DEVELOPING AN ARTIFICIALLY INTELLIGENT ROLL STABILIZATION SYSTEM FOR USE ON FISHING VESSELS

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Abstract

The stability of Fishing Vessels has long been a subject that provokes fervent discussion within the marine industry. With the advent of so called rule beating designs and increasing pressures being put on owners for their vessels to satisfy a range of roles, vessels are being built with far from favourable motion characteristics. With commercial fishing still being an extremely dangerous profession, there is a great need for the safety of these vessels to be improved. One method of increasing the safety of fishing vessels is the improvement of motion characteristics. This can help to make a vessel a safer and more comfortable platform to work on. In the case of this study safety improvement is sought through the reduction of the roll motion.

A variety of methods exist to reduce roll motion, including bilge keels, fin stabilisers, gyro systems and anti-roll tanks, the latter being the type developed in this study. In order to be effective an anti-roll system for use on fishing vessels must be capable of dealing with the ever changing loading and operating conditions. Most anti-roll tanks are only capable of reducing motions for a set range of conditions and so are limited in their applicability to fishing vessels. This paper reports on a programme of research and development undertaken at Newcastle University to incorporate intelligent control and so optimise the roll reduction performance of any stability tank. This paper will report the results of an extensive vessel monitoring programme recording the extreme motions of a fishing vessel operating in the Atlantic and the North Sea during the winter months. This monitoring is intended to record the unstabilised vessel's motions prior to the installation of the system currently under development. The outcome of this study will be an innovative system that is capable of greatly increasing the safety of fishing vessels while remaining economically viable.

1. INTRODUCTION

If there is still any doubt whether there is continued need for the safety of fishing vessels to be improved, the 2002 report by Dr. Stephen Roberts of Oxford published in the Lancet in 2002 [1] should leave us in no doubt at all. The report shows that Commercial Fishing is by far the most dangerous occupation in the UK; fishers are 50 times more likely to have a fatal accident than any other occupation; with this fact being mirrored in other countries around the world. The fact that merchant seafarers were second in the list is perhaps no surprise, but even these have significantly lower fatality rates than those of fishermen.

The reasons for the apparent imbalance between the safety of fishing and other maritime occupations are numerous. The recent investigations by the Marine Accident Investigation Branch in the UK go someway in analysing the causes of losses of both people and vessels [2]. In many respects it could be said that the fishermen do themselves no favours, with questionable maintenance regimes responsible for mechanical failures that subsequently cause catastrophic accidents. Coupling this with the fact that stability guidance is often ignored or simply believed to be unsound leads the fishermen into a very precarious situation, where they may perceive that their vessel is 'safe' and then suddenly find themselves in serious trouble due to incorrect loading and fundamental misunderstanding of the principles of stability and the safe loading of a vessel. It must be said that fishermen's condition is deserving of sympathy, with the ever increasing economic pressures being placed on them it is no wonder that they often put themselves into potentially dangerous situations in order to maximise their earnings.

There are many potential solutions to the safety problems of the fishing industry. Without doubt there needs to be a change in the safety culture, or lack there of. Though this may be very difficult to achieve with any real success. Better training of those entering the industry would go a long way to address the lack of stability knowledge that leads to many casualties. The endemic peer pressure to adopt traditional practices and ignore safety measures would obviously have a negative effect on this.

If the safety of a vessel can be improved without the intervention of the crew then perhaps some of the problems mentioned above could be solved. The system under development in the project, presented in this paper, aims to produce a frequency adaptive roll stabilisation tank that requires little or no intervention from the crew. Also, through the monitoring of the vessel's motions, safety guidance such as the current risk of capsize can be provided to the bridge based on real time data acquired as inputs for the artificially intelligent controller that governs the system. At first sight a system with the capability to alter the motions of a vessel, independent of any human intervention, might seem a risky proposal. This is even more apparent when coupled with an inherently busy and possibly fatigued crew. To account for this, the implementation of fail safe arrangements and an independent monitoring computer to ensure predefined limits are not exceeded will ensure that a device intended to improve safety does not do the opposite and endanger the crew more.

2. DESCRIPTION OF ROLL STABILISATION TANKS

Anti-roll tanks generally fall into two categories – Free surface and U-tube. Free surface tanks are simple rectangular containers with a central obstruction, such as a baffle, to impede the flow of water. U-tube tanks consist of two separate tanks connected by a water conduit at the base and an optional air conduit in the roof, with valves or baffles in the conduits to alter the fluid flow. The operation of an anti-roll tank is classified as either active, in which the water in the tanks is pumped from one side to the other, or passive, in which the water flows under the influence of gravity. The major roll stabilisation effect comes from the mass moment of the water and the creation of a significant anti-roll moment therefore requires large amplitude motions coupled with a significant phase difference between the water and the ship roll. For an active U-tube system this is easily achieved but the pumping systems are bulky and expensive to run. Consequently passive anti-roll tanks are far more common on fishing vessels and the creation of an effective anti-roll moment is more complicated.

Since both free-surface and U-tube tanks exhibit second order characteristics, the most common design procedure for passive tanks is to choose the geometry so as to give a natural frequency close to that of the ship [3],[4]. Then when the ship roll is worst the water in the tank will oscillate with large amplitude and a phase lag close to ninety degrees. Whilst this strategy is effective at reducing the roll at resonance, it can actually increase the roll amplitude at other wave frequencies. This is a particular problem at low wave frequencies when the ship is rolling slowly, since the water in the tank will then be closely in phase with the ship roll. This potentially dangerous situation has been resolved in commercial passive U-tube systems [5] by using valves in the air duct to reduce the flow of water, thereby extending the effective period of the tank. Installing the valve system in the air channel avoids the high forces and water hammer effects that would be involved with valves in the water channel, although the compressibility of the air adds extra complexity to the control system. The other drawback of passive-tanks, which is less easily addressed, is that if the vessel takes on cargo such as fish, the ship's natural roll frequency will change and the tank will no longer be correctly tuned. One option is to change the depth of water which will alter the tank natural frequency, however this will inevitably be slow and require expensive automated pumping systems to be installed, therefore it is more practical to adjust a valve mechanism in the water conduit. Whilst tanks of this type are already available the concept is currently only applied to U-tube tanks of known geometry that have well-defined flow characteristics. To make a frequency adaptive roll stabiliser more applicable to fishing vessels, the majority of which are already fitted with simple free-surface tanks, will therefore require a control system which can adapt to tanks of varying geometry with minimal prior knowledge of the vessel to which they are fitted. This is the primary objective of the research programme currently underway at the University of Newcastle aimed at developing a generic controlled-passive stabiliser system of this type.

2.1. Adaptive Tank Control

To assist in the development of the roll stabilisation system a working fishing vessel – the 56 metre stern trawler *Forever Grateful* – is being used as a test bed for the prototype system. The vessel is shown in Figure 1. The main particulars are shown in Table 1.

Figure 1: Fishing vessel Forever Grateful

Table 1: Principle particulars of fishing vessel Forever Grateful

Length Overall	=55.950 m
Length B.P.	=47.400 m
Breadth Mld	=11.500 m
Depth Mld. (Main Deck)	=6.000 m
Depth Mld. (Shelter Dk)	=8.400 m
Keel Depth	=0.830 m
Displacement at deepest draft	=3138.972 t
GM at this condition	=0.736 m

The ship is currently fitted with a stability tank (Beam = 8m, Height = 3.5m, Longitudinal Length = 1.8m), located 10 metres above the keel and using a central partition containing two large holes to act as a baffle. Half-filled the tank contains 26 tons of water whilst the displacement of the vessel varies between 2000 and 3000 tons, depending on the loading condition. The tank geometry presents three possible options – keep the existing partition to divide the tank into two sections, replace the central partition with two side partitions to divide the tank into three sections, or fit a box construction in the roof to create a rudimentary U-tube. Since the air volume above a partitioned tank is too large to allow control of the water flow-rate, the control valves must be placed in the water, using a set of vertical vanes rotated between 0 degrees (fully closed) and 90 degrees (fully open), as shown in Figure 2. The initial design for the vane mechanism involves a hydraulic actuator situated on top of the frame, with a simple position transducer providing the feedback signal. Whilst the double-partition design has useful stabilising properties [6], it would require two sets of vanes and will therefore not be considered on the grounds of cost. The practical alternatives are therefore a single partition or a pseudo U-tube, where the single-partitioned tank will hold a large volume of water but will have less well-defined flow characteristics than the U-tube.

