Non-Commercial Report

YACHT ANCHOR TRIALS 9TH FEBRUARY 2020

Prepared by: Dr Kim Klaka and Mr Richard Macfarlane
For: Public release
Project: Anchor loads
Report: KKM 20-2
Date: 12th March 2020

Klaka Marine
PO Box 369
South Fremantle
WA 6162
Australia

CONTENTS

1 AIMS

The aims of these trials were to measure the loads exerted:

- by a yacht motoring in reverse whilst stationary, and
- on the anchor rode of a yacht at anchor for different scopes.

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

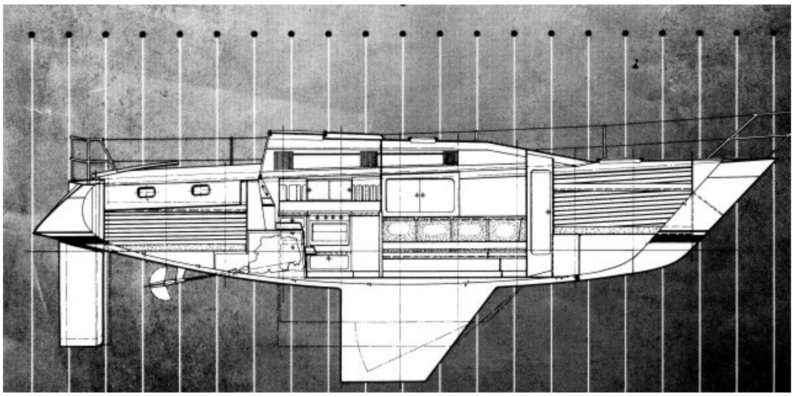

Figure 1: Vessel profile

The vessel was powered by a Volvo 2003 28hp diesel driving a Seahawk 3 bladed folding prop of diameter 16.5 inches (420mm) and pitch 11 inches (280mm). The vessel was equipped with a 16kg Delta anchor and 50m 5/16' diameter chain. A 3-strand nylon snubber of approximately 14mm diameter and 5m long was used.

A measurement and acquisition system was built by Richard MacFarlane for the trials. It is colloquially known 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 dry cell battery pack with ample capacity for one-day tests. The MAB recorded at 5Hz sample rate.

The MAB was deployed on deck behind the anchor winch. The aft end was tied back to the mast, with the forward end tied to the anchor snubber. The other end of the anchor snubber was attached to the anchor rode with a chain hook.

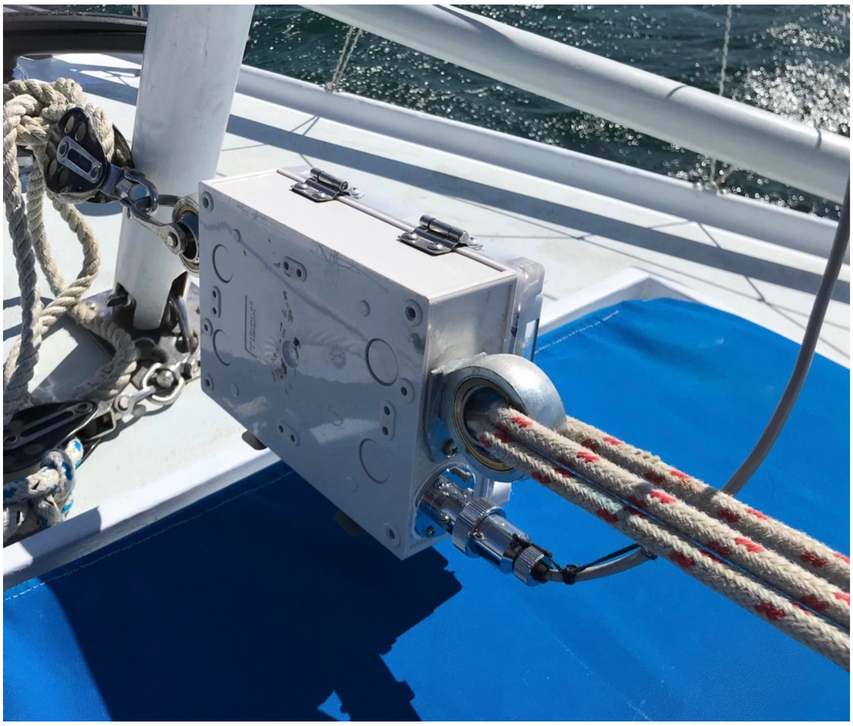

Figure 2: MAB attachment

Figure 3: MAB deployed

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 4: Anemometer deployment (photo from Dec 19 trial)

