Non-Commercial Report

YACHT ANCHOR TRIALS 5TH DECEMBER 2019

Prepared by: Dr Kim Klaka and Mr Richard Macfarlane

Reviewed by:

Project:

Report:

Date: 11th December 2019

CONTENTS

1 INTRODUCTION

The aim of this project was to assess the equipment and software developed to measure loads on the anchor rode of a yacht at anchor.

2 EQUIPMENT AND SETUP

The vessel used was a Van de Stadt 34 design. Principal characteristics are:

L_{OA} (m)	10.34
L_{WL} (m)	8.0
B_{max} (m)	3.3
Draft (m)	1.8
Canoe body draft (m)	0.55
Mass (measurement trim) (kg)	5300

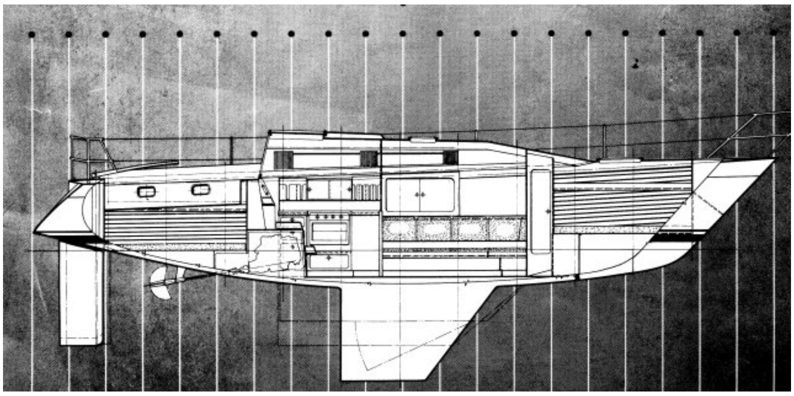

Figure 1: vessel profile

The vessel was equipped with a 16kg Delta anchor and 50m 5/16' diameter chain. A 3-strand nylon snubber of approx 14mm diameter and 5m long was also available.

A measurement and acquisition system was built by Richard MacFarlane for the trials. It is colloquially know as the Magic Anchor Box (MAB). It comprises a load cell, GPS and pitch tilt sensor. It also accepts the analogue signal from a separate anemometer. An internal Arduino Due board is used for data capture and pre-processing. Power was from a xxV dry cell battery pack with xx Whrs capacity.

The MAB was deployed over the bow just below the deck edge on the port side. The aft end was tied back to a deck cleat, with the forward (load-measuring) end tied to the anchor snubber. The other end of the anchor snubber was attached to the anchor rode with a chain hook.

The anemometer was lashed to the pulpit on the centreline of the vessel, approximately 2.5 m above sea level (1.4m above deck + 1.1m freeboard at stem).

Figure 2: Anemometer deployment and stem head configuration

Vessel motions were recorded on an iPhone using ScraMP app https://vesseldynamics.com/category/apps/scramp/. This records heave, sway and surge acceleration, and pitch, yaw and roll angle. The phone was located on the centreline at the base of the companionway steps. This was considered very close to the pitch point, being about 0.2m below the VCG and 0.5m aft of the LCG. Therefore contamination of vertical acceleration from other motions was minimised.

3 DATA ACQUISITION AND CONDITIONING

The MAB could be set to output smoothed (xx point moving average?) data at 1 Hz for anchor load, windspeed, Latitude & longitude, GPS speed and pitch angle; and in a separate file, the anchor load, pitch angle and wind speed at 5Hz sample rate.

The SCraMP output 6 degrees of freedom motion/acceleration. The data sample rate was chosen interactively as 5Hz.

4 TRIAL DESCRIPTION

The trial was conducted on Thursday 5th December 2019, starting at about 1030 and ending about 1215. There were two people on board the boat, Kim Klaka and Richard Macfarlane.

The vessel was motored out to S32.0753 E115.7257 i.e. approx 1mile SW of FSC harbour entrance, in a water depth 8m (6.2 on sounder + 1.8m offset). 30m of anchor chain were deployed on a seabed of mostly sand with some shallow weed patches. About 0.5m of snubber line was deployed.

1135 approx.	MAB turned on and deployed
1138	snubber taking load
1140 approx.	SCraMP record started
1144	motor started, set in reverse at 1500rpm
1150	motor off, SCraMP stopped, MAB recovered and turned off
1215 approx.	weighed anchor, head back to FSC

