargo				2.10	4.85	0.00	1.22	0.00
fishing gear				6.00	1.83	0.00	4.60	0.00
Fresh water				0.10	10.90	0.00	3.46	0.00
Crew				0.80	8.50	0.00	4.30	0.00
Prov.				0.10	9.50	0.00	4.00	0.00
Ice				1.40	2.00	0.00	2.25	0.00
Total Fixed				**10.50**	**3.12**	**0.00**	**3.54**	**0.00**
Lightweight				**79.20**	**4.57**	**0.00**	**2.54**	**0.00**
Total Displacement				**96.70**	**4.48**	**0.00**	**2.55**	**42.30**

Drafts at equilibrium angle

Draft at LCF	2.580	metres
Draft aft at marks	2.636	metres
Draft fwd at marks	2.477	metres
Draft at AP	2.636	metres
Draft at FP	2.477	metres
Mean draft at midships	2.557	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	0.000	degrees
Trim by the bow	0.159	metres
KG	2.553	metres
FSC	0.437	metres
KGf	2.990	metres
GMt	0.136	metres
BMt	0.983	metres
BMl	7.308	metres
Waterplane area	60.992	sq.metres
LCF	3.881	metres
TCF	0.000	metres
TPI	0.625	tonnes/cm
MCT	0.637	tonnes-m/cm
Range postive GZ	86.187	degrees
Max GZ	0.1229	metres
Shell thickness	0.015	mm

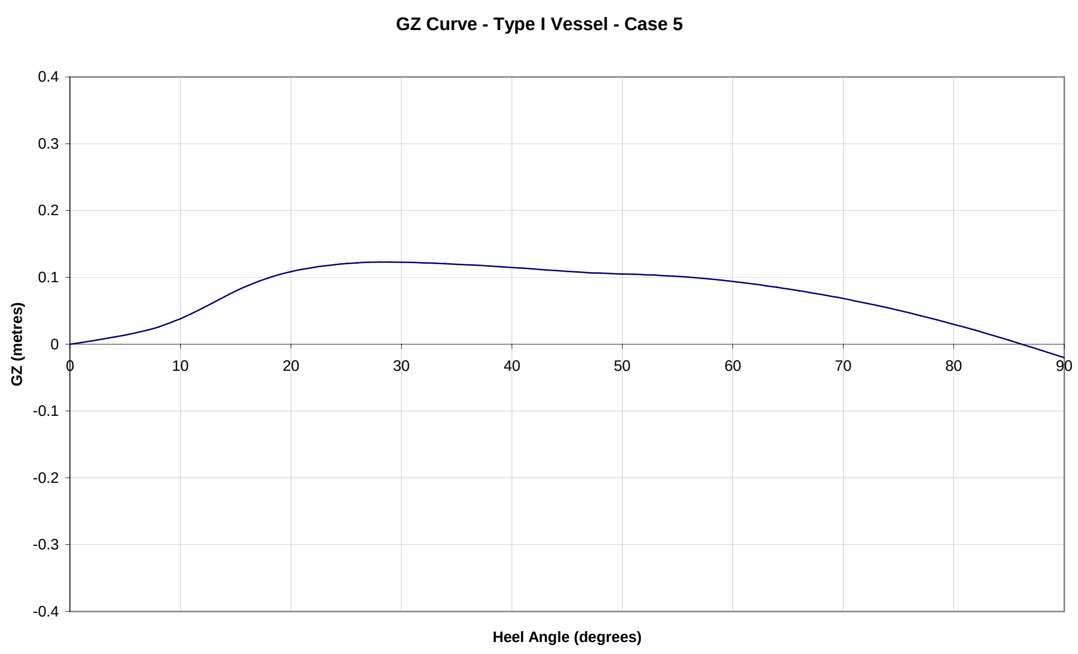
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.037	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.021	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.058	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.123	0.200
5	Initial GM to be at least 0.35 metres	0.136	0.350
6	Maximum GZ to be at an angle of => 25 degrees	28.5	25.0

Immersion Particulars

Deck Edge

Point #		X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
	0	5.40	2.75	4.175	1.616	29.867
	1	5.40	-2.75	4.175	1.616	99.000



