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Systematic mesh size measurements

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Contents

Summary

In this document the results of an investigation into the workings of the *objective mesh gauge*, known as OMEGA, are reported. The results show the OMEGA to be fit for purpose.
In addition, mechanical properties of fishing nets in conjunction with the usage of the OMEGA, which are of influence on mesh size measurements and hence on accuracy and reproducibility, were studied and gave the following results:

- mesh size measurements done with the TNO tensile test machine match with the OMEGA
- the operator of the OMEGA does not have a significant effect on the measurements
- no effect of temperature on the readings of mesh size was found,
- the maximum standard deviation found of the mesh size is 2.7 mm, while the minimum standard deviation found of the mesh size is 0.8 mm,
- repeated measurements on nets on board at time intervals of one week do not show an effect on the measured mesh sizes,
- a pre-load on the mesh has a large influence on the measured mesh size,
- when the pre-load at which meshes are measured is increased from 125 N to 300 N the reproducibility improves significantly,
- repeated readings of one mesh at a fixed pretension show an increasing mesh size with increasing number of readings. A maximum mesh size tends to be reached after about 5 repeated readings,
- repeated readings of meshes on board fishing vessels show a systematic increase of the measured average mesh size which can be as large as 1.15 mm.
- the probability of unjust[1] rejection depends heavily on the chosen rejection value of the average measured mesh size and the standard deviation.
- the measurements on board fishing vessels show that measuring a row of meshes three times and using the readings of the third reading to calculate the average mesh size reduces the probability of unjust rejection from 0.19 % to negligible.

To achieve more reproducible and reliable result with the OMEGA, two recommendations are made:

1 increase the pretension of the mesh size gauge,
2 measure each mesh at least three times and judge a mesh size on the last reading of these consecutive readings.

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[1] i.e. a net is rejected while the average of the mesh sizes lies above the required value

Samenvatting

In dit document wordt een onderzoek naar de werking van de *objective mesh gauge,* bekend onder de naam OMEGA, gerapporteerd. De resultaten tonen dat de OMEGA geschikt is voor het gebruiksdoel.
Aanvullend zijn mechanische neteigenschappen onderzocht met de volgende resultaten:

maaswijdte metingen uitgevoerd met de TNO trekbank stemmen overeen met metingen uitgevoerd met de OMEGA,
de persoon die de metingen uitvoerd met de OMEGA heeft geen noemenswaardige invloed op de resultaten,
temperatuur heeft geen waarneembaar effect op maaswijdtes,
de maximaal gevonden standaard deviatie in maaswijdtes is 2.7 mm, de minimum standaard deviatie is 0.8 mm,
herhaalde metingen op hetzelfde net, met een tussen gelegen tijd van een week, leveren geen waarneembare verschillen op,
de voorlast op een maas heeft een grote invloed op de gemeten maaswijdte,
wanneer de voorlast waarbij maaswijdtes worden gemeten toeneemt van 125 N tot 300 N neemt de reproduceerbaarheid toe,
herhaalde metingen bij een vaste voorlast tonen een toenemende maaswijdte, een maximum wordt bereikt na ongeveer vijf metingen,
herhaalde metingen van mazen aan boord visserijschepen tonen een systematische toename van de gemiddelde maaswijdte van 1.15 mm,
de kans op een onterechte afwijzing[2] hangt in hoge mate af van de gekozen afkeurwaarde en de standaarddeviatie,
uit de metingen aan boord van visserijvaartuigen blijkt dat het drie maal meten van een maas en het hanteren van de laatst gemeten waarde voor de berekening van de gemiddelde maaswijdte de kans op een onterechte afwijzing verlaagt van 0.19% tot nihil.

Om tot meer reproduceerbare en betrouwbare resultaten te komen worden twee aanbevelingen gedaan:

1. kies een hogere voorspanning waaronder een maaswijdte wordt gemeten,
2. meet een maas ten minste drie maal en beoordeel de wijdte op de laatst afgelezen waarde.

[2] d.w.z. dat een net wordt geweigerd terwijl de gemiddelde waarde van de maaswijdtes boven de vereiste waarde ligt

1 Introduction

In January 2010 a new measurement device was introduced for measuring mesh sizes of fishing nets, known as the **O**bjective **Me**sh **Ga**uge (OMEGA). Some cases were reported where the device was suspected to give unreliable readings. Moreover cases were filed where the OMEGAuge gave smaller readings than the wedge (the device previously in use to measure mesh sizes).

From the experiences of inspectors and fishermen at sea, various factors were identified that could have an effect on the readings of mesh sizes given by the OMEGA. Whether a net is new or old, wet or dry, what material it is made of and the temperature could all have an effect on the readings. Different readings were reported depending on who uses the OMEGA even when following the same measuring protocol. The pretension of the OMEGA was reported to be too low to objectively measure mesh sizes.

In order to investigate the working of the device independently of developers or users, TNO carried out an extensive measuring campaign. In a laboratory setting, tests were done in order to establish mechanical characteristics of the nets with respect to reproducibility of measured mesh sizes. The effects of temperature, net age and net material (nylon or polyethylene) were considered. To measure the effect of pretension on the mesh size, meshes were measured at various pretensions with a tensile machine. The readings of the OMEGA were compared to measurements carried out with a tensile machine. The influence of the operator of the OMEGA on the final mesh size readings was also investigated. Finally measurements on nets on board were done with an OMEGA, in order to investigate its behaviour in the day to day fishing practice.

The results of the lab tests are reported in Sections 3.1. through 3.4. The results of the measuring campaign on board ships are reported in Section 3.5. Results of data analysis are reported in Chapter 4. The results are discussed in Chapter 5. Conclusions are given in Chapter 6.

2 Description of the measurements

2.1 Laboratory tests

Laboratory tests were carried out in order to establish the workings of the OMEGA and the characteristics of 80 mm fishing nets. In order to investigate whether the OMEGA would yield results comparable with a tensile test machine, mesh size measurements were done with both the OMEGA and a small tensile test machine (Figure 1) available at TNO.

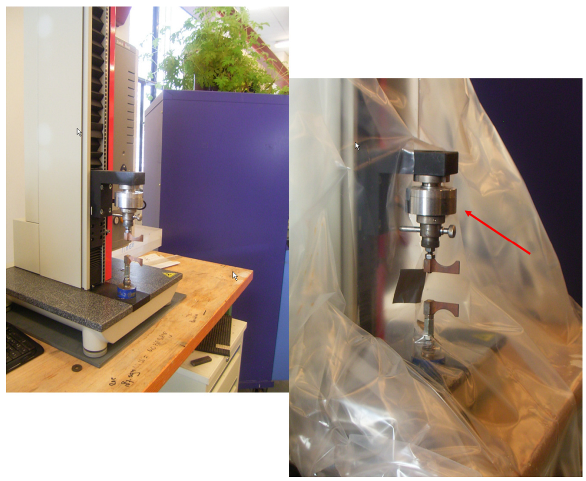

Figure 1 tensile test machine used for mesh size measurements under pre-load

The machine applies a pre-set tensile force to any object between the jaws, which is measured with a separate load cell as indicated in Figure 1 with the red arrow. When the pre-set tensile force is reached the machine stops increasing the distance between the jaws. Throughout the process both the load and the distance between jaws are registered which allows drawing of a force displacement curve as shown in Figure 4.
In addition mesh sizes were measured with the OMEGA. Measurements were done with the nets hanging vertically, as shown in Figure 2, and nets lying on the laboratory floor.

Figure 2 measurements with OMEGA

2.2 Measurements on board

Nets were measured on board ten vessels with the OMEGA in order to investigate the workings of the device in the day to day practice of fishing activities (Figure 3). Some vessels were measured two or three times with at least a week between the readings to test the repeatability of the mesh sizes over time (see Table 1). All measurements were taken on board. TNO crew decided the nets to be measured and the locations in the nets. In accordance with current inspection procedures, the nets were wetted with outboard water and three rows of 20 meshes each were measured [1]. However, each row was measured three times, which is not according the protocol.

Figure 3 typical mesh size measurement with objective mesh gauge (OMEGA)

Table 1 dates of measurements

		date
ship	1	4-6-2010
ship	2	11-6-2010
ship	3	18-6-2010
ship	3	11-6-2010
ship	4	11-6-2010
ship	4	18-6-2010
ship	5	4-6-2010
ship	6	11-6-2010
ship	7	18-6-2010
ship	7	4-6-2010
ship	7	11-6-2010
ship	8	11-6-2010
ship	8	18-6-2010
ship	8	4-6-2010
ship	9	18-6-2010
ship	9	11-6-2010
ship	10	12-6-2010

3 Results

3.1 Lab tests net mechanics

A typical characteristic of nets is their flexibility which makes it difficult to measure dimensions. In order to get insight into this characteristic both a new and a used net were subjected systematically to tension tests with the TNO tension test machine. Force displacement curves were determined of which typical examples are shown in Figure 4 and Figure 5. Meshes were ‘tensile tested’ several times up to pre-set loads of 120 N, 180 N and 300 N.

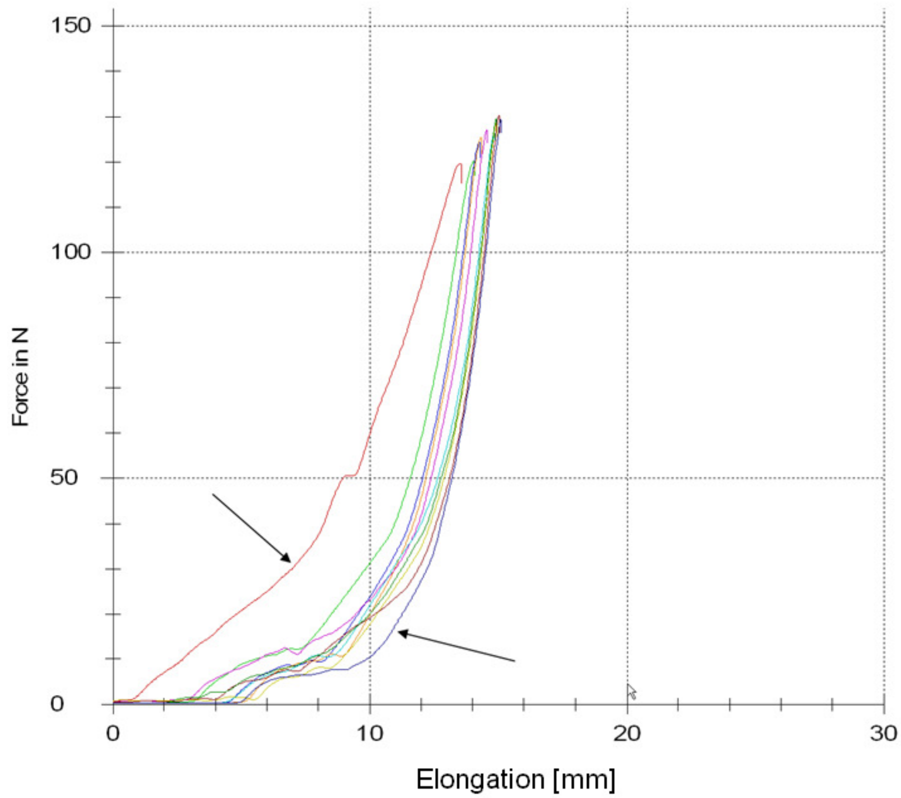

Figure 4 typical tensile test curves, new polyethylene net, maximum Force 120 N

Figure 4 shows a result of the tests in case of a new polyethylene net loaded up to 120 N. The graph shows force elongation curves for one mesh which is loaded 10 times. The repeated loadings show different force elongation curves, the first loading is indicated with the arrow on the left in the graph, the last loading with the arrow on the right. The maximum elongation varies about 2 mm.

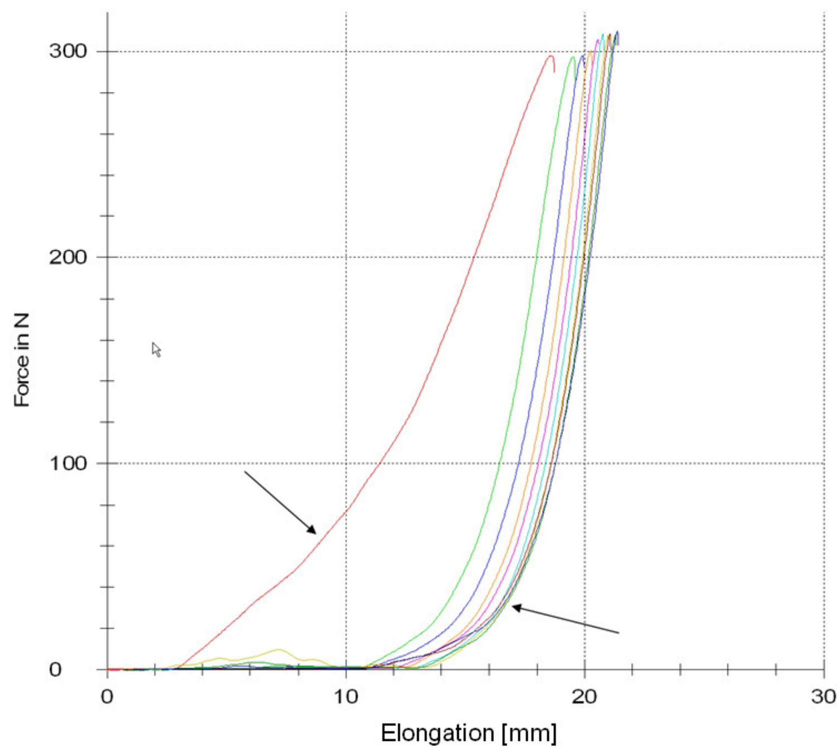

Figure 5 typical tensile test curves, new Polyethylene net, maximum force 300 N

Figure 5 shows a result of the tests in case of a new polyethylene net loaded up to 300 N. Again the graph shows force elongation curves for one mesh which is loaded 10 times. Here also the repeated loadings show different force elongation curves, the first loading is indicated with the arrow on the left, the last loading with the arrow on the right. The maximum elongation varies about 3 mm.

Both diagrams clearly demonstrate the effect of repeated measurements on the measured mesh width.

This effect of repeated readings at different tension loads with the tensile machine is also demonstrated in Figure 6 and Figure 7, for the new and the used polyethylene net respectively.

