Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Hydraulic Model Tests on Modified Wave Dragon

Hald, Tue; Lynggaard, Jakob

Publication date:
2001

Document Version
Publisher's PDF, also known as Version of record

HYDRAULIC MODEL TESTS ON MODIFIED WAVE DRAGON

Phase 3 project, Danish Energy Agency

" Wave Dragon. Reconstruction of an existing model in scale 1:50 and sequentiel tests of changes to the model geometry and mass distribution parameters"

Project no: ENS-51191 / 00-0067

Tue Hald & Jakob Lynggaard

November 2001

Hydraulic & Coastal Engineering Laboratory
Aalborg University

1. INTRODUCTION

A floating model of the Wave Dragon (WD) was built in autumn 1998 by the Danish Maritime Institute in scale 1:50, see Sørensen and Friis-Madsen (1999) for reference. This model was subjected to a series of model tests and subsequent modifications at Aalborg University and in the following this model is denoted the 1. generation model. Details concerning model tests and modifications are found in Kofoed and Frigaard (1999), Frigaard et al. (1999), Martinelli and Frigaard (1999a) and Martinelli and Frigaard (1999b). Based on the previous findings the WD has been redesigned by Friis-Madsen and Armstrong Technology (2000).

The purpose of this report is to describe the model tests conducted with a new designed 2. generation WD model as well as obtained model test results. Tests are conducted as sequentiel reconstruction followed by physical model tests. All details concerning the reconstruction are found in Hald and Lynggaard (2001). Model tests and reconstruction are carried out during the phase 3 project: ”Wave Dragon. Reconstruction of an existing model in scale 1:50 and sequentiel tests of changes to the model geometry and mass distribution parameters” sponsored by the Danish Energy Agency (DEA) wave energy programme. The tests will establish a well documented basis for the development of a 1:4.5 scale prototype planned for testing Nissum Bredning, a sea inlet on the Danish West Coast.

2. MODEL DESIGN AND SETUP

The structural configuration of the 2. generation WD is the Wave Dragon prototype designed for Nissum Bredning. Thus, reconstruction of the model for use in the laboratory is based on the structural drawings ”Wave Dragon Prototype 1:4” by Friis-Madsen dated 8. March 2001. Details concerning the reconstruction are described in Hald and Lynggaard (2001) and in Table I an overview of the different modifications is given.

Table I. Test and modification programme for 2. generation WD. *) planned test.

Test ID	Test description
A)	Stern wise expansion of reservoir, volume increased by 82% to 4764 m^3. Construction of additional open air chambers behind centre of gravity and separation of existing air chambers from bow to stern. Extension of reflectors by 25 m. Tests conducted by +1.5 m crest freeboard.
B)	Expansion of the reflector draught by 2 m.
C)	Expansion of the reflector draught by 2 m. Tests conducted by +1.5 m crest freeboard.
D)	Trimming the bow 1 m below the stern at different wave situations: • Wave situation 2: 2 m bow freeboard, 3 m stern freeboard (1-2)+(2-3). • Wave situation 3: 3 m bow freeboard, 4 m stern freeboard (2-3)+(3-4). • Wave situation 4: 3 m bow freeboard, 4 m stern freeboard (3-4)+(4-5). • Wave situation 5: 4 m bow freeboard, 5 m stern freeboard (4-5).
E)	Construction of doubly-curved overtopping ramp.
F)	Construction of perforated double-walled wave damper in turbine pit.
G)	Like D with wave situation 4 changed: • Wave situation 4: 4 m bow freeboard, 5 m stern freeboard (4-5).
H)	Construction of two guiding walls on overtopping ramp and modifying the wave damper to a perforated single-walled wave damper at the back of the turbine pit.
I)	Adding ballast (973 t). Increasing height of guiding walls by 1.5 m
J)	Fixing reflectors to the shoulders with WD located with a crest freeboard of 4 m.
K)	Combine bow and stern air chambers by tube system.*
L)	Construction pitch stabilizing air chamber above MWL at stern.*
M)	Open reflectors above pontoon near shoulders to allow for entrapped ice to escape.*

Also in Table I the different aspects of the test programme is outlined. In Table II the different measured mass distribution parameters of the 2. generation model are shown and compared to the 1. generation model. The location of the centre of gravity and the mass moment of inertia is measured by weighing the model on three load cells and by measuring the eigenperiod in air in yaw and pitch motion. This method of identifying the mass distribution parameters is similar to the method applied to the 1. generation model described in Frigaard et al. (1999).

Table II. Mass distribution parameters.

Model:		1. generation	2. generation	
Scale:		1:50	1:51.8	
Mass:	[t]	14100	11675	16100
Centre of gravity: (see Fig. 2)				
Surge	[m]	23.0	31.9	36.8
Sway	[m]	0.0	0.26	0.0
Heave	[m]	6.5	7.0	6.8
Mass moment of Inertia:				
Yaw	[kg m^2]	1.08 10^{10}	1.69 10^{10}	1.73 10^{10}
Pitch	[kg m^2]	1.98 10^{9}		5.54 10^{9}
Roll	[kg m^2]	1.03 10^{10}		

The hydraulic behaviour of the WD is not only dependent of the structural geometry and mass distribution but depends also on the stiffness of tension cables linking the two reflector arms and the stiffness of the moorings. The Nissum Bredning WD is intended moored to a single pile in front by a single cable, see Figure 1. This cable is split in two in proximity of the WD body and in the 1. generation model the mooring elasticity of the central cable was 1.4 MN / m and finally, from the stern two mooring lines are fixed to the sea bed. The two tension cables fix the reflector arms to the central mooring cable, both cables hawing an elasticity of 0.5 MN / m. For the 2. generation model these stifnesses have been kept. Both the tension cables and the mooring cable has been pretensioned to approximately 1.0 MN and 1.5 MN respectively.

3. SCALING

All modifications were made on the 1:50 scaled 1. generation WD model described in Martinelli and Frigaard (1999) and to be able to reuse major parts of this old model a scale of 1:51.8 was necessary for the 2. generation WD model to match the existing model.

Quantities describing the geometrical and hydraulic conditions will be scaled to prototype conditions. The Froude scaling law applies for scaling the data from model to prototype and accordingly all quantities will scaled as follows:

Quantity	Scaling law	Scaling factor
Length	λ_L	51.8
Time	$\lambda_L^{0.5}$	$51.8^{0.5}$
Discharge	$\lambda_L^{2.5}$	$51.8^{2.5}$
Volume, mass, forces	λ_L^{3}	51.8^{3}
Stiffness	λ_L^{2}	51.8^{2}

4. Test conditions and test programme

Tests were run for a different number of wave conditions according to the parameters in Table III. Wave situations 1 through 5 correspond to normal operating conditions while situation 6 and 7 are estreme wave conditions corresponding to a 50 years and 100 years return period respectively. The duration of each run was 30 minutes corresponding to approximately 4 hours in prototype and each 30 minute wave run was generated to match a JONSWAP spectrum with $\gamma = 3.3$. Accordingly the number of waves ranged from 1400 to 2500 depending on the wave period. Water depth was kept constant at 25 m which is fairly shallow for a North Sea location but fits the Nissum Bredning conditions when scaled 1:4.

Table III. Wave data in the Danish part of the North Sea and related crest freeboard.

Wave ID	R_c [m]	H_s [m]	T_p [s]	Probability [% time]	Percentage of total energy [%]
		0		11	
NS 1	1.25	1.0	6.0	38	6.29
NS 2	2.0	2.0	7.7	27	22.90
NS 3	3.0	3.0	8.8	14	30.47
NS 4	4.0	4.0	9.7	6	25.76
NS 5	4.0	5.0	10.6	2	14.48
NS 6	-	9.0	13.4	0.00091	-
NS 7	-	10.0	14.1	0.00046	-
NS 8	-	12.0	15.0	≈0	-

R_c = crest free board relative to MWL
H_s = significant wave height
T_p = peak period
NS = North Sea

In Figure 1 the WD in the normal configuration is depicted and each of the force registration points can be seen. In the cables used to tension the two reflector arms forces are registered in the across cable A, the total mooring force was measured in one single line where the structure was acchored, and finally, three force components were measured in the junction between the right reflector and the shoulder. Movements were registrered for three dregrees of freedom (heave, pitch and surge). Finally, also the amount of overtopping water in the reservoir was registered.