4.1 Environmental conditions

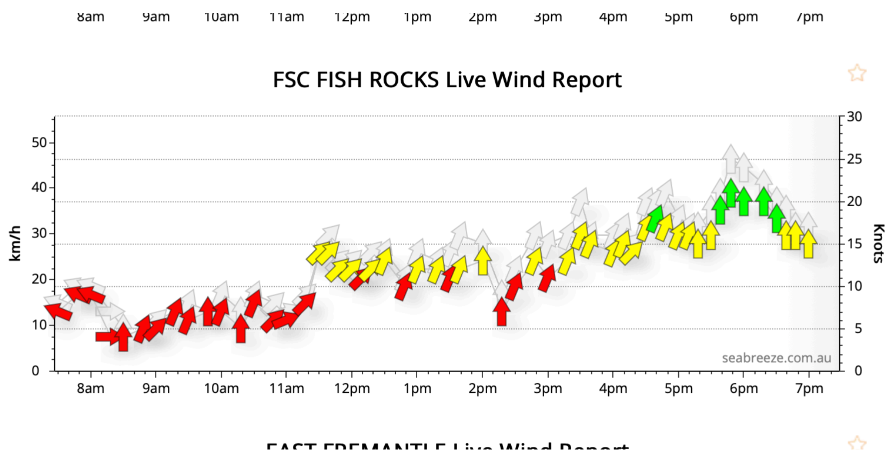

Figure 3: Fish Rocks wind record

Visual estimate of wind was SW 6-9kn at the start of the trial, building to SW 14-16kn during the trial. This was subsequently confirmed by the anemometer readings and the recordings from the nearby Fish Rocks anemometer from www.seabreeze.com.au, shown in Figure.

It is standard practice to compare wind data at 10m above the surface. The vertical wind velocity profile can be represented by a power law, with a coefficient of 0.11 recommended over open water for neutral stability atmosphere. (https://en.wikipedia.org/wiki/Wind_profile_power_law)

Therefore an 11kn wind speed at 2.5m above sea level equates to 12.8kn at 10m height. The height of the anemometer at Fish Rocks is estimated by eyeball as 5m above mean sea level. Tidal height prediction for the trial was 0.65m, which is approximately mean sea level. Therefore 11kn at the trials anemometer would correspond to about 12kn at the Fish Rocks anemometer.

Waves were estimated as from SW, starting at 0.1m height, building to 0.2-0.3m, with a period 1.5 – 2 sec. This was supported by the subsequent analysis of the SCraMP data (see section 5.2)

5 DATA ANALYSIS

5.1 Vessel heave response

The heave Response Amplitude Operator (RAO) for the vessel was required in order to estimate the wave height from the vessel motions. This had been obtained from earlier trials and strip theory calculations (Klaka, 2004), and was modelled in 3 segments:

0-0.29Hz	1.0
0.29-1.0Hz	4th order polynomial $-25.33f^4 + 70.99f^3 - 68.944f^2 + 25.486f - 2.1824$ with $r^2 = 0.977$
>1Hz	0.0

5.2 SCraMP data – wave spectrum

The primary reason for analysing the SCraMP data was to obtain an estimate of the wave spectrum. The SCraMP output file was in csv format with some headers and columns not readable by the script file. The file was first read into Excel where the unwanted columns and rows were removed. The times series were then examined and found to contain spurious readings near the beginning and end of the data, with significant drift over the series. There was also high frequency noise during the period when the motor was run in in reverse.

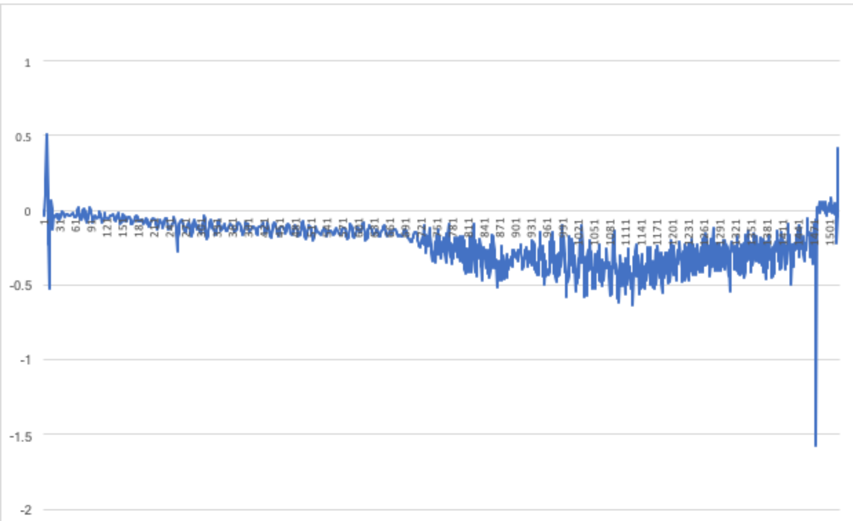

Figure 4: heave acceleration time series

Consequently, the selection of data segment was carried out manually. A section of the time series prior to the motor starting was chosen which showed minimal drift. It was approximately 100 seconds long. This segment of the heave acceleration time series was processed in Octave programming environment using the script file *scramp_to_waves_v1.m* The segment was linear de-trended then an FFT was applied using segment lengths 512 with 50% overlap and a Hanning window. It was then double integrated to obtain the heave amplitude spectrum.The heave RAO was applied to convert from wave amplitude spectrum to heave amplitude spectrum. Inspection of the resulting wave amplitude spectrum showed unrealistic spikes at the low frequencies, introduced through amplification of small errors during the double integration to convert from acceleration to amplitude. This was addressed by truncating the low frequency end of the wave spectrum at the point where the ordinates were starting to rise artificially. Fortunately this point was quite clear because of the lack of swell at the trials location. The outcome was to use only that part of the spectrum between 0.11Hz and 1.0Hz to calculate the wave spectrum statistics.