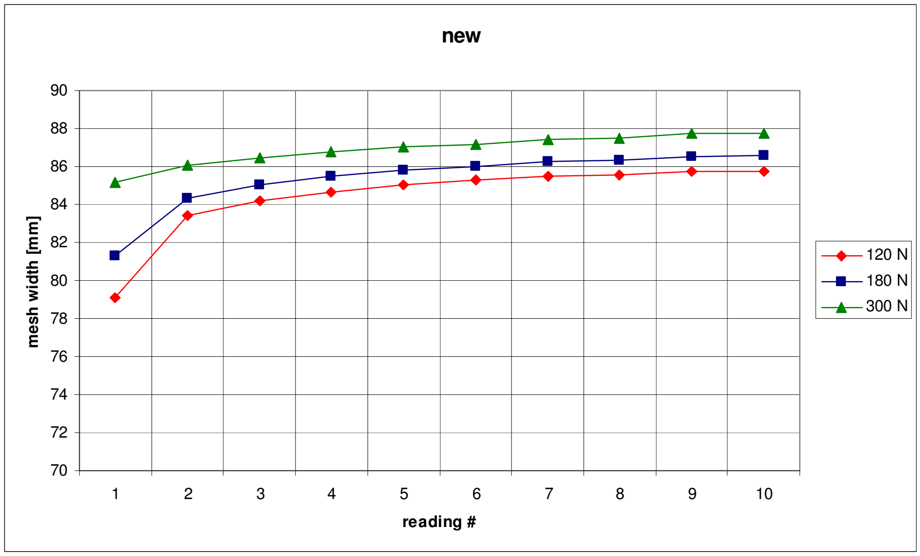

Figure 6 10 consecutive mesh size readings on one mesh at three different pre-loads (the tensile test machine) on a new polyethylene net

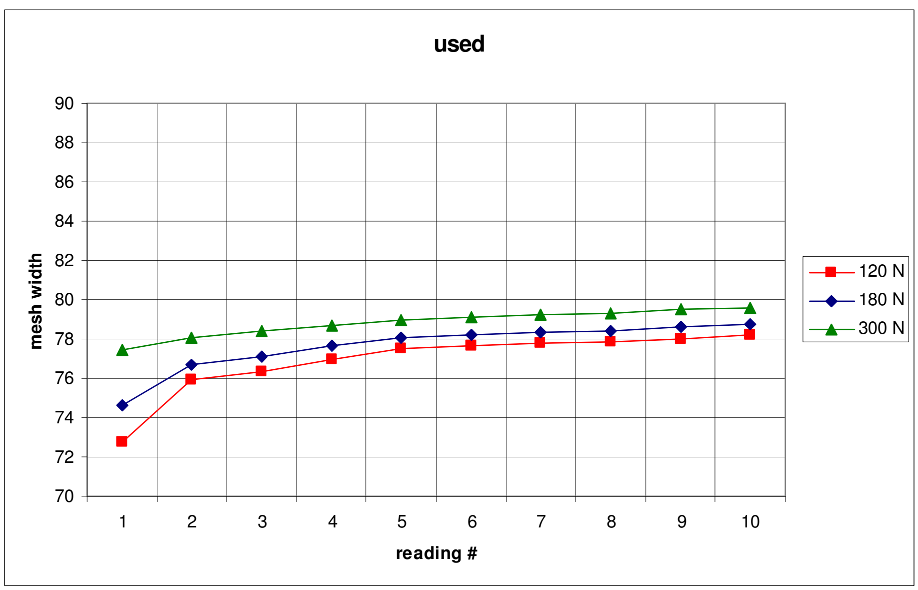

Figure 7 10 consecutive mesh size readings on one mesh at three different pre-loads (tensile test machine) on a used polyethylene net

A clear trend is observed of increasing mesh sizes with increasing tension loads. Again a trend is visible where mesh sizes tend to increase towards an asymptote after repeated readings (after about 3 readings). The latter trend is confirmed by measurements on board (see section 3.5).

The effect of repeated readings can be reduced by increasing the pre-tension. A pre-tension of 300 N will improve the reproducibility of the measurements considerably. A similar observation can be made with respect to repeated measurements. Increasing the number of consecutive measurements per mesh from one to at least 3 or more improves reproducibility considerably.

3.2 Lab tests validation OMEGA

The OMEGA which was used by TNO on board was compared with the results from the tension test machine. In addition to the new and used polyethylene nets a nylon net was also included. The results are shown in Figure 8 through Figure 10. The vertical bars indicate the average measured mesh size minus the standard deviation (lower edge) and the average measured mesh size plus the standard deviation (upper edge). There are also vertical lines which indicate the minimum value of the measurements (lower end) and the maximum value (upper end). The mean value is at the mid height of the bar. These diagrams are often referred to as box-plots.

The nets were measured at a pre-tension of 125 N. A row of meshes was measured, where each mesh was measured three times consecutively. The measurements were done with the tensile test machine followed by the same series of measurements with the OMEGA.

From the results reported in the previous section on mechanical behaviour of nets, it is clear that reproducibility of tests is limited, especially at a pre-tension of 125 N. Therefore differences in results are mostly to be attributed to the net characteristics.

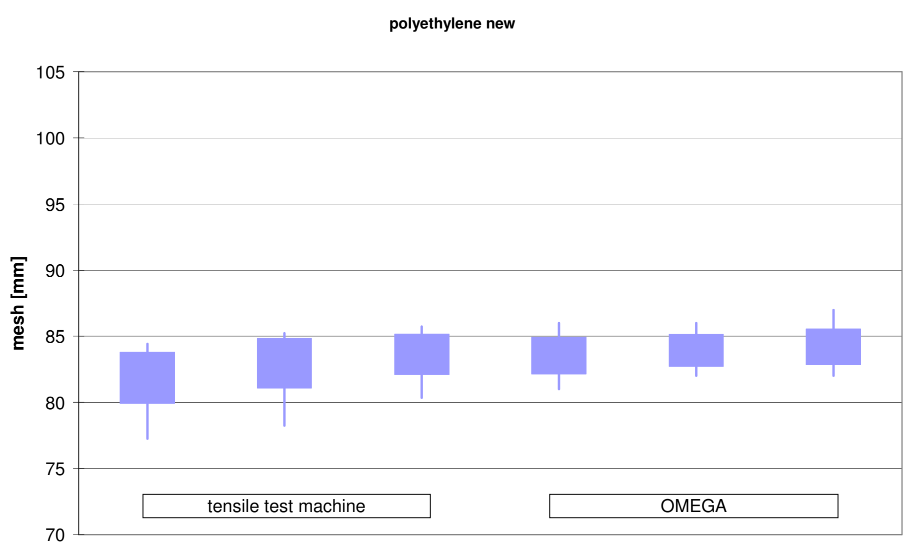

Figure 8 new polyethylene net, tensile test machine versus OMEGA

Figure 8 shows the results on the new polyethylene net.

It is noted that the mean values of the final series of the measurements with the tensile test machine match well with the first series taken with the OMEGA. This is because they were done consecutively. The used polyethylene net and the nylon net show similar trends (Figure 9 and Figure 10).

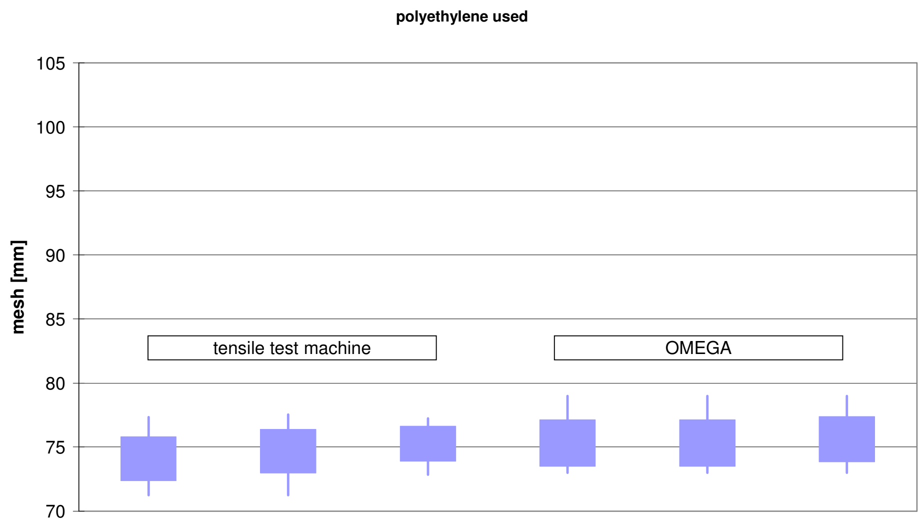

Figure 9 used polyethylene net, tensile test machine versus OMEGA

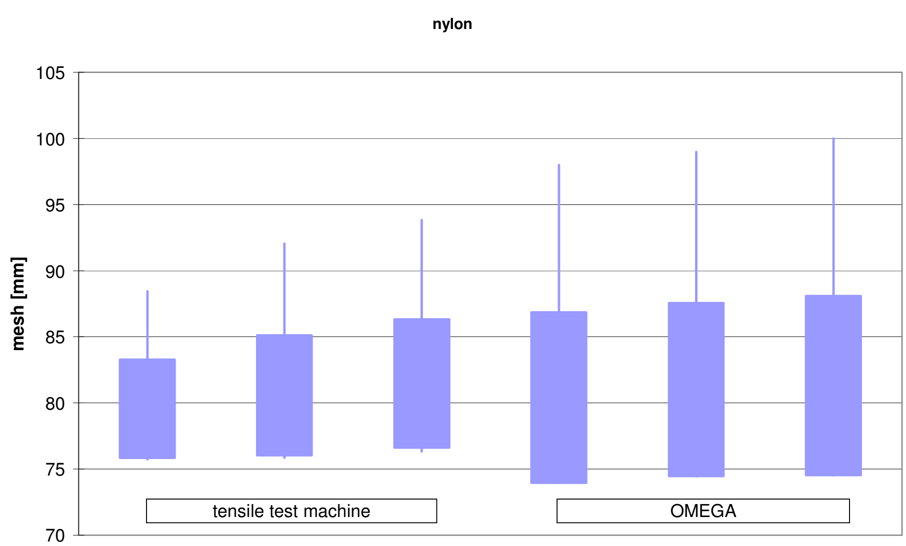

Figure 10 nylon net, tensile test machine versus OMEGA

For discussion purposes, the specifications of the OMEGA are given in the table below.

Table 2 specification OMEGA, used by TNO

Annex 1 – Technical specifications

Length measurement range: 10-300 mm
- 10…70 mm: small jaws
- 40…200 mm: standard jaws
- 140…300 mm: extended jaws

Accuracy: +/- 1 mm
Display resolution: +/- 1 mm (internal resolution 0.125 mm)

Force measurement
- Range: 0…180 N
- Accuracy: 1 N
- Fixed measuring forces: 10, 20, 50, 125N

Data storage
- Memory of 1000 measurements
- Calculation of average and number of measurements
- Download via an infrared transmitter

Temperature range:
- Operating: -10° to 45°C
- Storage[2]: -30° to +70°C

Waterproof IP 56

Shockproof

Weight: 2370 g

The internal resolution is 0.125 mm. However the display resolution is 1 mm. This latter resolution implies that a mesh size of 79.499 mm will yield a reading of 79 mm. A mesh size of 79.501 mm will yield a reading of 80 mm.

3.3 Lab tests effect of operator with OMEGA

To study the effect of the operators using the OMEGA, two operators measured a new polyethylene net with the OMEGA. On four different rows 20 readings were taken (Figure 11).

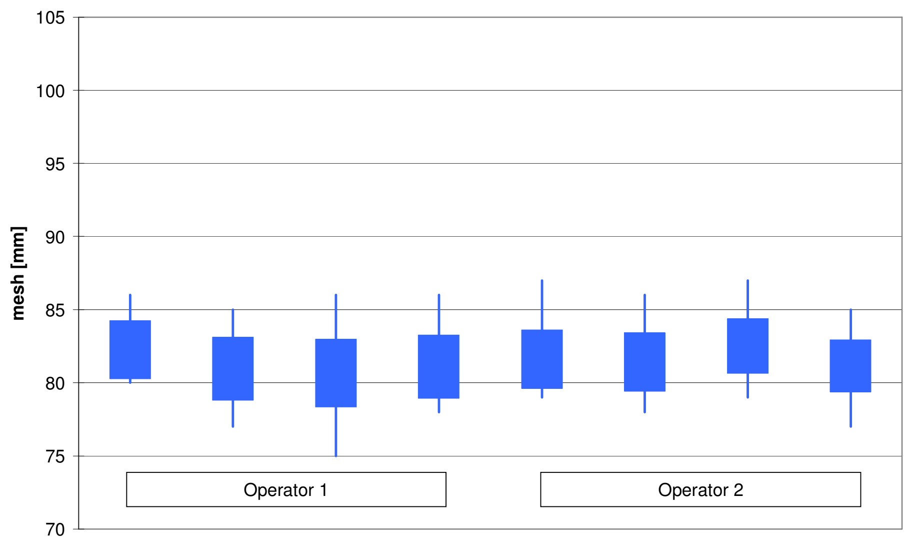

Figure 11 results of mesh measurements on a new polyethylene net by two different operators

The maximum average value found is 82.5 mm, while the minimum equals 80.7 mm, i.e. a maximum difference of 1.5 mm. This difference is well within the ranges reported for mesh size variability in section 3.1. Figure 12 shows a box-plot of measurements done on one and the same mesh row of 20 meshes, carried out by three different operators. The maximum average value found is 82.5 mm, the minimum 81.1 mm, i.e. a difference of 1.4 mm.