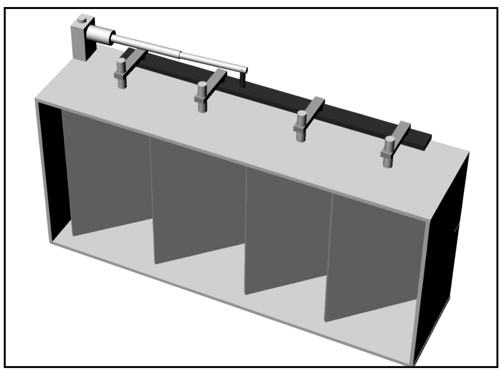

Figure 2: Initial Design of Baffle and Actuator Arrangement

2.2. Intelligent Control Algorithms

Two different control strategies will be considered during the project, based on adopting either an intermittent or continuous flow profile. Since the mass moment provides the majority of the roll reduction effect, the intermittent flow control strategy will attempt to maximise this by trapping as much water as possible on the side that opposes the roll. Thus as the ship rolls to port the majority of the water will be held in the starboard tank with the vanes closed and the vanes only opened close to the maximum port roll angle, thereby transferring the water into the port tank ready for the roll to starboard. A proto-type U-tube stabiliser of this type [7] has already been tested on a twelve metre vessel and the reported results indicate that the worst-case roll with the control system activated was approximately 40% of the worst roll with the vanes kept shut and 65% of the worst roll with the vanes kept open. It was also reported that the stabiliser performance degraded if the ship roll frequency was not significantly less than the tank natural frequency, so a pre-requisite of this strategy is that there is sufficient time to allow the majority of the water to be transferred in a reasonable fraction of the roll period. The control logic for the intermittent strategy is summarised below.

```
IF T = (0.5 x RollPeriod  -  0.25 x TankPeriod)
        IF RolltoPort & StrbrdLevel>PortLevel
        FILLTANK=Port                    Vane=Open


        IF RolltoStrbrd & PortLevel>StrbrdLevel
        FILLTANK=Strbrd          Vane=Open

        ENDIF
ENDIF

IF Vane=Open
        IF FILLTANK=Strbrd & FlowtoStrbd<0
                                 Vane=Closed
        IF FILLTANK=Port & FlowtoPort<0
                                 Vane=Closed
        ENDIF
ENDIF
```

3. UNSTABILISED VESSEL MONITORING

Opportunities to conduct full scale sea trials are always rare; however this project is fortunate to be able to monitor a working fishing vessel for the entire duration of the project. The results presented in this paper cover the fishing period of the vessel from October 2002 to March 2003.The period obviously covers the winter and so the harshest conditions the vessel is likely to encounter during the year.

As previously mentioned the vessel being used in this project is the 56m stern trawler *Forever Grateful*. The vessel operates from the port of Fraserburgh on the east coast of Scotland. The main catch species for the vessel are mackerel and herring. The vessel primarily operates in the North Sea, landing its catch predominantly in Scottish and Norwegian ports. The general arrangement of the vessel is shown in Figure 3.

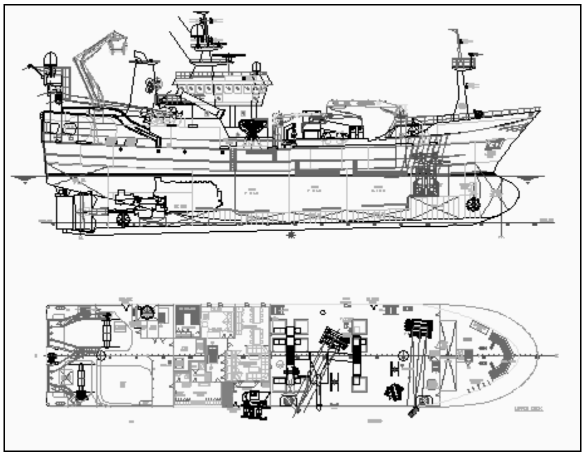

Figure 3: General Arrangement of Forever Grateful

The monitoring results presented here and those which are currently being collected are intended to be used for comparison purposes, to evaluate the effectiveness of the stabilisation system when it is installed on the vessel later this year. The vessel is presently installed with a passive partitioned roll stabilisation tank. Periods where the current tank is in operation are also being recorded to classify the improvement the new stabilisation tank provides over the present configuration. The monitoring is being carried out continuously to ensure data is collected about a wide range of loading and weather conditions. This is achieved by automated recording of the motion and wave data.

3.1. Monitoring Regime

For a sensible seakeeping analysis to be carried out the records need to contain around a 100 oscillations. This ensures the records are reliable and the chance recording of unusually severe or moderate conditions, that shorter records might produce, is avoided. Taking into account the available computer storage, and the fact that for very long records real changes in the wave conditions may take place due to changes in wind speed and the arrival of distant storms, the above noted size seems particularly reasonable. With a roll period of 12 seconds, common for the test vessel, this gives the length of each record as 1200 seconds or 20 minutes duration. It was decided to record the data every 2 hours in a compromise between data storage availability, the amount of data to be analysed, and the desire to collect as much information about the sea conditions and vessel's motions as p ossible.

The motion data being collected consists of Roll, Pitch, Heave and Sway displacements. The wave data collected consists of wave height, relative wave height, zero crossing period, and significant wave height. These are recorded as digital signals with a sampling rate of 10 Hz. The files have the prefix FV and are numbered sequentially. In the event of a power black out the monitoring computer needs restarting. The file numbering system resets itself however no data is lost as new data blocks are simply added to the existing file if it already exists. The data is sorted using the date and time code at the start of each block of data recorded to a file.

One might imagine a power black out at sea is a rare event on a modern fishing vessel; however, it's worth noting that this has occurred three times during this initial monitoring period. The first occasion being shortly after the vessel left the port of Egersund, after the researchers from Newcastle left the vessel, as is mentioned in the discussion of effectiveness of the current stability tank design in section 4.

The monitoring equipment consists of a Kongsberg Seatex MRU to record the ship motions and a TSK Remote Wave Height Meter to record the wave conditions.

It is usual to mount the wave sensor on a boom to ensure that interference from bow waves is avoided. The *Forever Grateful* thankfully has a large enough bow flare though so this is not required. A boom mounted over the bow would undoubtedly experience severe impacts in the harsh conditions of the North Sea.

The wave sensor has a wave height range of 0 to 30 m, a resolution of 1.4 cm and an accuracy of 10 cm. The wave period range is 0 to 20 seconds. The sensor unit contains a Gunn oscillator, two detector diodes, a microwave horn, and two amplifiers. X–Band microwaves are emitted vertically downwards onto the moving sea surface. Deflected microwaves which have undergone a Doppler shift caused by the moving sea surface are mixed with the original microwave signal in the sensor wave guide; this shift is used to measure the distance between the sensor and the sea. To calculate the actual wave heights, the motion of the sensor must be removed from this measurement. This is accomplished by double integrating the output of the accelerometer which is mounted in the whaleback directly under the deck, so as to be as close as possible to the sensor's location without being exposed to the elements.

The motion measurement unit contains 3-axis angular rate sensors and 3-axis acceleration sensors providing higher performance than simpler devices. It provides a very high dynamic accuracy of 0.030º RMS for angular motions and 5 cm for heave displacements even in extreme conditions. The sensor is mounted as close to the CG of the vessel as possible on a transverse bulkhead. Obviously, the CG of the vessel varies as the loading condition changes. This will produce a small error in the measurements for loading conditions other than that with which the sensor is configured. This is unavoidable though for the type of automated monitoring being conducted, without crew intervention.

3.2. Vessel Log

In order to ascertain what the current vessel condition is for each motion and wave record, a vessel log is completed by the crew. It is intended that this log is filled in whenever the condition of the vessel changes, either in terms of loading or operation, for example no fish onboard, on route to fishing grounds, small catch, searching for fish. The vessel log takes the form of a Microsoft Access database. There are a number of options with buttons to tick for the current condition, such as wind speed, heading, operating condition, sea state, vessel speed, loading condition etc, as shown in Figure 4.

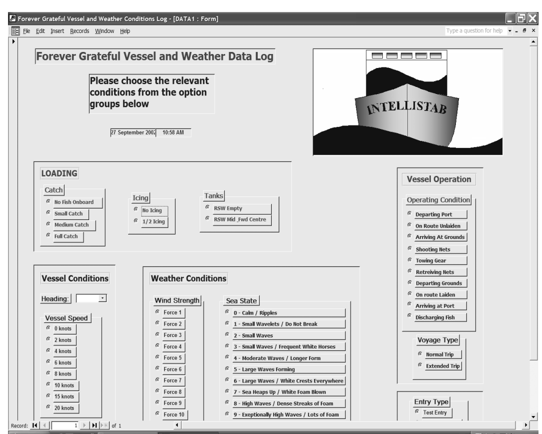

Figure 4: Microsoft Access Vessel Log

4. MONITORING RESULTS

The following section details a summary of the monitoring carried out for the winter 2002 – 2003 fishing period of the Forever Grateful. The vessel left Fraserburgh to begin fishing on the 16th October 2002. She continued fishing constantly, aside from one to two day stops at various ports as catches were unloaded during this time. The vessel and crew returned to Fraserburgh on the 23rd December 2002 for a short Christmas break, and began fishing again on the 2nd January 2003 until the 8th February.