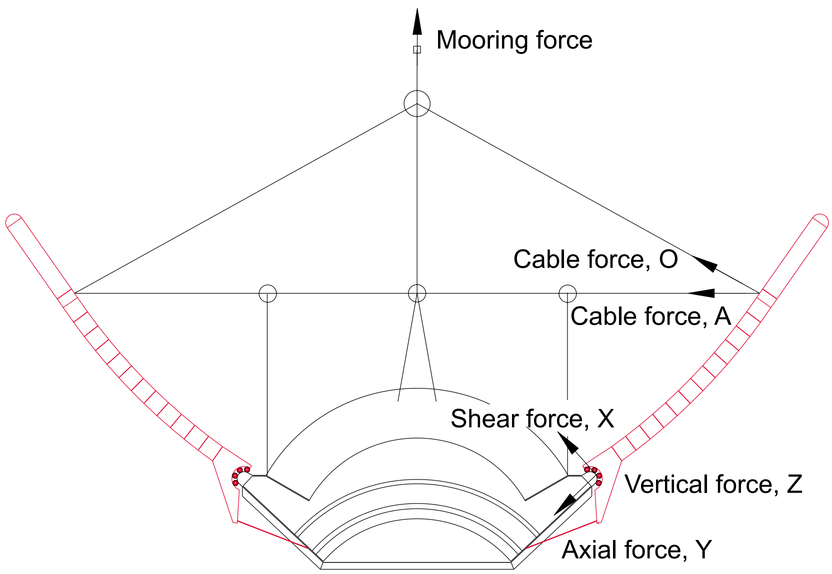


Figure 1. Normal configuration of Wave Dragon and force registration positions.

5. TEST RESULTS

Waves were registered by two resistance type wave gauges placed on either side of the WD outside the reflector arms. The measured waves were not always coincident to the target values, thus registered forces, movements and overtopping were referred to measured waves. Wave situation 6-8 resulted in breaking waves in front and on the WD, thus measured significant wave heights were smaller than in Table III.

Mooring forces were registred by a load cell designed and manufactured by Aalborg University whereas cable forces and forces in the junction were registered by a 3D load cell and a z-gauge designed and manufactured by Danish Maritime Institute. Two characteristic values were retrieved from the signals: the root mean square (rms) value F_{rms} for fatigue design and the average of the highest 1/250 of the peak forces $F_{1/250}$ being a representative for the maximum peak force.

Movements were registered by three ultrasound gauges: two places above the WD to register heave being the average of the two and pitch being the difference of the two, and one placed behind the WD to register surge motions. Heave, pitch and surge were obtained accordingly:

$$\text{(heave)} = \frac{y_1 + y_2}{2}$$

$$\text{(pitch)} = \frac{y_1 - y_2}{d}$$

$$\text{(surge)} = x$$

where

x = horisontal ultrasound signal
y_1, y_2 = two vertical ultrasound signals
d = distance between the two vertical ultrasound signals, d = 25 m

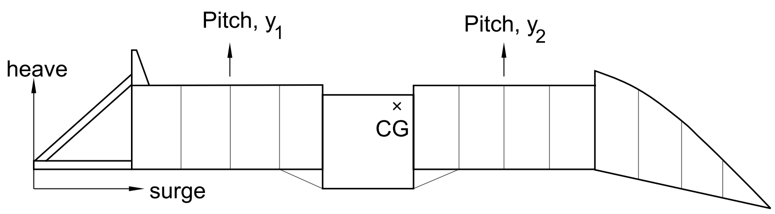


Figure 2. Definition of movements.

The characteristics of interest are the root mean square value and the maximum value being defined as the average of the highest 1/250 of the positive and negative oscillations. Heave and surge movements were non-dimensionalized by the significant wave height and the pitch was non-dimensionalized by multiplying with half the distance between the two vertical ultrasound signals and dividing by the significant wave height, thus describing the vertical oscillations of such two points induced by the picth. With a distance d = 25 m this corresponds to a position half the distance to the front and half the distance to the rear of the reservoir from the midpoint of the reservoir.

All signals were sampled at 10.0 Hz and the force signals were additionally low pass filtered at 8 Hz.

Overtopping was measured by collecting the water present in the reservoir into three exhaust tubes leading the water into a reservoir outside the wave basin. The water was lead into the outside reservoir by gravity from where the water was pumped back into the wave basin through an automatically controlled pump. To control switching the pump on and off, the water level in the reservoir was registered, and when exceeding a fixed level the pump was switched on for 3 sec. To estimate the amount of overtopping water the pump was calibrated according to the water level to give certain average discharge during the 3 sec and by counting the number of switching on the total amount of water was claculated by multiplying the discharge. In consequence of this measuring technique, the model reservoir of the WD is drained during each wave. This is not the situation in the prototype where the amount of drainage depends on the turbine management strategy.

According to the previous tests measured values of overtopping were non-dimensionalized and presented in the following form:

$$Q^* = 0.017\,exp(-48R^*) \qquad \text{(eq. 1)}$$

where,

$$Q^* = \frac{q\sqrt{s_{op}/2\pi}}{\sqrt{gH_s^3 L}}$$

$$R^* = \frac{R_c}{H_s}\sqrt{\frac{s_{op}}{2\pi}}$$

q = discharge due overtopping

H_s = significant wave height

L = ramp width = 86.6 m

s_{op} = wave steepness defined as $s_{op} = H_s/L_{op}$

L_{op} = deep water wave length defined as $L_{op} = \frac{g}{2\pi}T_p^2$

T_p = peak period

R_c = Mean value of crest freeboard relative to MWL

Obtained results can be found in appendices A through H. Mooring forces, cable forces and X,Y and Z forces on the shoulders are presented as function of significant wave height. Movements are presented as function of peak period and overtopping is presented in discharge as function of wave height and in dimensionless form showing Q^* as function of R^*.

Results of all overtopping tests are summarized in Figure H.10, H.11 and I.8 and a reevaluation of the existing overtopping equation is fitted based on measurements obtanied with the new doubly-curved overtopping ramp. The new overtopping equation is modified to:

$$Q^* = 0.025\,exp(-40R^*) \qquad \text{(eq. 2)}$$

6. Summary and conclusions

Within the programme the effects of the modifications on the WD on forces, movements and overtopping were analyzed. Details concerning results are found in appendices A through H and Table IV gives a short summary.

Table IV. Summary of results..

Test ID	Results
A)	• Force in cable A, H_s = 5 m: peak force: 0-3.5 MN, rms force 0.5-1.5 MN. • Mooring force, H_s = 5 m: peak force ≈ 4.5 MN, rms force ≈ 2.3 MN. • Shoulder force, H_s = 5: $X_{1/250}$ ≈ 2.8 MN, X_{rms} ≈ 0.5 MN, $Y_{1/250}$ ≈ 5.0 MN, Y_{rms} ≈ 1.0 MN $Z_{1/250}$ ≈ 10.0 MN, Z_{rms} ≈ 1.9 MN • *rms*-motions: Surge: ≈ $0.2\times H_s$, heave: ≈ $0.15\times H_s$, pitch: ≈ $\pm 0.15\times H_s$. • Overtopping up to 21 m^3/s. 40% overall increase compared to 1. generation model.
B)	No effect on cable force. 10% increase in mooring forces. Increase in $X_{1/250}$, $Y_{1/250}$ and $Z_{1/250}$. Overtopping increases compared to 1. generation model.
C)	10% increased in cable and mooring forces. 50% increase in $X_{1/250}$ and $Z_{1/250}$. Some (5%) increase in overtopping.
D)	All forces and movements are comparable to test C. No increase in the amount of overtopping. However, the average freeboard along the ramp is higher than the freeboard without trimming. The trimming is adjusted to position the WD horizontal when the reservoir is full.
E)	All forces are comparable to test B and C. Increased *rms* movements: Surge: 0.15-0.3×H_s, heave: 0.15-0.3×H_s, pitch: ±0.15-0.3×H_s. Overtopping increases by a factor 2.
F)	Large increase force in cable A perhaps due to failure on load cell. Remaining forces and movements comparable to E. Further increases in overtopping.
G)	Like D. Load cell in cable A failed.
H)	All forces and movements comparable to test F. Load cell in cable A failed. Overtopping comparable to test E.
I)	• Mooring force, H_s = 5 m: peak force ≈ 5 MN, rms force ≈ 2.5 MN. • Shoulder force, H_s = 5: $X_{1/250}$ ≈ 4 MN, X_{rms} ≈ 0.7 MN, $Y_{1/250}$ ≈ 7.0 MN, Y_{rms} ≈ 1.6 MN $Z_{1/250}$ ≈ 18.0 MN, Z_{rms} ≈ 3.8 MN • *rms*-motions: Surge: ≈ $0.2\times H_s$, heave: ≈ $0.15\times H_s$, pitch: ≈ $\pm 0.1\times H_s$. 100% overall increase in overtopping compared to 1. generation model.
J)	No effect on overtopping, mooring forces similar. Shoulder force: $X_{1/250}$ comparable, $Y_{1/250}$ small increase (15%), $Z_{1/250}$ large decrease (100%).

7. REFERENCES

Armstrong Technology, *Wave Dragon Prototype – Basic structural design*, Internal report, JOULE-CRAFT project: "Low pressure turbine and control equipment for wave energy converters / Wave Dragon", 2000

Friis-Madsen, E., Sørensen, H.C., *Wave Dragon. Comments to report on phase A tests* (in Danish), Löwenmark, F.R.I., 1999.

