



Escape causes in the Norwegian salmon industry



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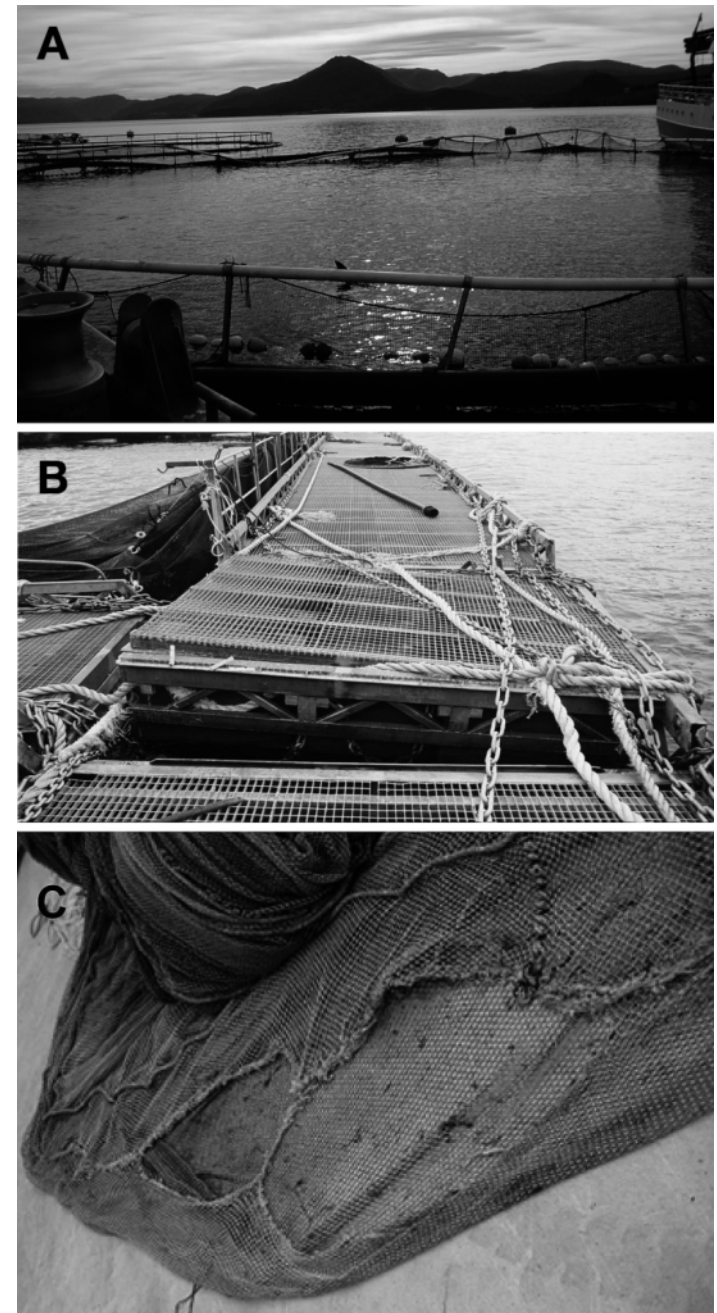
Overview of Norwegian industry

- 2010: ~1 million tons production
- Approx. ~ 500 sites in the sea
- Two trends
 - movement to more exposed locations
 - increases in average cage and farm size
- Cages typically 20000-40000 cubic metres, up to 80000
- Size of the industry allows robust assessment of escape causes

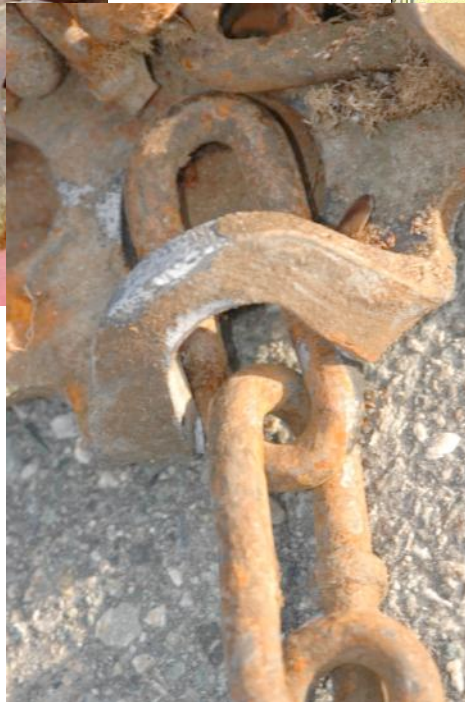


Typical structural failure causes

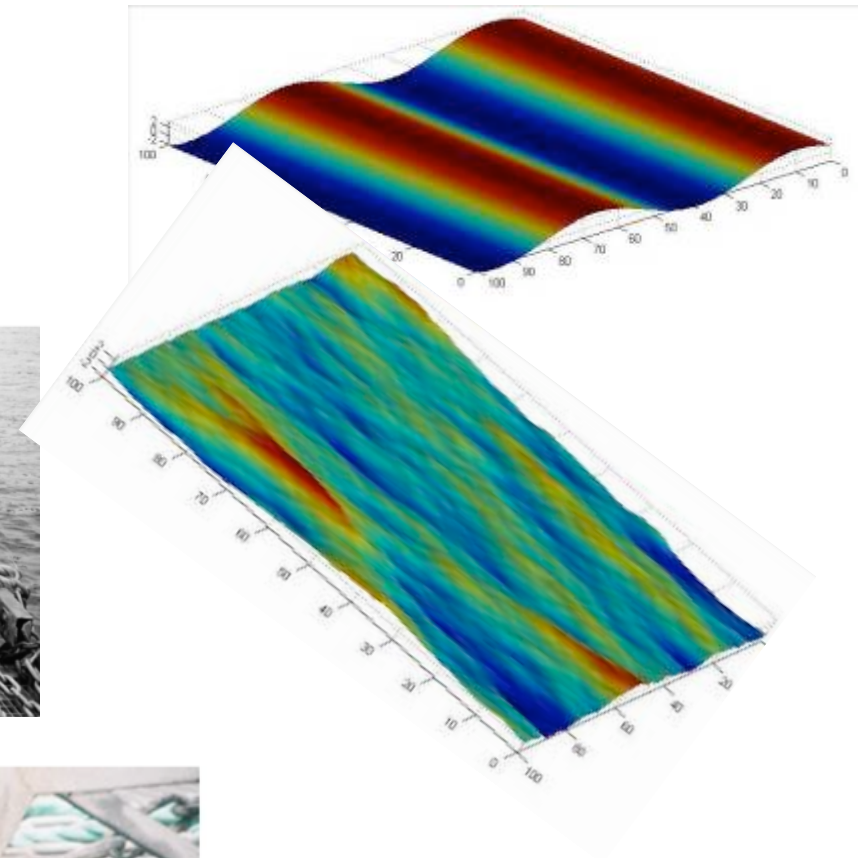
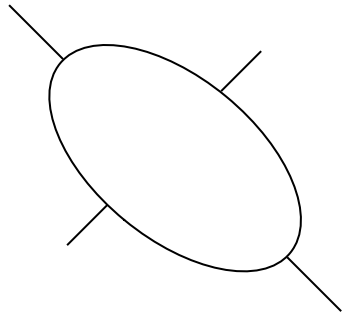
- Progressive collapse of mooring lines
- Collapse of floating collar
- Hole in the net



Progressive collapse of mooring system



Collapse of floating collar



The main cause of escape in Norway 2008-2010

NS9415 Section 9.5:

”Floating collars
which are used
together with a
stretching system
shall:

-be stuitable

.....so that the

stretching system

does not lead to

chafing of the net

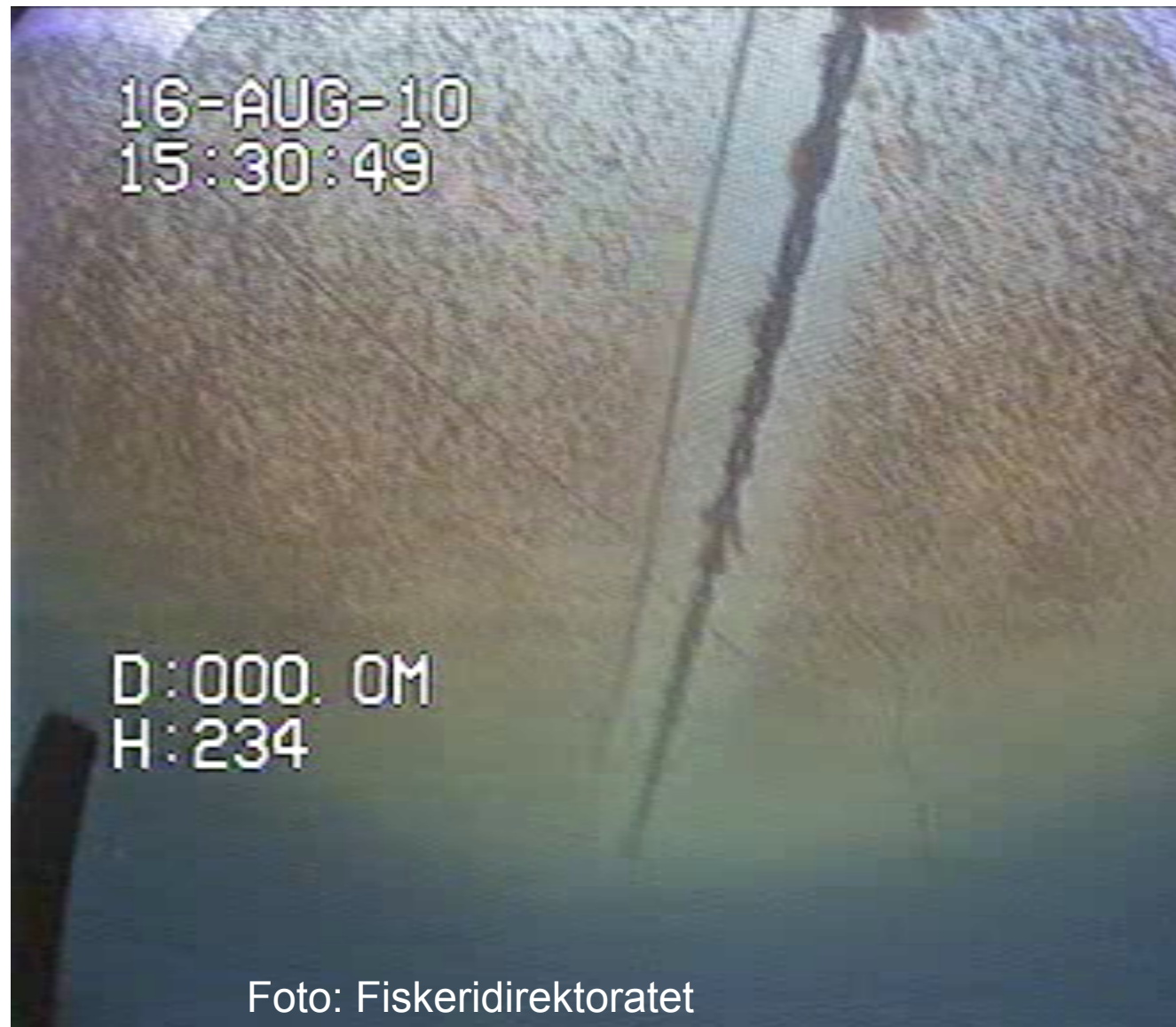
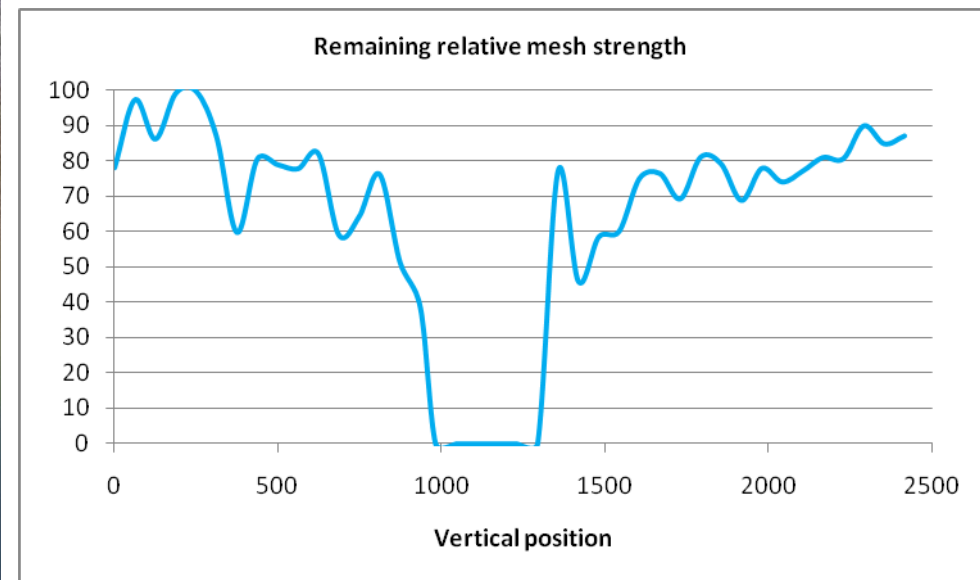
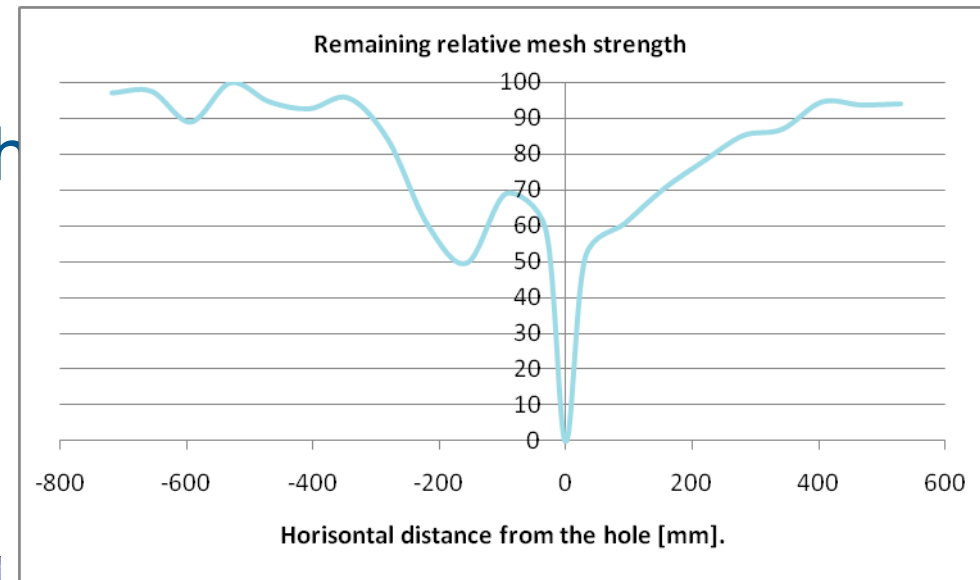
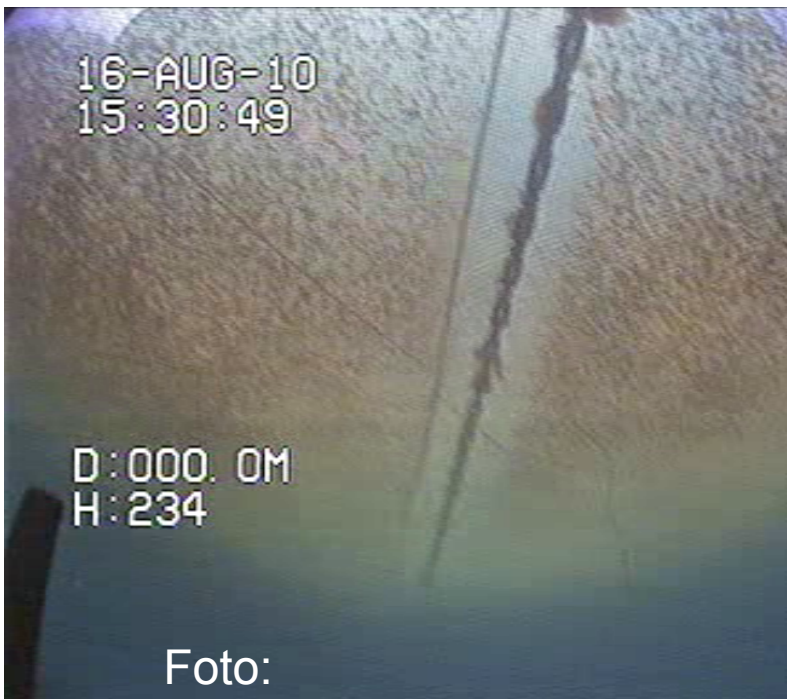