5.3 MAB data

The analysis focussed on the 5Hz time series output. The time series were plotted in Excel and manually inspected. Segments showing quasi-steady conditions for both the wind-wave loading condition and the reversed engine condition were identified and processed separately.

6 ERRORS

6.1 Wave data

The wave field was for an underdeveloped sea breeze, so both height and period were increasing over the duration of the trial. The results are therefore representative of the trial, but not an accurate estimate for the conditions during the entire trial.

The derivation of the wave spectrum from the heave acceleration time series created errors from many sources. By far the greatest of these was the amplification of noise and other errors in the acceleration time series, as a result of the double integration in the frequency domain. Whilst the low frequency truncation point was well defined, it is possible that long period waves were omitted from the spectrum.

The statistical estimates of wave period are influenced by the double peaked nature of the spectrum, leading to discrepancies between the various measures. The peak period estimate is of questionable validity for a double-peaked spectrum.

6.2 Wind data

The anemometer had previously been calibrated by tying it to a car, driving at various speeds then comparing the readout with the GPS speed. This did not take into account the sea breeze that was blowing at the time. Calibration was probably accurate to within less than 10%. The output had a resolution of 1kn, which amounts to about +- 5% error. This is taken as the accuracy of the instrument.

The instrument was deployed during the trial at about 1.5m above sea level, which must be taken into account when comparing wind data from other sources.

6.3 Anchor load

The anchor load cell had not been calibrated at time of writing. The output has a resolution of 1kg and an apparent offset of 2kg.

6.4 Rode angle

The pitch tilt had not been calibrated at time of writing. The output has a resolution of 1 degree and appears to only be recorded at 1Hz (the 5Hz data consistently shows the same reading in groups of five). The likely largest error source is the angle of the BAM being slightly different from the angle of the rode as a consequence of its deployment configuration. This is very difficult to estimate but it could be as much as 5 degrees. The alignment is probably closer at higher loads (shallower angles) than at lower loads.

6.5 Other

Water depth is accurate to +-0.1m.

Rode length deployed is accurate to +-2m.

7 RESULTS

7.1 Waves

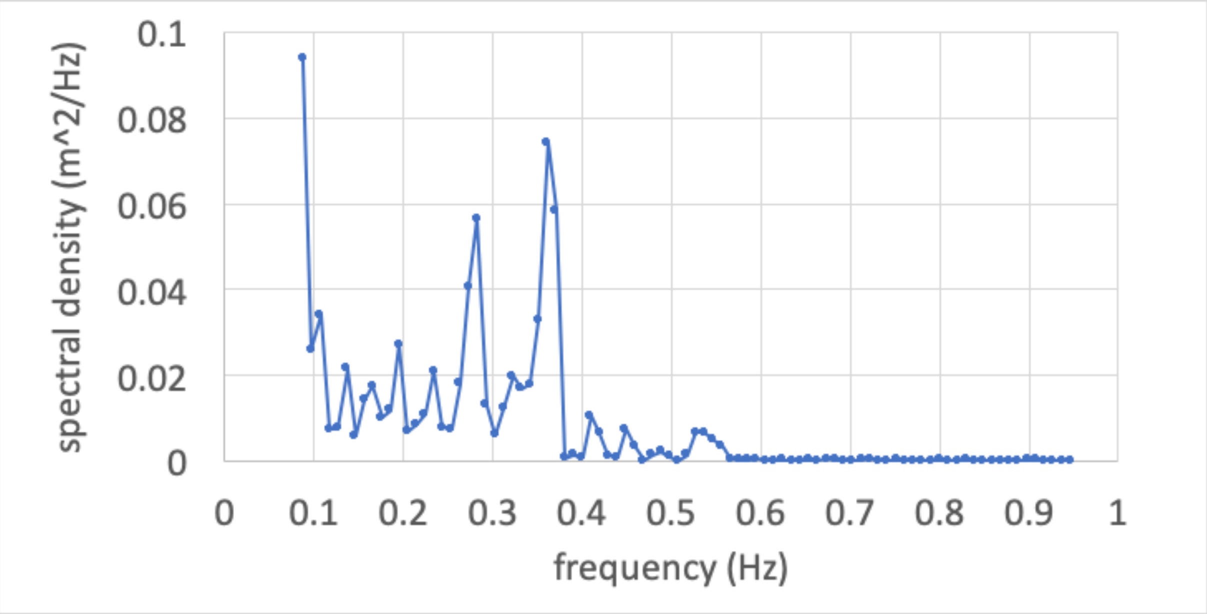

Figure 5: wave spectrum

The wave spectrum (Figure) shows spurious high value ordinates below 0.1Hz, which were discarded as described in section 5.2. The true peak is at 0.36Hz (2.77sec), with a substantial secondary peak at 0.28Hz.