Frigaard, P., Lauridsen, H., Andreasen, M., *Minimizing pitch movement of the Wave Dragon*, Hydraulics and Coastal Engineering Laboratory, Aalborg University, 1999.

Hald, T., Lynggaard, J., *Ombygning af Wave Dragon* (in Danish), Hydraulics & Coastal Engineering Laboratory, Aalborg University, DEA phase 3 report, 2001.

Kofoed, J.P., Frigaard, P., *Evaluation of the hydraulic response of the Wave Dragon*, Hydraulics & Coastal Engineering Laboratory, Aalborg University, DEA phase A test report, 1999.

Martinelli, L., Frigaard, P. *The Wave Dragon: 3D overtopping tests on a floating model*, Hydraulics and Coastal Engineering Laboratory, Aalborg University, Wave Dragon - DEA and CRAFT project test report, 1999.

Martinelli, L., Frigaard, P. *The Wave Dragon: tests on a modified model*, Hydraulics and Coastal Engineering Laboratory, Aalborg University, Wave Dragon - DEA and CRAFT project test report, 1999.

Sørensen, H.C., Friis-Madsen, E., *Wave Dragon – Tests to evaluate the hydraulic response,* DEA phase A, report phase A, 1999.

Testseries A

Effect af enlarged reservoir and enlarged open air chambers

Crest freeboard: +1.5 m compared to table III

Figure A.1. Mooring force.

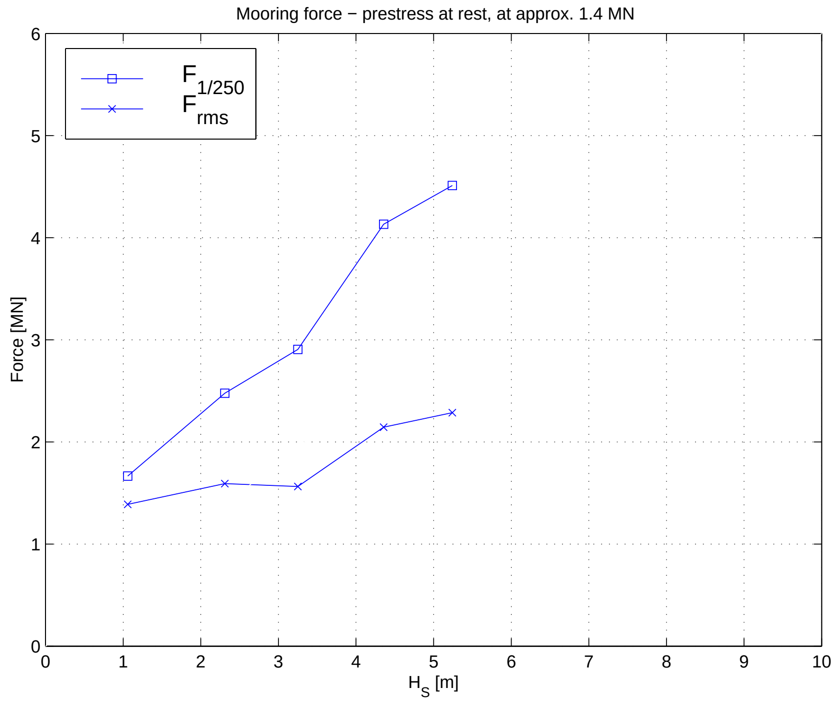


Figure A.2. Force along across cabel A

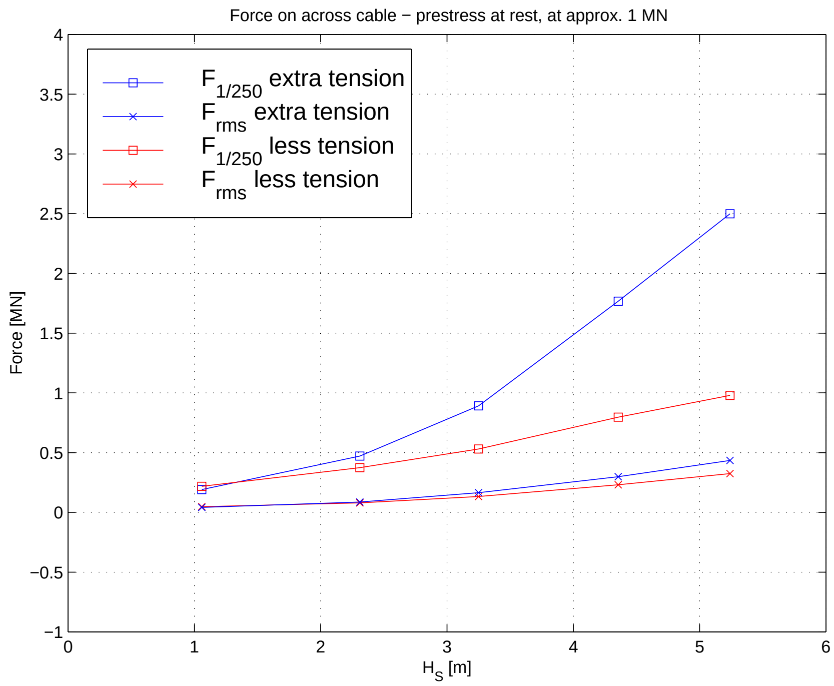


Figure A.3. Shear force X on shoulder.

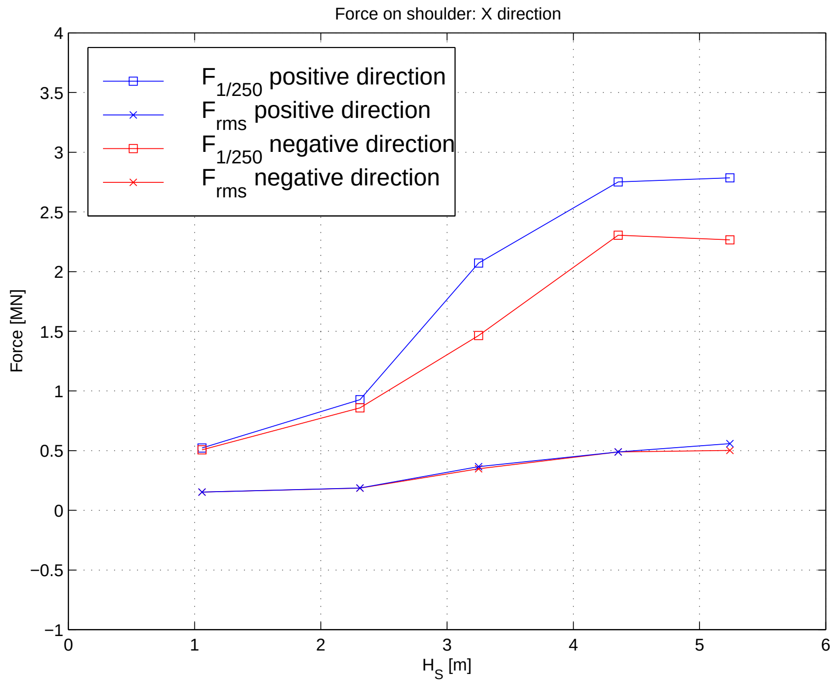


Figure A.4. Axial force Y on shoulder

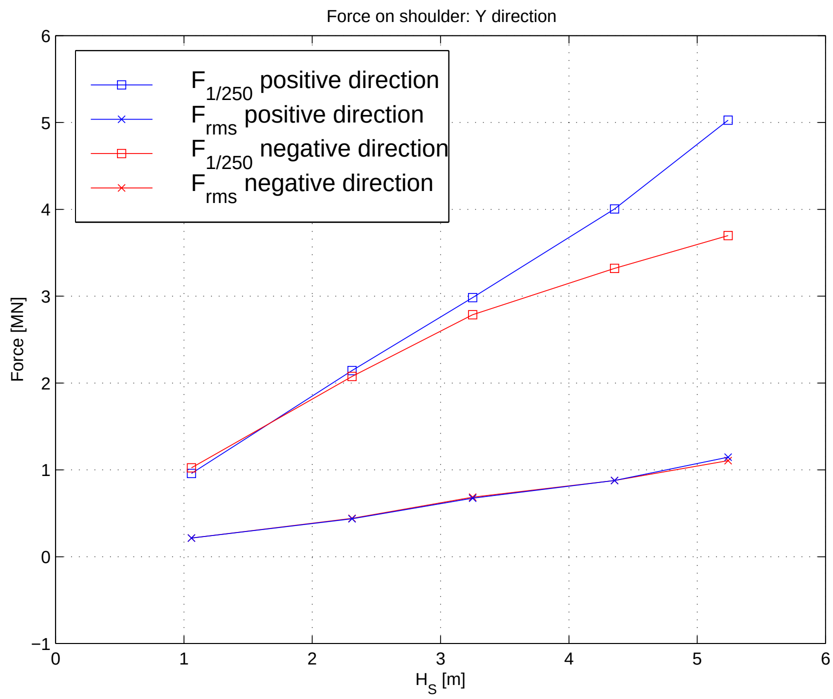


Figure A.5. Vertical force Z on shoulder.