4.1. Roll Responses

Roll Periods

As the system under development is intended to be frequency adaptive, that is to *retune* the frequency of the anti rolling moment produced by the flow of water across the tank to the current roll period, the distribution of roll periods provides us the operational boundaries for the system. Figure 5 shows the distribution of roll period as recorded in the winter fishing period.

The modal period is 12.46 seconds which corresponds to various loading conditions. With reference to the *Forever Grateful's* stability booklet the loading conditions which have a natural period similar to the modal period recorded are: Departure from fishing grounds with a small catch onboard – 12.41 s, and Arrival in Port with a small catch onboard – 12.80 s.

Although the existing passive stabilisation tank could be modified and tuned to match this modal period, its effectiveness away from this tuned period would be significantly reduced, as has been shown in numerous past studies [3]. The system under development will be capable of adapting to the changing roll period so that effective roll reduction is achieved across a much wider range of roll periods.

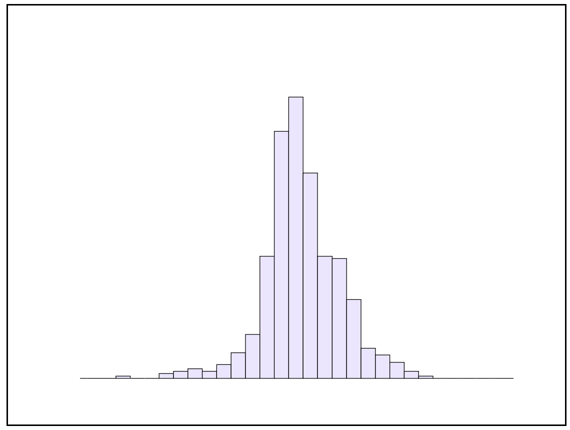

Figure 5: Distribution of Roll Periods

Extreme Motions

A fishing vessel of this size will undoubtedly experiences some severe weather operating in the North Sea in winter, the maximum roll amplitude found in each motion record gives an indication of the severity of the motions experienced by the vessel and crew.

As can be seen in Figure 6, the roll amplitudes are widely distributed, with values ranging up to 45 degrees, although this is only a small proportion of the total. Figure 7 however, shows that slightly over 25 % of the values lie above 23 degrees, suggesting that large rolls are fairly common. The probability the roll amplitude being over say 40 degrees is only 0.0202 however.

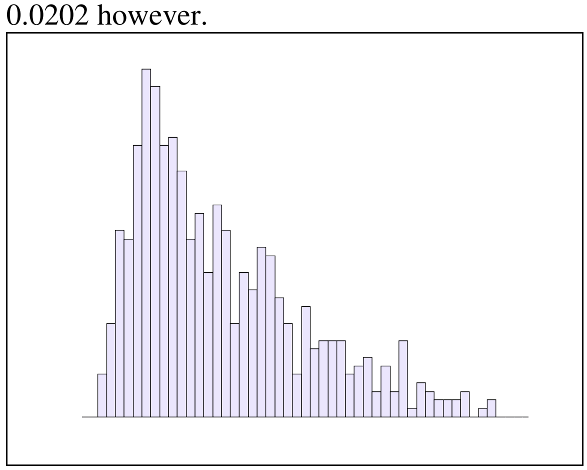

Figure 6: Distribution of Maximum Roll Amplitudes

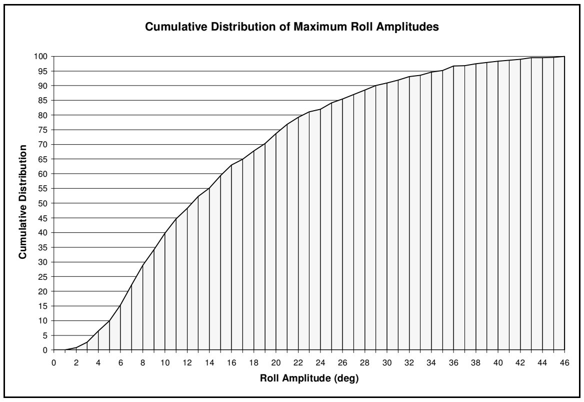

Figure 7: Cumulative Distribution of Roll Amplitudes

<u>Significant Roll Motions</u>

The distribution of significant roll responses of the vessel is shown in Figure 8. The significant response is the average of the largest third of a set of measurements. This is calculated using equation (1), where (ϕ) is the roll amplitude and (σ) is the variance of the signal.

$$\phi_{1/3} = \sqrt{4}\sigma \qquad (^{\circ}) \qquad (1)$$

The responses are widely distributed with values ranging up to 30º. A large proportion of the values lie between 5 and 10º (48.3 %) indicating moderate but not extreme motion. The distribution is not without severe motions though, the probability of the motion being greater than 15º being, 0.193 (19.3 %).

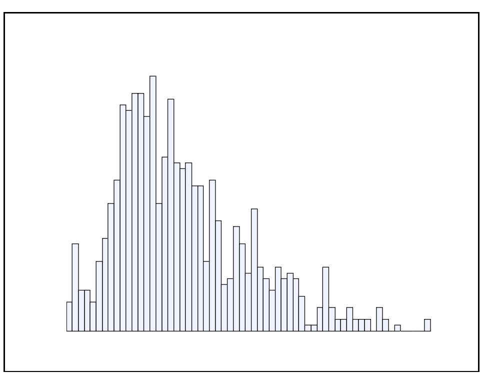

Figure 8: Distribution of Significant Roll Angle Wave Conditions

A common method of representing the severity of sea conditions is the significant wave height. This is a useful measure as it corresponds well with visual observations as people tend to notice larger waves when observing the sea surface. The significant wave height is calculated in the same manner as significant roll angle.

The actual distribution is shown in Figure 9, and Figure 10 shows the cumulative distribution. Figure 9 shows the modal wave height to be 3 metres. The values range up to 13m, the equivalent to a Force 8 or 9 gale.

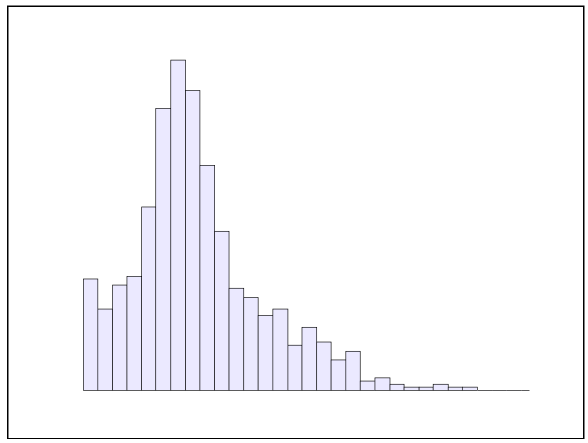

Figure 9: Distribution of Significant Wave Heights

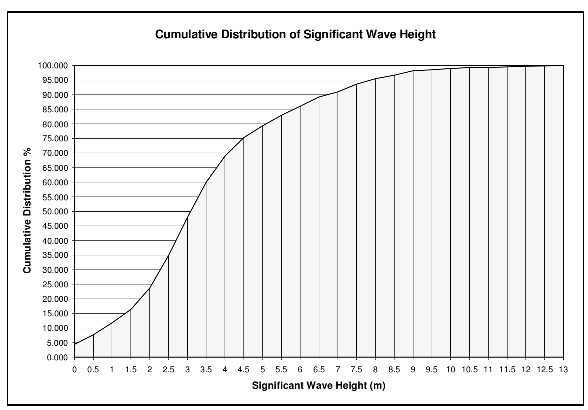

Figure 10: Cumulative Distribution of Significant Wave Height

As can be seen from Figures 9 and 10, a large proportion of the wave records lay between 2 and 5 m (63 %). Some very large readings are present though only 5% of the readings were above 8m.

Scatter diagrams of sea conditions provide a means to determine whether the conditions encountered during the monitoring period were more or less severe than normally expected [8]. Figure 11 shows the boundaries of the areas for which the wave statistics are calculated. The areas relevant to the Forever Grateful are Areas 4 and 11. The vessel spent the majority of its time in Area 4; however the port of Fraserburgh lies just inside Area 11 so this cannot be discounted.