Type II Vessel - Case 1 - Minimum Stability Condition

Title	Cargo	% full	SG (t/m3)	Weight (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t-m)
Fuel								
FO_day: Daily FO tank	FO	50.70	0.90	0.70	6.90	2.45	1.90	0.10
Total Fuel				**0.70**	**6.90**	**2.45**	**1.90**	**0.10**
Fish								
fish_hold: fish hold	CARGO	65.70	0.40	15.00	9.68	0.00	1.77	0.00
Total Fish				**15.00**	**9.68**	**0.00**	**1.77**	**0.00**
Fixed								
trawl gear				3.50	7.30	0.00	3.80	0.00
Crew				0.60	3.10	0.00	3.20	0.00
FW P				0.10	10.30	0.00	0.41	0.50
FW S				0.10	10.30	0.00	0.41	0.50
Total Fixed				**4.30**	**6.85**	**0.00**	**3.56**	**1.00**
Lightweight				**96.50**	**6.60**	**0.00**	**2.61**	**0.00**
Total Displacement				**116.50**	**7.01**	**0.01**	**2.53**	**1.10**

Drafts at equilibrium angle

Draft at LCF	2.328	metres
Draft aft at marks	2.246	metres
Draft fwd at marks	2.435	metres
Draft at AP	2.246	metres
Draft at FP	2.435	metres
Mean draft at midships	2.340	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	1.270	degrees
Trim by the bow	0.189	metres
KG	2.541	metres
FSC	0.001	metres
KGf	2.542	metres
GMt	0.664	metres
BMt	1.727	metres
BMl	11.630	metres
Waterplane area	79.855	sq.metres
LCF	6.376	metres
TCF	0.066	metres
TPI	0.819	tonnes/cm
MCT	0.922	tonnes-m/cm
Range postive GZ	49.651	degrees
Max GZ	0.219	metres
Shell thickness	0.015	mm

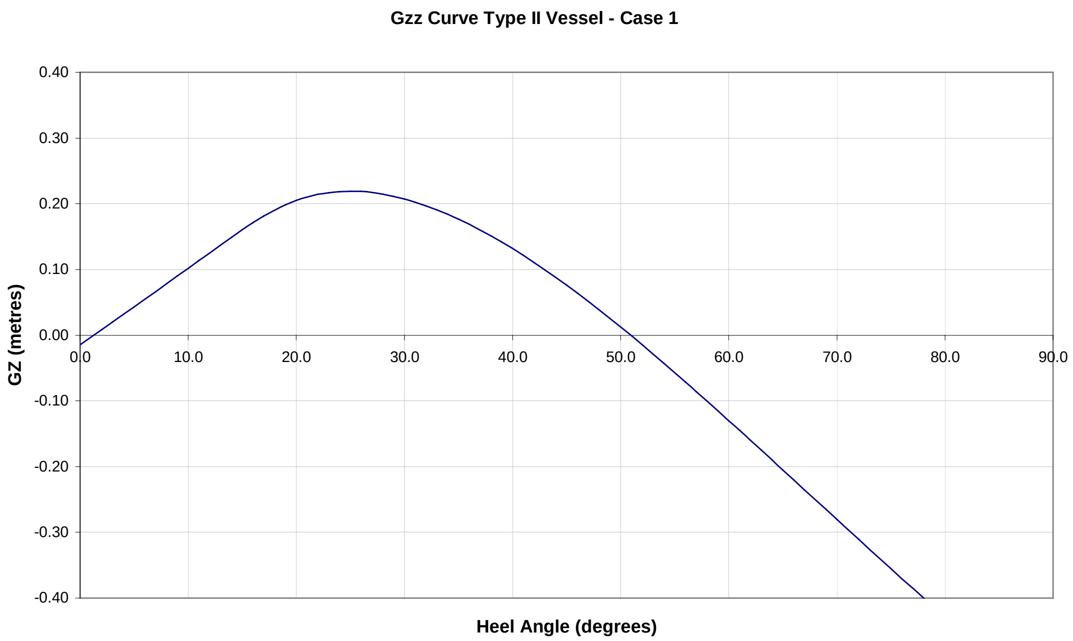
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.073	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.030	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.103	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.207	0.200
5	Initial GM to be at least 0.35 metres	0.664	0.350
6	Maximum GZ to be at an angle of => 25 degrees	25.0	25.0