Yaw was measured by observing the yacht's magnetic compass. Engine revs was measured by observing the engine instrumentation analogue dial.

3 TRIALS DESCRIPTION

The trials were conducted on the afternoon of 9th February 2020. There were two people on board the boat, Kim Klaka and Richard Macfarlane.

For the reverse motoring trial the vessel was in pen B33 at Fremantle Sailing Club (FSC), attached to the concrete walkway by a single line from the bow, approximately horizontally. The engine was engaged in reverse at constant revs for approximately one minute at each setting, according to the schedule in Table 1.

1417	engine in neutral
1419:15	800 rpm reverse
1420:15	1400 rpm reverse
1421:15	1750 rpm reverse
1422:15	neutral
1423:50	MAB turned off

Table 1: Engine test schedule

The vessel was then motored out to the FSC "pool" at S32° 4.00' E115° 44.71', and anchored in a water depth 5.2m (3.4m on sounder + 1.8m offset). The pool is an area about 200m diameter fully sheltered from waves. There is a breakwater of 5m height about 100m to windward for these trials, offering slight shelter from the wind.

The anchor was set in a seabed of sandy mud and dug in by the effects of windage and by motoring in reverse. About 1.5m of snubber line was deployed. The rode scope was varied according to the schedule in Table 2.

1450 - 1457	25m chain. MAB recording
1459-1503	35m chain
1503	MAB turned off
1507	15m chain. MAB recording
1511 approx.	recover anchor
1520	back in pen

Table 2: Anchoring test schedule

3.1 Environmental conditions

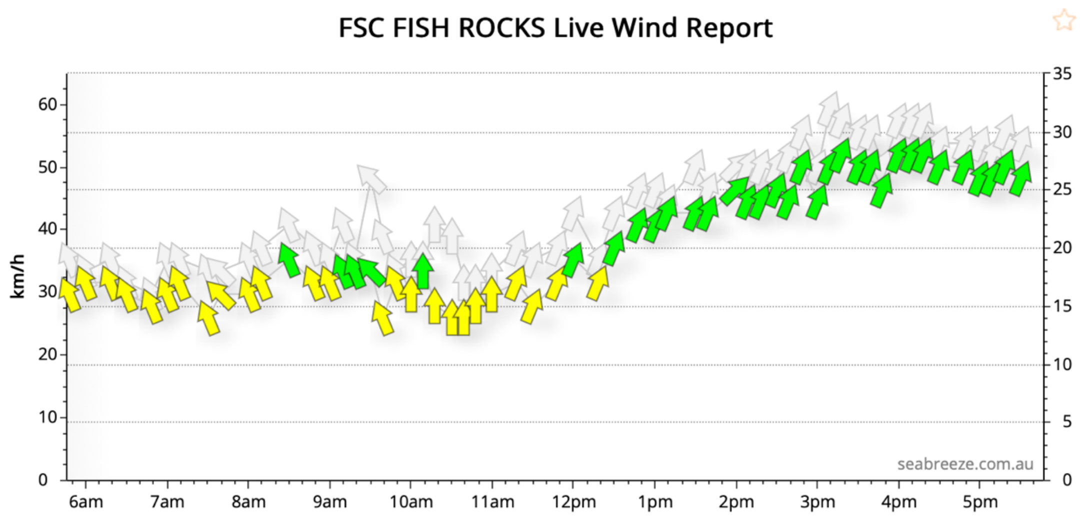

Figure 5: Wind record from Fish Rocks

Visual estimate of wind was SW 25kn. This was subsequently supported by the on-board anemometer readings, and the recordings from the nearby Fish Rocks anemometer from www.seabreeze.com.au, shown in Figure 5. That anemometer is estimated to be about 5m above mean sea level. Analysis of the on-board anemometer measurements is described in section 6.1.