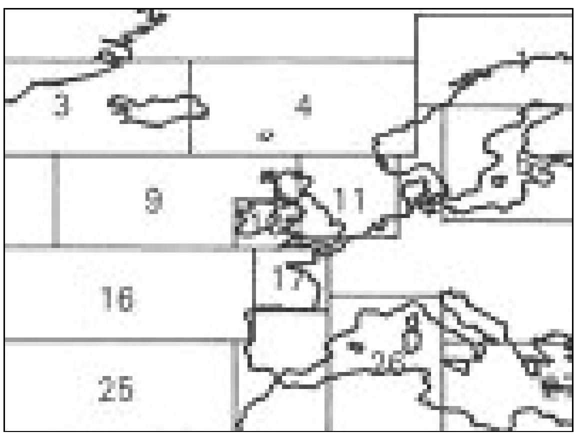

Figure 11: Map showing areas for which wave statistics are calculated

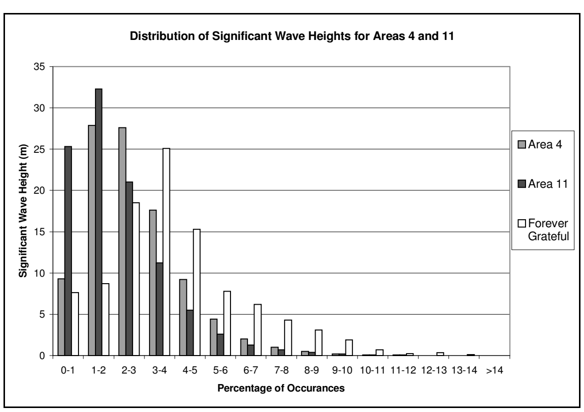

Figure 12: Distribution of Significant Wave Heights for Areas 4 and 11

Figure 12 shows the distribution of significant wave heights for areas 4 and 11, and also the distribution of the monitored results grouped in the same manner as the wave statistics. It appears that the conditions encountered by the Forever Grateful were slightly worse than those normally expected in these areas. Area 4 shows a higher proportion of larger waves than Area 11 as one might expect. The distribution for the Forever Grateful is shifted towards larger waves and shows a less skewed distribution. It also shows far more waves above 5m in height.

5. EFFECTIVENESS OF CURRENT STABILITY TANK

Although the vessel is currently installed with a passive stability tank the effectiveness of this tank was unknown at the outset of this project. Obviously it is not possible to present all the data records that include the use of the stability tank. The results presented here were recorded on the 18th October 2002 and the 19th December 2002. Both these data sets show a period when the stability tank was empty followed by a period where the tank was filled. During the first October data set, members of the research team from Newcastle were aboard the Forever Grateful for a 10 day period overseeing the commencement of the monitoring programme. In both cases the data was recorded after a medium sized catch was brought aboard the vessel, and the vessel departed the fishing grounds. In the October records the vessel then set course for the Norwegian port of Egersund where the catch was to be landed. Both these records represent a period where the loading condition of the vessel remained essentially constant, apart from the obvious reduction in fuel mass as this was used on route, though this has been neglected in the comparison of results. Once on route to port the heading and speed of the vessel also remained constant. The vessel log for the October records is shown in Table 2.

5.1. Developing an artifically intelligent roll stabilisation system

Table 2: Vessel Log data recorded for October results

Date	18 October 2002	18 October 2002	18 October 2002	18 October 2002	18 October 2002
Time	11:50:00	13:15:00	14:10:00	15:15:00	18:00:00
Catch	Medium Catch	Medium Catch	Medium Catch	Medium Catch	Medium Catch
Icing	None	None	None	None	None
Tanks	RSW Mid & Fwd Centre	RSW Mid & Fwd Centre	RSW Mid & Fwd Centre	RSW Mid & Fwd Centre	RSW Mid & Fwd Centre
Stability Tank Condition	Empty	Empty	Empty	16 m3	24 m3
Wind Strength	5	6	3	4	4
Wind Direction	W	N	N	N	N
Sea State	6	6	4	5	5
Heading	SW	S	SE	SE	SE
Vessel Speed	2 knots	2 knots	10 knots	10 knots	12 knots
Operating Condition	Towing Gear	Towing Gear	Departing Grounds	Departing Grounds	Departing Grounds
Voyage	Normal Trip	Normal Trip	Normal Trip	Normal Trip	Normal Trip
Entry Type	Genuine Entry	Genuine Entry	Genuine Entry	Genuine Entry	Genuine Entry

5.2. October Records

The vessel log shows the filling level was initially set to 16 m^3, this corresponds to a depth of 1.11 m. Using the standard formula for the natural period of a free surface tank the corresponding period of the tank for this depth is 4.9 seconds. With reference to the vessel's stability booklet the natural roll period for this loading condition (Departure from grounds, medium catch) is calculated to be 11.14 seconds. The tank is clearly not tuned to the current rolling period; however the internal structure of the tank provides significant damping of the water flow across the tank partition, so a reasonable reduction in roll may be achieved. However, the above mentioned internal structure and the fact that the tank contains a central partition with only relatively small holes through which the water can flow, as shown in Figure 13, may well produce such large damping that the flow of water across the tank is severely restricted, thus the subsequent anti rolling moment may only produce a small reduction in roll motion.

The wave and motion data files spanning the time period of the stability tank adjustments were found to be FV45 to FV49. FV45 being recorded from 10:31 am to 10:51 am on the 18th October 2002. Every file is stamped with a date and time code at the end of the 20 minute period it covers.

Table 3 shows the average roll period, amplitude and maximum amplitude for the four files being considered. The response spectra, calculated using Fast Fourier Transforms of the time histories of the roll motion and wave height for files FV45 to FV49 are shown in Figures 14 to 18 in Appendix 1. Figures 14 to 16 show the response of the unstabilised vessel, each having a clear frequency at which the peak response occurs. Figure 17 (File 48) appears to show a reduction in the response peak due to the action of the stability tank. There is a clear frequency in the centre of the response spectra, at which the roll response has been reduced. Figure 18 for file FV49 shows a more general reduction in the response spectrum.

Table 3: Roll response data for files FV 45 to FV49

File	Period (s)	Std Dev	Mean Roll Amplitude (deg)	Maximum Roll Amplitude
45	10.26	1.41	10.14	20.60
46	10.29	1.80	13.89	31.30
47	10.70	1.80	12.30	30.20
48	11.04	1.74	9.95	22.60
49	11.98	1.76	9.53	26.40

Figure 13: Existing Stability Tank Central Partition and Openings

5.3. December Records

The vessel log data for this period are shown in Table 4. As can be seen the stability tank was filled with 4 m^3 of water at 7.56 am on the 19th December. This volume of water corresponds to a natural period of the stability tank of 9.69 seconds. This is much closer to the natural roll period of the vessel in this loading condition so some significant reduction in the roll response is expected. The average roll period, amplitude and maximum amplitude for files FV 112 to FV118 are shown in Table 5. Figures 19 to 24 show the response spectra and time histories for the corresponding period of monitoring. The results shown begin at 00:06 am on the 19/12/2002 with File FV 112.

Table 4: Vessel log data recorded for December Results

Date	19 December 2002	19 December 2002
Time	02:01:53	07:56:45
Catch	Medium Catch	Medium Catch
Icing	None	None
Tanks	RSW Mid & Fwd Centre	RSW Mid & Fwd Centre
Stability Tank Condition	Empty	4 m3
Wind Strength	3	5
Wind Direction	S	SW
Sea State	2	3
Heading	SE	SE
Vessel Speed	10 knots	10 knots
Operating Condition	Departing Grounds	Departing Grounds
Voyage	Normal Trip	Normal Trip
Entry Type	Genuine Entry	Genuine Entry

The roll response for File 115 (Figure 122) appears a little erroneous, in that is shows a similar spectrum to that for Files 116, 117 and 118 where, noting the vessel log data, the tank is filled, but is supposedly recorded before this took place. It is likely that the tank was filled sometime before the crew completed the vessel log. This result can therefore either be ignored, or assigned as being when the tank was in operation. Taking this into account the average roll amplitude for Files 112 to 114 is 8.46º, and for Files 116 to 118 is 5.52º (a reduction of 35

%). There is indeed a reduction in the roll motion after the stability tank is filled.

Another simply method of comparing the responses of the vessel in the stabilised and unstabilised conditions is to calculate the ratio of significant roll angle to significant wave height. The results for all the files are shown in Table 6. The ratios for the October results show little variation, the value for File 48 is slightly lower, indicating the tank may be having some effect here but it is inconclusive. The results for the December period are more conclusive showing a definite reduction in the roll response, and thus the ratio. The wave heights for the stabilised December cases are however lower than the October files, which means the anti rolling moment needn't be as large to have a positive effect on the ship's motion. Alternatively with a small filling depth, as in the December cases, the tank may prove less effective in larger waves due to the small amount of water necessitated by the depth (0.28 m).