Standard deviation (m)	0.082
Significant wave height uncorrected H_s (m)	0.329
Significant wave height corrected H_{cor} (m)	0.30
Broadness parameter e	0.586
Average period T_0 (s)	3.31
zero-crossing period T_z (s)	3.13

Average period of peaks T_p (s)	2.54
peak period T_k (s)	2.77

7.2 Wind speed

The anemometer record shows a wind speed range of 9-14 kn. The mean increased from about 11 kn to 12kn over the period of the trial.

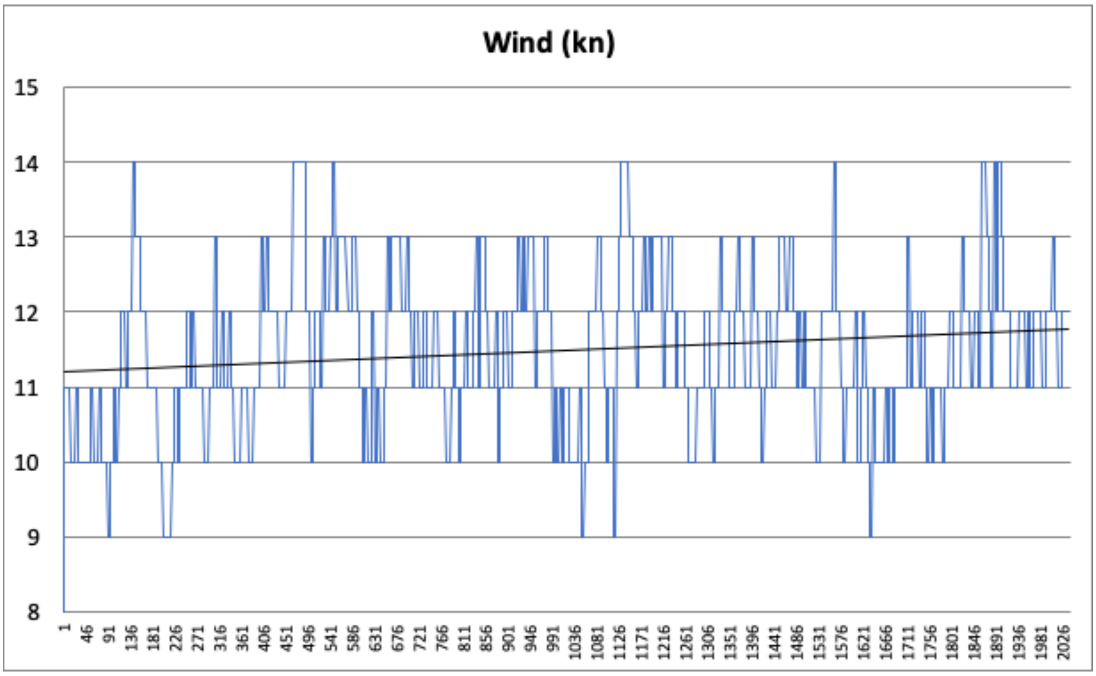

Figure 6: anemometer time series

7.3 Anchor loads

Comparison between the 5Hz data and the 1Hz averaged data shows that the 1Hz data is clipping the peak loads by about 25%:

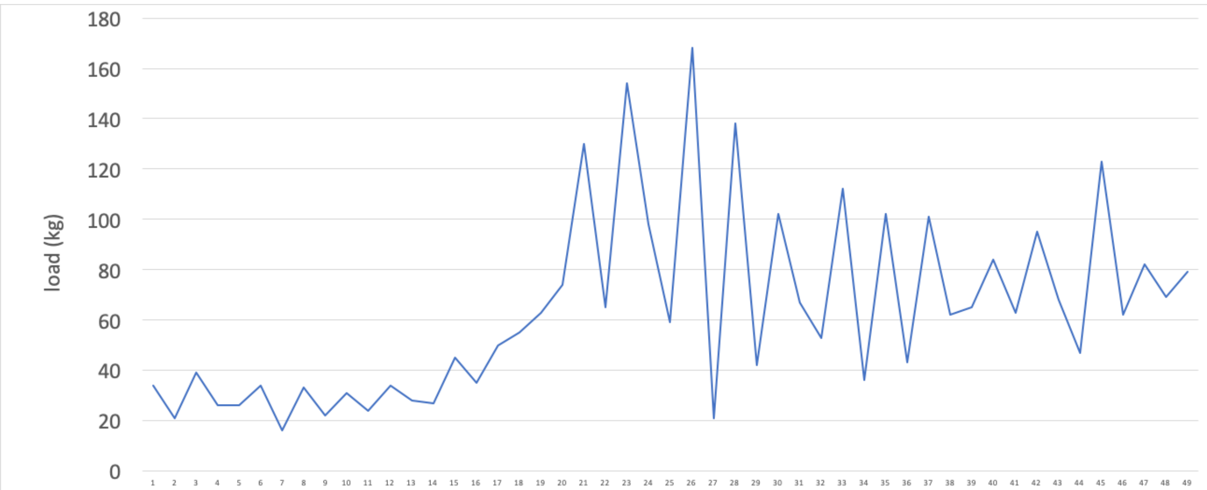

Figure 7: load time series averaged over 1 second

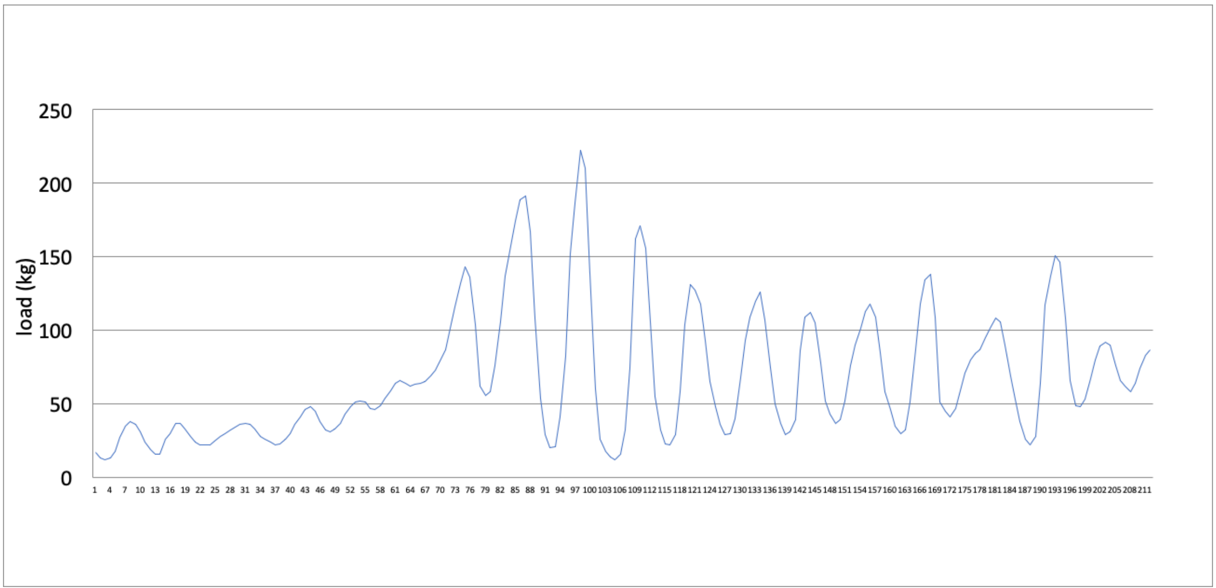

Figure 8: load recorded at 5Hz

This is to be expected, given that there is a dominant period of about 2-3 seconds.

(Figure and Figure above are for the trial segment when the engine was put in reverse.)