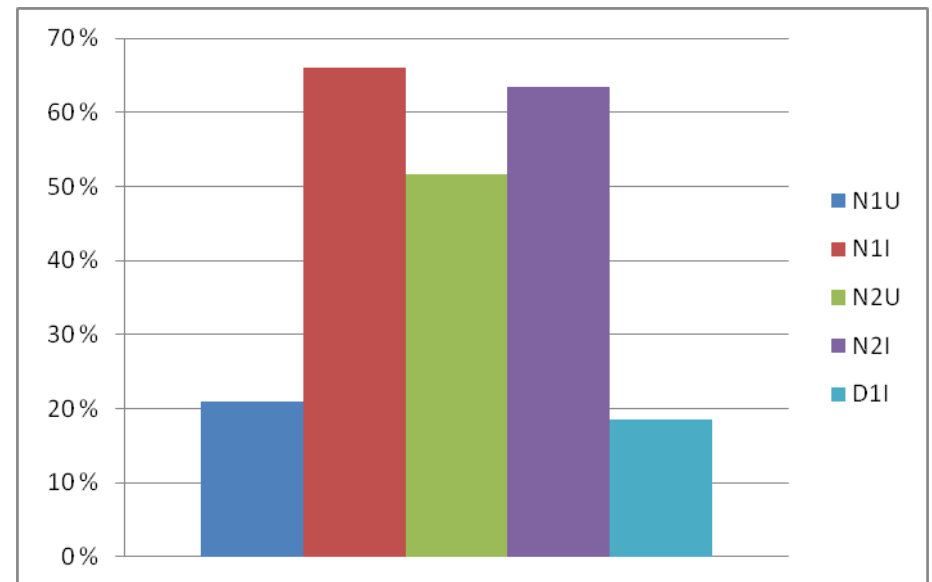
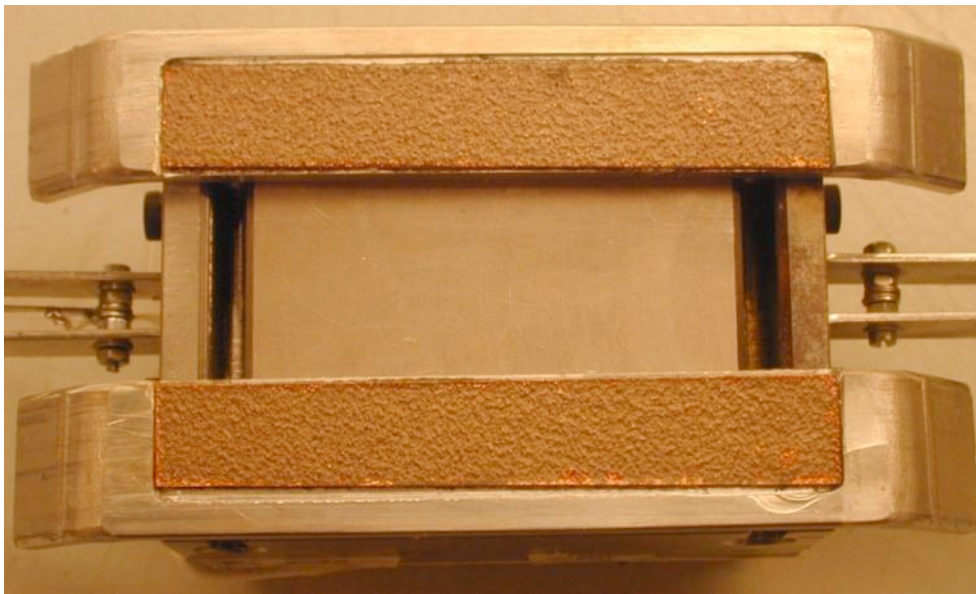
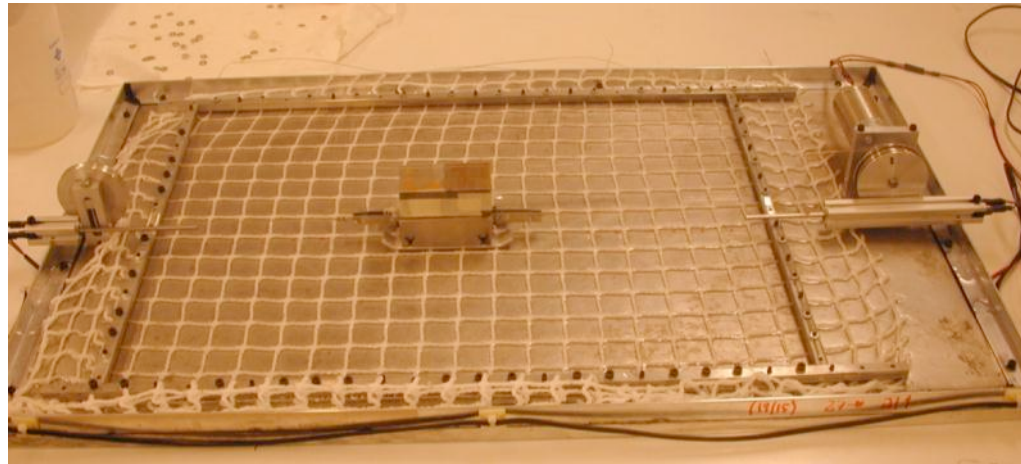
Foto: Fiskeridirektoratet

Remaining mesh strength

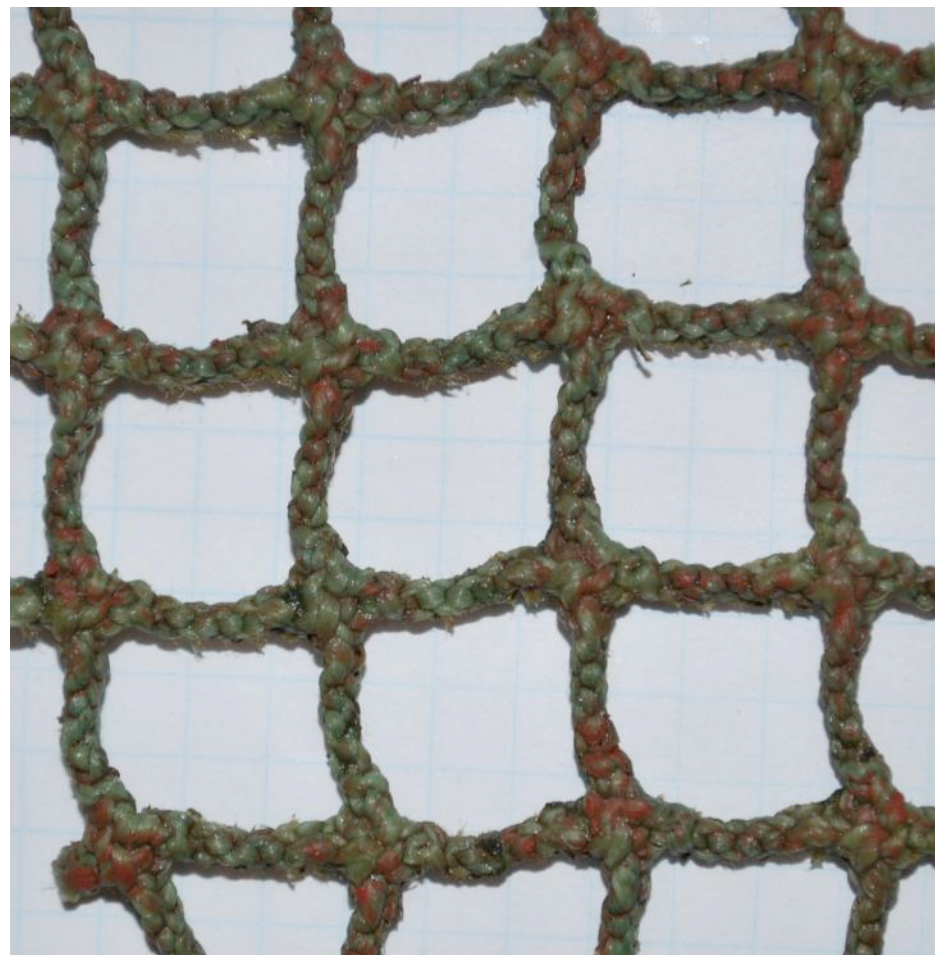
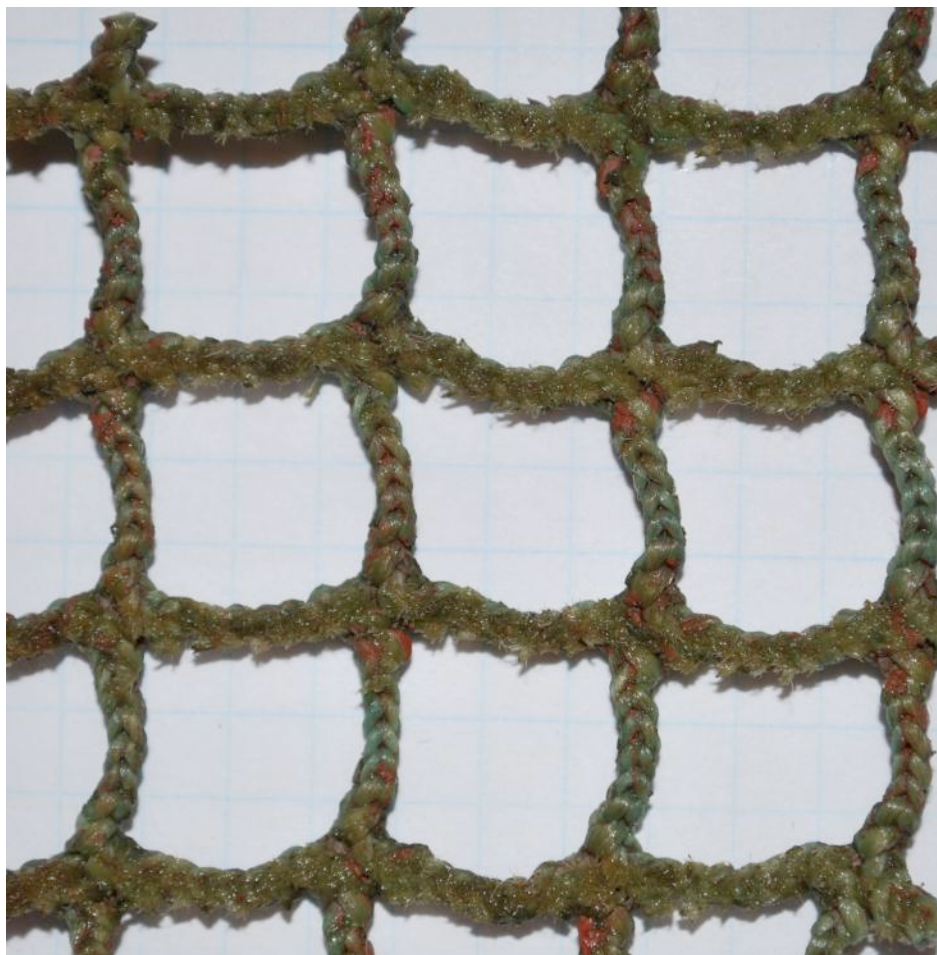
- 256 mesh strength tests(ISO 1806)
- Narrow band of reduced strength due to abrasion



Abrasion



Visuell inspeksjon



Effect of machine washing on net strength

- Service for repairs and maintenance => net are washed in washing machines.
- Washed once a year
- The net is put into the rotating drum.
- Seawater with no detergent is used.
- Washing cycle = typically 3-5 hours