Table 5: Roll response data for files FV 112 to FV 118

File	Period (s)	Std Dev	Mean Roll Amplitude (deg)	Maximum Roll Amplitude
112	13.18	1.32	9.11	20.20
113	13.12	1.45	7.90	20.90
114	13.31	1.21	8.37	21.00
115	13.06	1.48	5.99	10.60
116	13.26	1.43	6.00	14.50
117	13.17	1.28	5.50	10.40
118	12.86	1.26	5.07	11.30

Table 6: Significant Response Ratios

FV File No.	Sig. WH (m)	Sig. Roll Angle (deg)	Significant Response Ratio
45	3.77	15.34	4.07
46	4.25	20.96	4.93
47	4.23	18.74	4.43
48	3.80	15.37	4.05
49	3.06	13.88	4.54
112	3.23	13.46	4.17
113	2.53	11.39	4.49
114	2.71	12.52	4.62
115	2.32	8.44	3.64
116	2.75	8.49	3.08
117	2.83	7.35	2.59
118	2.84	6.88	2.42

6. FAIL SAFE CONSIDERATIONS

The presence of an anti-roll tank of the type proposed in this study means there is an additional free-surface acting to reduce the effective metacentric height of the vessel. When the system is operating under normal conditions this additional free-surface would not pose a threat to the stability of the vessel and indeed should be acting to reduce the roll response through the generation of an anti rolling moment. However, in the case of a complete power black out on the vessel, as has occurred during the initial monitoring, the free-surface tank may act in a way that worsens the motions of the vessel. Under these circumstances it must be possible to remove the free-surface and thus increase the vessel's stability. Although this may produce more severe accelerations the vessel will be in an inherently safer condition.

For the above reasons it is essential that the system be rendered inoperable in the event of power loss. This can be achieved in a number of ways. Firstly, closing the central valves within the tank, and thus reducing the area of the free-surface by half, will have the effect of quartering the free-surface effect on the vessel's stability. This could be achieved by having a spring mechanism on the valves which would automatically close them in the event of power loss. Secondly, and more importantly, the water should only be held in the tank if power is present, i.e. water dumping valves on the tank should be held closed under power, and open automatically due to the weight of water if power is lost. With the tank drained the detrimental free surface is removed entirely. Once power has been restored the tank could be refilled and normal operation restored.

7. CONCLUSIONS

The initial monitoring results show clearly that the vessel does undergo large rolling motions and experience severe wave conditions. Due to this the crew will obviously be attempting to carry out their duties on a violently moving platform, which is inherently dangerous. This need not be the situation though.

The results showing the stability tank operation presented here show that the existing stability tank is in some cases not effectively being operated or is simply poorly designed for the vessel on which it is located, and in others produces a reasonable roll reduction. In either case there is significant room for improvement on the roll reduction currently being provided. The proposed solution to both these problems is the implementation of a self governing system that can not only adapt to changing loading and environmental conditions, but also monitor the stability of the vessel and alert the crew accordingly when an unsafe regime has been entered.

Implementation of the prototype system is due to be carried in time for the winter 2003-2004 fishing period, the results of which will be available in 2004. These should show a large reduction in the roll motion of the vessel over a wide range of conditions.

8. ACKNOWLEDGEMENTS

The authors wish to thank the Skipper and crew of the Forever Grateful, without their assistance and cooperation this monitoring exercise would not have been possible. Thanks must also go to Mr David Lamb at Newcastle University whose expertise was invaluable in preparing and configuring the monitoring system. This work constitutes part of the EU Craft project INTELLISTAB currently being carried out in collaboration with Johnson and Smart Projects Ltd, Dantech and AJA Consulting.