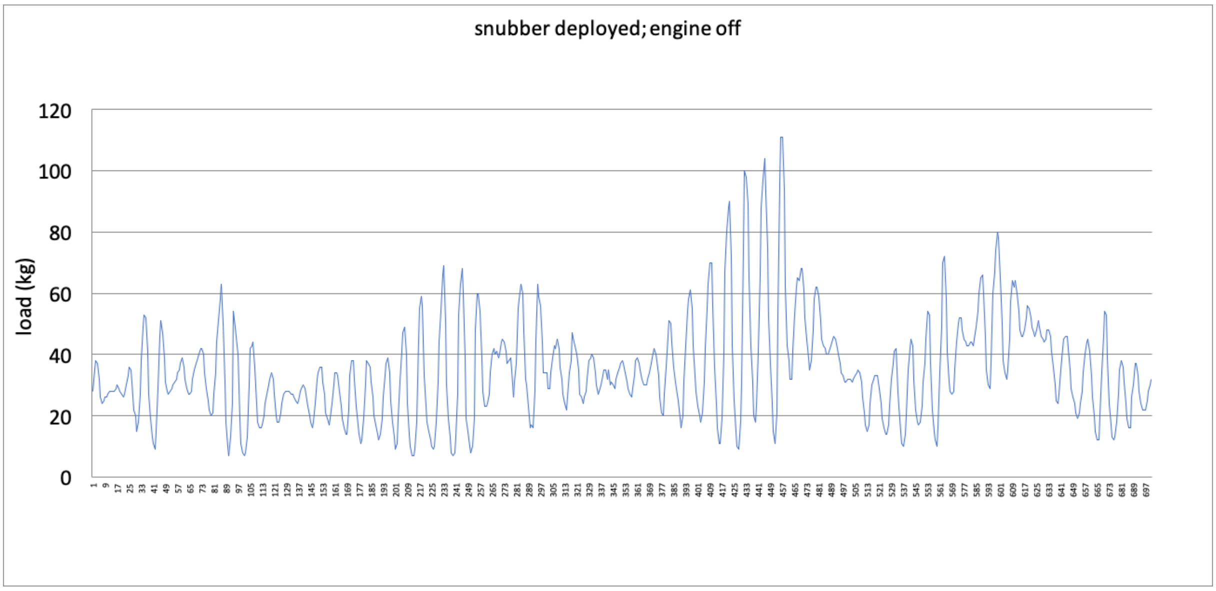

Figure 9: load at 5Hz, engine off

When under normal anchoring (snubber deployed, engine off), the average load was 35kg and the peak load was 111kg.

In order to assess the validity of these values, a benchmark is needed. The ABYC has produced a table of load v wind speed for different sizes of vessel (Poiraud et al, 2008). The load in the trials data is a combination of wind and wave load. However, if we assume that the wave effects are exhibited mainly by the load variation, then the mean load is approximately that due to the wind. In practice, the waves will also contribute to the mean load, guesstimated at 10% of the mean value. The load due to the wind is therefore about 32kg. The lowest windspeed given by ABYC is 30kn. For a 10.5m vessel they estimate the wind load at 30kn is 900lb (408 kg). Load varies as approximately windspeed squared, therefore in the trials condition of 11.5kn average windspeed the ABYC load estimate is 60kg. This is nearly twice the recorded load.

With the engine in reverse at 1500rpm the average load was 78kg and the peak load was 222kg.

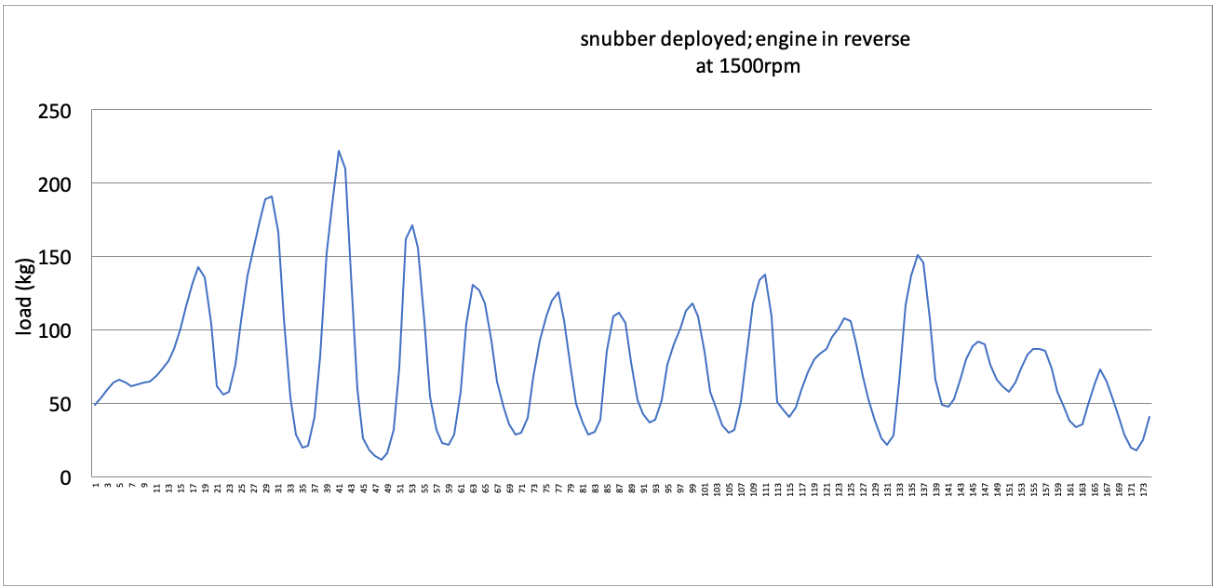

Figure 10: anchor load; engine in reverse

7.4 Rode angle

With the snubber deployed and the engine off, the mean rode angle was 49 degrees from horizontal and the shallowest angle was 25 degrees. At times the rode was almost vertical.