Machine wash tests

-test set-up

- Pieces of netting material were washed together with commercial net cages in a traditional washing machine (in 9°C sea-water)
 - 10 panels subjected to 1-5 washing cycles

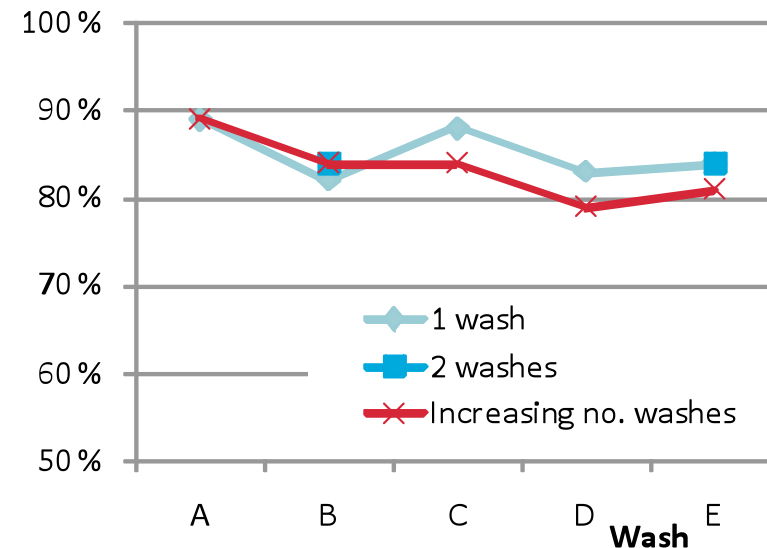
Netting panel										
	1a	2b	3c	4d	5e	1b	1c	1d	2e	1e
Wash A	X	X	X	X	X					
Wash B		X	X	X	X	X				
Wash C			X	X	X		X			
Wash D				X	X			X	X	
Wash E					X				X	X

Wash no.	Bio-fouling	Size of net cage	Duration (hours)
1	Little, green algae	120 x 15 large fish	3
2	Medium, green algae and shells	120 x 15 smolt	5
3	Medium, green algae and shells	120 x 15 large fish	5
4	Little, green algae and shells	160 x 15 large fish	4
5	Little, green algae and shells	160 x 15 large fish	4

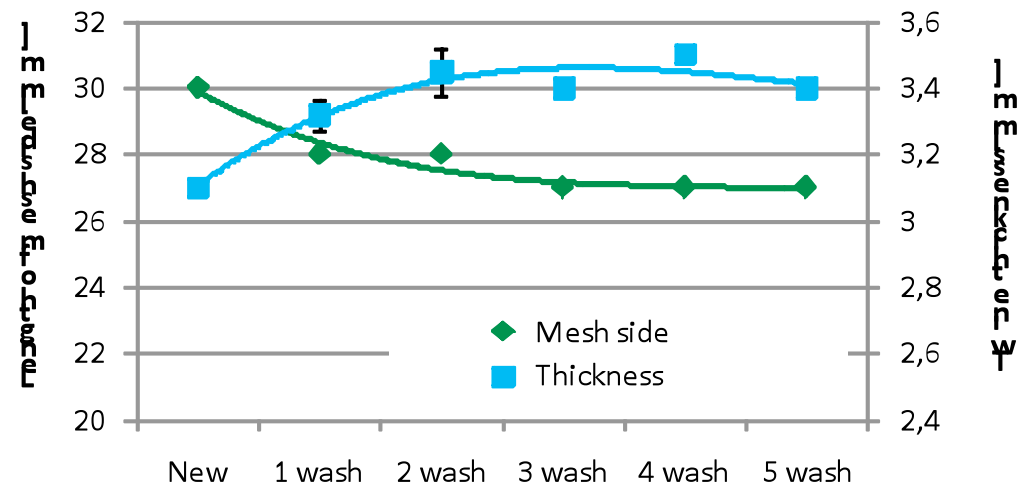
Machine wash tests -results

- Reduced strength
 - 1 wash: 11-18 % reduction
 - 147-161 kg (new: 180 kg)
 - Max: 21 % reduction
 - 4 washes, 143 kg
 - Most reduction in first wash
- Increased solidity
 - Increased twine thickness
 - Reduced mesh size

Remaining strength



Average thickness and width



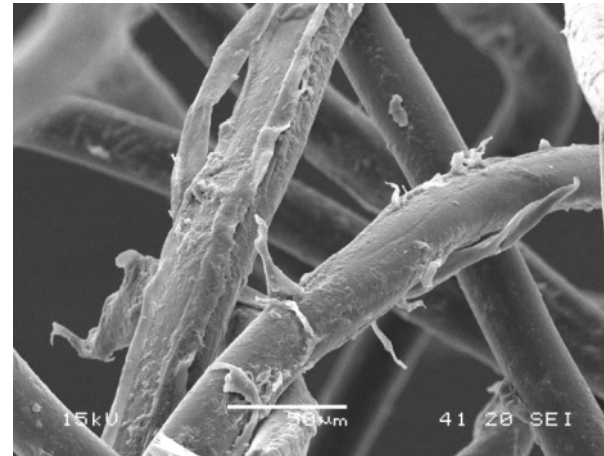
Machine wash tests

- Visible effects

- Visible effects:
 - Slight fraying, increased twine thickness and reduced mesh s



Netting panel number 5, washed 5



Net with
abrasion
damage



Net filament with
abrasion
damage from
machine wash

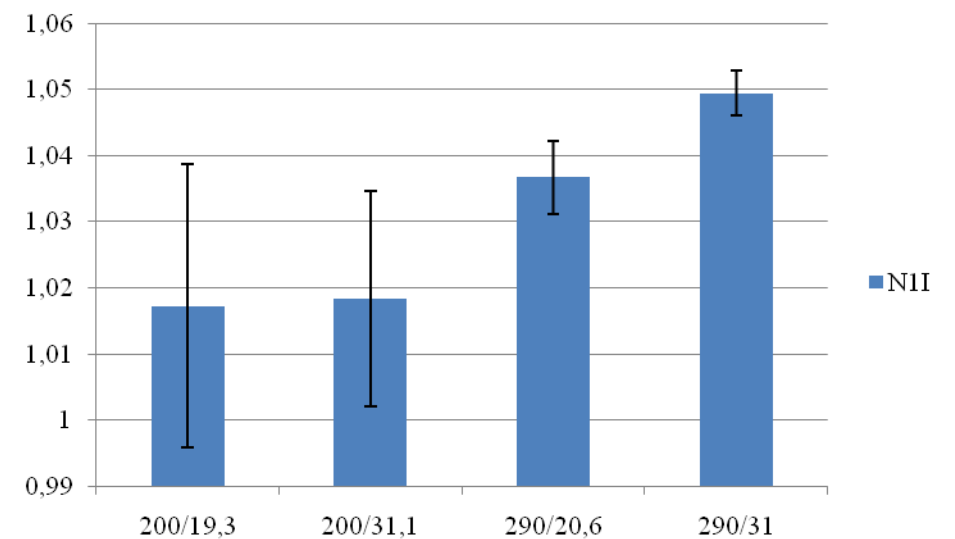
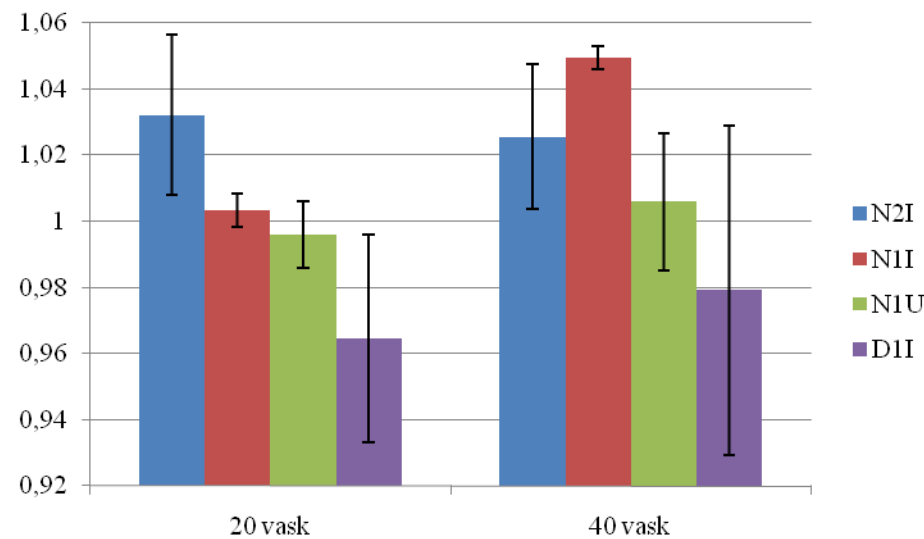