Waves were estimated visually as from SW with a maximum height of less than 0.1m.

4 DATA ANALYSIS

The time series were plotted in Excel and manually inspected. Segments showing quasi-steady conditions for both the anchoring tests and the reversed engine tests were identified and processed independently.

5 ERRORS.

5.1 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, but at car speeds of more than 20kn the calibration was probably accurate to within less than 5%. The output had a resolution of 1kn, which amounts to about +- 5% error. This is taken as the accuracy of the instrument.

5.2 Anchor load

The anchor load cell had been calibrated up to 1,000kg against a certified load cell and was found to agree within +- 1%. The output has a resolution of 1kg and an apparent offset of 2kg. Temperature was found to affect the output by 3% per 10°C. The calibration used was for a temperature of 22°C, which corresponds closely with the air temperature during the trials. The load cell had also been checked for long-term drift, and none was found over a 14-hour period, other than from the temperature effects already described.

5.3 Other

Water depth is accurate to +-0.1m.

Rode length deployed is accurate to +-2m.

Yaw range estimated as accurate to +-5°.

6 RESULTS

6.1 Wind speed

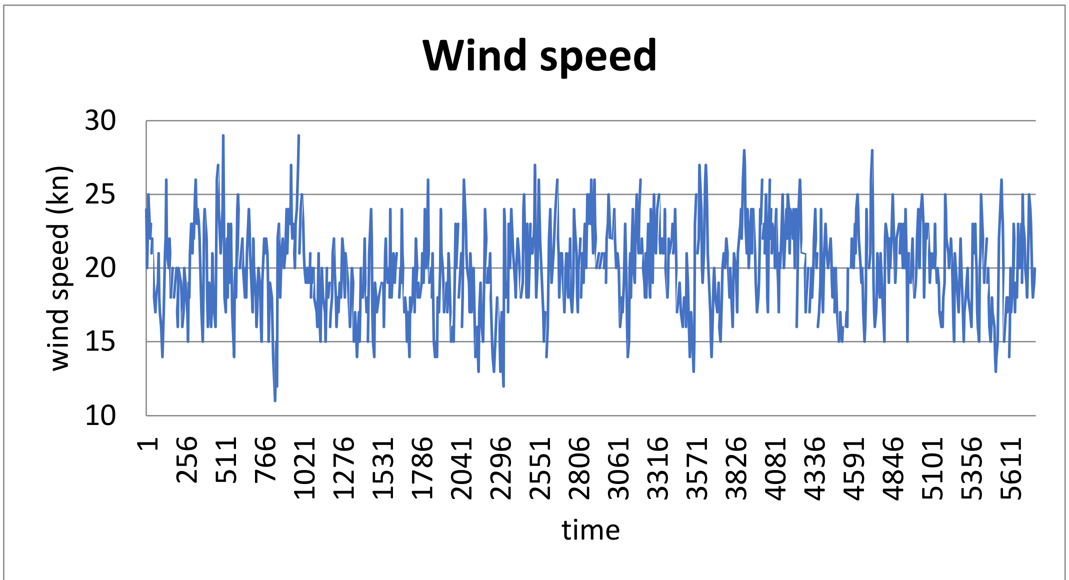

Figure 6: Wind speed measured on board during trials

The on-board anemometer record of Figure 6 shows an average wind speed of 20kn that was consistent over the duration of the trials. The standard deviation was 2.9kn and the highest recorded value was 29kn i.e. 3 standard deviations above the mean.

Wind speed increases with height above the water surface. It is common practice when comparing wind data from different locations to correct them to a common datum of 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 the 20kn average wind speed recorded at 2.5m above sea level equates to 23.2kn at 10m height and the peak recorded speed of 29kn corresponds to a speed of 33.8kn at 10m height.

6.2 Motoring astern loads

The processed results for motoring in astern in the pen are shown in Table 3. The proportions of full power are calculated from the maximum continuous rating of 3,200 rpm stated in the owner's manual (Volvo, 1987).