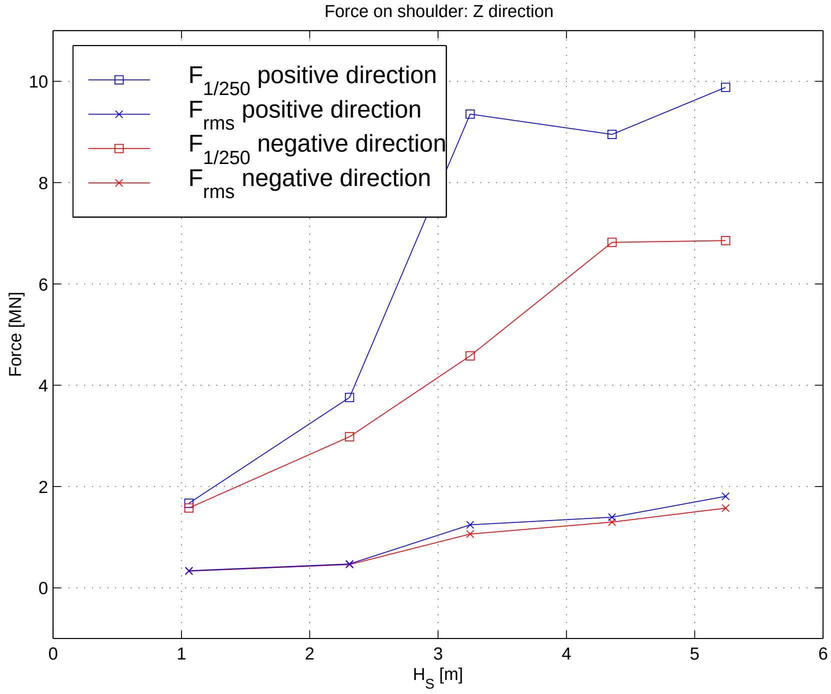


Figure A.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

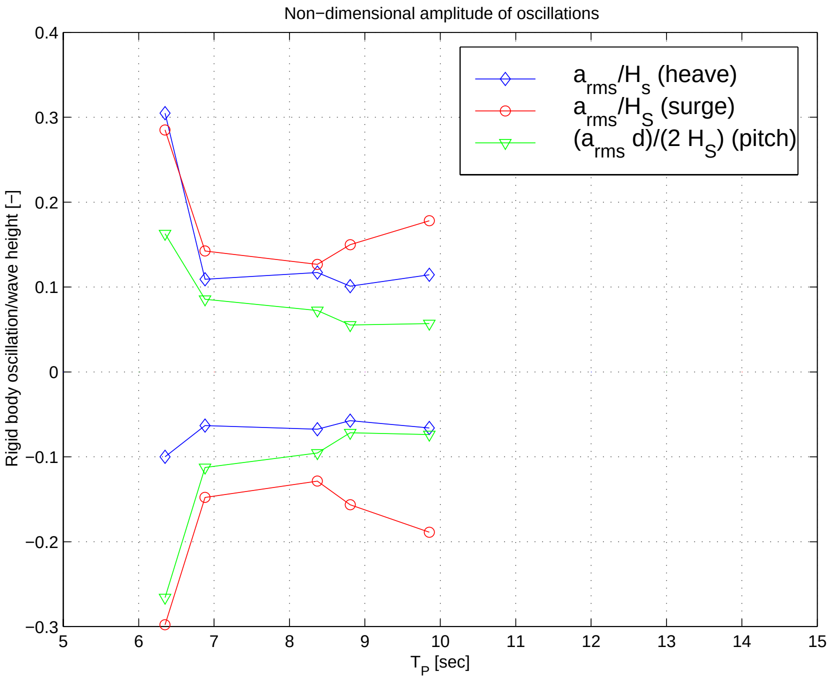


Figure A.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

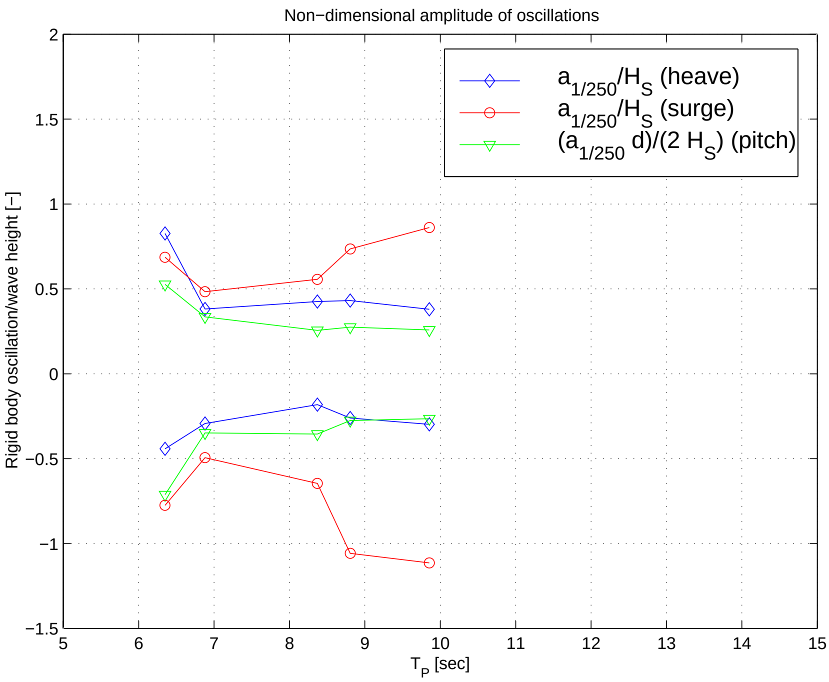


Figure A.8. Non-dimensional overtopping.

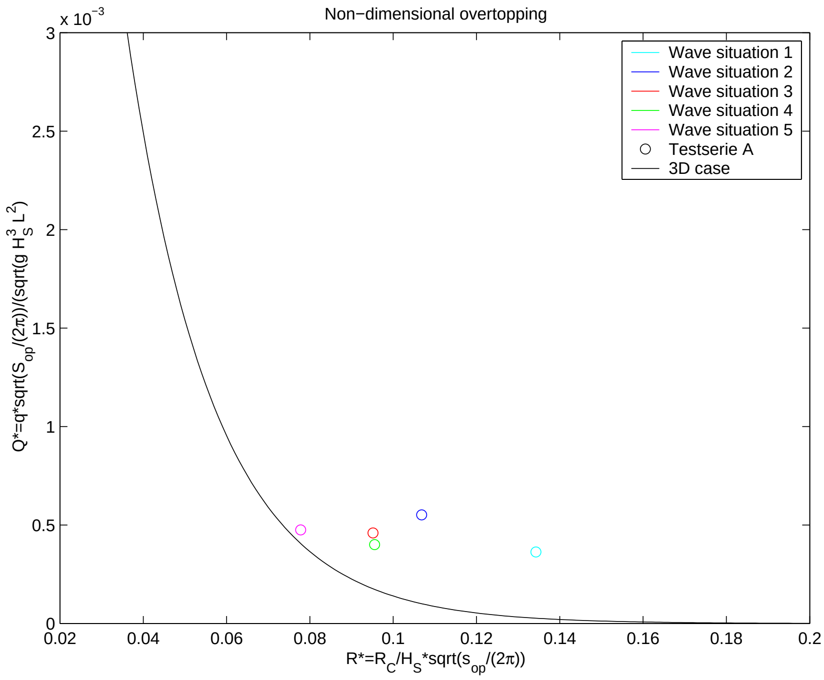
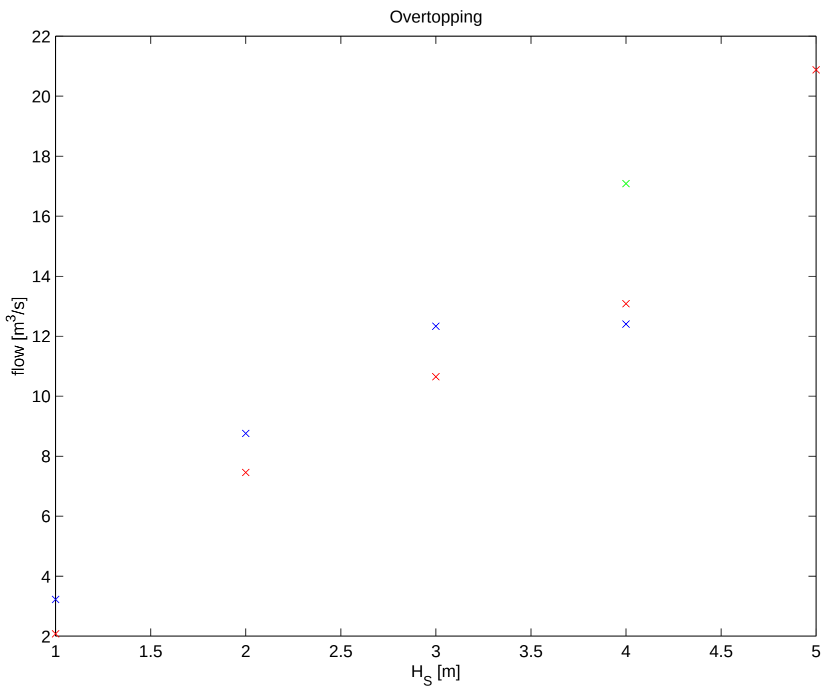


Figure A.9. Overtopping.