Filament
covered in wax
particles with
abrasion
damage

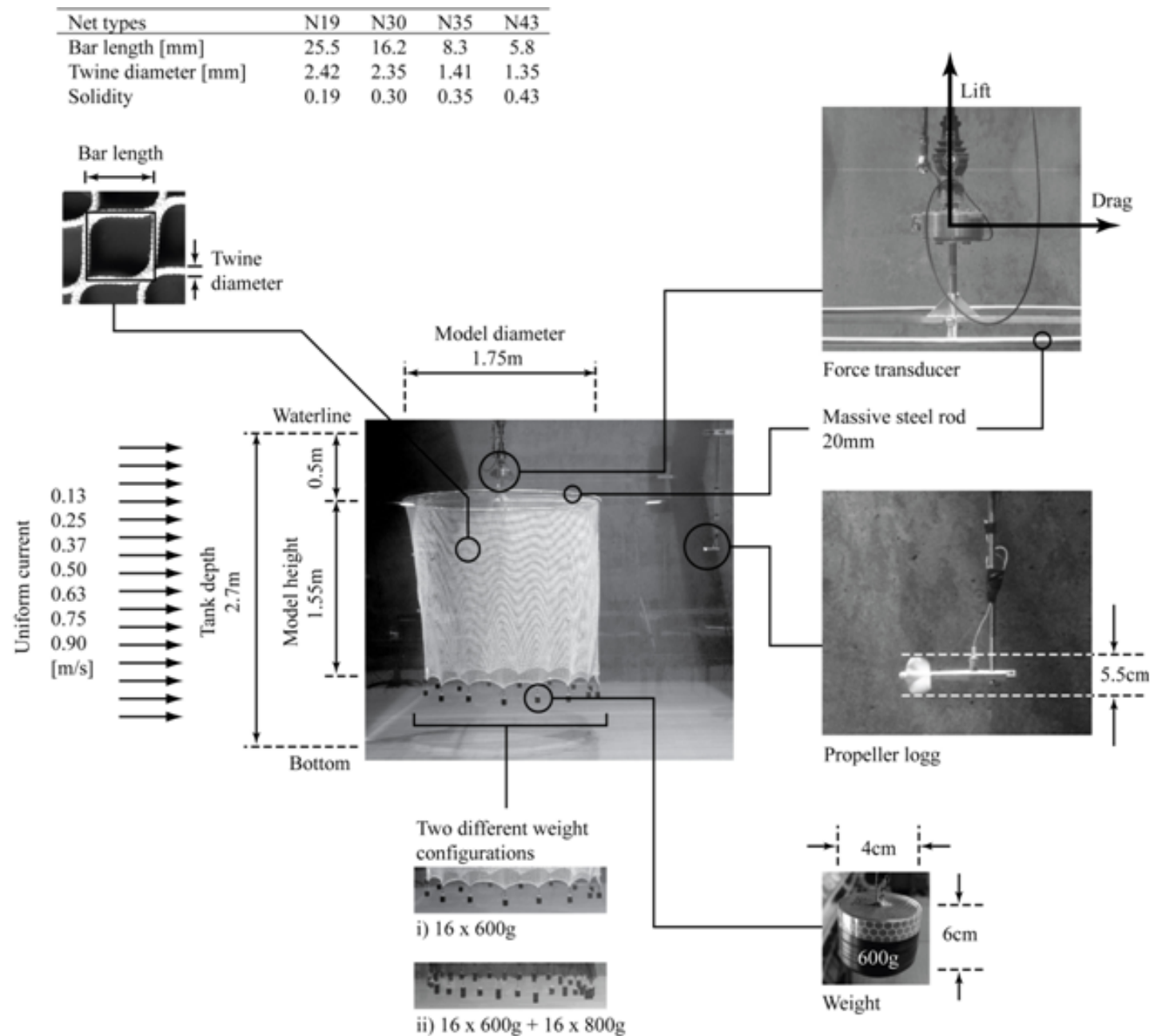
In Situ high pressure cleaning of nets

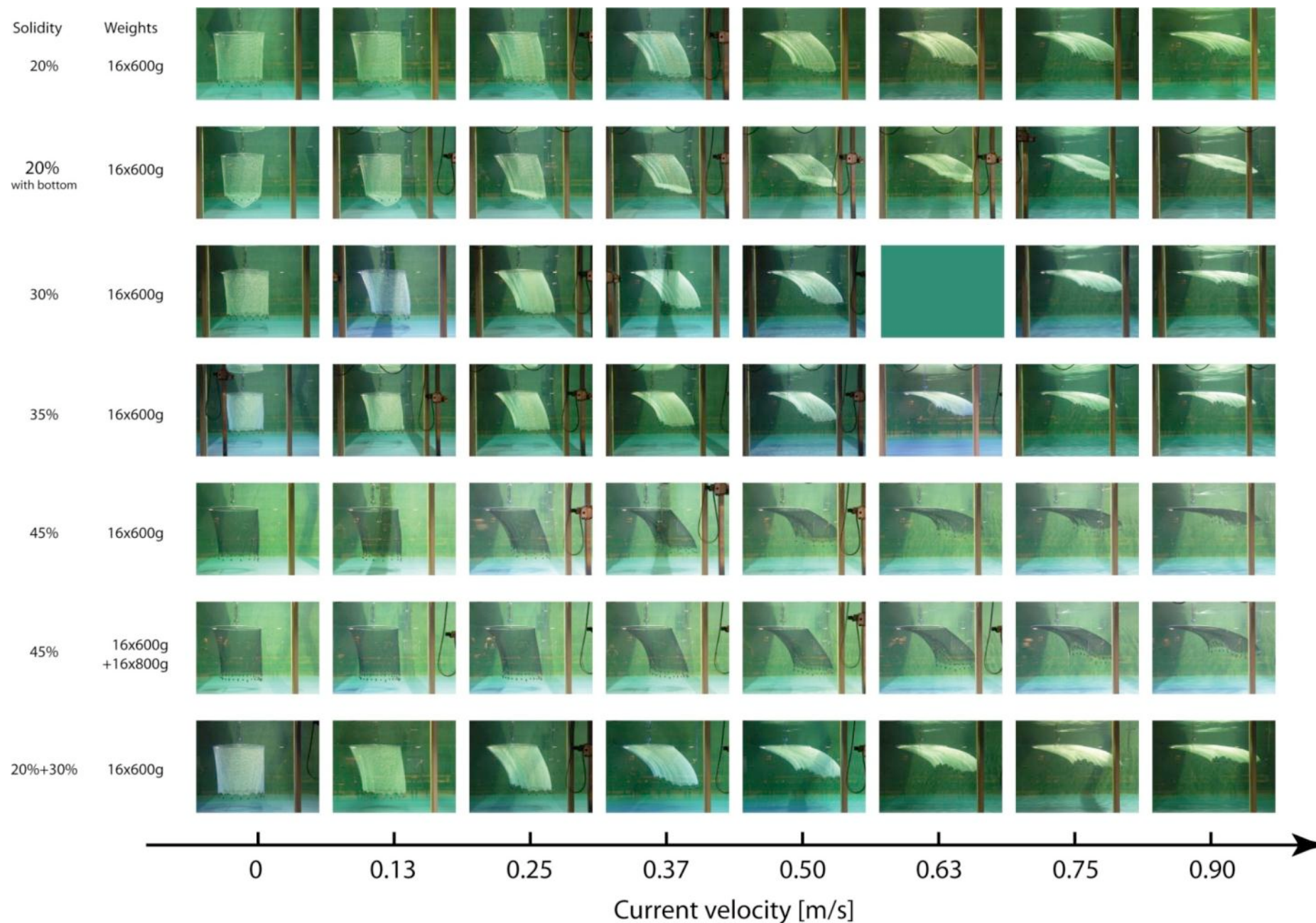


Netmaterial	Condition	Series 1 Water pressure/water flow= 290 bar/31 l/min		Series 2 Number of washing cycles = 40			
		Number of washing cycles		Water pressure (bar) and og flow (l/min)			
		20	40	200/19,3	200/31,1	290/20,6	290/31,1
N1	Uncoated	X	X				
	Coated	X	X	X	X	X	X
N2	Coated	X	X				
D1	Coated	X	X				

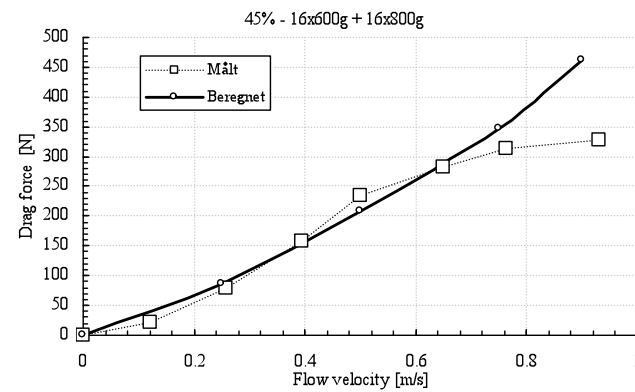
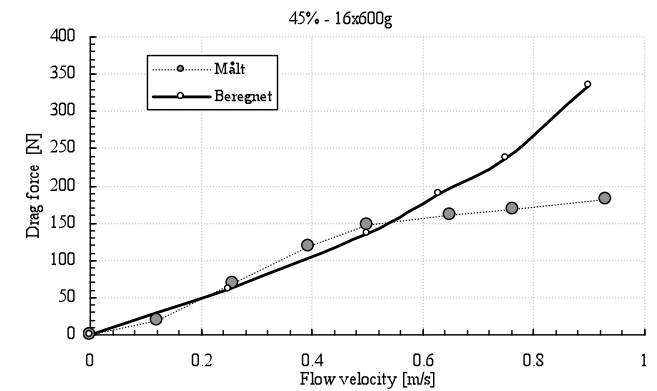
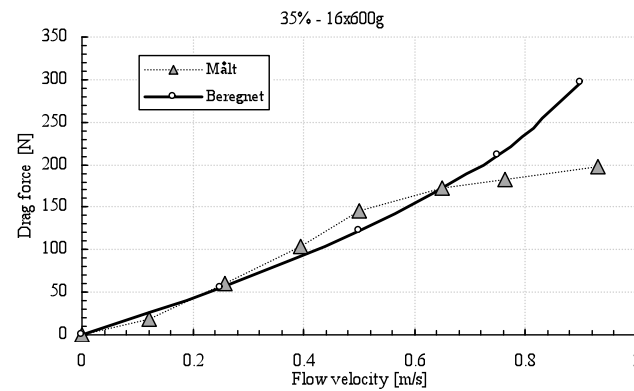
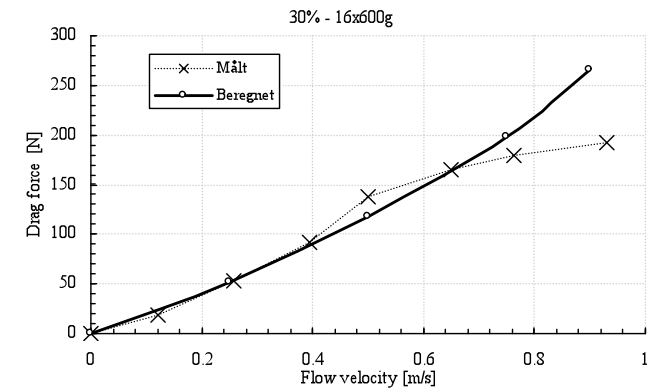
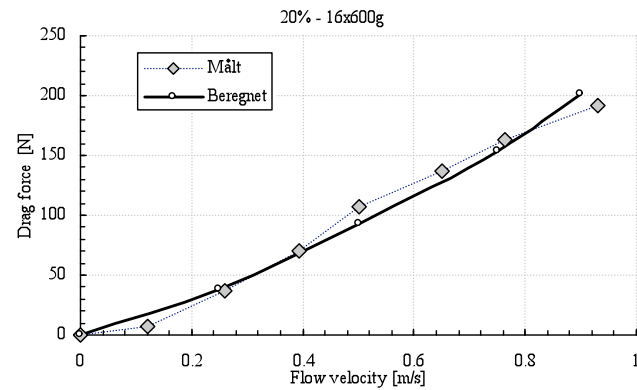