Immersion Particulars

Deck Edge

Point #	X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
0	7.35	3	4.5	2.093	35.441
1	7.35	-3	4.5	2.225	133.828



Type II Vessel - Case 2 - Additional Operational Load Applied

Title	Cargo	% full	SG (t/m3)	Weight (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t-m)
Fuel								
FO_day: Daily FO tank	FO	50.70	0.90	0.70	6.90	2.45	1.90	0.10
Total Fuel				**0.70**	**6.90**	**2.45**	**1.90**	**0.10**
Fish								
fish_hold: fish hold	CARGO	65.70	0.40	15.00	9.68	0.00	1.77	0.00
Total Fish				**15.00**	**9.68**	**0.00**	**1.77**	**0.00**
Catch on deck								
Catch				**5.00**	**9.20**	**0.00**	**5.49**	**0.00**
Total Catch on deck				**5.00**	**9.20**	**0.00**	**5.49**	**0.00**
Fixed								
trawl gear				3.50	7.30	0.00	3.80	0.00
Crew				0.60	3.10	0.00	3.20	0.00
FW P				0.10	10.30	0.00	0.41	0.50
FW S				0.10	10.30	0.00	0.41	0.50
Total Fixed				**4.30**	**6.85**	**0.00**	**3.56**	**1.00**
Lightweight				**96.50**	**6.60**	**0.00**	**2.61**	**0.00**
Total Displacement				**121.50**	**7.10**	**0.01**	**2.65**	**1.10**

Drafts at equilibrium angle

Draft at LCF	2.389	metres
Draft at AP	2.232	metres
Draft at FP	2.593	metres
Mean draft at midships	2.413	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	1.540	degrees
Trim by the bow	0.361	metres
KG	2.663	metres
FSC	0.001	metres
KGf	2.663	metres
GMt	0.524	metres
BMt	1.670	metres
BMl	11.292	metres
Waterplane area	80.288	sq.metres
LCF	6.451	metres
TCF	0.081	metres
TPI	0.823	tonnes/cm
MCT	0.933	tonnes-m/cm
Range postive GZ	40.402	degrees
Max GZ	0.150	
Shell thickness	0.015	mm

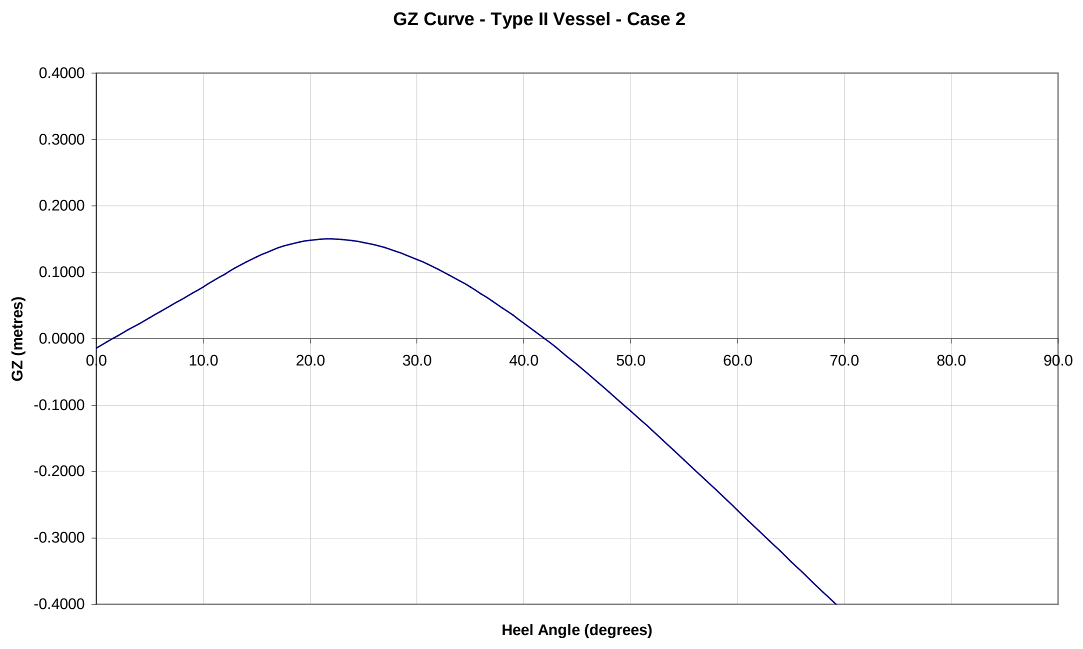
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.051	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.013	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.065	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.120	0.200
5	Initial GM to be at least 0.35 metres	0.524	0.350
6	Maximum GZ to be at an angle of => 25 degrees	21.8	25.0