Testseries B

Effect af enlarged draught of reflectors

Figure B.1. Mooring force.

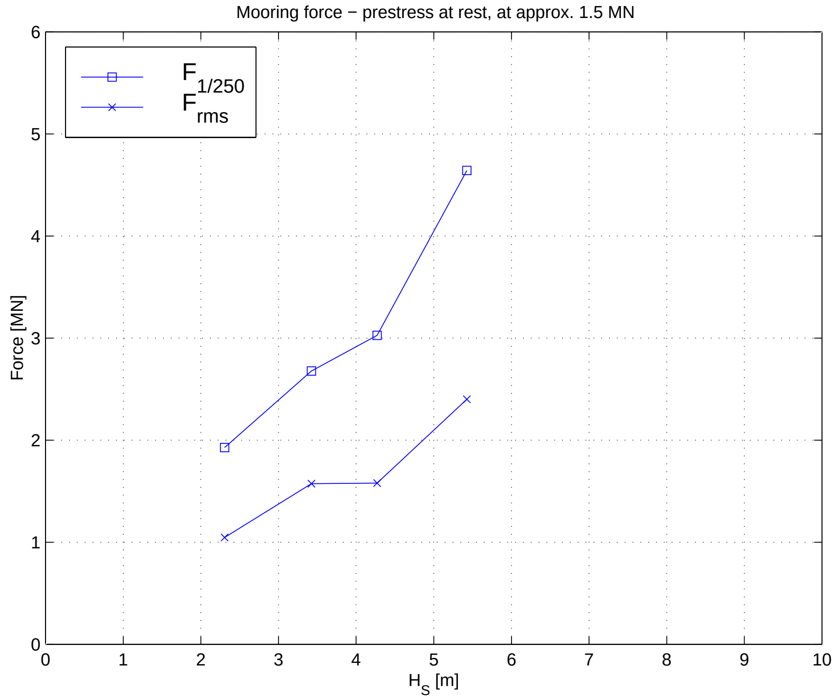


Figure B.2. Force along across cabel A

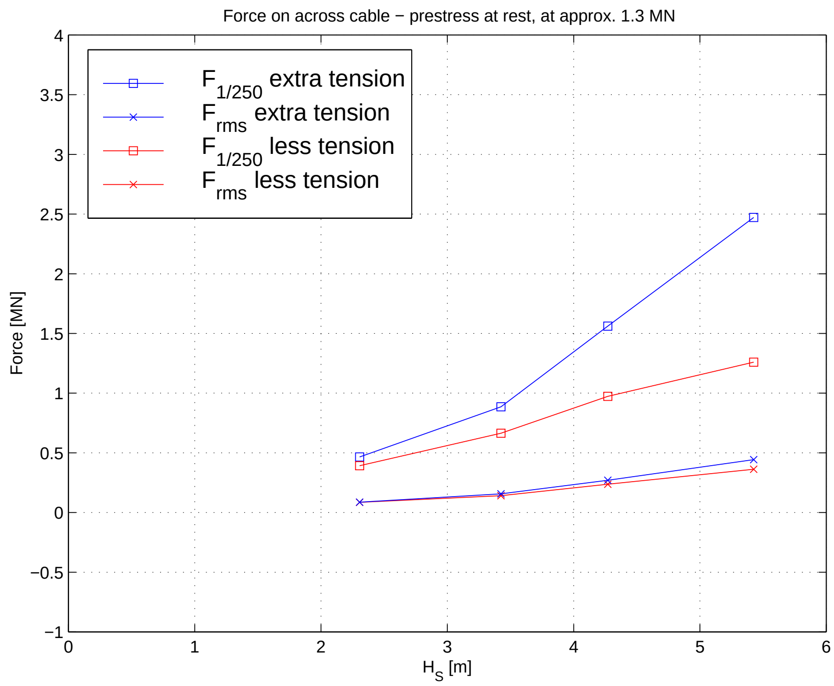


Figure B.3. Shear force X on shoulder.

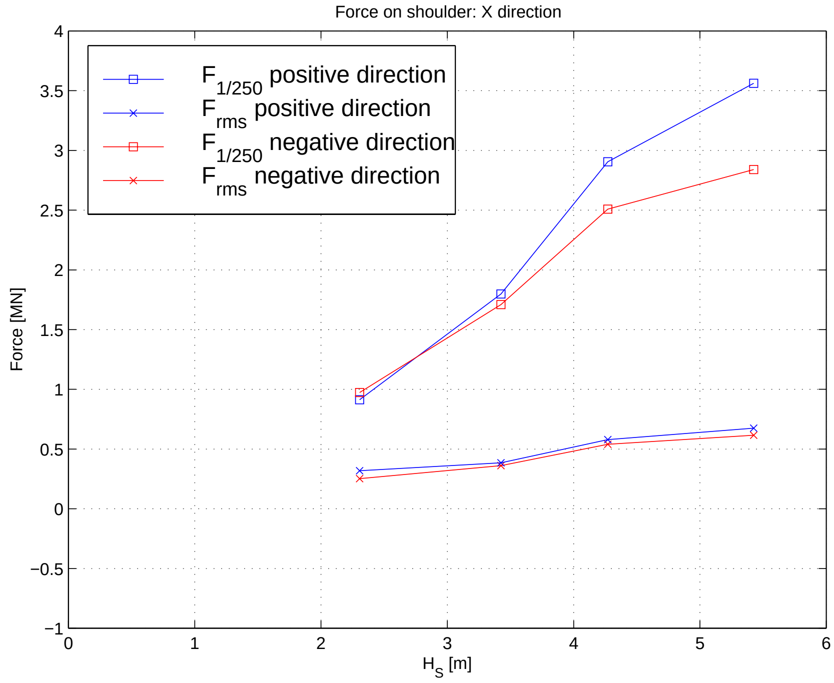


Figure B.4. Axial force Y on shoulder

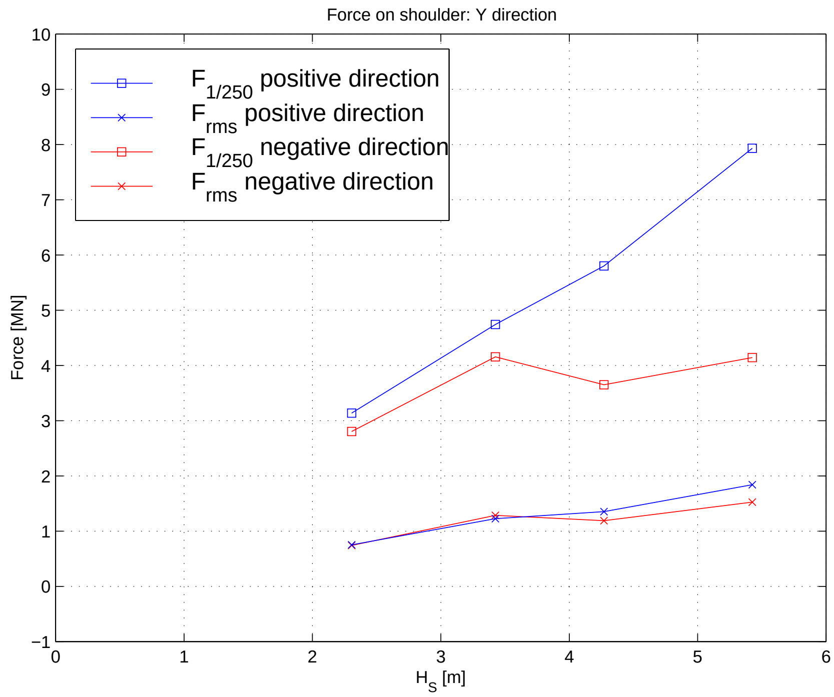


Figure B.5. Vertical force Z on shoulder.