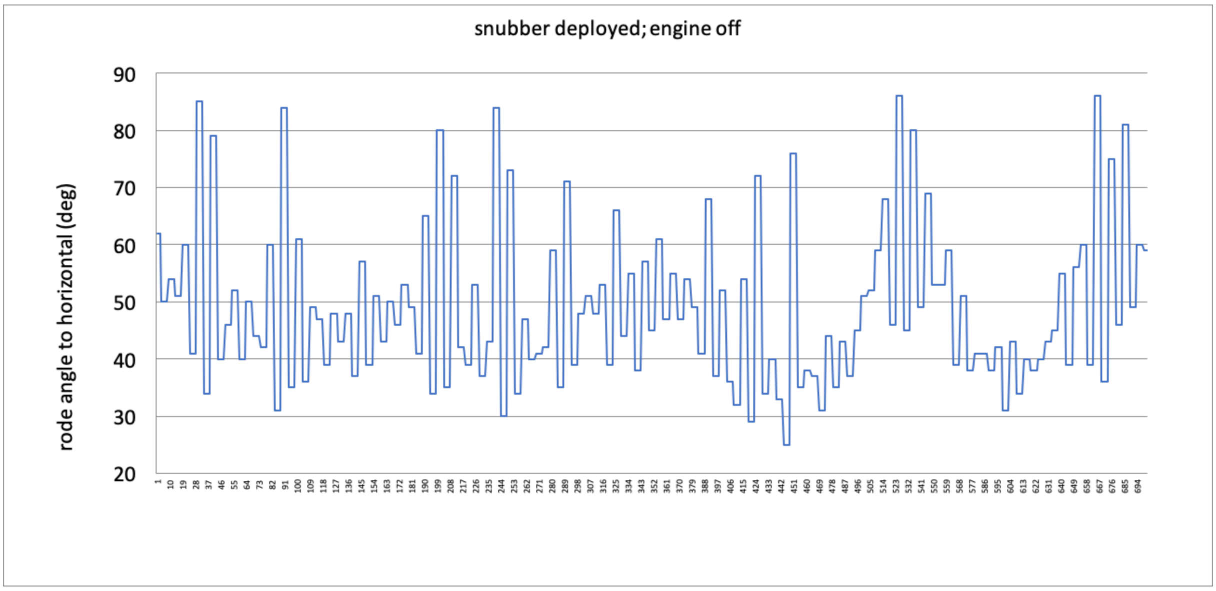

Figure 11: rode angle; snubber deployed, engine off

The correlation between anchor load and rode angle was investigated.