9. REFERENCES

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APPENDIX 1

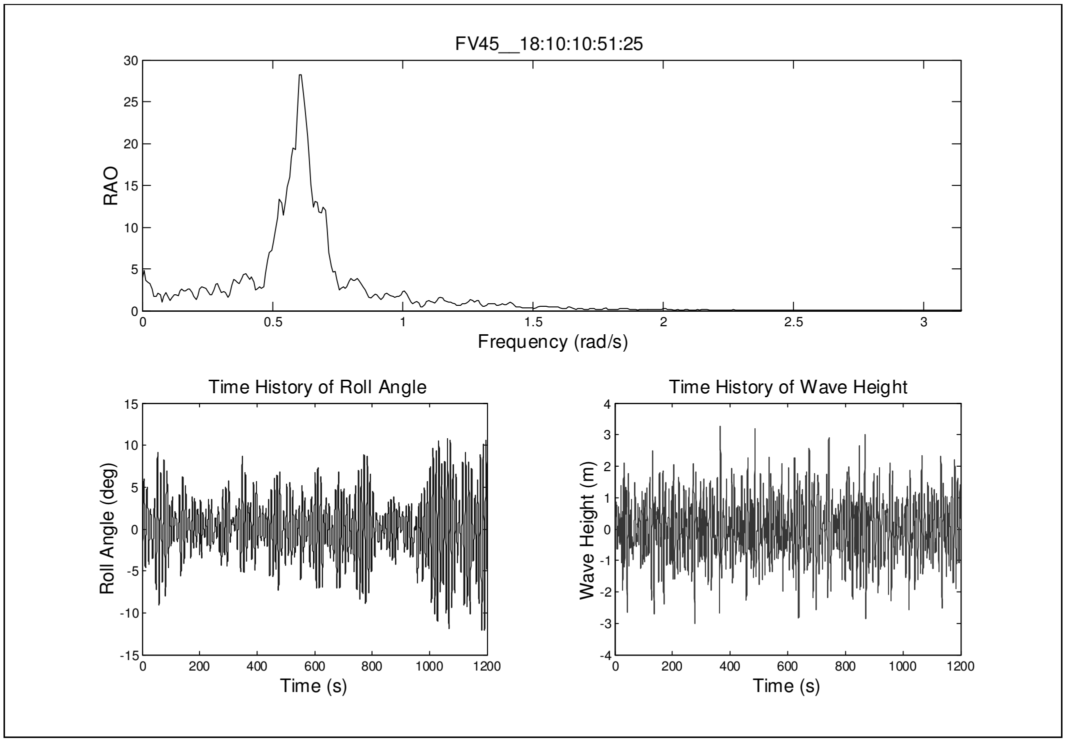

Figure 14: Roll Response Spectrum and Time Histories for File 45

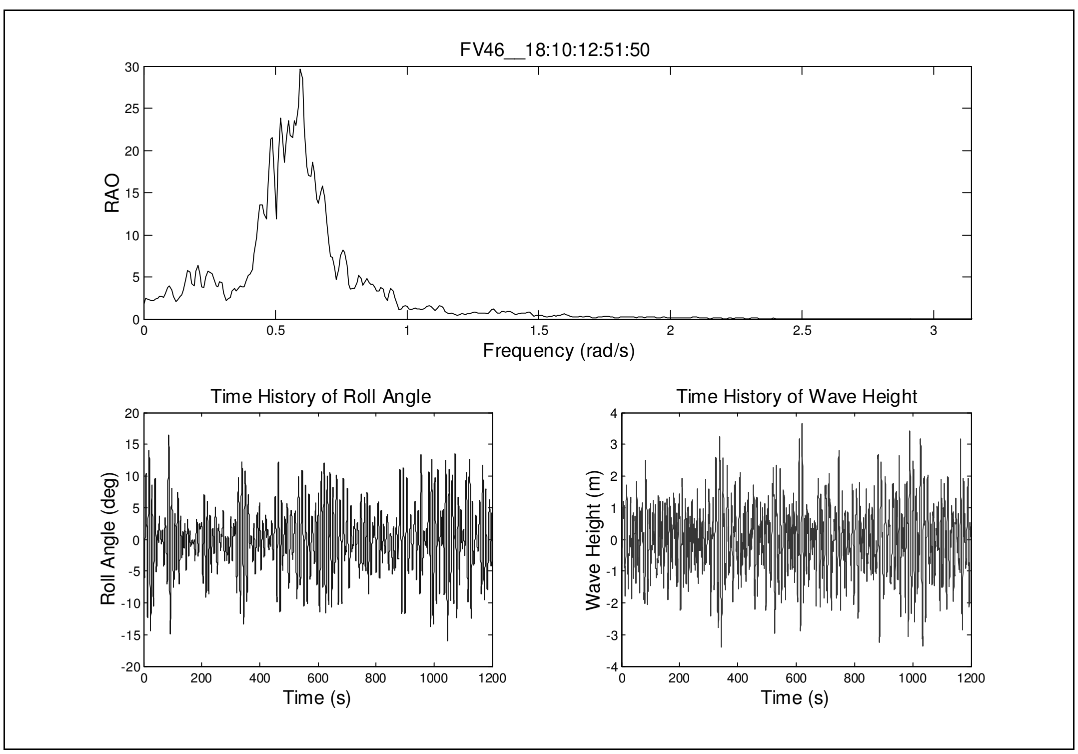

Figure 15: Roll Response Spectrum and Time Histories for File 46

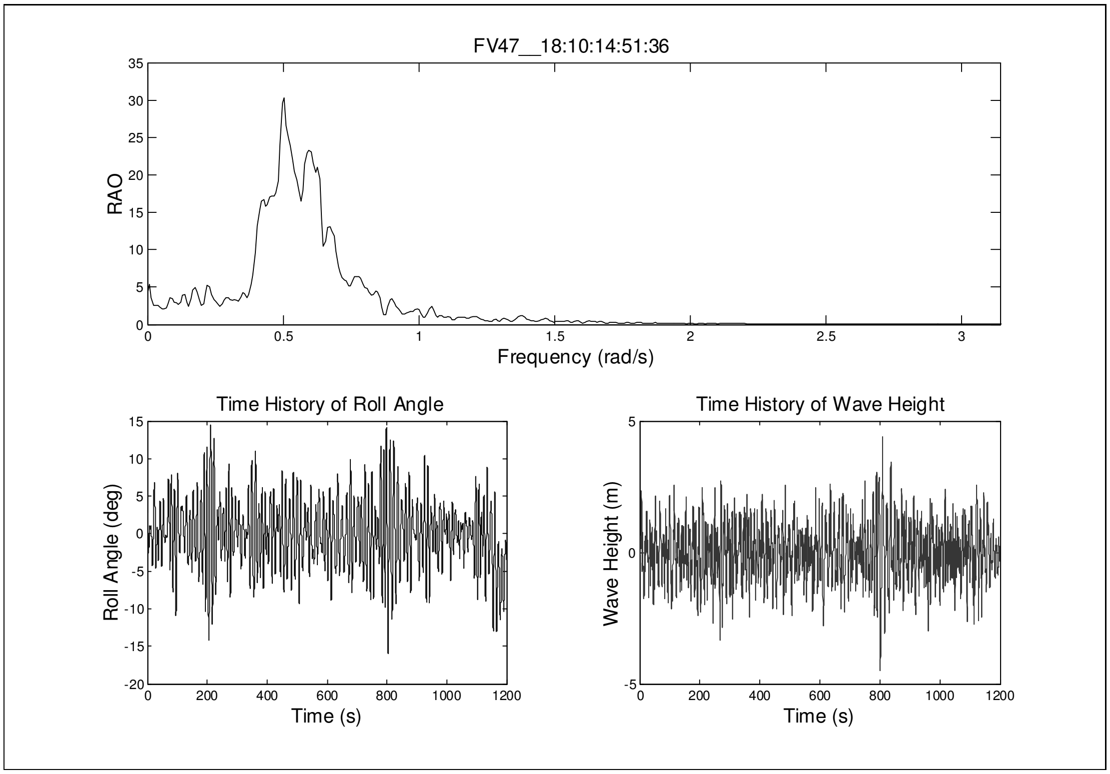

Figure 16: Roll Response Spectrum and Time Histories for File 47

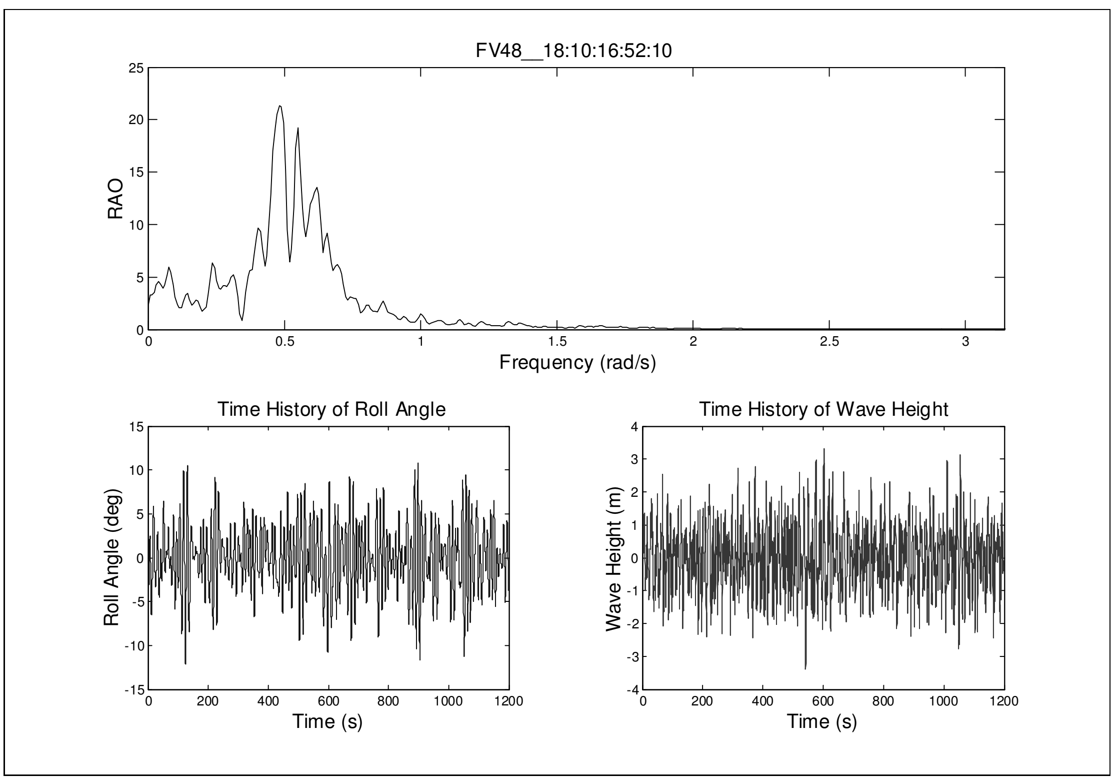