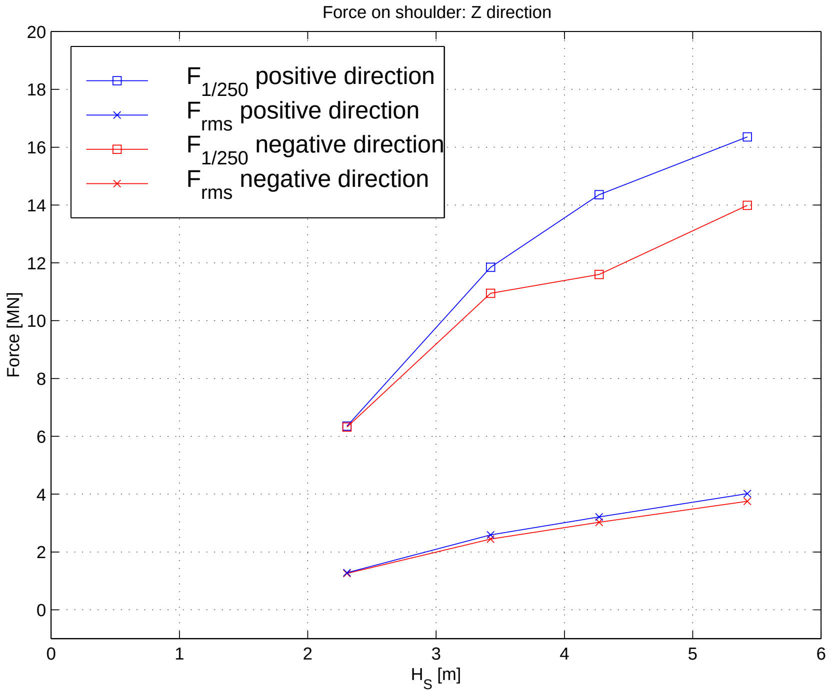


Figure B.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

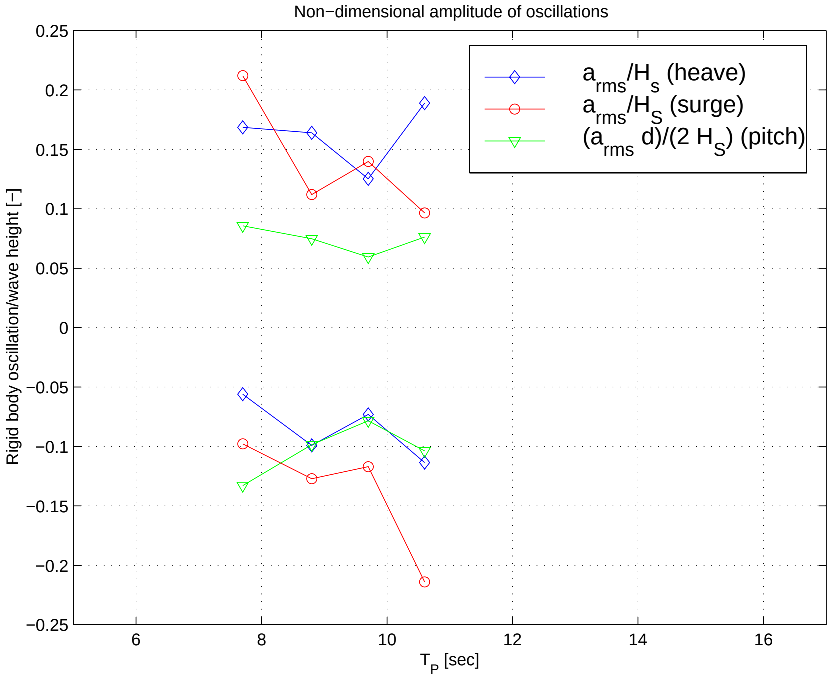


Figure B.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

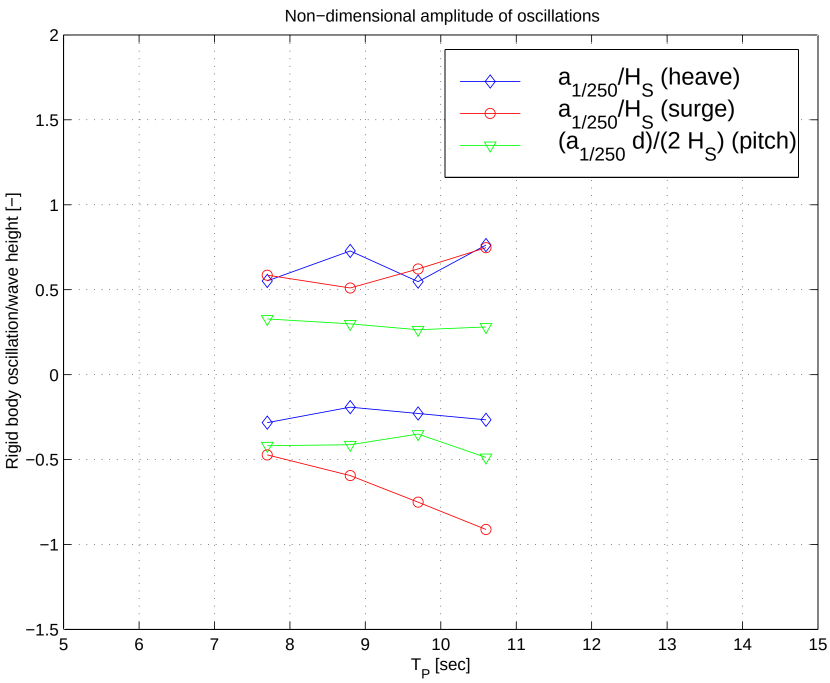
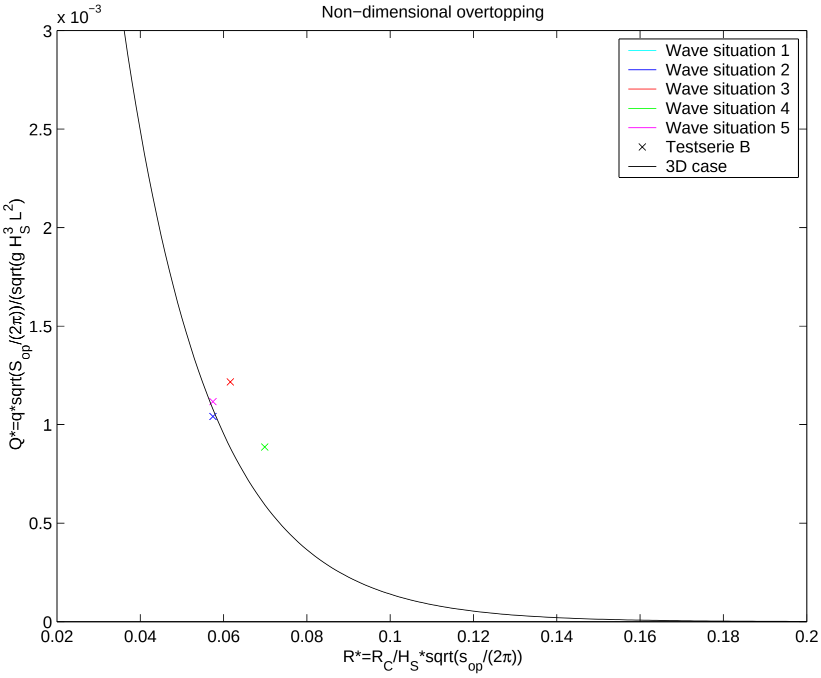


Figure B.8. Non-dimensional overtopping.



Testseries C

Effect of enlarged draught of reflectors

Crest freeboard: +1.5 m compared to table III

Figure C.1. Mooring force.