Test setup

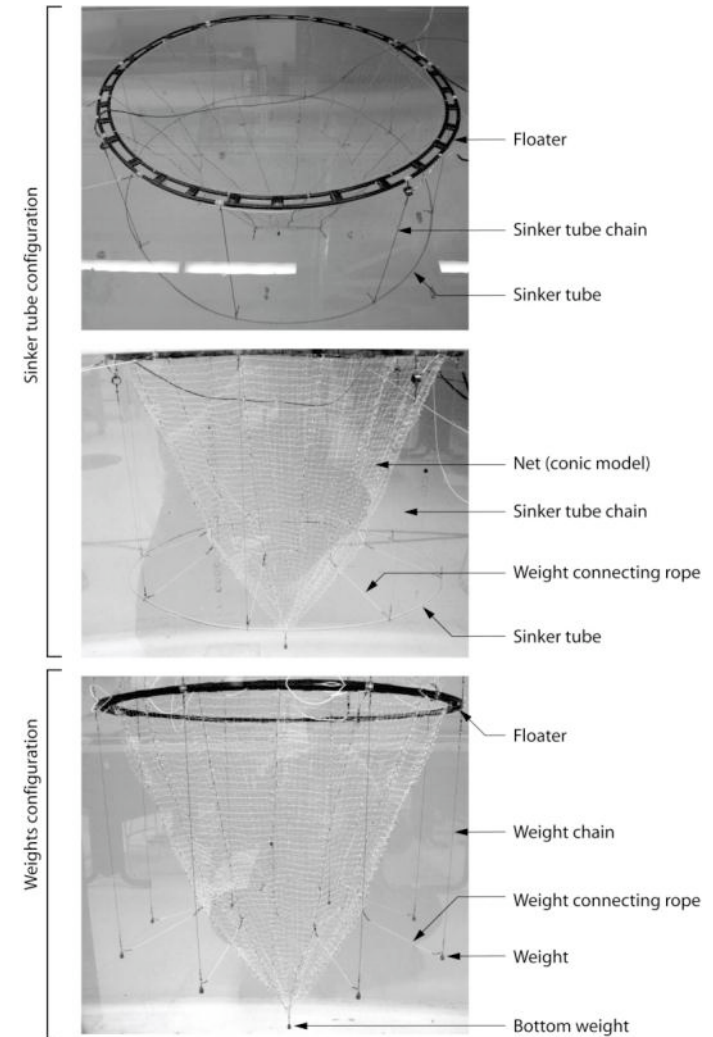
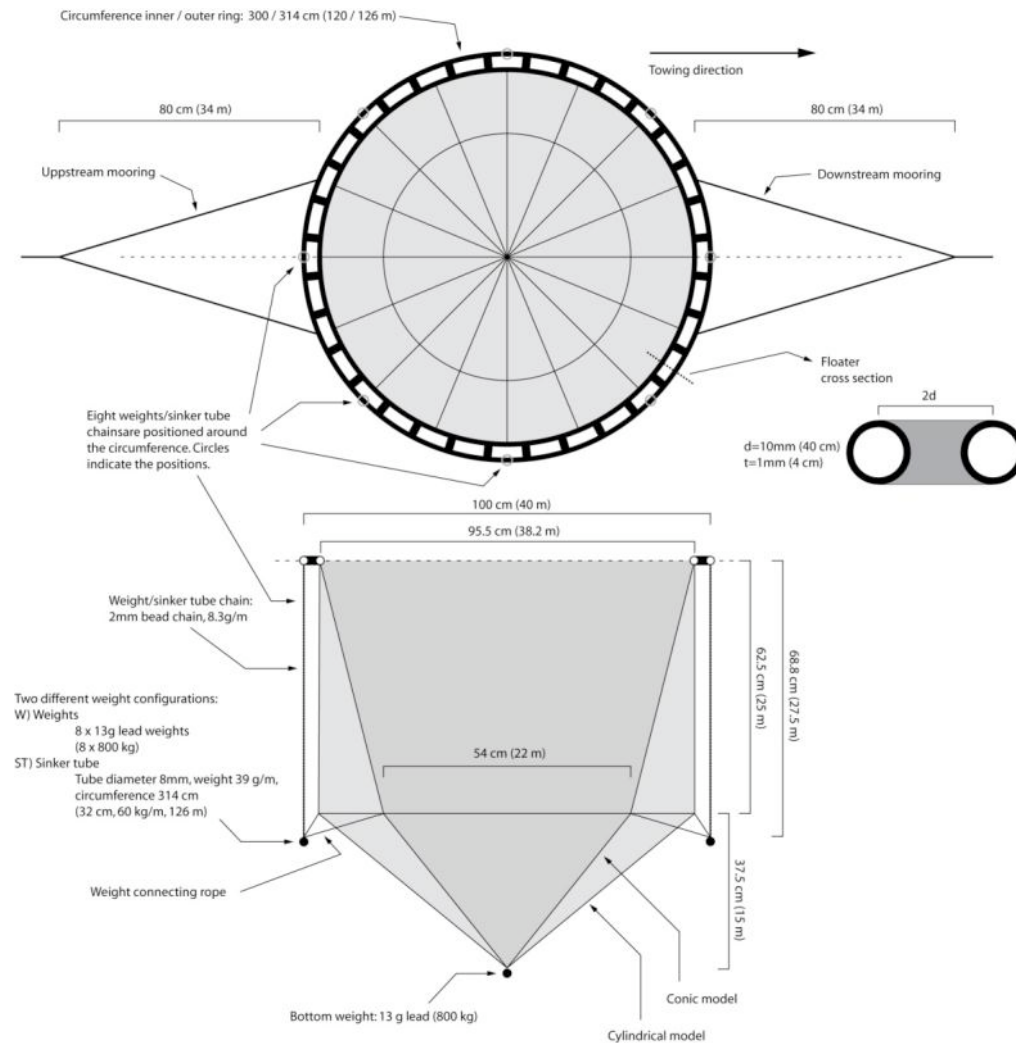




Measured and calculated forces



December 2009: Single cage setup



Model test – test set up

Weight configuration

Model geometry

C

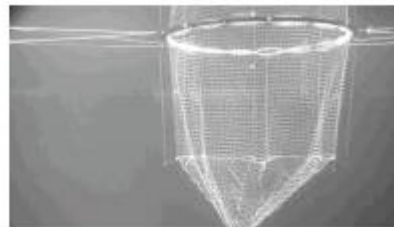
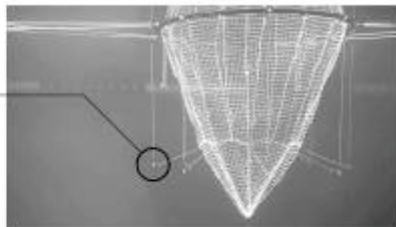
Conic model

S

Cylindrical model

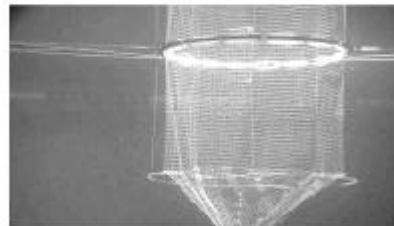
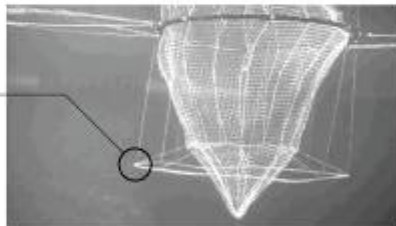
WF

Weights Fixed
(8 x 13g lead weights)