Immersion Particulars

Deck Edge

Point #	X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
0	7.35	3.00	4.50	2.005	34.090
1	7.35	-3.00	4.50	2.166	132.207



Type II Vessel - Case 5 - Fish Hold Flooded

Title	Cargo	% full	SG (t/m3)	Weight (t)	LCG (m)	TCG (m)	VCG (m)	FSM (t-m)
Fuel								
FO_day: Daily FO tank	FO	50.70	0.90	0.70	6.90	2.45	1.90	0.10
Total Fuel				**0.70**	**6.90**	**2.45**	**1.90**	**0.10**
Flood Water								
fish_hold: fish hold	WB	8.50	1.025	5.00	9.77	0.00	1.11	29.60
Total Flood Water				**5.00**	**9.77**	**0.00**	**1.11**	**29.60**
Fixed								
Cargo				15.00	9.68	0.00	1.77	0.00
trawl gear				3.50	7.30	0.00	3.80	0.00
Crew				0.60	3.10	0.00	3.20	0.00
FW P				0.10	10.30	0.00	0.41	0.50
FW S				0.10	10.30	0.00	0.41	0.50
Total Fixed				**19.30**	**9.05**	**0.00**	**2.17**	**1.00**
Lightweight				**96.50**	**6.60**	**0.00**	**2.61**	**0.00**
Total Displacement				**121.50**	**6.60**	**0.06**	**2.48**	**30.70**

Drafts at equilibrium angle

Draft at LCF	2.386	metres
Draft aft at marks	2.206	metres
Draft fwd at marks	2.617	metres
Draft at AP	2.206	metres
Draft at FP	2.617	metres
Mean draft at midships	2.411	metres

Hydrostatics at equilibrium angle

Density of water	1.025	tonnes/cu.m
Heel to starboard	7.160	degrees
Trim by the bow	0.411	metres
KG	2.485	metres
FSC	0.244	metres
KGf	2.729	metres
GMt	0.315	metres
BMt	1.281	metres
BMl	11.233	metres
Waterplane area	80.249	sq.metres
LCF	6.495	metres
TCF	0.380	metres
TPI	0.823	tonnes/cm
MCT	0.929	tonnes-m/cm
Range postive GZ	43.201	degrees
Max GZ	0.146	metres
Shell thickness	0.015	mm