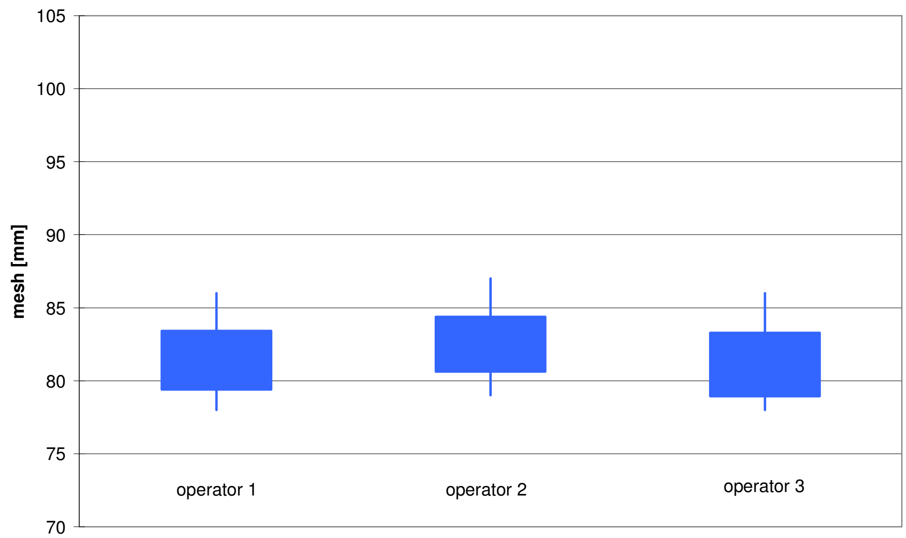

Figure 12 two different operators same mesh row

Again this difference is well within the ranges reported in section 3.1. Therefore, it is concluded that the operator does not have any influence on the results.

3.4 Lab tests effect of temperature with OMEGA

To investigate the effect of temperature on the results of the mesh size measurements with the OMEGA a new polyethylene net, a used polyethylene net and a nylon net were measured at 0°C, 18°C and 35°C (Figure 13, Figure 14 and Figure 15).

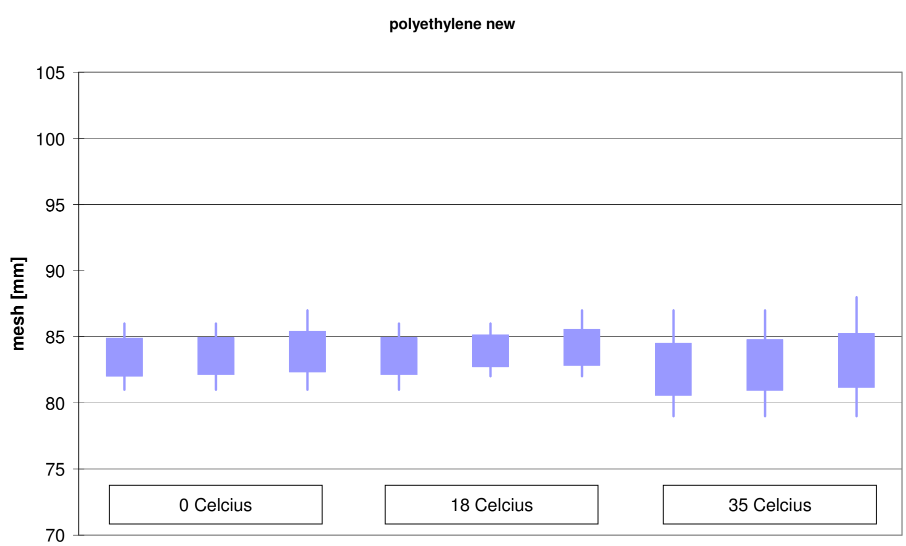

Figure 13 effect of temperature on mesh sizes of a new polyethylene net

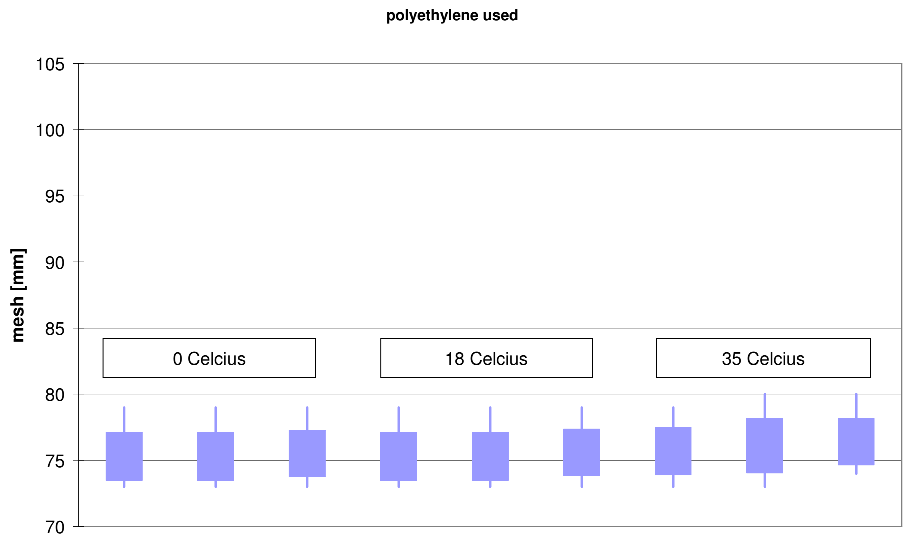

Figure 14 effect of temperature on mesh sizes of a used polyethylene net,

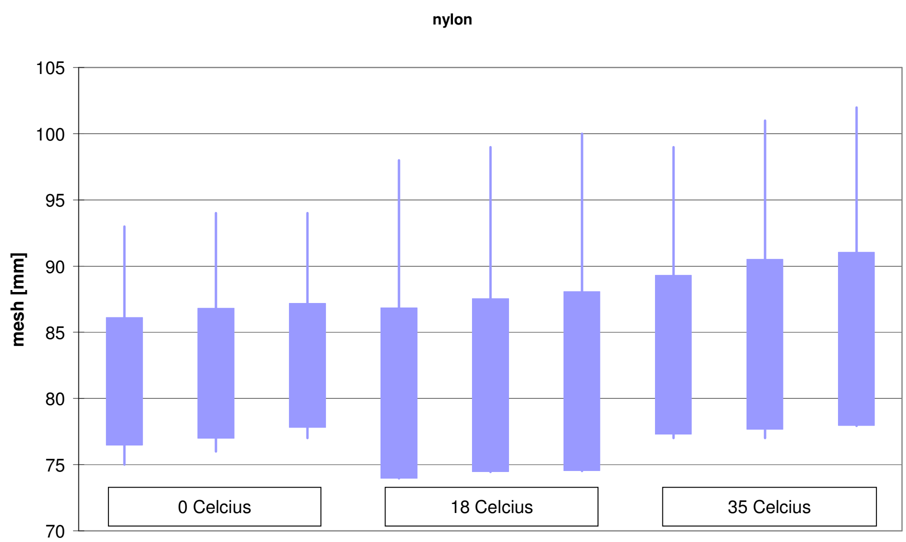

Figure 15 effect of temperature on mesh sizes of a nylon net

The diagrams do not show a clear relation between temperature and mesh size. Additional tests at different temperatures are reported in appendix A, where the same observation is made. It is noted that used polyethylene net is a rejected because of the mesh sizes well below 80 mm. For the purpose of understanding net characteristics this is not considered a draw back.

3.5 Measurements on board with OMEGA

Three sets of measurements on three adjacent mesh rows of 20 meshes were done on board various vessels with the OMEGA. A typical result is shown in Figure 16. The full set of results is reported in appendix B. Please refer to section 3.2 for an explanation of the diagrams.

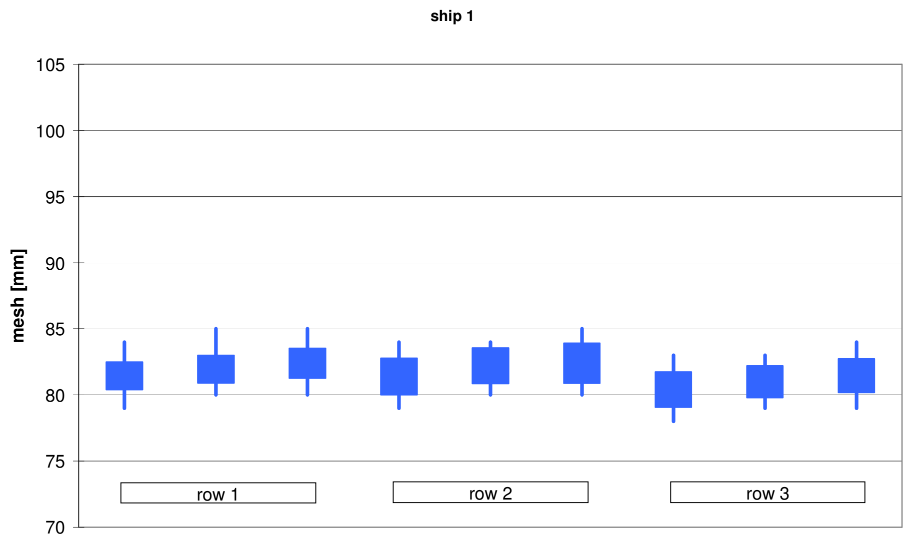

Figure 16 mesh size ship 1

The diagrams clearly show the effect of repeated measurements. Measuring the same mesh tree times produces an increase of the average mesh sizes of up to 1.1 mm. It is also quite clear that the mesh size always increases when repeating the measurement.

The results for all ships and all visits are listed in Table 3 through Table 5. Results of all '1st readings' are shown in Table 3. Results of the '2nd readings' are shown in Table 4, while results of the '3rd readings' are shown in Table 5.

Table 3 measured results 1st reading

			n=20 1 st reading					
			Xavg			s(Xavg)		
			row no.			row no.		
		date	1	2	3	1	2	3
ship	1	04/06/2010	81.45	81.40	80.40	1.05	1.39	1.35
ship	2	11/06/2010	83.60	83.00	82.35	1.82	1.03	1.31
ship	3	11/06/2010	80.85	81.10	78.50	1.27	1.07	1.19
ship	3	18/06/2010	78.85	80.95	79.45	1.57	1.73	1.82
ship	4	11/06/2010	80.35	80.00	79.15	0.93	1.41	1.53
ship	4	18/06/2010	79.95	80.10	78.55	1.28	1.25	1.28
ship	5	04/06/2010	82.75	82.55	83.30	1.89	1.28	1.42
ship	6	11/06/2010	83.20	82.15	79.90	1.44	1.27	2.69
ship	7	04/06/2010	80.75	81.15	81.30	1.71	1.50	1.45
ship	7	11/06/2010	79.90	81.05	80.90	1.33	1.57	2.02
ship	7	18/06/2010	81.15	81.05	81.40	1.35	1.47	1.39
ship	8	04/06/2010	80.35	80.80	79.80	1.27	1.20	1.11
ship	8	11/06/2010	81.45	81.65	82.65	1.28	1.42	1.27
ship	8	18/06/2010	80.85	79.95	81.80	1.23	1.64	1.11
ship	9	11/06/2010	81.15	81.70	81.20	1.27	1.17	1.40
ship	9	18/06/2010	79.85	80.95	80.30	1.35	1.28	1.45
ship	10	12/06/2010	82.70	81.90	82.00	1.98	1.41	1.65
					avg	81.05		*avg*	1.42
					max	83.60		*max*	2.69
					min	78.50		*min*	0.93

The nets studied should comply with the 80 mm minimum mesh size requirement. Given the accuracy of the OMEGA of 1 mm, a rejection value of 79 mm is considered reasonable. Therefore, for the purpose of this study, this value is chosen as rejection criterion.

It is noted that in the first reading three nets did not comply with the 79 mm rejection criterion (indicated with the yellow shading).

The average of all averages in the first reading equals 81.05 mm, while the average of the standard deviations is 1.42 mm.

In the second reading only two nets do not comply, while in the third reading all nets comply.

Average mesh sizes are 81.53 mm and 81.84 mm for the second and the third reading respectively. Average standard deviations are 1.42 mm and 1.40 mm respectively.

The non compliant nets do not show any particular high or low standard deviation.

Table 4 measured results 2nd reading

			n=20 2 nd reading					
			Xavg			s(Xavg)		
			row no.			row no.		
		date	1	2	3	1	2	3
ship	1	04/06/2010	81.95	82.20	81.00	1.05	1.36	1.21
ship	2	11/06/2010	84.15	83.60	83.05	1.69	0.94	1.36
ship	3	11/06/2010	81.25	81.40	78.90	1.21	1.05	1.33
ship	3	18/06/2010	79.30	81.45	79.85	1.63	1.73	1.73
ship	4	11/06/2010	80.85	80.55	79.85	0.88	1.32	1.60
ship	4	18/06/2010	80.40	80.50	78.95	1.35	1.10	1.23
ship	5	04/06/2010	83.45	83.25	83.95	1.82	1.21	1.57
ship	6	11/06/2010	83.65	82.30	80.40	1.42	1.22	2.78
ship	7	04/06/2010	81.15	81.55	81.70	1.73	1.61	1.49
ship	7	11/06/2010	80.50	81.15	81.25	1.28	1.66	1.97
ship	7	18/06/2010	81.70	81.55	82.05	1.08	1.70	1.39
ship	8	04/06/2010	80.95	81.30	80.10	1.15	1.38	1.02
ship	8	11/06/2010	81.80	82.15	83.25	1.28	1.57	1.25
ship	8	18/06/2010	81.15	80.45	82.30	1.18	1.67	1.08
ship	9	11/06/2010	81.80	82.20	81.75	1.44	1.15	1.21
ship	9	18/06/2010	80.30	81.25	80.75	1.38	1.21	1.33
ship	10	12/06/2010	82.70	82.20	82.65	2.00	1.44	1.84
					avg	81.53		*avg* 1.42
					max	84.15		*max* 2.78
					min	78.90		*min* 0.88

Table 5 measured results 3rd reading

			n=20 3 rd reading					
			Xavg			s(Xavg)		
			row no.			row no.		
		date	1	2	3	1	2	3
ship	1	04/06/2010	82.40	82.40	81.45	1.14	1.54	1.28
ship	2	11/06/2010	84.40	83.90	83.30	1.85	0.91	1.45
ship	3	11/06/2010	81.35	81.80	79.25	1.18	0.95	1.29
ship	3	18/06/2010	79.55	81.70	80.40	1.67	1.81	1.70
ship	4	11/06/2010	81.05	80.85	80.30	0.83	1.35	1.66
ship	4	18/06/2010	80.75	80.90	79.30	1.29	1.21	1.17
ship	5	04/06/2010	83.60	83.55	84.10	1.73	1.10	1.55
ship	6	11/06/2010	83.90	82.55	80.70	1.33	1.15	2.60
ship	7	04/06/2010	81.35	81.75	81.90	1.76	1.59	1.45
ship	7	11/06/2010	80.60	81.45	81.35	1.31	1.47	2.08
ship	7	18/06/2010	82.10	81.85	82.35	1.37	1.60	1.35
ship	8	04/06/2010	81.35	81.65	80.55	1.14	1.27	0.94
ship	8	11/06/2010	82.10	82.50	83.50	1.17	1.54	1.28
ship	8	18/06/2010	81.55	80.80	82.70	1.19	1.67	1.08
ship	9	11/06/2010	82.15	82.50	82.20	1.18	1.10	1.28
ship	9	18/06/2010	80.60	81.55	81.30	1.35	1.10	1.17
ship	10	12/06/2010	83.55	82.50	82.80	1.76	1.47	1.85
					avg	81.84		*avg* 1.40
					max	84.40		*max* 2.60
					min	79.25		*min* 0.83

Five vessels were measured at intervals of about a week apart to test the effect of time on the measured mesh size. Figure 17 and Figure 18 show the plots related to three consecutive visits for ship 7 and ship 8 respectively (the other three ships are reported in the appendix). From this data it can be concluded that mesh sizes do not change over time.