Figure 17: Roll Response Spectrum and Time Histories for File 48

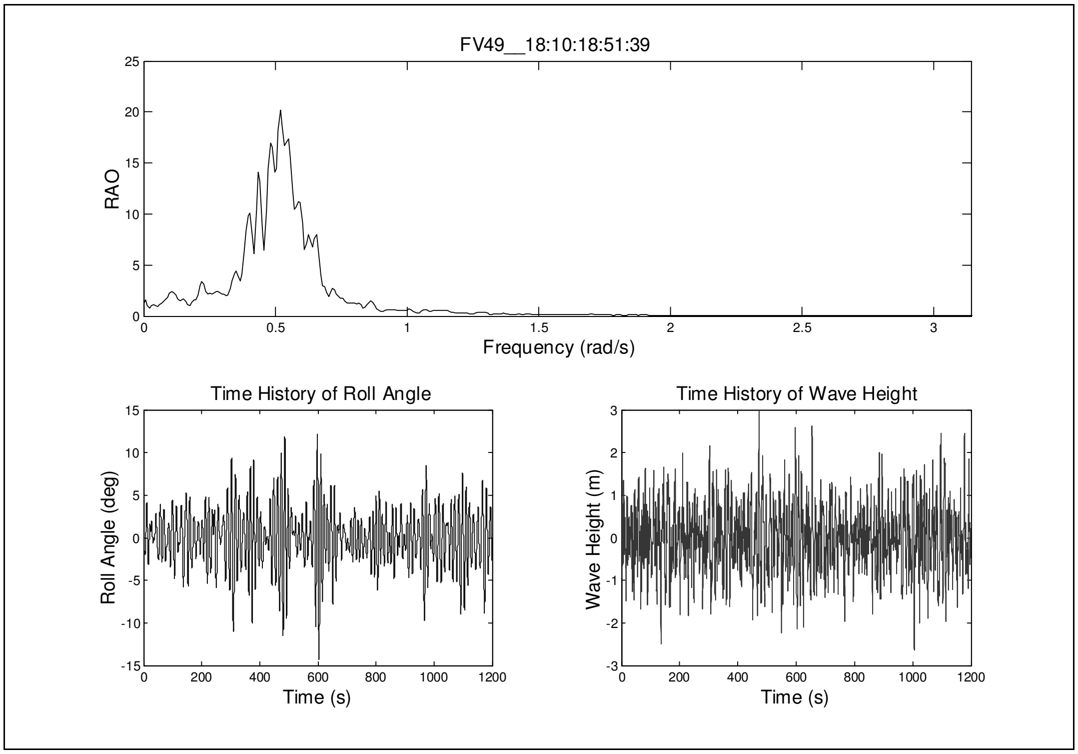

Figure 18: Roll Response Spectrum and Time Histories for File 49

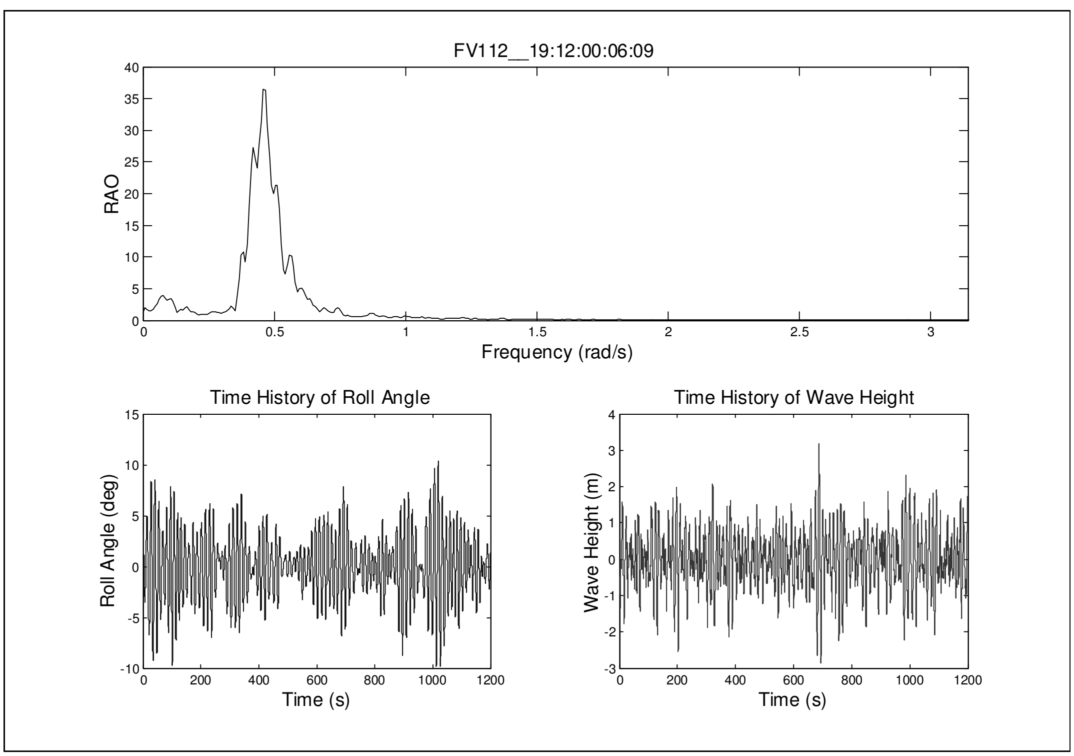

Figure 19: Roll Response Spectrum and Time Histories for File 112

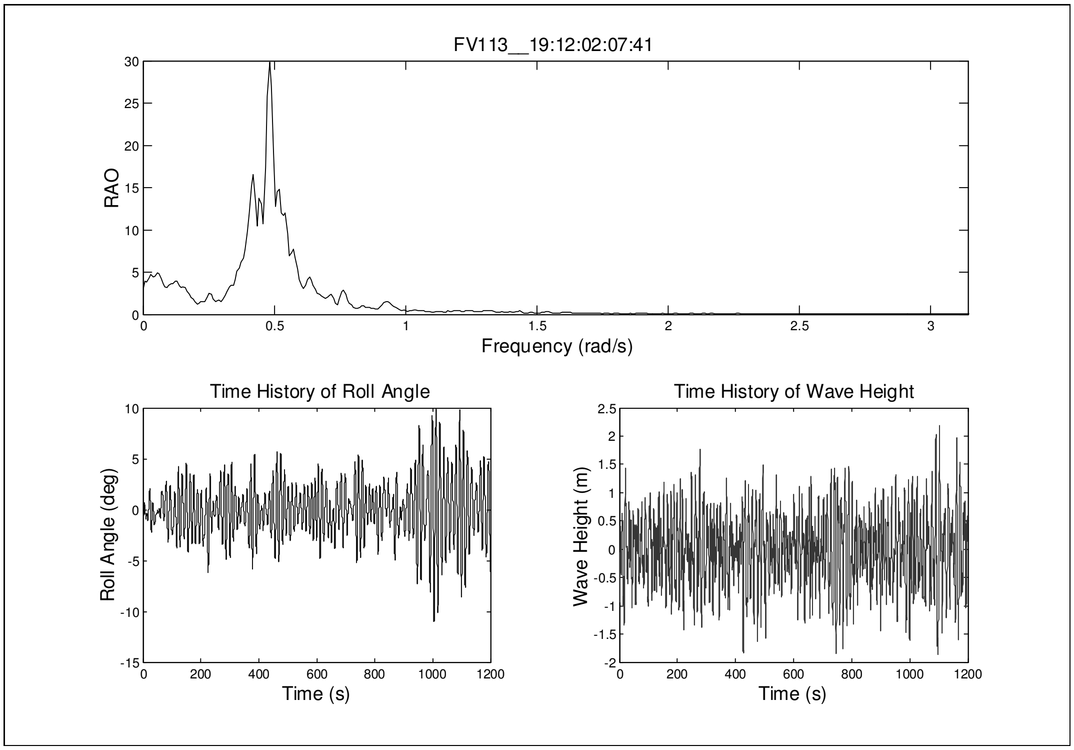

Figure 20: Roll Response Spectrum and Time Histories for File 113

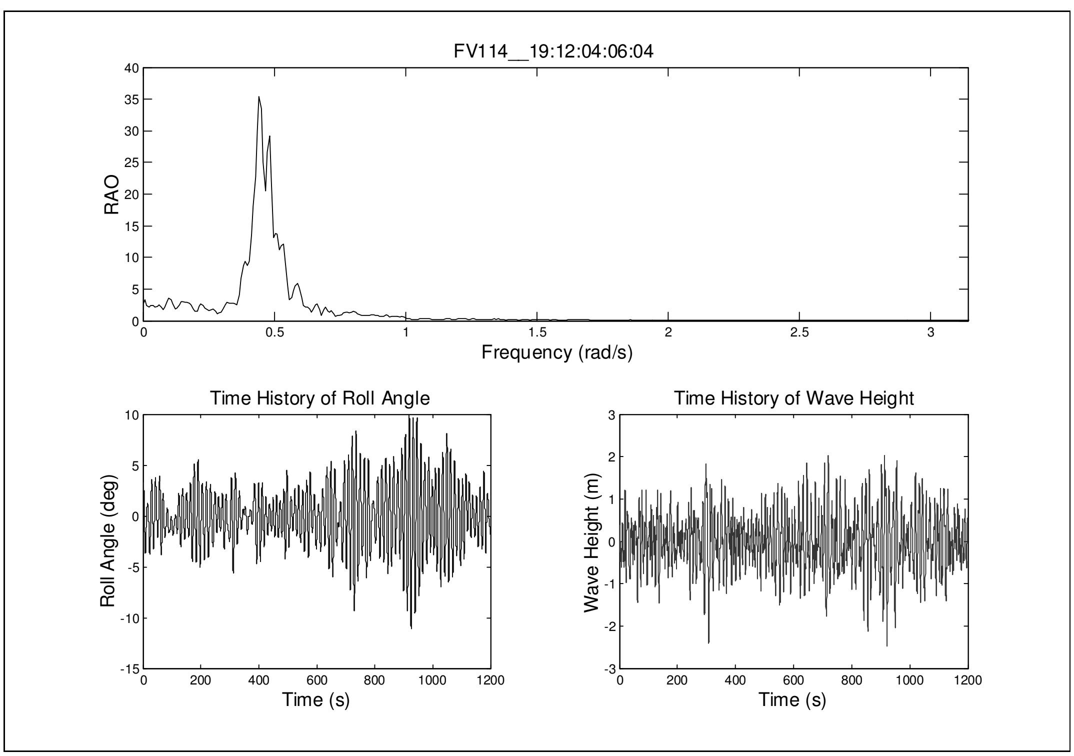

Figure 21: Roll Response Spectrum and Time Histories for File 114