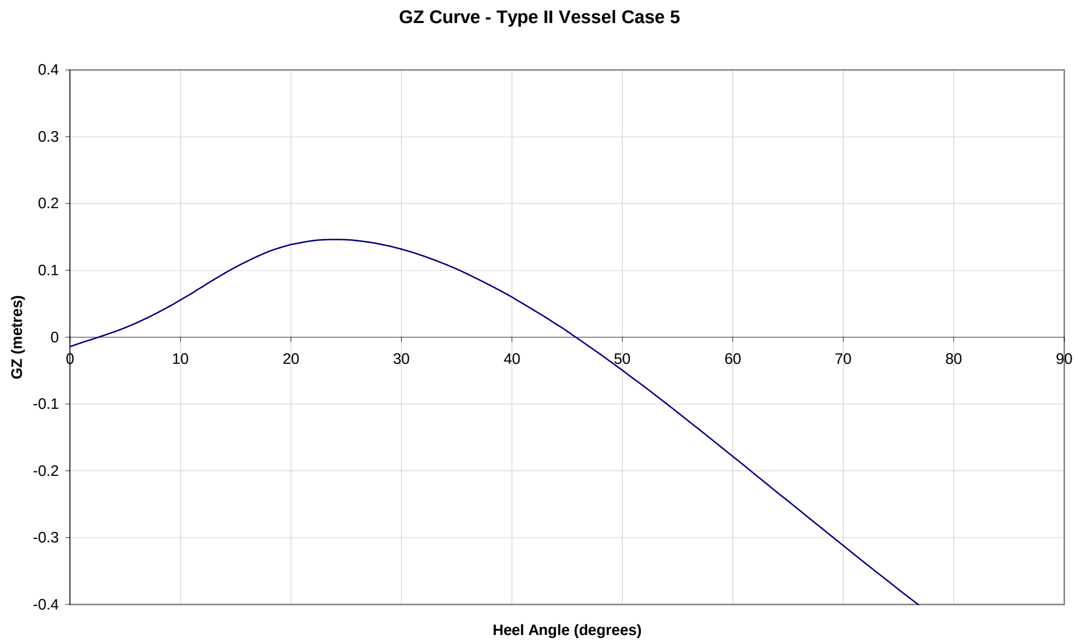
Stability Criteria

#	Criterion	Actual Value	Critical Value
1	Area under GZ curve up to 30 degrees > 0.055	0.046	0.055
2	Area under GZ curve from 30 to 40 deg. or downflood > 0.03	0.017	0.030
3	Area under GZ curve up to 40 deg. or downflood > 0.09	0.063	0.090
4	GZ to be at least 0.20 metre at 30 degrees or above	0.132	0.200
5	Initial GM to be at least 0.35 metres	0.315	0.350
6	Maximum GZ to be at an angle of => 25 degrees	24.0	25.0

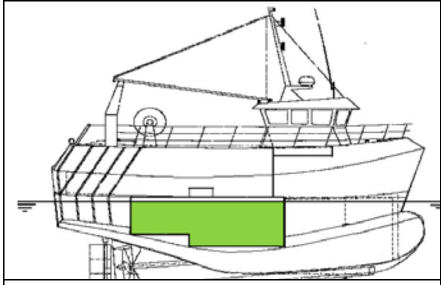
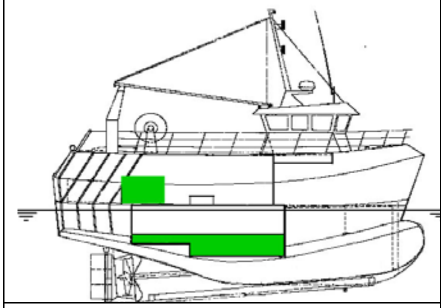
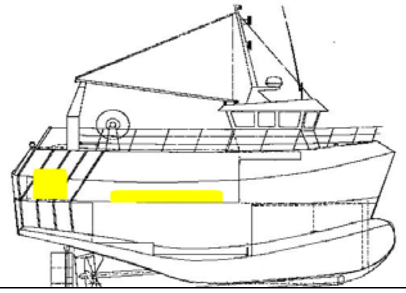
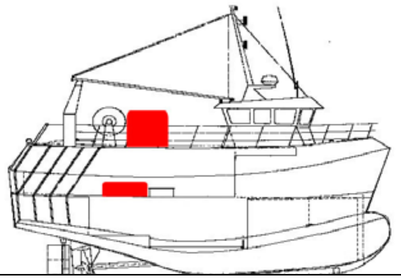
Immersion Particulars

Deck Edge

Point #	X position (m)	Y position (m)	Z position (m)	Ht. above WL (m)	Flood Angle (deg)
0	7.35	3.00	4.50	1.947	34.086
1	7.35	-3.00	4.50	2.216	132.164



APPENDIX 2 – EXAMPLE STABILITY NOTICE

STABILITY NOTICE				
Vessel Name, number, port, length, Owner's names etc	STOWAGE OF GEAR & CATCH	STABILITY		
		Acceptable	On the Limit	Danger of Capsize
	• Catch in cargo hold			
	• Part load in hold • Some catch in fishroom			
	• Gear on main deck • Some catch in fishroom • Empty cargo hold			
	• Empty cargo hold • Some catch in fishroom • Large catch on shelter deck			

Simple efforts for maintaining stability:

- Ensure watertight doors remain shut at sea
- Close doors of all hatches
- Ensure scuppers are open and clear of obstructions to allow water to drain
- Move gear and catch from shelter deck to cargo hold and secure against shifting
- Freeboard amidships should be X cm
- Avoid following and quartering seas
- Large heeling moments when hauling gear are to be avoided
- Vessel may become unsafe if points of lifting are moved or larger gear is installed
- Ensure Fish Hold remains free from flooding