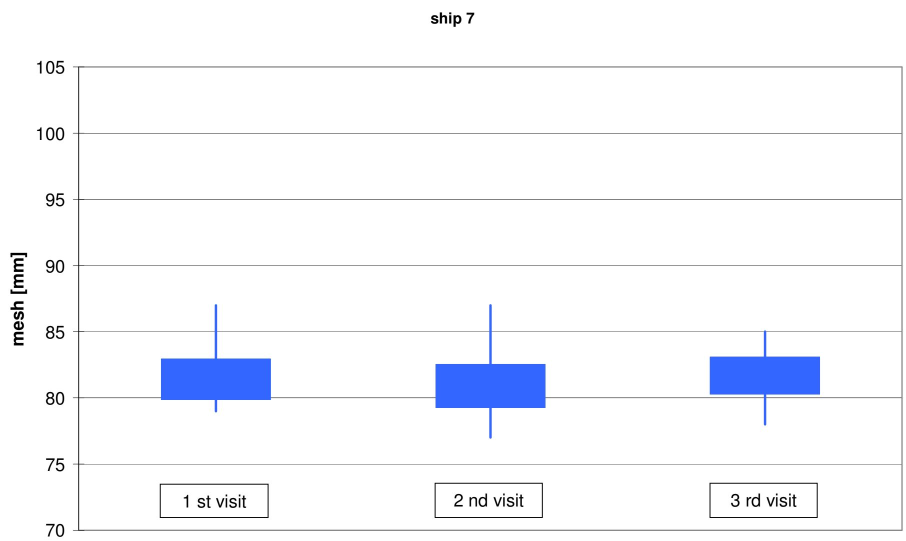

Figure 17 results mesh size measurements ship 7, three different visits

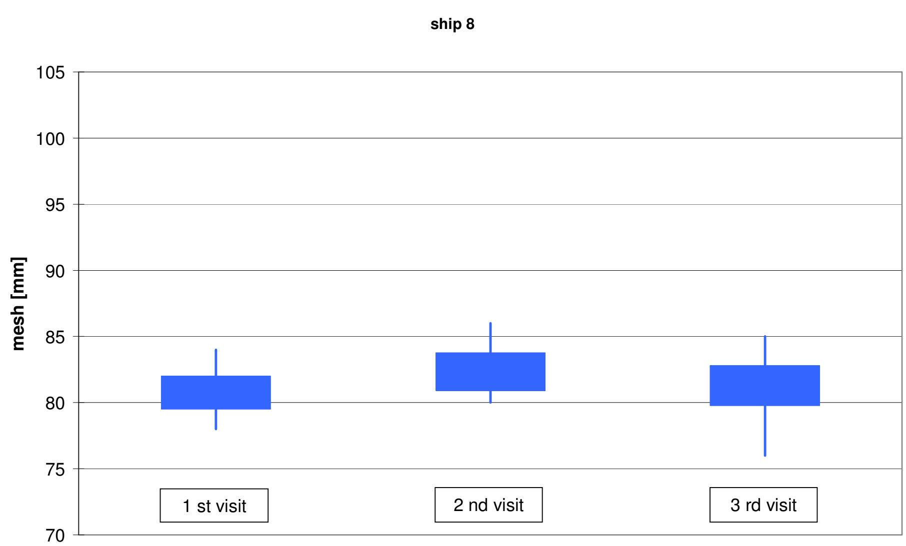

Figure 18 results mesh size measurements ship 8, three different visits

4 Data analysis

4.1 Analysis method

There exists a relation between the standard deviation in the measured data, the choice of the rejection value and the probability of unjust rejection. The larger the standard deviation the larger the probability of unjust rejection becomes once a rejection value is chosen. Also the lower the rejection value the lower the probability of unjust rejection becomes (see Figure 46). The theoretical formulation dealing with the qualitative description given in this section can be found in Appendix C.

4.2 Analysis results

Table 6 shows again the averages and standard deviations of the 1st measurements, for three meshes per net. However now it is also indicated whether the nets would be accepted if the 79 mm rejection value is used. There are three cases were the nets will be rejected. For these three cases the probabilities that the rejections are unjust are indicated.

Table 6 measured averages, standard deviations, unjust rejection probabilities, 1st reading

			n=20 1 st reading						n=20 1st reading		
			Xavg			s(Xavg)			row 1	row 2	row 3
			row no.			row no.					
		date	1	2	3	1	2	3			
ship	1	04/06/2010	81.45	81.40	80.40	1.05	1.39	1.35	accepted	accepted	accepted
ship	2	11/06/2010	83.60	83.00	82.35	1.82	1.03	1.31	accepted	accepted	accepted
ship	3	11/06/2010	80.85	81.10	78.50	1.27	1.07	1.19	accepted	accepted	0.001%
ship	3	18/06/2010	78.85	80.95	79.45	1.57	1.73	1.82	0.194%	accepted	accepted
ship	4	11/06/2010	80.35	80.00	79.15	0.93	1.41	1.53	accepted	accepted	accepted
ship	4	18/06/2010	79.95	80.10	78.55	1.28	1.25	1.28	accepted	accepted	0.003%
ship	5	04/06/2010	82.75	82.55	83.30	1.89	1.28	1.42	accepted	accepted	accepted
ship	6	11/06/2010	83.20	82.15	79.90	1.44	1.27	2.69	accepted	accepted	accepted
ship	7	04/06/2010	80.75	81.15	81.30	1.71	1.50	1.45	accepted	accepted	accepted
ship	7	11/06/2010	79.90	81.05	80.90	1.33	1.57	2.02	accepted	accepted	accepted
ship	7	18/06/2010	81.15	81.05	81.40	1.35	1.47	1.39	accepted	accepted	accepted
ship	8	04/06/2010	80.35	80.80	79.80	1.27	1.20	1.11	accepted	accepted	accepted
ship	8	11/06/2010	81.45	81.65	82.65	1.28	1.42	1.27	accepted	accepted	accepted
ship	8	18/06/2010	80.85	79.95	81.80	1.23	1.64	1.11	accepted	accepted	accepted
ship	9	11/06/2010	81.15	81.70	81.20	1.27	1.17	1.40	accepted	accepted	accepted
ship	9	18/06/2010	79.85	80.95	80.30	1.35	1.28	1.45	accepted	accepted	accepted
ship	10	12/06/2010	82.70	81.90	82.00	1.98	1.41	1.65	accepted	accepted	accepted
					avg	81.05		*avg*	1.42		
					max	83.60		*max*	2.69		
					min	78.50		*min*	0.93		

These probabilities were obtained through the statistical analysis as explained in section 4.1. The rejection criterion was set at 79 mm while the required minimum value was set at 80 mm.

Table 7 and Table 8 show the measured averages and standard deviations of the 2nd and 3rd measurement respectively, again appended with ‘acceptance’ columns.

It can be seen that the number of measured averages smaller than the target value reduces with an increasing number of measurements. After three measurements all averages are above the lower limit of 79 mm.

Table 7 measured averages, standard deviations, unjust rejection probabilities, 2nd reading

		n=20 2 nd reading						n=20 2nd reading		
		Xavg			s(Xavg)			row 1	row 2	row 3
		row no.			row no.					
	date	1	2	3	1	2	3			
1	04/06/2010	81.95	82.20	81.00	1.05	1.36	1.21	accepted	accepted	accepted
2	11/06/2010	84.15	83.60	83.05	1.69	0.94	1.36	accepted	accepted	accepted
3	11/06/2010	81.25	81.40	78.90	1.21	1.05	1.33	accepted	accepted	0.078%
3	18/06/2010	79.3000	81.45	79.85	1.6254554	1.73	1.73	accepted	accepted	accepted
4	11/06/2010	80.85	80.55	79.85	0.88	1.32	1.60	accepted	accepted	accepted
4	18/06/2010	80.40	80.50	78.95	1.35	1.10	1.23	accepted	accepted	0.060%
5	04/06/2010	83.45	83.25	83.95	1.82	1.21	1.57	accepted	accepted	accepted
6	11/06/2010	83.65	82.30	80.40	1.42	1.22	2.78	accepted	accepted	accepted
7	04/06/2010	81.15	81.55	81.70	1.73	1.61	1.49	accepted	accepted	accepted
7	11/06/2010	80.50	81.15	81.25	1.28	1.66	1.97	accepted	accepted	accepted
7	18/06/2010	81.70	81.55	82.05	1.08	1.70	1.39	accepted	accepted	accepted
8	04/06/2010	80.95	81.30	80.10	1.15	1.38	1.02	accepted	accepted	accepted
8	11/06/2010	81.80	82.15	83.25	1.28	1.57	1.25	accepted	accepted	accepted
8	18/06/2010	81.15	80.45	82.30	1.18	1.67	1.08	accepted	accepted	accepted
9	11/06/2010	81.80	82.20	81.75	1.44	1.15	1.21	accepted	accepted	accepted
9	18/06/2010	80.30	81.25	80.75	1.38	1.21	1.33	accepted	accepted	accepted
10	12/06/2010	82.70	82.20	82.65	2.00	1.44	1.84	accepted	accepted	accepted

	Xavg		s(Xavg)
avg	81.53	*avg*	1.42
max	84.15	*max*	2.78
min	78.90	*min*	0.88

Table 8 measured averages, standard deviations, unjust rejection probabilities, 3rd reading

			n=20 3 rd reading						n=20 3rd reading		
			Xavg			s(Xavg)			row 1	row 2	row 3
			row no.			row no.					
		date	1	2	3	1	2	3			
ship	1	04/06/2010	82.40	82.40	81.45	1.14	1.54	1.28	accepted	accepted	accepted
ship	2	11/06/2010	84.40	83.90	83.30	1.85	0.91	1.45	accepted	accepted	accepted
ship	3	11/06/2010	81.35	81.80	79.25	1.18	0.95	1.29	accepted	accepted	accepted
ship	3	18/06/2010	79.55	81.70	80.40	1.67	1.81	1.70	accepted	accepted	accepted
ship	4	11/06/2010	81.05	80.85	80.30	0.83	1.35	1.66	accepted	accepted	accepted
ship	4	18/06/2010	80.75	80.90	79.30	1.29	1.21	1.17	accepted	accepted	accepted
ship	5	04/06/2010	83.60	83.55	84.10	1.73	1.10	1.55	accepted	accepted	accepted
ship	6	11/06/2010	83.90	82.55	80.70	1.33	1.15	2.60	accepted	accepted	accepted
ship	7	04/06/2010	81.35	81.75	81.90	1.76	1.59	1.45	accepted	accepted	accepted
ship	7	11/06/2010	80.60	81.45	81.35	1.31	1.47	2.08	accepted	accepted	accepted
ship	7	18/06/2010	82.10	81.85	82.35	1.37	1.60	1.35	accepted	accepted	accepted
ship	8	04/06/2010	81.35	81.65	80.55	1.14	1.27	0.94	accepted	accepted	accepted
ship	8	11/06/2010	82.10	82.50	83.50	1.17	1.54	1.28	accepted	accepted	accepted
ship	8	18/06/2010	81.55	80.80	82.70	1.19	1.67	1.08	accepted	accepted	accepted
ship	9	11/06/2010	82.15	82.50	82.20	1.18	1.10	1.28	accepted	accepted	accepted
ship	9	18/06/2010	80.60	81.55	81.30	1.35	1.10	1.17	accepted	accepted	accepted
ship	10	12/06/2010	83.55	82.50	82.80	1.76	1.47	1.85	accepted	accepted	accepted

	Xavg		s(Xavg)
avg	81.84	*avg*	1.40
max	84.40	*max*	2.60
min	79.25	*min*	0.83

4.3 Probability versus rejection value and standard deviation

In order to investigate how the probability of unjust rejection depends on standard deviation of the mesh sizes and the average values, these probabilities were calculated systematically (Figure 19). The horizontal axis refers to the standard deviation while the vertical axis refers to probabilities. The curves indicate the probability of unjust rejection as function of the standard deviation. Four curves are plotted for the rejection values 77.5, 78.0, 78.5 and 79.0 mm. The target value is set at 80 mm. In appendix D the data can be found in table format.

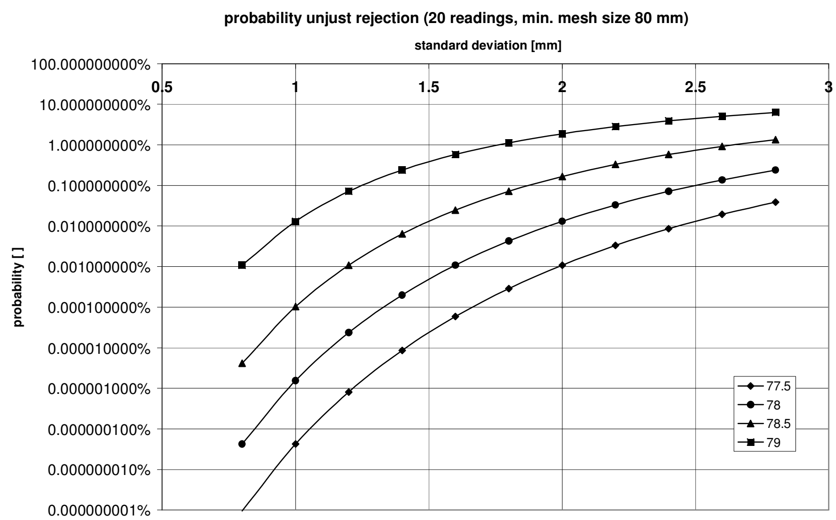

Figure 19 Sensitivity unjust rejection as function of rejection value and standard deviation

It is interesting to note that with a standard deviation of 2.8 mm, and a rejection criterion of 79.0 mm, the probability of an unjust rejection would be 6.3 %. It is also noted that standard deviations measured on board vary between 0.83 and 2.78 mm.