The measured load is a combination of engine load and windage. However, the pen was in a sheltered area, with the hull hidden behind the concrete jetty and nearby moored vessels. The windage component has been estimated as the load in neutral gear, which was then subtracted from the measured load to determine the load solely from the engine.

rpm	average total measured load (kg)	engine load component (kg)	standard deviation (kg)
neutral (wind load)	23.7		2.8
800 (25% max)	33.5	9.9	6.5
1400 (44% max)	49.9	26.3	3.1
1750 (55% max)	85.8	62.1	3.0

Table 3: Engine loads in reverse gear

The time series of Figure 8, Figure 9 and Figure 10 for the three trials each show significant variability, especially for the 800 rpm measurements. This is most likely due to low-damped surge resulting from the mooring line elasticity and the presence of wind gusts.

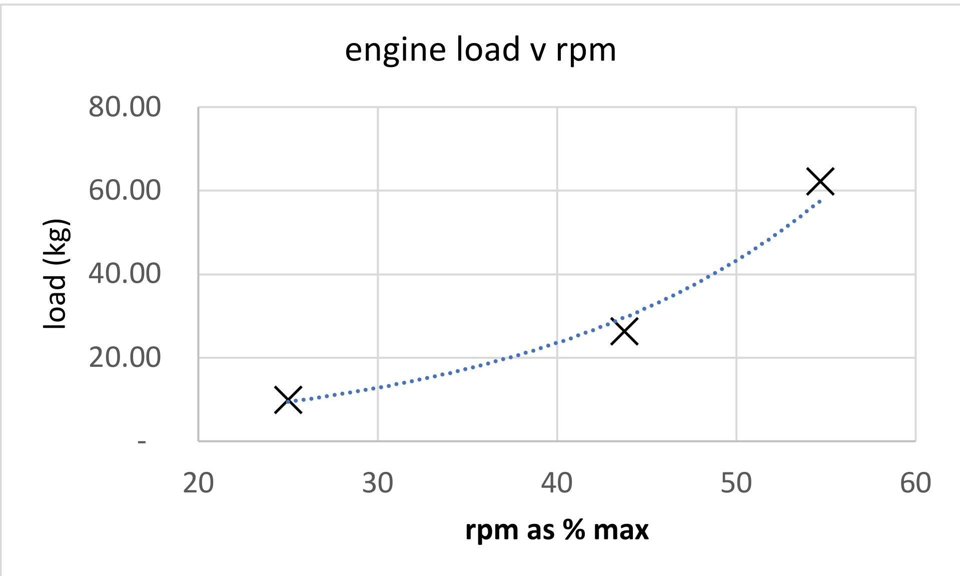

Figure 7: Engine load v rpm

The results can be compared with those of McNeill (2007). He measured the anchor loads on a similar yacht (Sigma 33C) equipped with a lower powered propulsion system (18hp with 2-blade folding prop), in no wind. Three different motor revs were used, but were only specified as "half, three-quarters and full revs astern". The age and model of his engine is unknown, but the owner's manual for Volvo 18hp engines of that era (Volvo, 1987) state that it has the same maximum engine revs as the engine used in the current tests.

The only setting with close agreement in both tests is near 50% of max revs. McNeill measured 58kg at 50% max revs compared with 62.1kg at 55% measured in these tests. Interpolating the results from the current tests yields about 59kg at 50% revs i.e. about the same as the McNeill figure. This is surprising considering the lower rated power available from his engine. Perhaps the prop on his boat is a larger diameter.