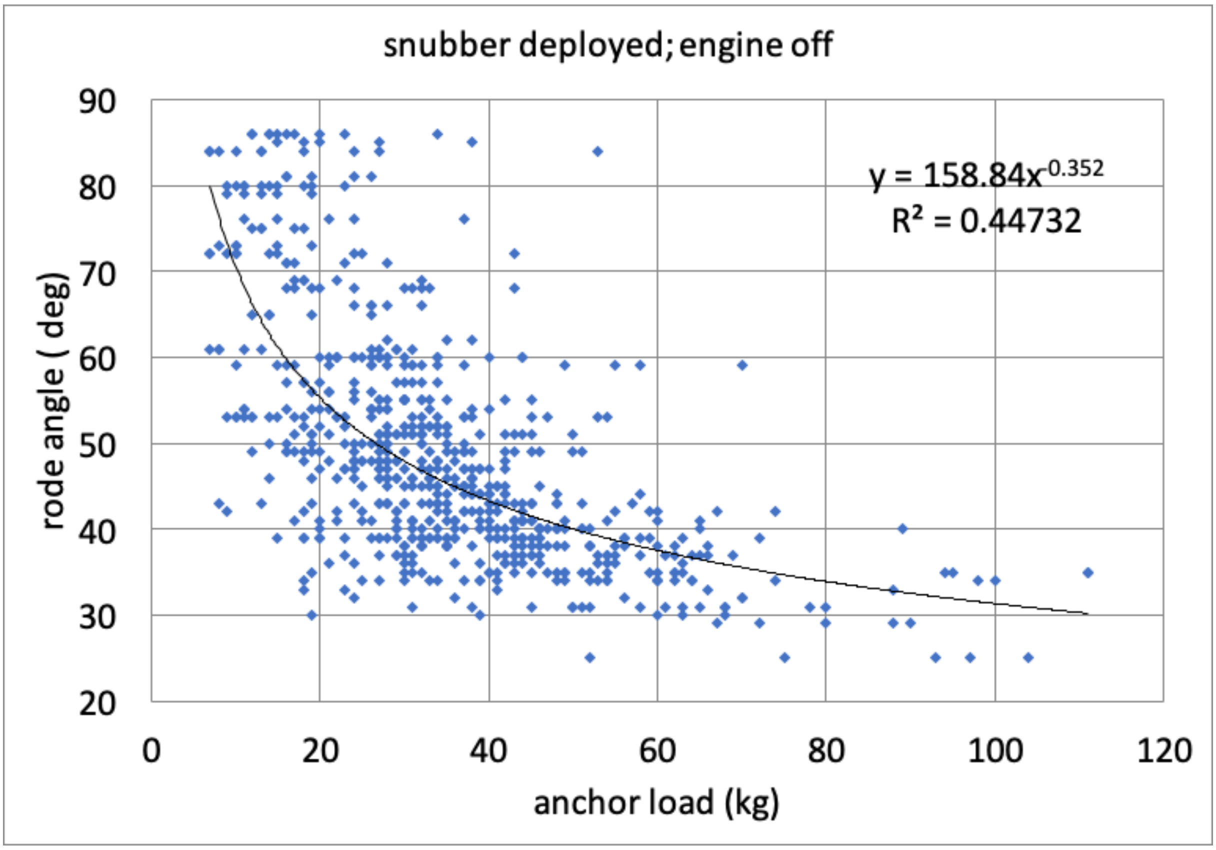

Figure 12: rode angle v anchor load; 5Hz data

The best fit for the 5Hz data was found to be a power law, showing an inverse cube root relationship. Goodness of fit was low at $r^2 = 0.45$. However, for the 1Hz data an inverse square law gave best fit, with $r^2 = 0.61$.

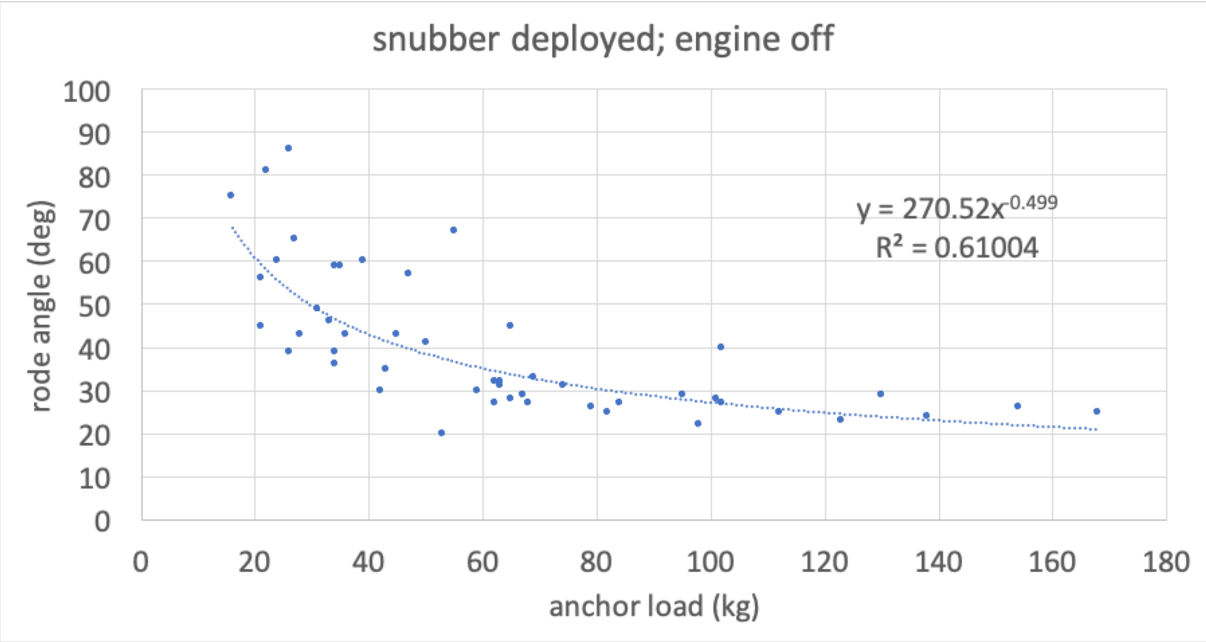

Figure 13: rode angle v anchor load; 1Hz data

8 CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

- The trial proved effective at testing the equipment.
- It is possible to obtain an estimate of the wave spectrum from the heave acceleration time series.
- A sample rate of 1Hz underestimates the peak loads by about 25% compared with a 5Hz sample rate.
- With the vessel subject to 12kn wind and 0.3m significant wave height the average load on the anchor rode was 35kg and the average load was 111kg.
- With the engine in reverse at 1500rpm the average load on the anchor rode was 78kg and the peak load was 222kg.
- There is an inverse square relationship between rode angle and average anchor load.
- There is a weaker inverse cube relationship between rode angle and peak anchor load.

It is recommended that:

- The anemometer be recalibrated by car driving in calm conditions.
- The load cell be calibrated and checked for long-term drift.
- Load is to be recorded at a sample rate of at least 5Hz.
- Further trials be conducted at a location with minimal wave field in order to measure the loads due to wind alone.

- More trials be conducted for different water depths, rode scope and snubber length.

9 REFERENCES

Poiraud A., Ginsberg-Klemmt A., & Ginsberg-Klemmt E. (2008) *"The complete anchoring handbook"* International Marine/McGraw Hill. Also Kindle e-book.

Hodges T. & Springer W. (2006) *"Ultimate holding power"* Yachting Monthly December 2006, also in Sail magazine.

Klaka K. (2004) *Roll motion of yachts at zero Froude number. PhD thesis, Curtin University*

SCraMP app https://vesseldynamics.com/category/apps/scramp/