5 Discussion

The measured average mesh size systematically increases with the number of repeated readings taken on a mesh row, both in measurements made on board and in the laboratory. It is interesting to note that the Handbook of fibre rope technology, Ref. [2], describes the difficulty of measuring lengths of fibre ropes unambiguously. The main issue is the need to stabilise a rope before any rope length can be established. In fibre rope technology a standard is used CI 1500 ref. [4], which suggests a stabilisation procedure involving cyclic testing at both 20% and 50% of anticipated break strength (ref. [2], chapter 10, sections 10.8.5 and 10.8.3). Although breaking strengths are not actually known to the authors for the materials considered, they are bound to be well above 5 times 125 N, i.e. 625 N (62.5 kgf). As an example 3 mm polyethylene twine is mentioned, which may have a breaking strength of about 2200 N (220 kgf) [3]. The best procedure for measuring mesh sizes, would therefore be to increase the pretension drastically which however is not very practical. A second best option is to repeat measurements on meshes and use the last reading. Figure 6 and Figure 7 demonstrate that such repeated measurements tend to show an increase towards asymptotic values.

The screen of the OMEGAuge enables readings with an accuracy of 1 mm. The internal resolution of the OMEGAuge is better than 0.125 mm, according factory specifications [8]. This value is well within the smallest standard deviation of 0.8 mm which is obtained from the onboard measurements. Therefore the OMEGA does not contribute to the uncertainty of measured mesh size values.

The mesh size measurements on board (section 3.5) confirm the findings in the laboratory regarding the improving reproducibility in relation with repeated consecutive readings on one and the same mesh. Increasing the number of repeated readings improves reproducibility substantially.

The data obtained from measurements on board can be used to determine probabilities of unjust rejection of the nets based on rows of 20 meshes (Chapter 4).

6 Conclusion

The OMEGA is fit for purpose.

Mesh sizes measured with the OMEGA are in accordance with results measured with the TNO tensile test machine.

The influence of an operator on the measured mesh size is negligible.

No trend could be observed between measured mesh size and net temperature.

The data gathered on board was used to determine scatter inherent to the mesh sizes, mesh size variations can be as much as 5.1 mm in case of single readings and 2.3 mm in cases of three readings.

Typical standard deviations of mesh sizes vary between 0.8 and 2.7 mm.

Repeated measurements on nets in operation at time intervals of one week do not show an effect on the measured mesh sizes.

The pre-load on a mesh has a large influence on the measured mesh size.

When the pre-load at which meshes are measured is increased from 125 N to 300 N the reproducibility improves significantly.

Repeated readings at a fixed pretension of one mesh shows an increasing mesh size with increasing number of readings, a asymptotic value of the mesh size is reached after about 5 repeated readings.

Repeated readings of meshes on board fishing vessels show a systematic increase of the measured average mesh size which can be as large as 1.15 mm.

The probability of unjust rejection depends heavily on the chosen rejection value of the average measured mesh size and the standard deviation.

The measurements on board fishing vessels show that measuring a row of meshes three times and using the third reading to calculate the average mesh size reduces the probability of unjust rejection from 0.19 % to negligible. It is therefore recommended to measure each mesh at least three times and use the third value for calculating averages.

To achieve the most reproducible and reliable result two recommendations are made:
1. increase the pre-load of the mesh size gauge,
2. measure each mesh at least three times and judge a mesh size on the last reading of these consecutive readings.

References

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[4] Cordage Institute (2002) CI 1500: Test Methods for Fibre Ropes, Cordage Institute, Wayne, Pennsylvania

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[6] The Cartoon Guide to Statistics, Harper Perenial, Copyright © 1993 by Larry Goninck and Woolcott Smith. © Dutch translation Epsilon Uitgaven, ISBN 90-5041-037-5

[7] Kansen in de civiele techniek, deel 1: Probabilistisch ontwerpen in theorie. CUR, Civieltechnisch Centrum Uitvoering Research en Regelgeving, Directoraat Generaal Rijkswaterstaat, 1997, ISBN 90 376 0102 2

[8] MARELEC, OBSERVATOR, Objective Mesh Gauge, User Manual, v 5.1

Appendix A Measurements in laboratory

Figure 20, Figure 21 and Figure 22 show box-plots on laboratory tests carried out on the new polyethylene net at three different temperatures.

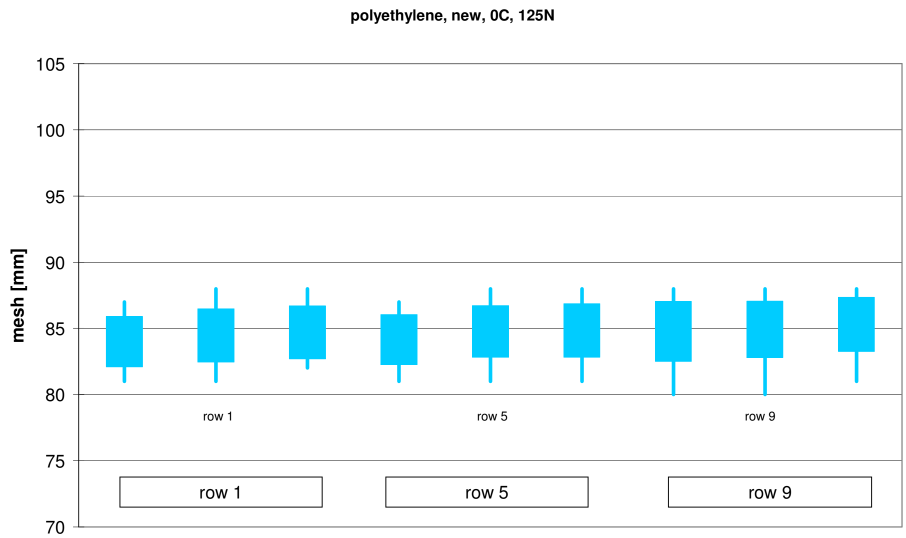

Figure 20 laboratory test, polyethylene new net, with Ω meter, at 0 ˚C

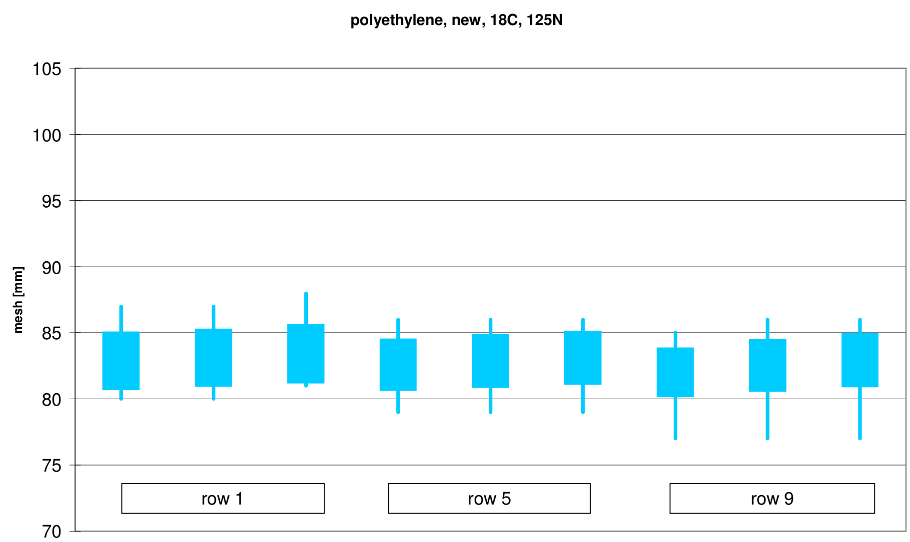

Figure 21 laboratory test, polyethylene new net, with Ω meter, at 18 ˚C

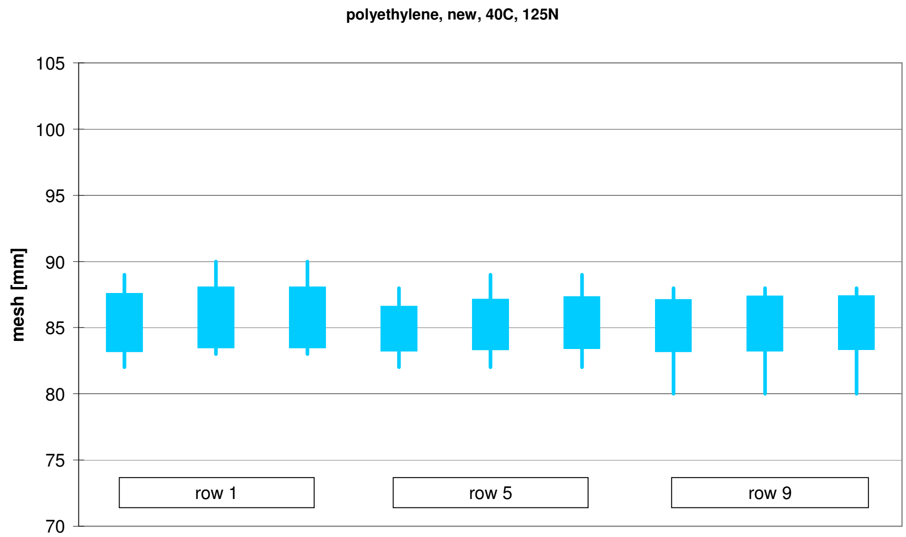

Figure 22 laboratory test, polyethylene new net, with Ω meter, at 40 ˚C

From these plots it can be seen that the average mesh size at 0 ˚C is similar to mesh size at 40 ˚C, while at 18 ˚C, the average seems to be slightly lower.

Figure 23, Figure 24 and Figure 25 show box-plots on laboratory tests carried out on the used polyethylene net at three different temperatures.

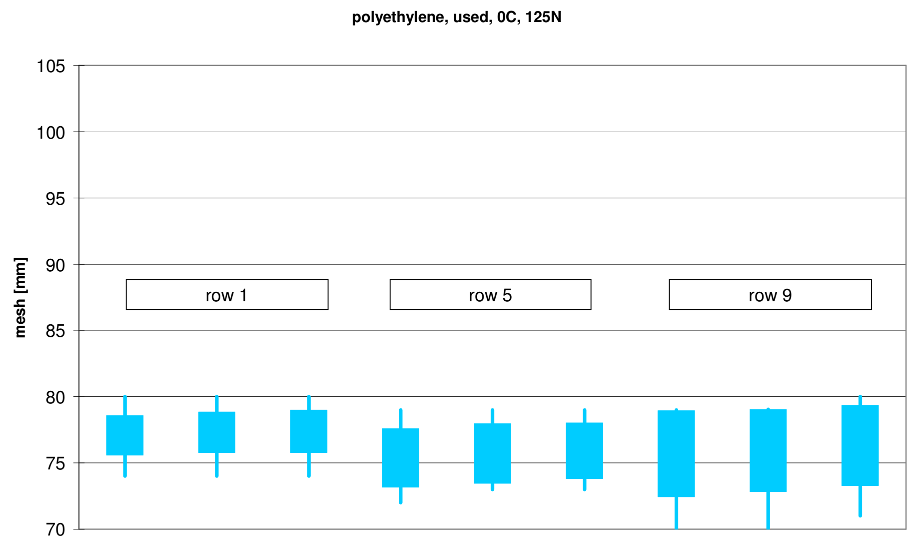

Figure 23 laboratory test, polyethylene old net, with Ω meter, at 0 ˚C

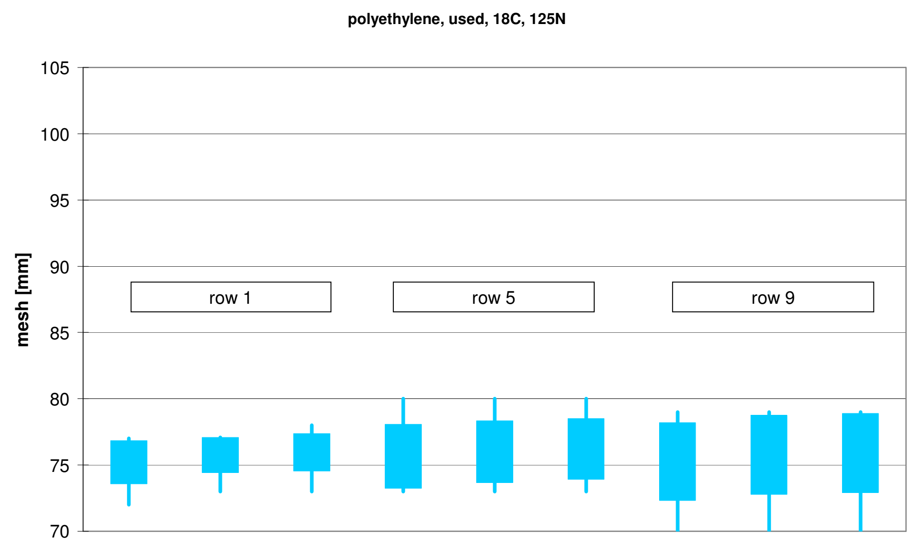

Figure 24 laboratory test, polyethylene old net, with Ω meter, at 18 ˚C

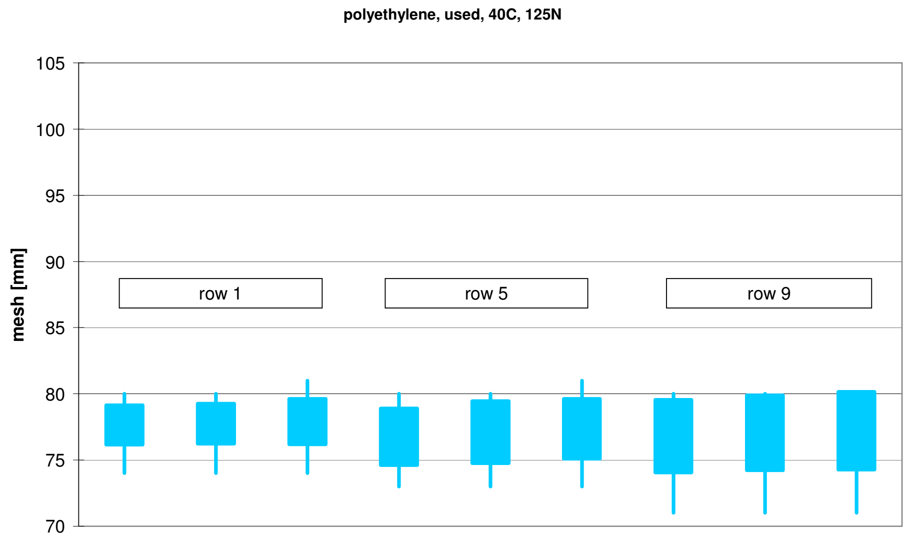

Figure 25 laboratory test, polyethylene old net, with Ω meter, at 40 ˚C

Also from these plots it can be seen that the average mesh size at 0 ˚C is similar to mesh size at 40 ˚C, while at 18 ˚C, the average seems to be slightly lower.