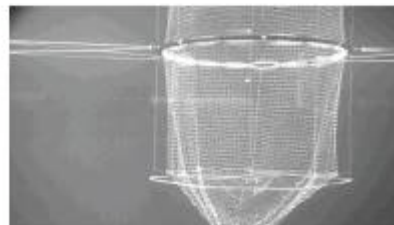
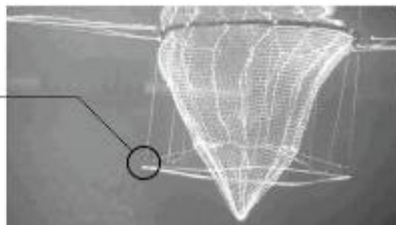
STF

Sinkertube Fixed
(8mm, 39 g/m,
circumference 314 cm)



STS

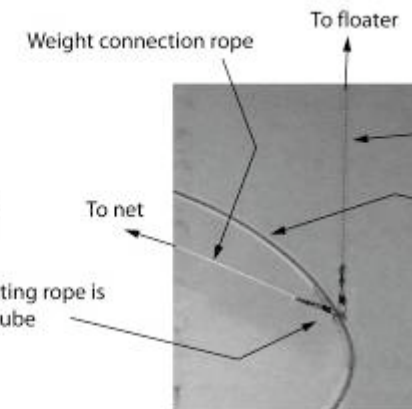
Sinkertube Sliding
(8mm, 39 g/m,
circumference 314 cm)



STF

Sinker Tube Fixed

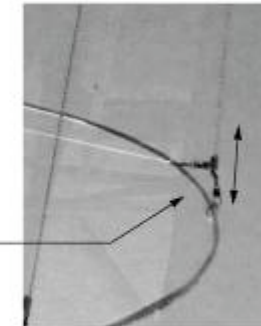
The weight connecting rope is fixed at the sinker tube



STS

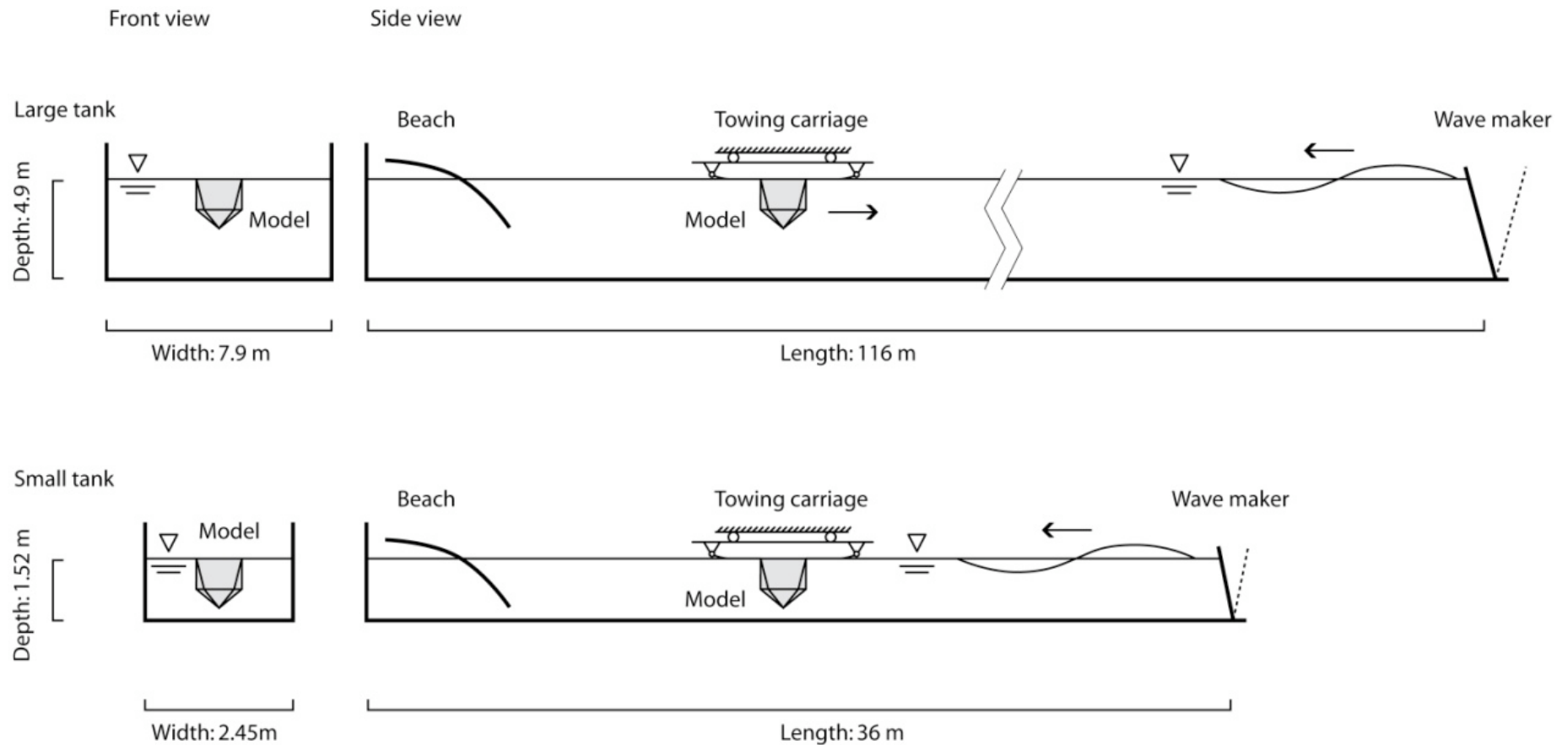
Sinker Tube Sliding

The weight connecting rope can slide freely along the chain

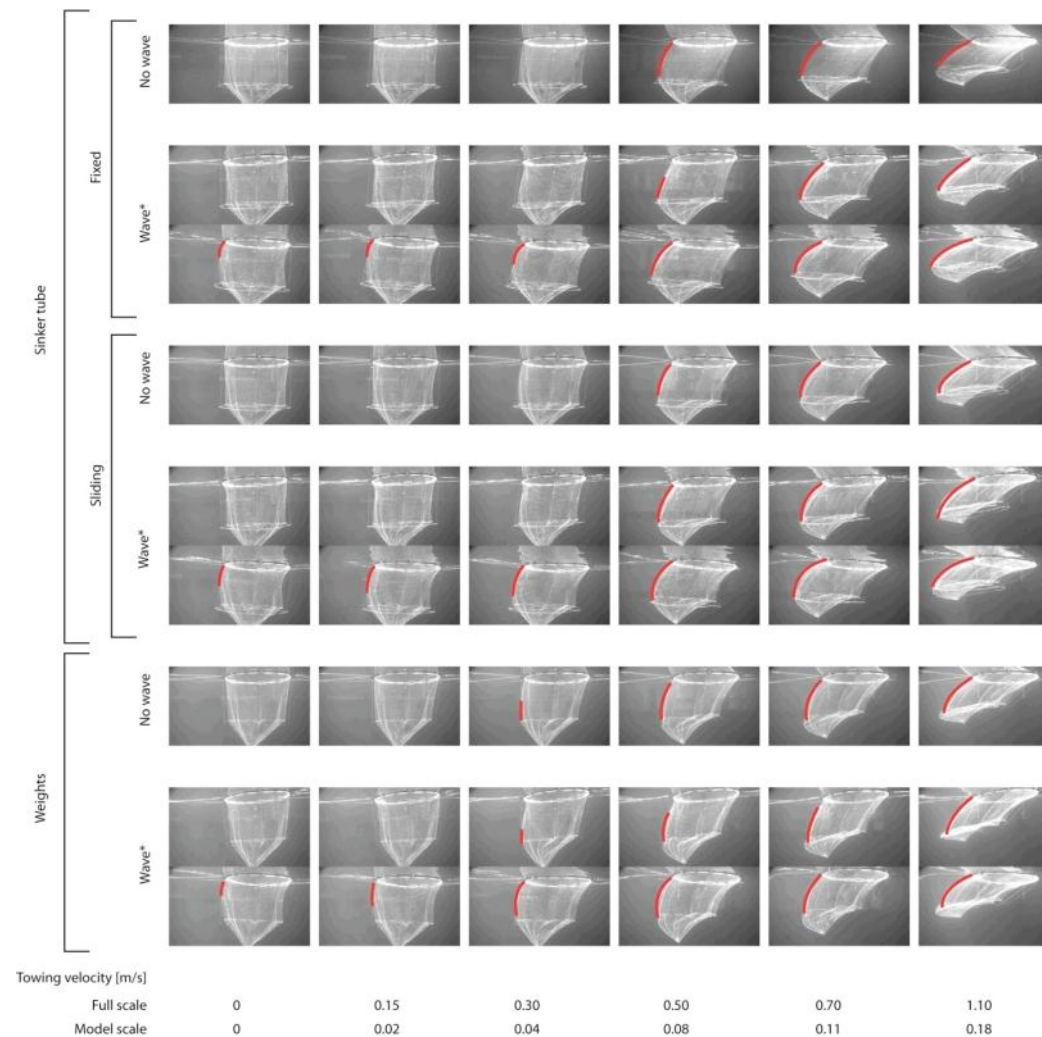


- Scale 1:40
- 120 meter circumference
- Lead line at 25 meter
- Total depth of 40 meter
- Wave height of 6,7 m and periode 7,2 s.
- Current 0 – 1.5 m/s