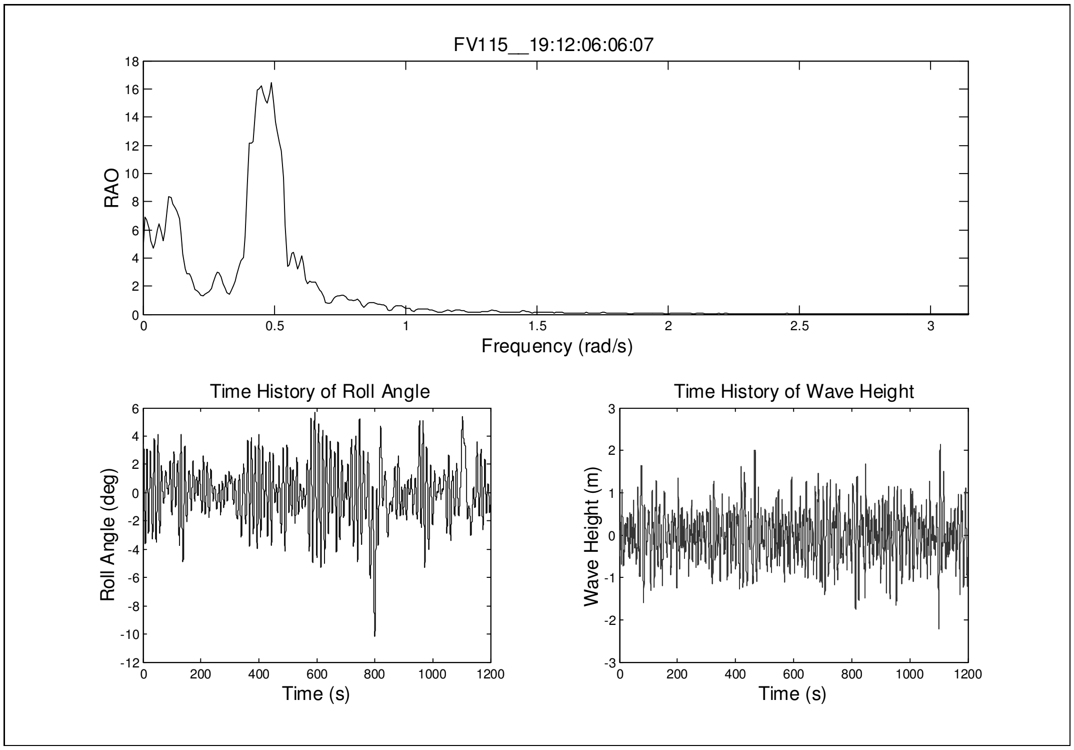

Figure 22: Roll Response Spectrum and Time Histories for File 115

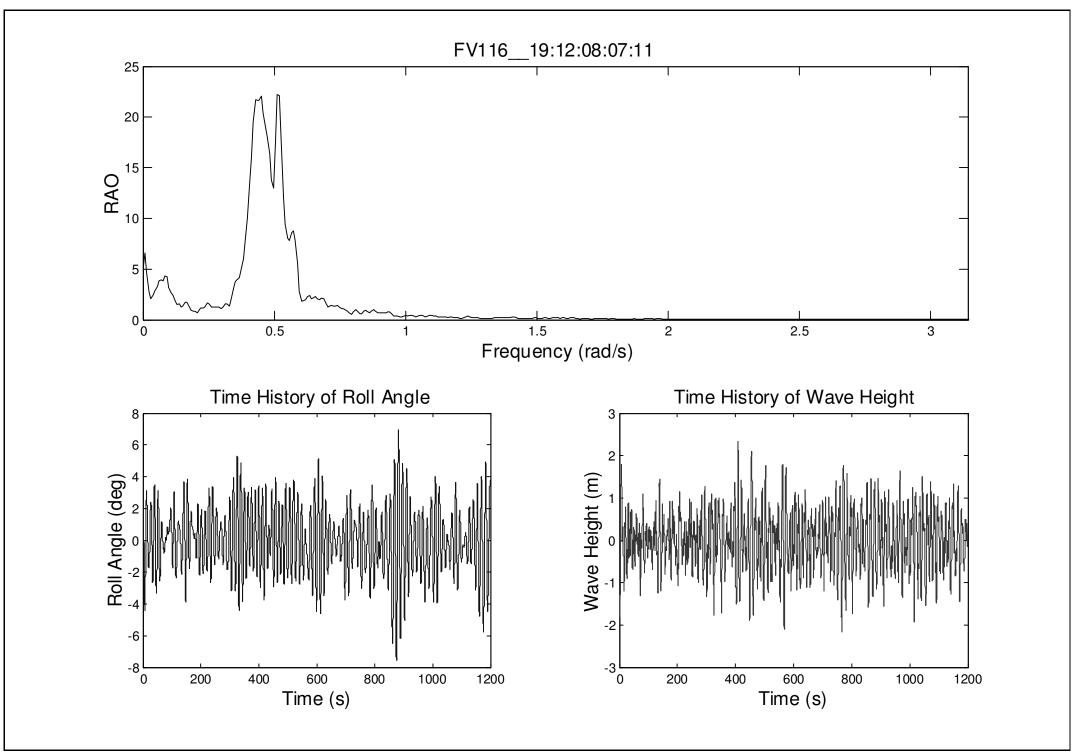

Figure 23: Roll Response Spectrum and Time Histories for File 116

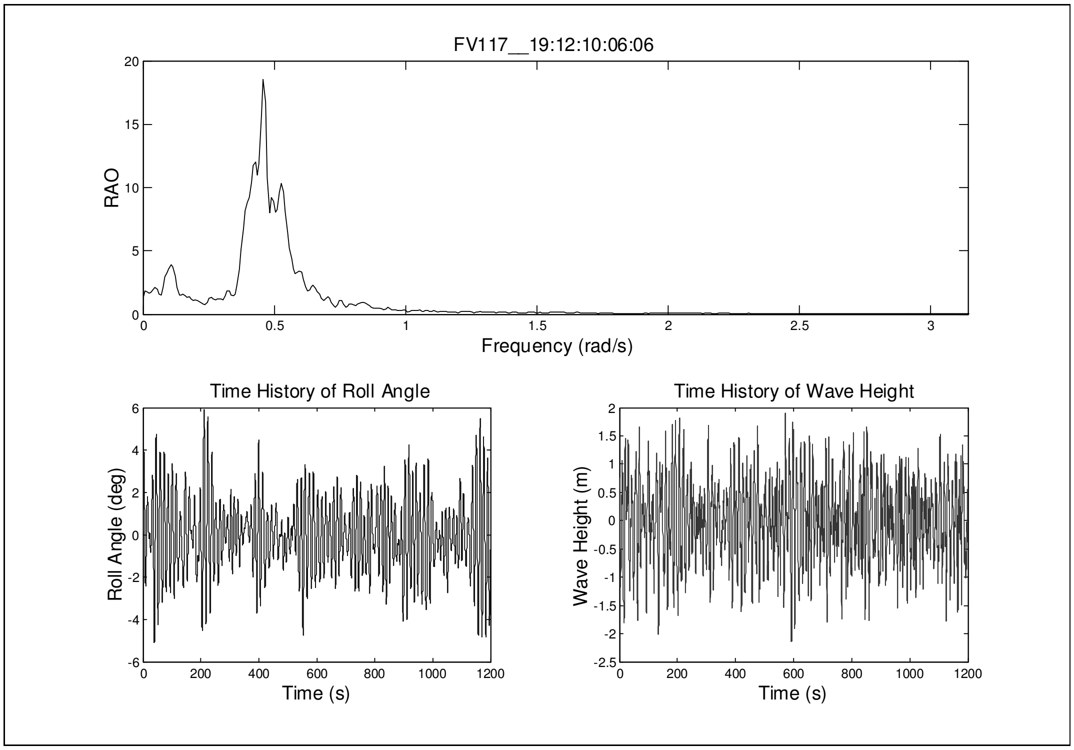

Figure 24: Roll Response Spectrum and Time Histories for File 117

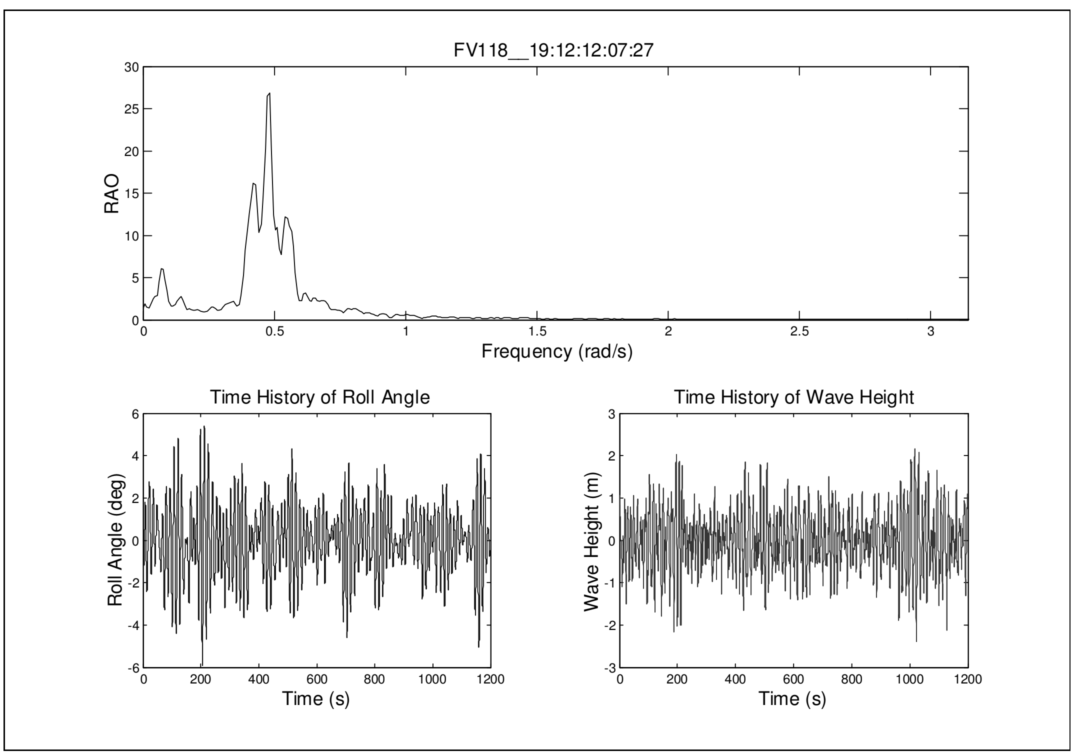

Figure 25: Roll Response Spectrum and Time Histories for File 118