Figure 26, Figure 27 and Figure 28 show box-plots on laboratory tests carried out on a nylon net, again at three different temperatures.

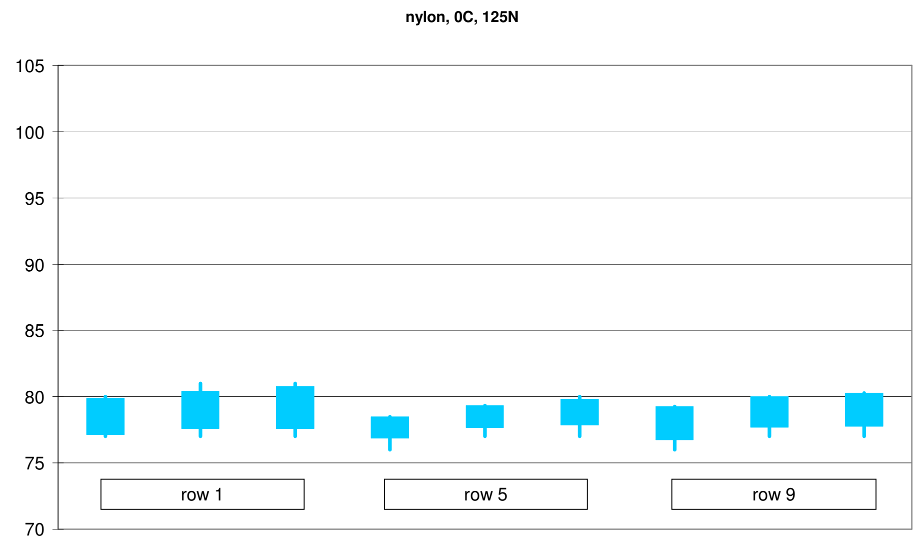

Figure 26 laboratory test, nylon net, with Ω meter, at 0 ˚C

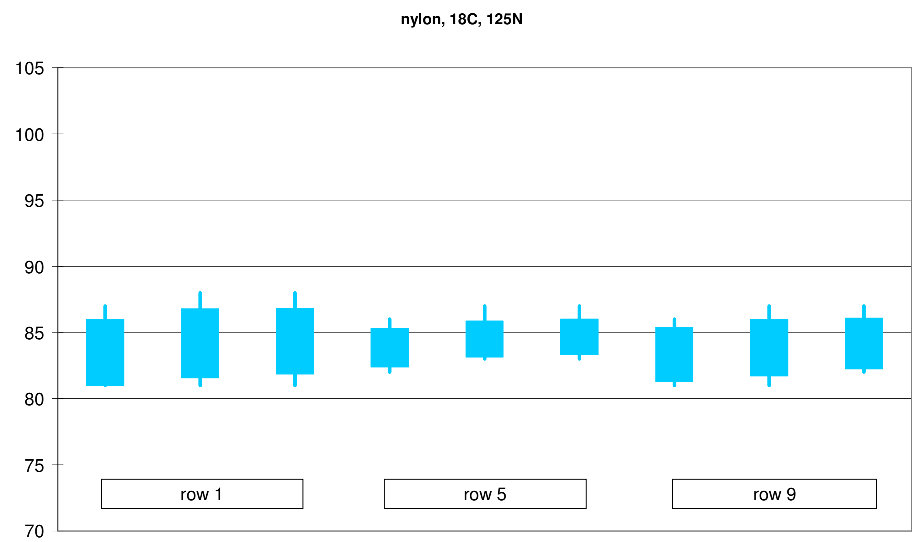

Figure 27 laboratory test, nylon net, with Ω meter, at 18 ˚C

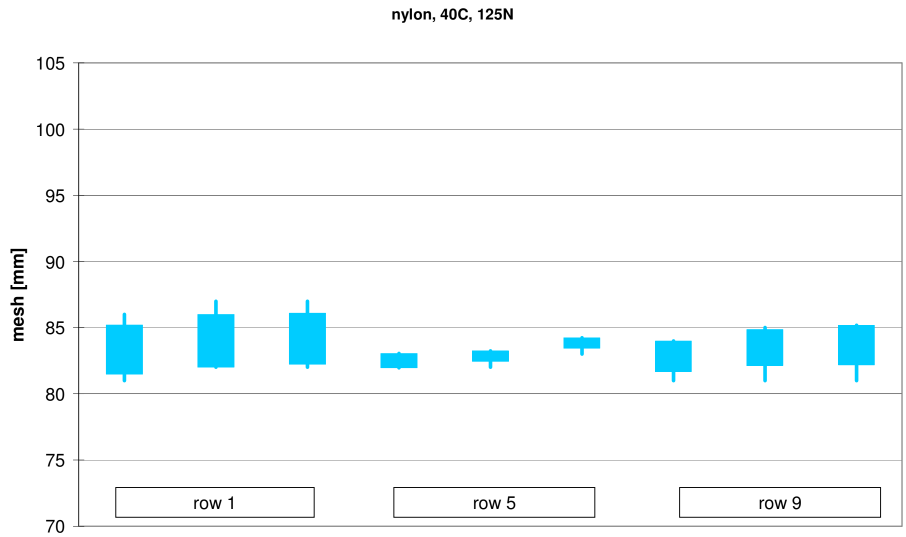

Figure 28 laboratory test, nylon net, with Ω meter, at 40 ˚C

From these plots it can be seen that the average mesh size at 0 ˚C is slightly smaller than the mesh size at 18 ˚C and 40 ˚C. This finding differs with the finding on the polyethylene nets.

Appendix B Measurements on board

Figure 29 through Figure 45 show the results of mesh size measurements. Each diagram shows three sets of measurements on three adjacent mesh rows, indicated along the horizontal axis;
1st mesh row, three consecutive measurements,
2nd mesh row, three consecutive measurements,
3rd mesh row, three consecutive measurements.

The vertical axis refers to the mesh sizes in mm.

The vertical boxes show upper and lower values of average mesh size plus standard deviation and average mesh size minus standard deviation. The vertical lines show maximum and minimum values.

The diagrams clearly show the effect of repeated measurement. Measuring the same mesh tree times may produce differences in the average mesh sizes of about 1 mm. It is also quite clear that the mesh size increases when repeating the measurement.