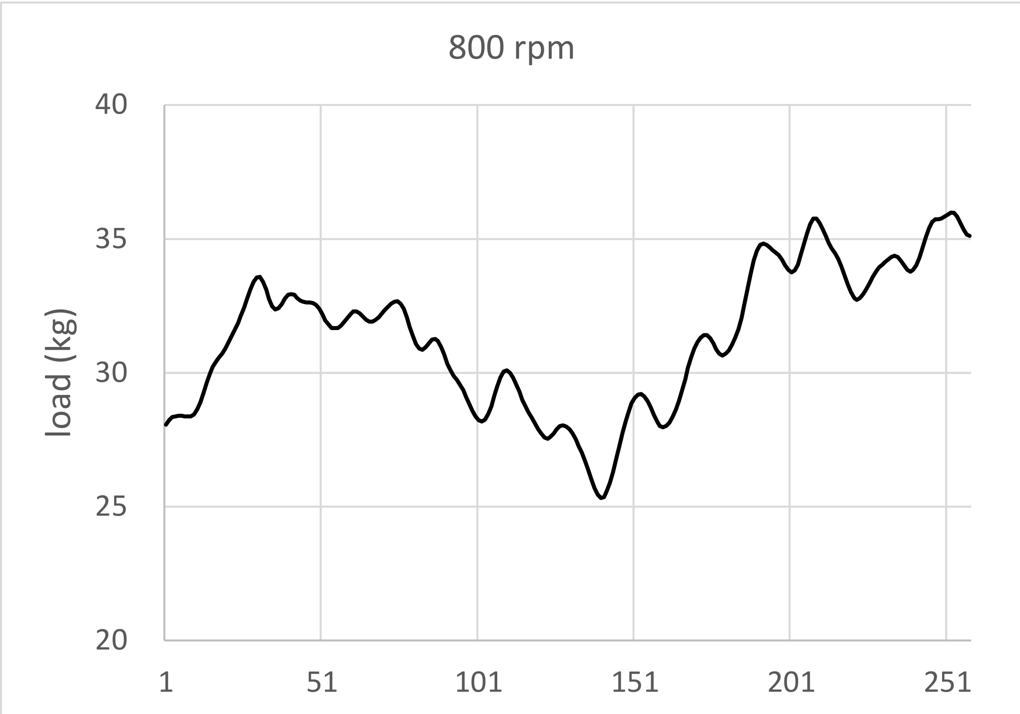

Figure 8: Reverse motoring, measured load at 800 rpm

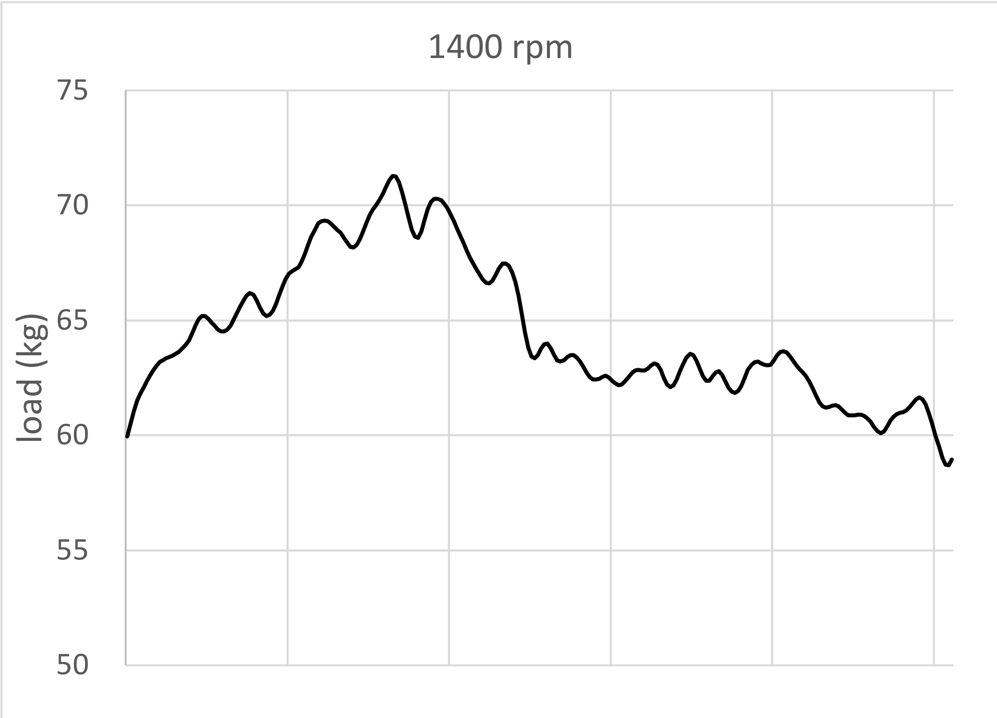

Figure 9: Reverse motoring, measured load at 1400 rpm

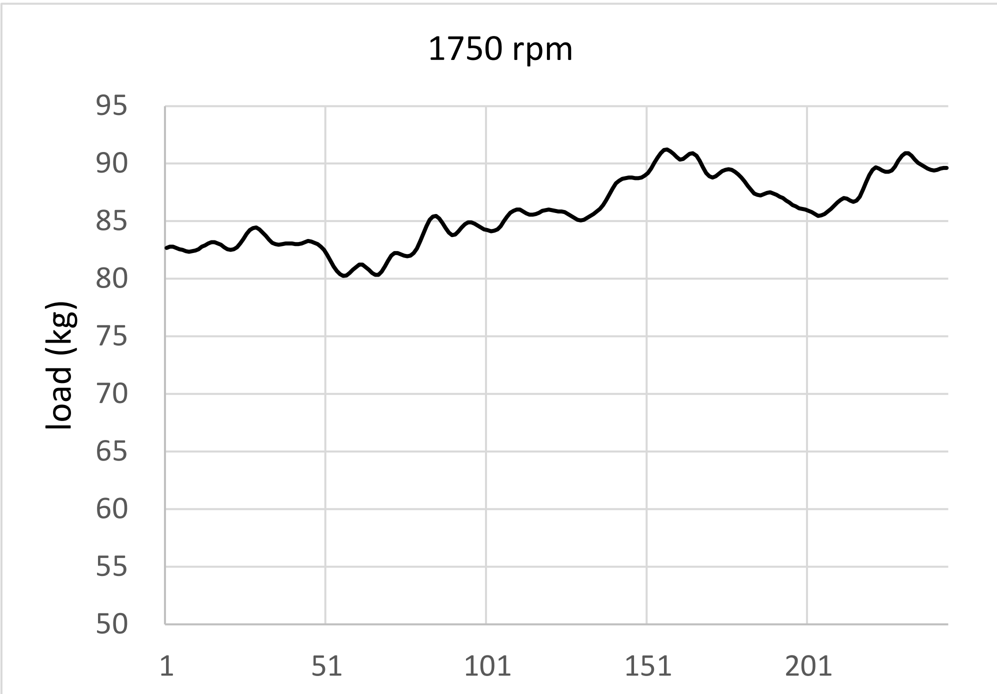

Figure 10: Reverse motoring, measured load at 1750 rpm

6.3 Anchor loads

The results from the anchor load trials are shown in Table 4 and the corresponding time series are shown in Figure 11.

rode length(m)	scope ratio	average load (kg)	max load (kg)	standard deviation (kg)	yaw range out-to-out (deg)
15	2.4	47.4	104	10.3	35
25	4.0	47	77	9.7	40
35	5.6	49.8	69	7.9	45

Table 4: Anchor loads v scope

.