United States Naval Academy facilities

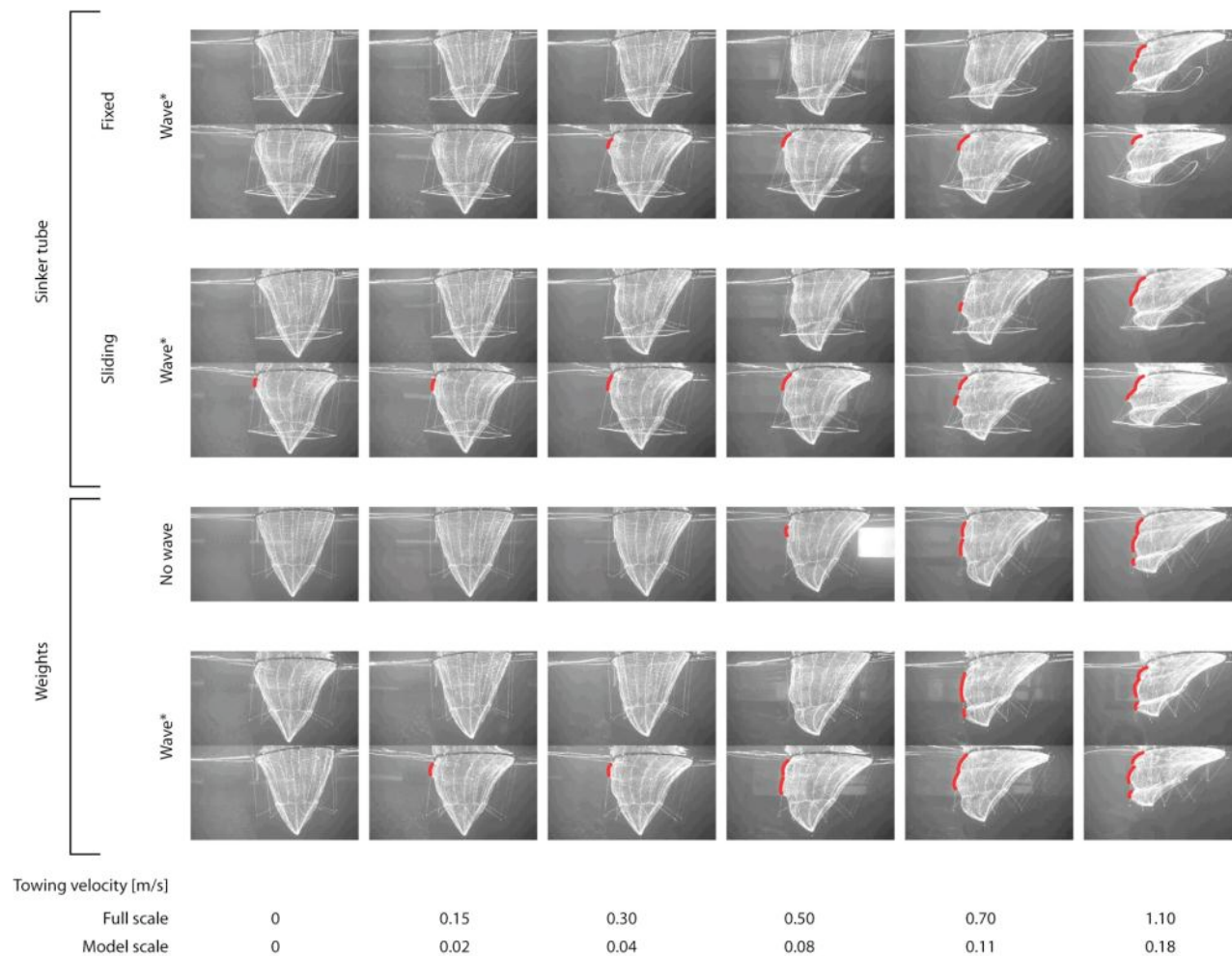


Cylindrical shaped model



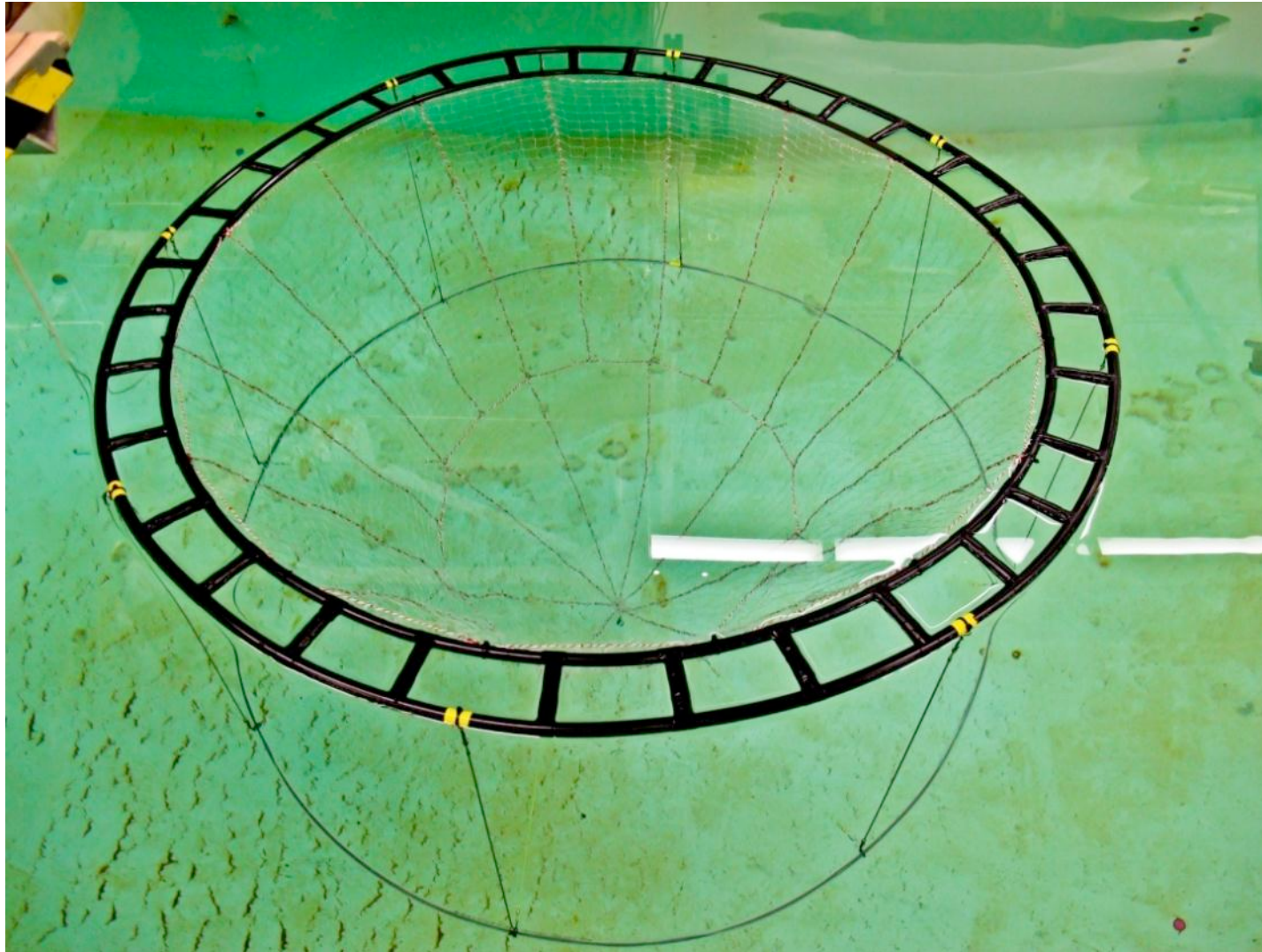
* The wave used in these experiments was a regular wave with period $T=2s$ and wave height $H=14cm$ (steepnes $1/45$). The full scale equivalent wave would according to geometric scaling have a period of $T=12.7s$ and a wave height of $H=5.6m$.

Conic shaped model



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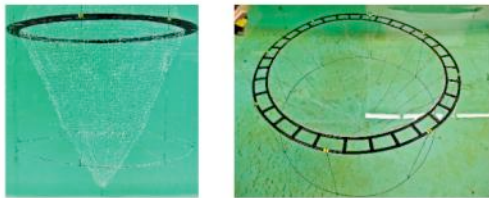
Larger outer-ring diameter



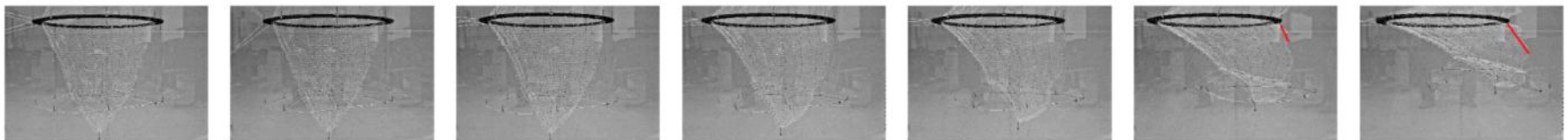
Alternative design

- Increased distance between inner and outer ring
- Sinkertube has the same diameter as the outer ring

Larger outer ring floater.



- Contact at a current velocity of 1,0 m/s (0,5 m/s for the standard design)



Model scale	0 m/s	0.02 m/s	0.04 m/s	0.08 m/s	0.11 m/s	0.18 m/s	0.23 m/s
Full scale	0 m/s	0.13 m/s	0.26 m/s	0.51 m/s	0.74 m/s	1.16 m/s	1.50 m/s