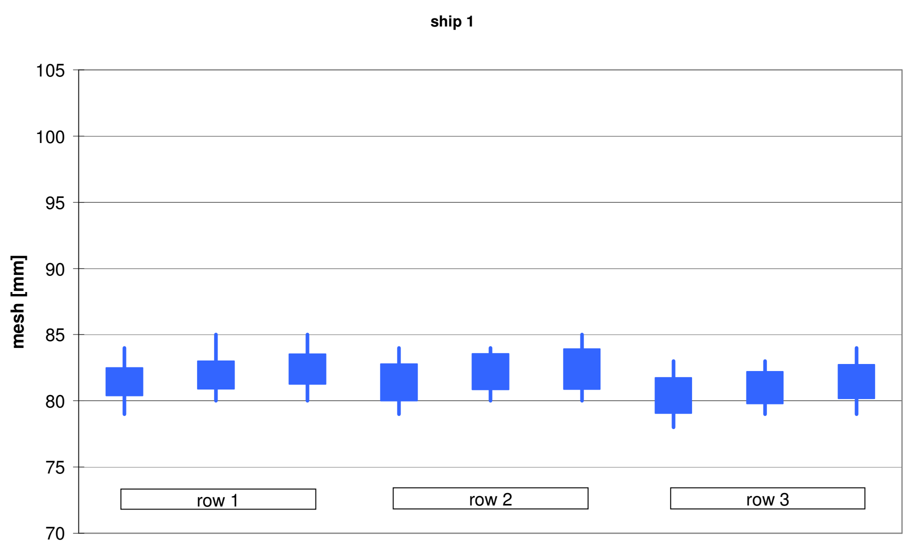

Figure 29 mesh size ship 1

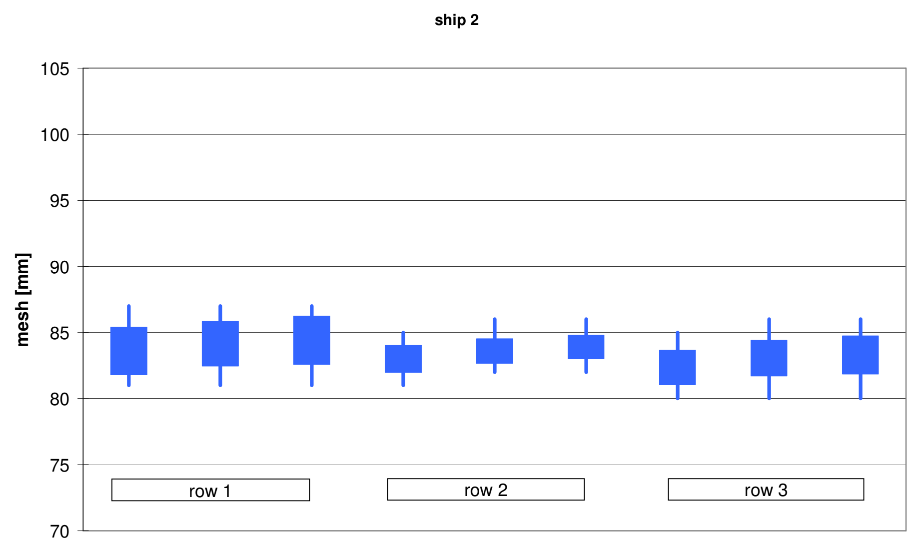

Figure 30 mesh size ship 2

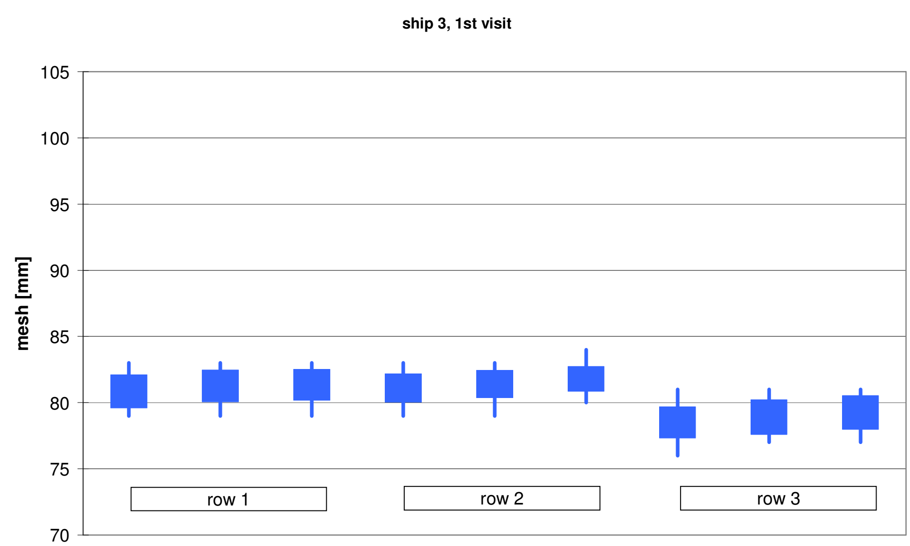

Figure 31 mesh size ship 3, 1st measurement

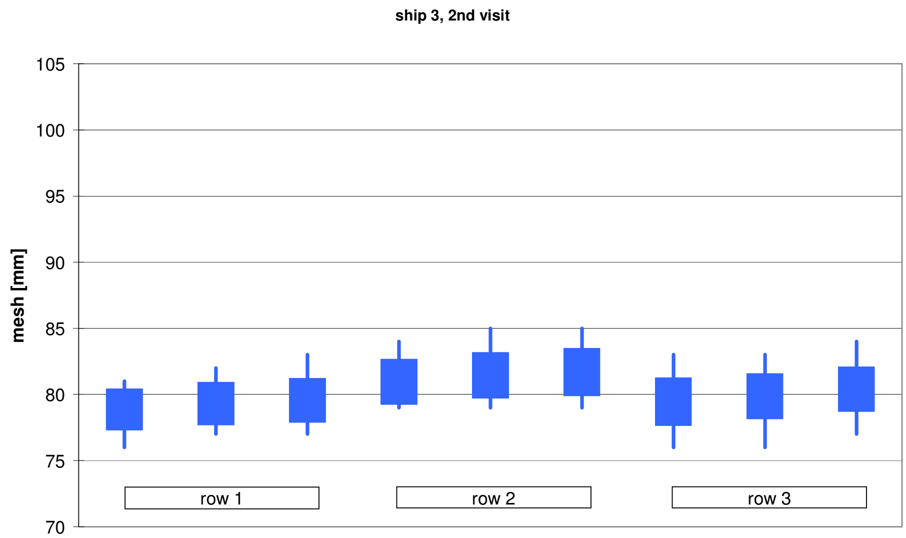

Figure 32 mesh size ship 3, 2nd measurement

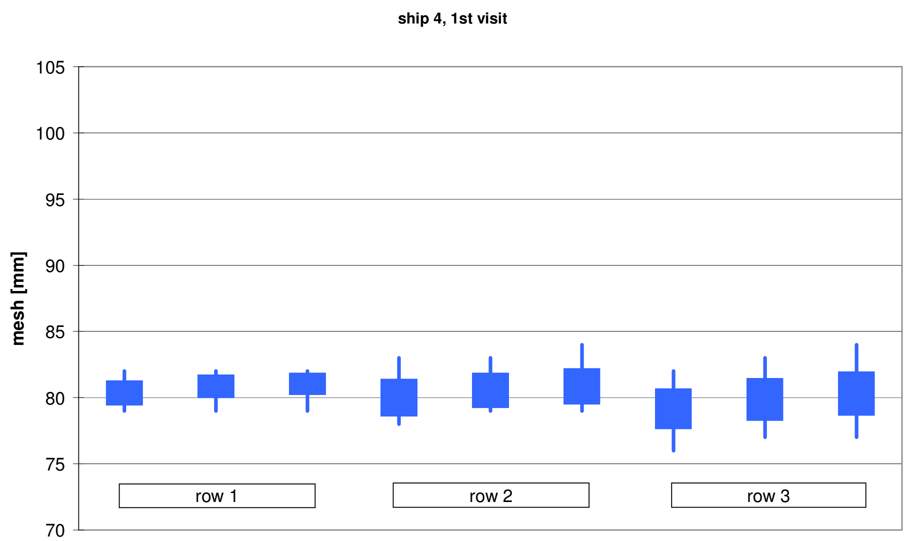

Figure 33 mesh size ship 4, 1st visit

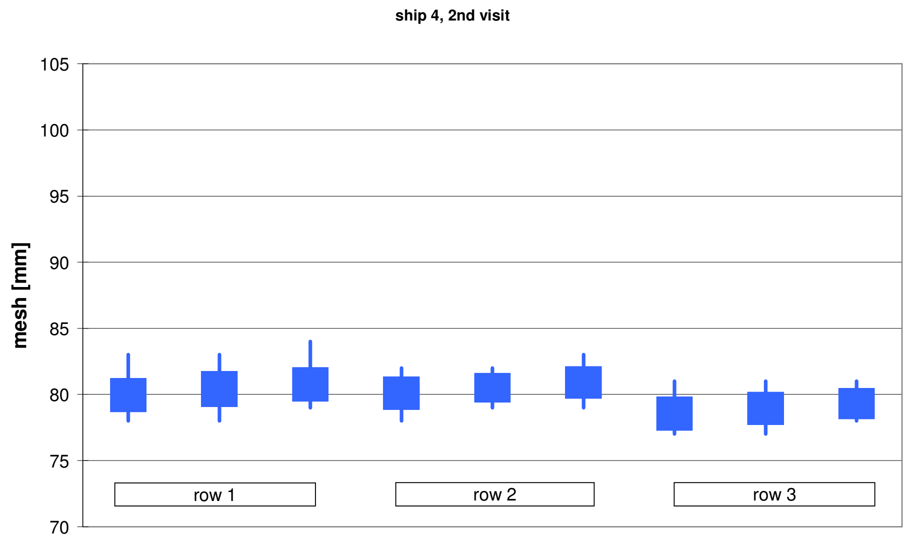

Figure 34 mesh size ship 4, 2nd visit

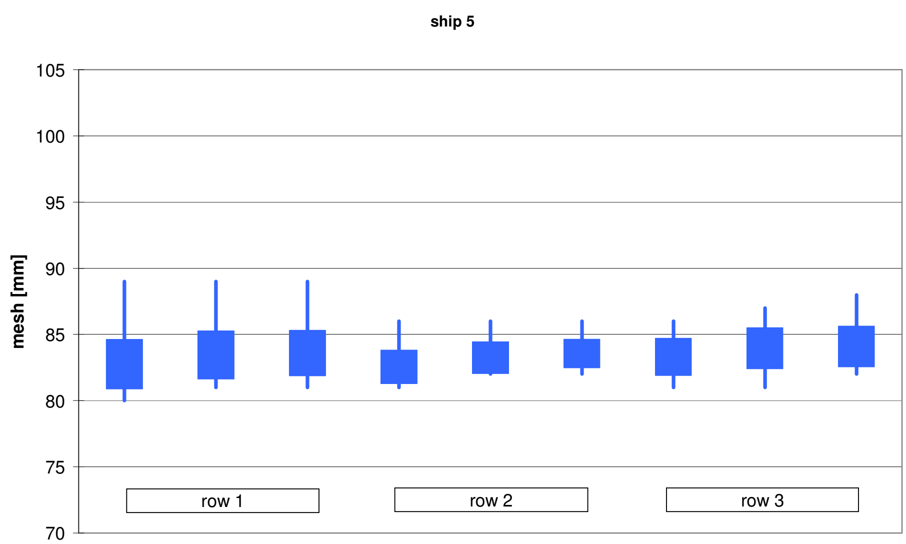

Figure 35 mesh size ship 5

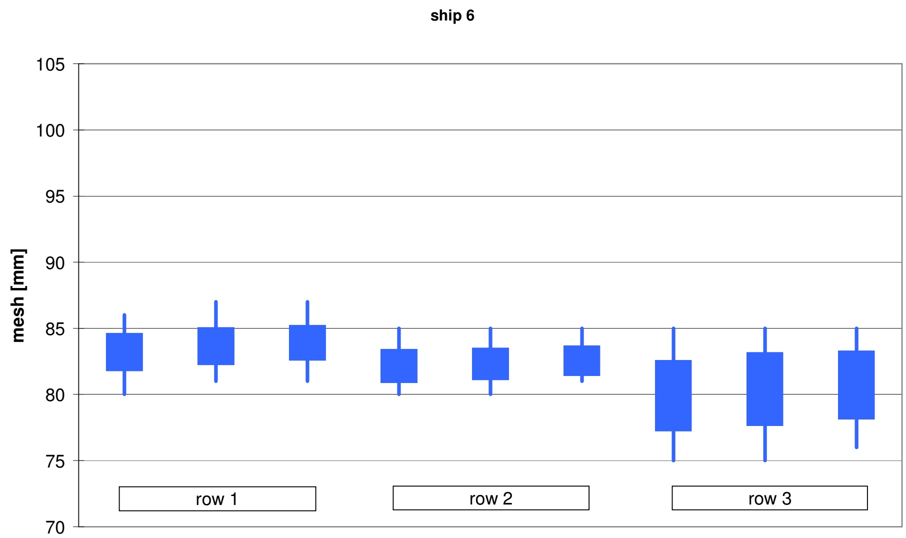

Figure 36 mesh size ship 6

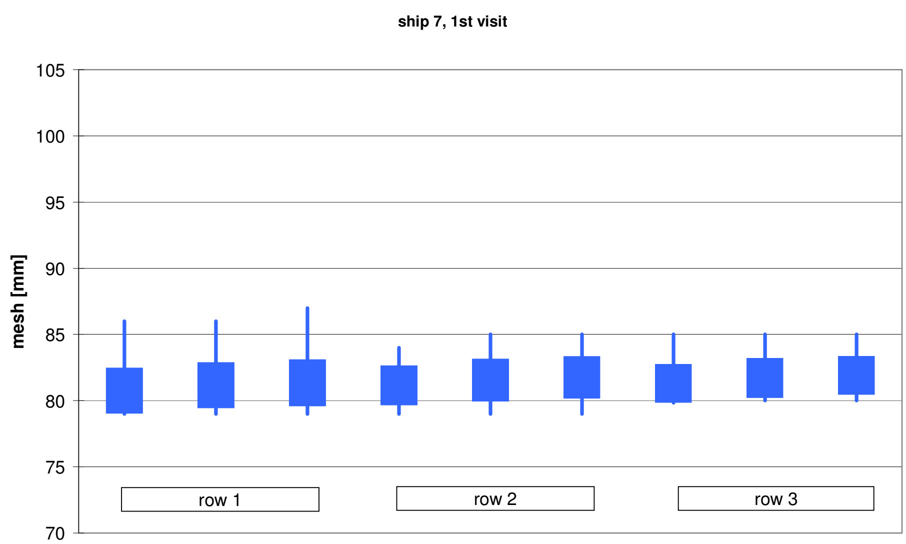

Figure 37 mesh size ship 7, 1st visit

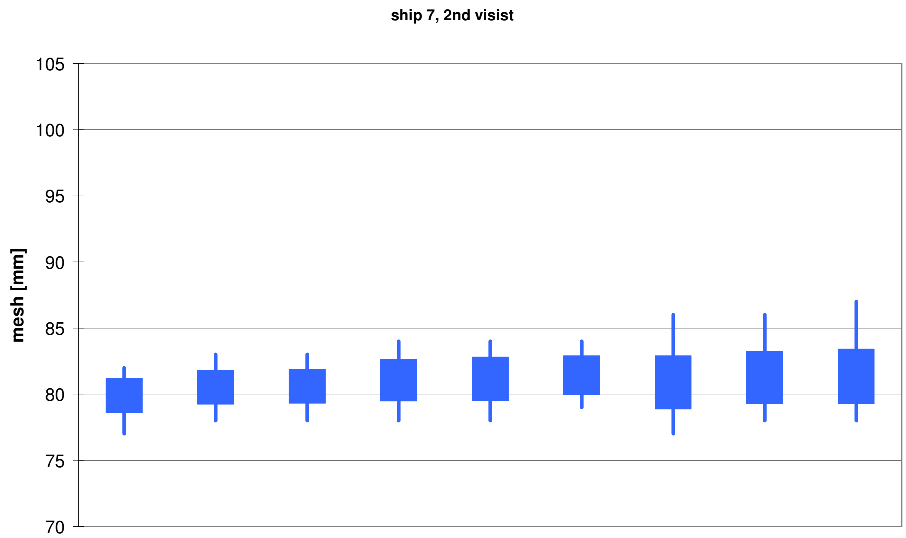

Figure 38 mesh size ship 7, 2nd visit

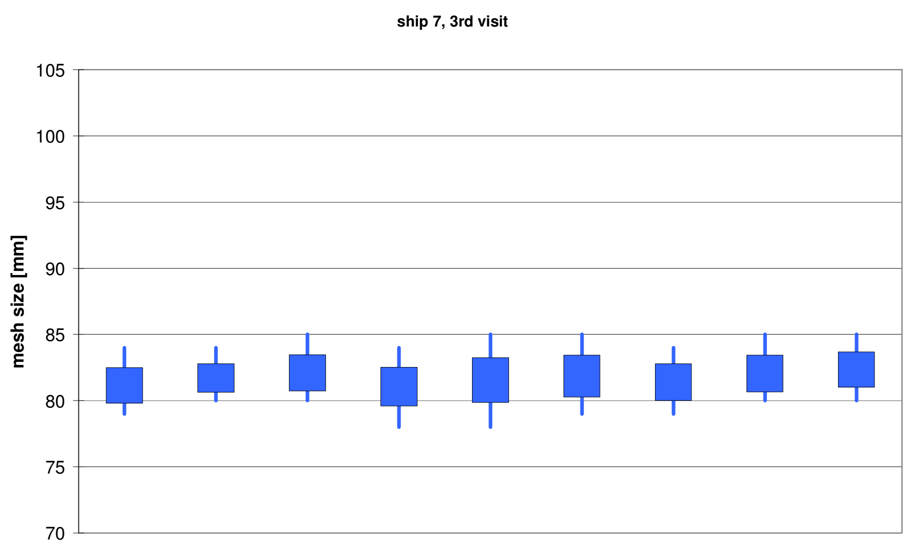

Figure 39 mesh size ship 7, 3rd visit

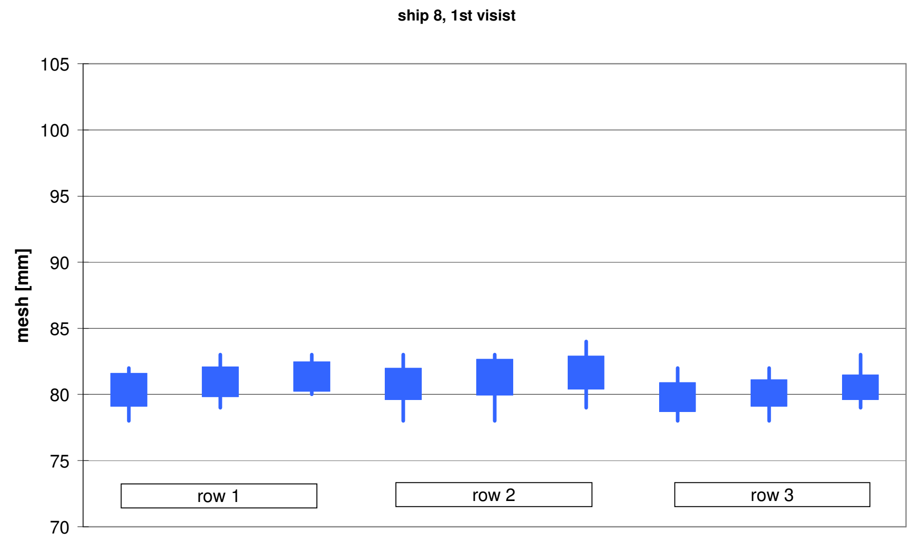

Figure 40 mesh size ship 8, 1st visit

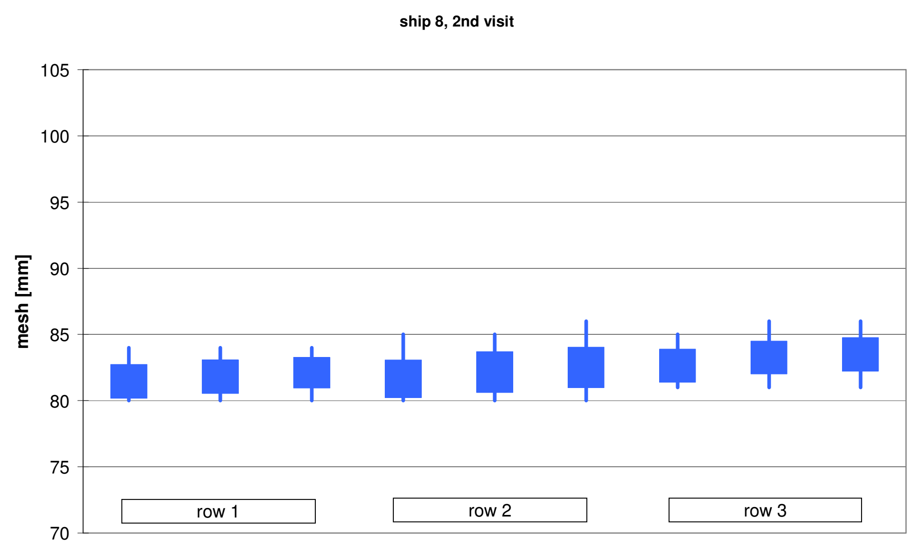

Figure 41 mesh size ship 8, 2nd visit

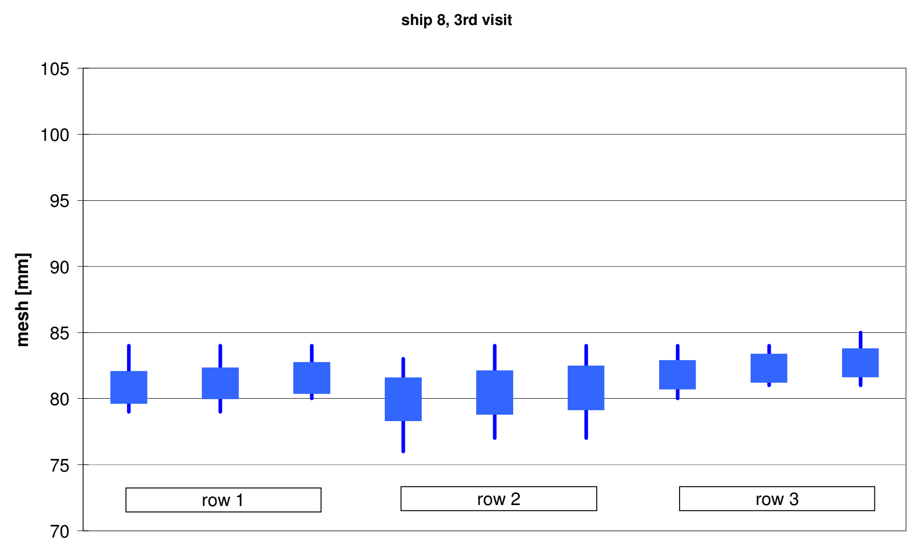

Figure 42 mesh size ship 8, 3rd visit

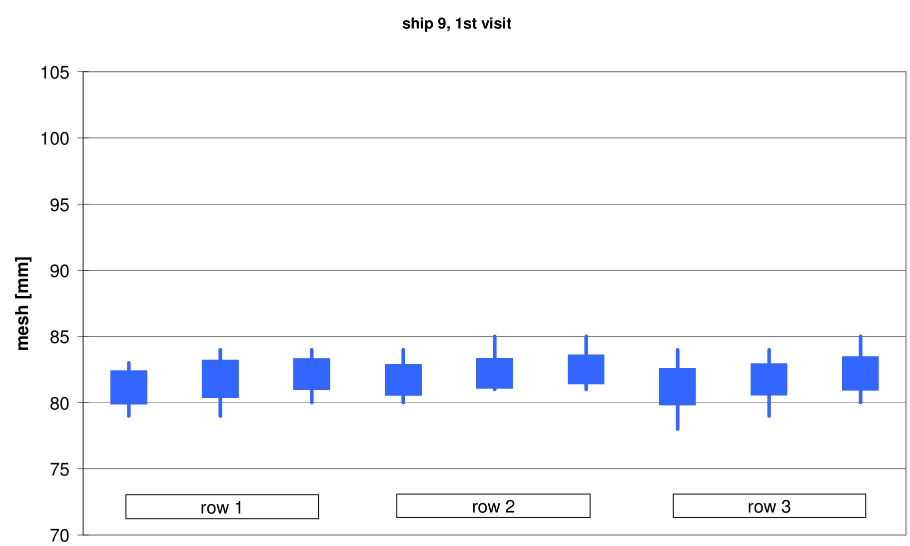

Figure 43 mesh size ship 9, 1st visit

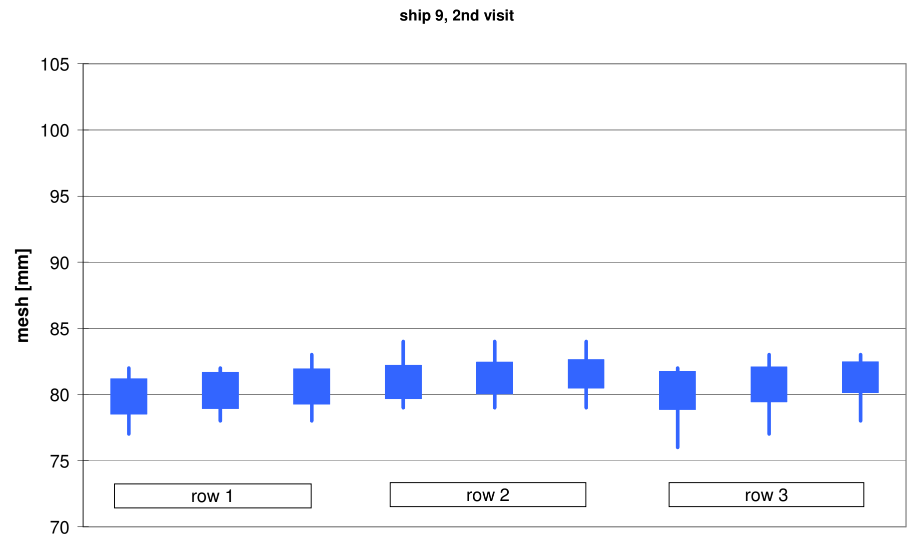

Figure 44 mesh size ship 9, 2nd visit

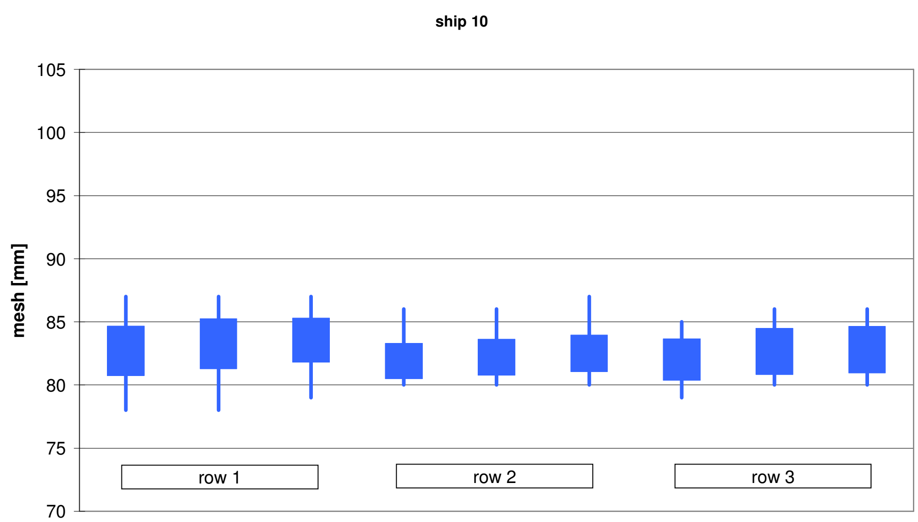

Figure 45 mesh size ship 10

Appendix C Statistical data analysis

Statistically the practice of measuring a limited number of meshes with the intention to determine the average mesh size of the entire net can be seen as taking a limited number of samples *n* from a population, which will be used to estimate the average value of the entire population from which the samples were drawn. In this case this is the average of all mesh sizes in a net.

Assuming a normal distribution for the mesh sizes, the classical approach is to use a student-t distribution. This practice is explained in many text books e.g. refs. [5] and [6].

The test parameter used is:

$$t = \frac{\overline{X}_n - {}_0}{\frac{s_n}{\sqrt{n}}} \qquad (1)$$

With : t test variable [1/mm],

$\overline{X}_n$ average value measured mesh sizes [mm],

${}_0$ minimum allowed (target) mesh size (80 mm in cases under consideration),

s_n standard deviation of measured values,

n number of readings (20 in cases under consideration, i.e. according to inspection protocol [1]).

With a given number of samples, a standard deviation *s* calculated from the samples and a target value for ${}_0$, this equation can be rewritten as

$$\overline{X}_n = t\frac{s_n}{\sqrt{n}} + {}_0 \qquad (2)$$

The probability density function for the parameter t (student-t distribution) is shown in Figure 46. The curves refer to three different standard deviations. The number of samples is 20. With equation (2) the t-values can be associated with measured average mesh sizes, also shown.

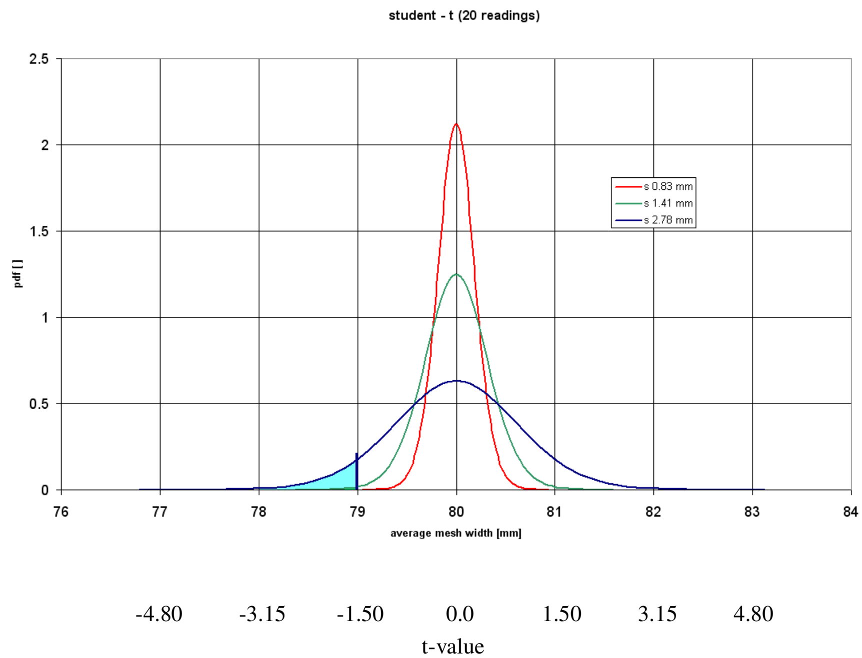

Figure 46 student t, probability density function expressed as function of average mesh width, for 20 readings at different standard deviations[3]