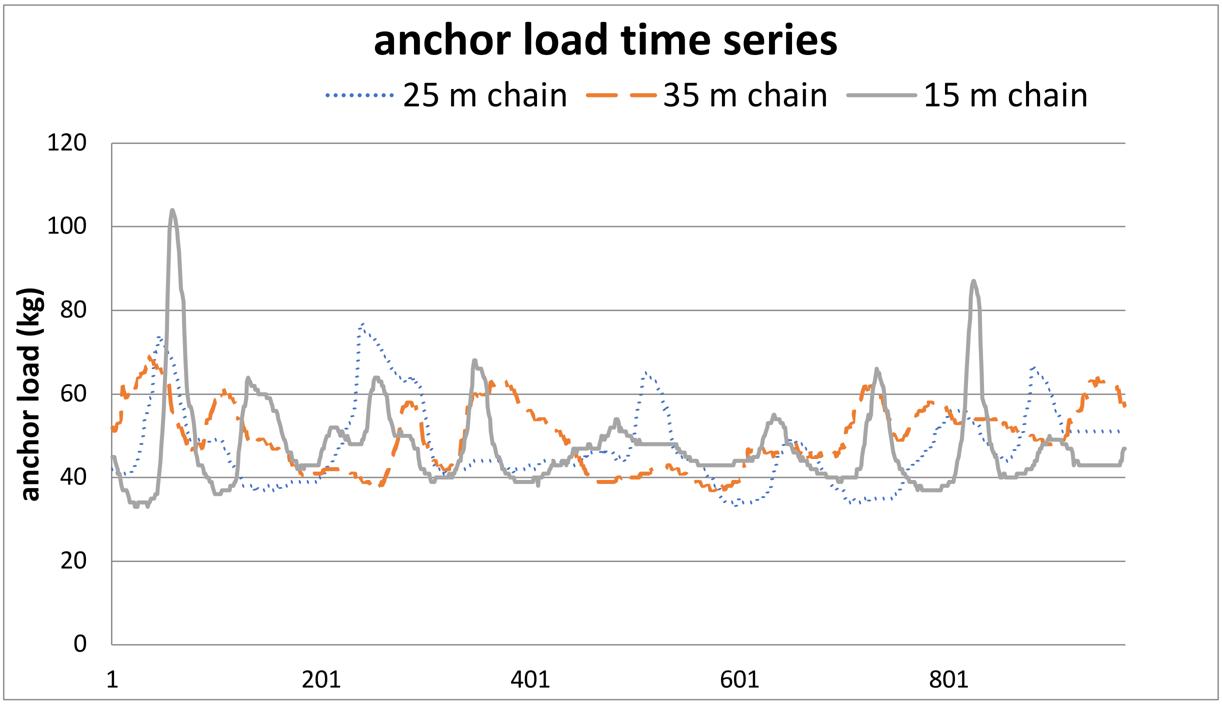

Figure 11: Anchor load time series

As might be expected, the average load does not vary significantly with scope, but the standard deviation and the maximum load both increase as scope is reduced. This illustrates the benefit of using a long scope. There is a surprising and strong inverse correlation between the maximum load and the yaw range. This would suggest that the peak loads are caused by surge rather than yaw. However, the yaw range differences between the three different tests were only slightly greater than the estimated error range.

In order to assess the validity of these measurements, a benchmark was applied. The American Boat and Yacht Council (ABYC) has produced a table of load v wind speed for different sizes of vessel (Poiraud et al, 2008). The lowest wind speed given by ABYC is 30kn. For a 10.5m vessel they estimate the wind load at 30kn is 900lb (408kg). Load varies as approximately wind speed squared, therefore in the trials condition of 23.2kn mean wind speed the ABYC load is about 245kg and for the peak wind gust of 29kn it is 382kg. This is about 5 times the loads measured in the current tests. Clearly the ABYC figures include a very large safety factor indeed, which merits further investigation.

It is possible to relate the engine load tests to corresponding wind speeds by assuming a wind speed squared relationship with load. With the engine in reverse at 1750rpm (approximately 55% max revs) the average load of 62kg was comparable with a wind-induced load in 26kn of breeze.

7 CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

- With the vessel subject to 23.2kn wind speed (at 10m height) the average load on the anchor rode was about 50kg for all scopes used.
- The maximum load, which was generated using the shortest scope, was 104kg.
- The shorter the scope, the higher the peak load but the average load does not change.
- Peak loads are inversely correlated with yaw amplitude, implying they are caused by surge motion. However, errors are high.
- Wind loads predicted by ABYC include a safety factor of about 5.
- With the engine in reverse at 55% max revs the average load was comparable with the load induced by a 26kn breeze.
- More trials should be conducted for different water depths and snubber length.
- For subsequent trials, yaw and surge should be measured in sync with anchor load and wind speed measurements.

8 REFERENCES

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

McNeill P. (2007) *"Digging in"* Yachting Monthly January 2007 pp51

Volvo (1987) "*Owner's manual 2001, 2002, 2003, 2003T"* AB Volvo Penta, publ. no. 7552910-58 1987.