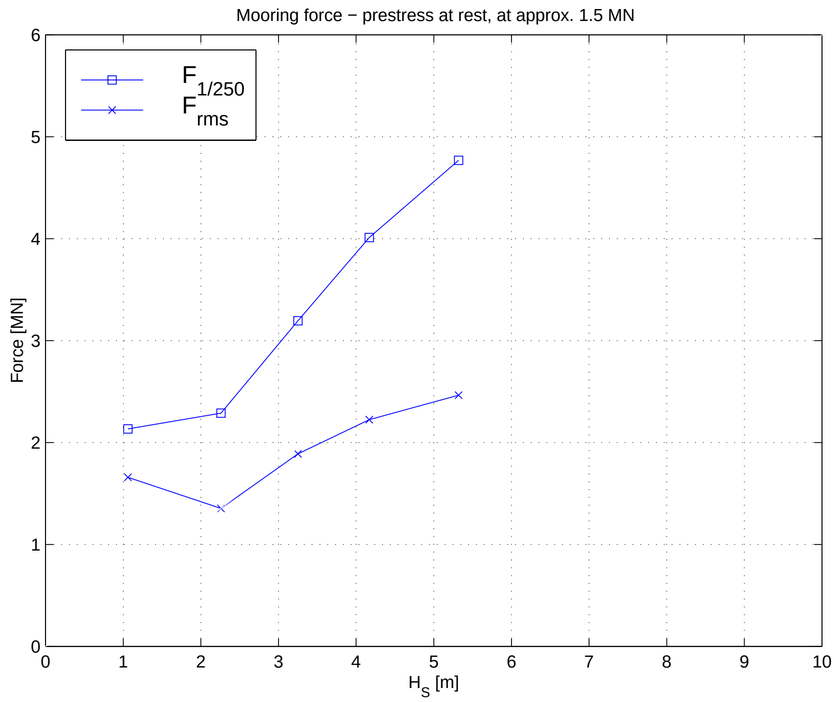


Figure C.2. Force along across cabel A

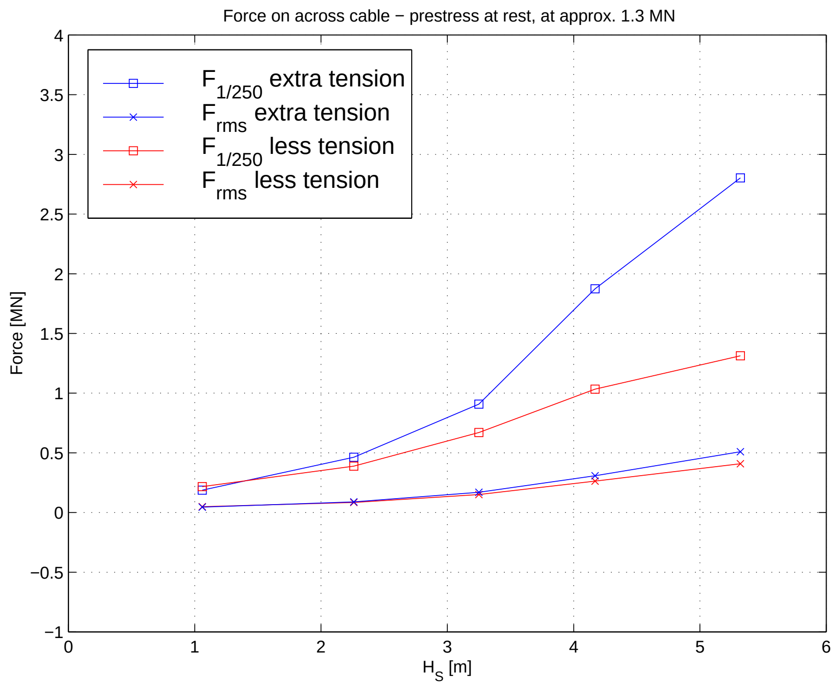


Figure C.3. Shear force X on shoulder.

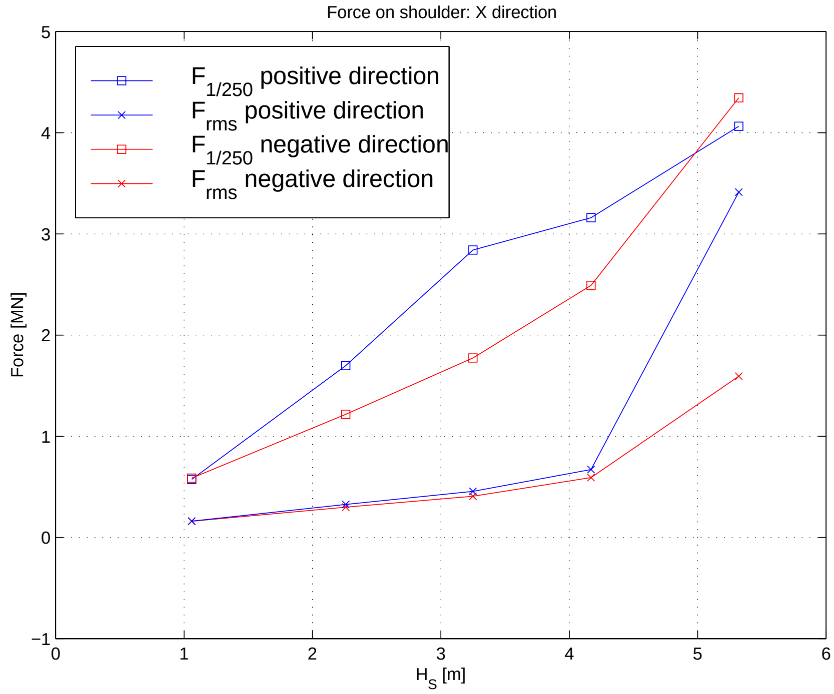


Figure C.4. Axial force Y on shoulder

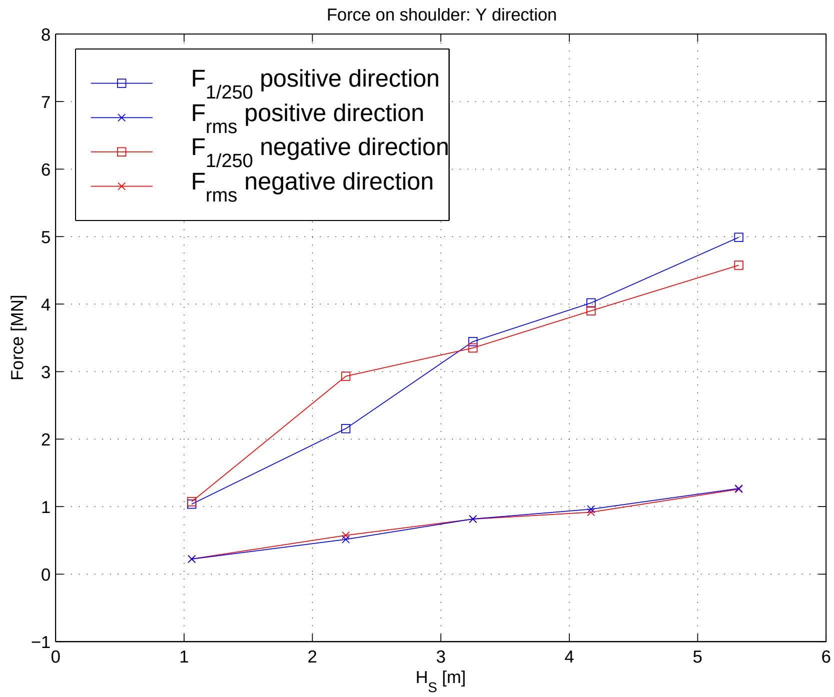


Figure C.5. Vertical force Z on shoulder.