The minimum required mesh size of 80 mm is at the centre of the curve. The rejection value of 79 mm is indicated with a vertical line.

This function can be used to calculate the probability of a measured average mesh size lying below a chosen value, while the average of all meshes lies at 80 mm. This probability equals the area below the curve at the left hand side of the chosen rejection value. Taking 79 mm as rejection value and assuming the curve for the standard deviation s of 2.78 mm (blue) yields a probability of 0.057 (5.7 %), which is the area as indicated. When the s = 1.41 mm-curve is valid (green), the probability reduces to 0.002 (0.2 %). In case of the s = 0.83 mm curve (red) the probability is negligible.
These values are a measure for unjust rejection, i.e. the average mesh size of the entire net is at or above 80 mm, while the net is rejected based on the measurements of 20 meshes.

[3] Please note that the standard deviations mentioned in the legenda refer to deviation observed from 20 mesh size readings, they do not refer to the t-distributions as depicted in the figure.

Appendix D Unjust rejection vs rejection value and standard deviation

		probabilities [ ]										
		s [mm]										
		0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8
μ rejection [mm]	77.5	9.48848E-12	4.24E-10	8.12E-09	8.6E-08	5.88E-07	2.88E-06	1.08E-05	3.31E-05	8.56E-05	0.000193	0.000389
	77.6	1.92534E-11	8.32E-10	1.54E-08	1.57E-07	1.03E-06	4.86E-06	1.76E-05	5.21E-05	0.000131	0.000286	0.000561
	77.7	4.00393E-11	1.67E-09	2.96E-08	2.9E-07	1.83E-06	8.27E-06	2.89E-05	8.24E-05	0.0002	0.000423	0.000807
	77.8	8.54644E-11	3.42E-09	5.81E-08	5.43E-07	3.28E-06	1.42E-05	4.76E-05	0.000131	0.000305	0.000627	0.001161
	77.9	1.87543E-10	7.16E-09	1.16E-07	1.03E-06	5.93E-06	2.45E-05	7.87E-05	0.000207	0.000467	0.000928	0.001666
	78	4.23808E-10	1.54E-08	2.36E-07	1.99E-06	1.08E-05	4.26E-05	0.000131	0.00033	0.000715	0.001372	0.002387
	78.1	9.8803E-10	3.38E-08	4.88E-07	3.88E-06	2E-05	7.44E-05	0.000217	0.000525	0.001093	0.002023	0.003409
	78.2	2.38074E-09	7.64E-08	1.03E-06	7.66E-06	3.71E-05	0.000131	0.000362	0.000834	0.001666	0.002973	0.004849
	78.3	5.94048E-09	1.77E-07	2.22E-06	1.53E-05	6.94E-05	0.00023	0.000603	0.001324	0.002534	0.004353	0.006865
	78.4	1.53789E-08	4.22E-07	4.86E-06	3.1E-05	0.000131	0.000405	0.001004	0.002095	0.003835	0.006339	0.009666
	78.5	4.13827E-08	1.03E-06	1.08E-05	6.34E-05	0.000247	0.000715	0.001666	0.0033	0.005773	0.009174	0.01352
	78.6	1.15933E-07	2.59E-06	2.45E-05	0.000131	0.000467	0.001258	0.002754	0.005167	0.00863	0.013179	0.01877
	78.7	3.38563E-07	6.68E-06	5.63E-05	0.00027	0.000884	0.002204	0.00452	0.008026	0.012791	0.01877	0.025837
	78.8	1.0313E-06	1.76E-05	0.000131	0.000561	0.001666	0.003835	0.007355	0.012347	0.01877	0.02647	0.035225
	78.9	3.27556E-06	4.76E-05	0.000305	0.001161	0.003119	0.006607	0.011832	0.01877	0.027226	0.036912	0.047519
	79	1.08265E-05	0.000131	0.000715	0.002387	0.005773	0.01123	0.01877	0.028144	0.03897	0.050835	0.063361