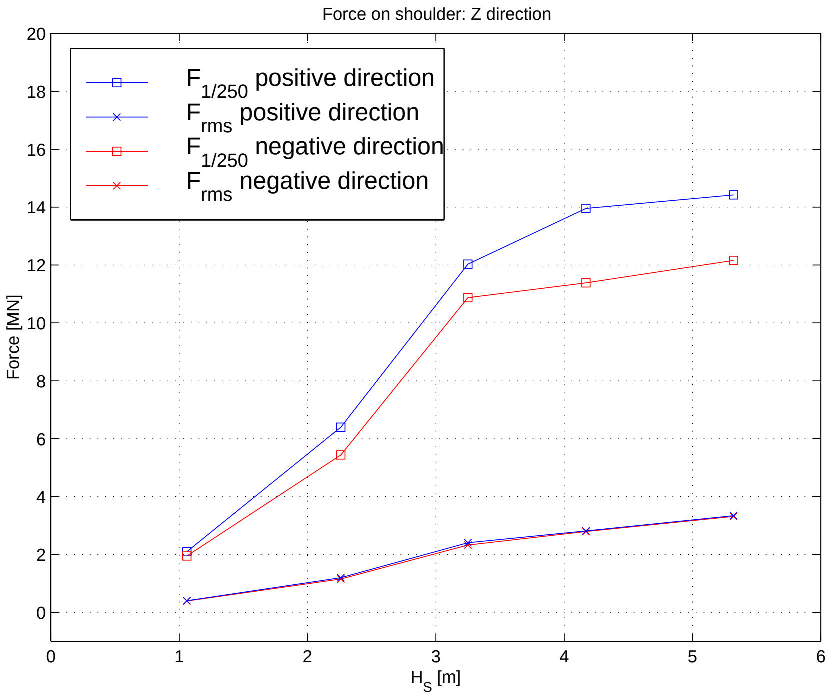


Figure C.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

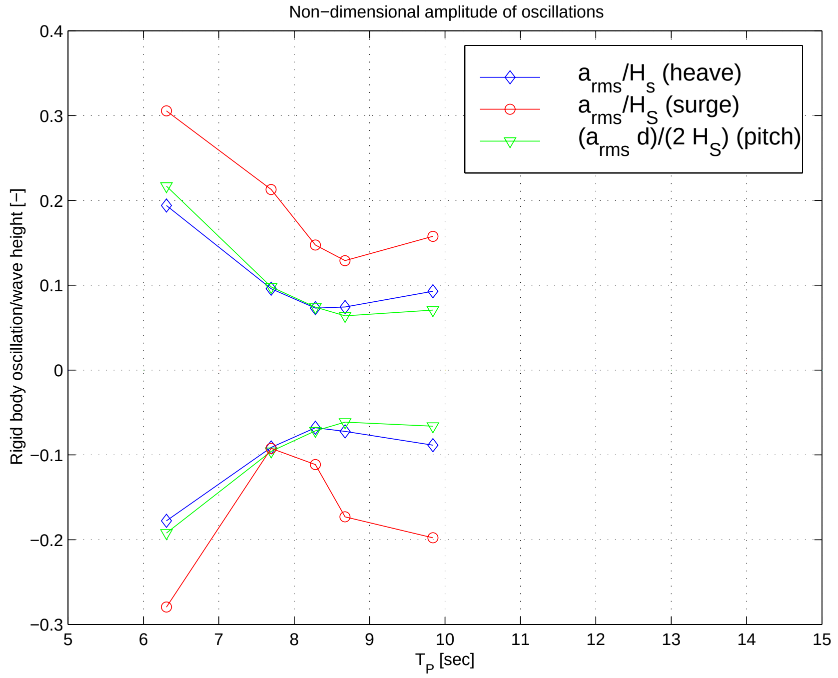


Figure C.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

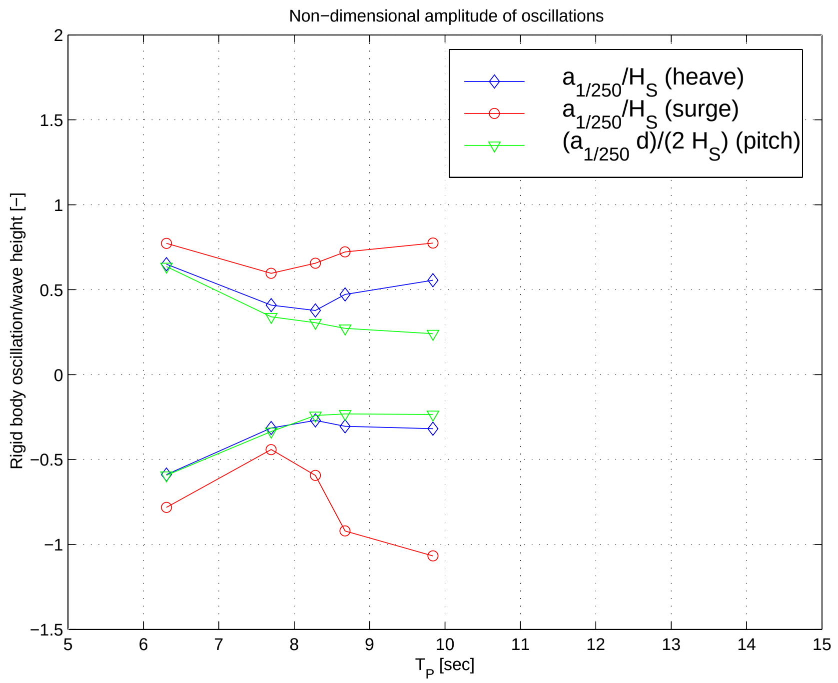
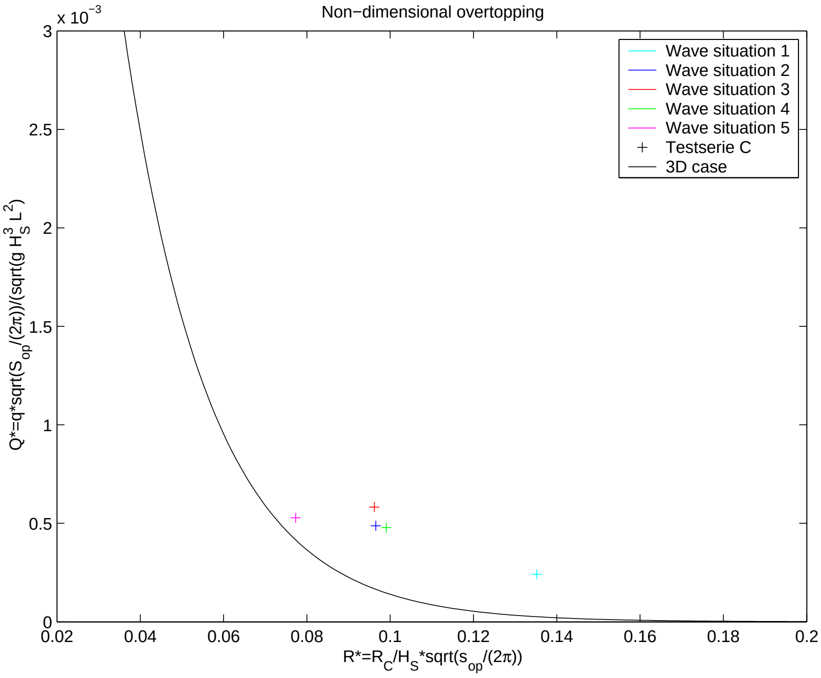


Figure C.8. Non-dimensional overtopping.



Testseries D

Effect of triming

Test conditions:

	Waves	Crest freeboard	
Trim 1	NS 3	Bow: 3m	Stern: 4m
Trim 2	NS 2	Bow: 2m	Stern: 3m
Trim 3	NS 3	Bow: 2m	Stern: 3m
Trim 4	NS 2	Bow: 1m	Stern: 2m
Trim 5	NS 4	Bow: 3m	Stern: 4m
Trim 6	NS 4	Bow: 4m	Stern: 5m
Trim 7	NS 5	Bow: 4m	Stern: 5m

Figure D.1. Mooring force.

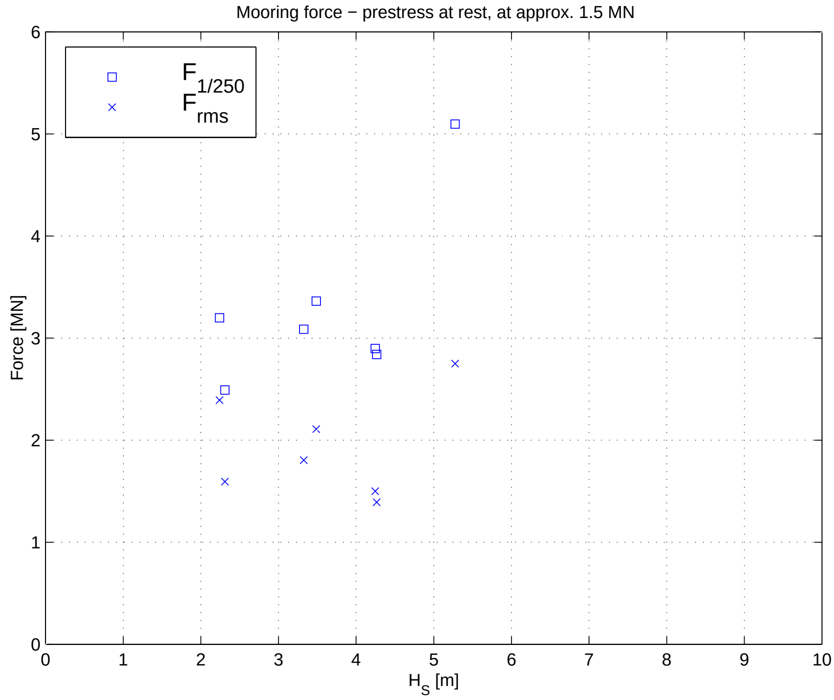


Figure D.2. Force along across cabel A

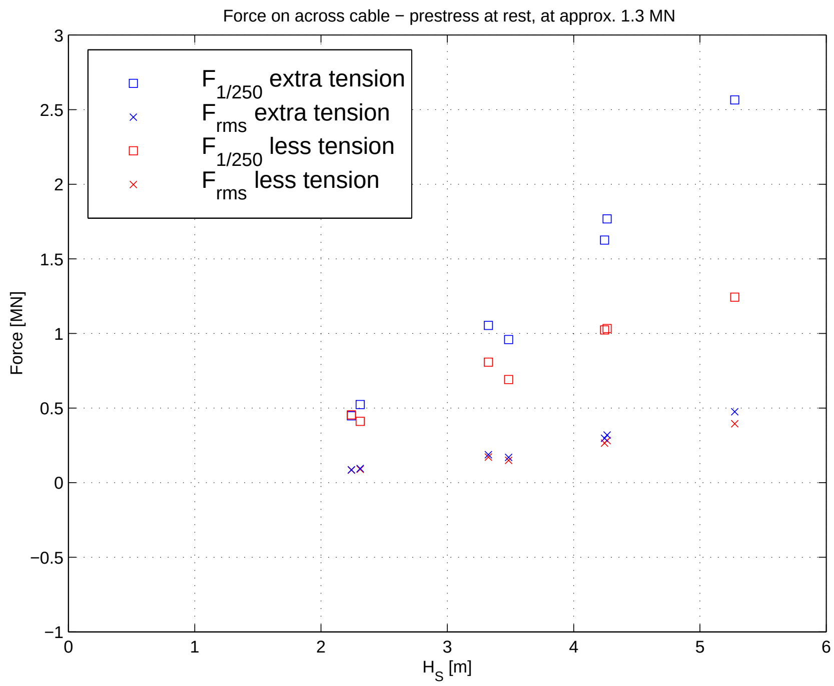


Figure D.3. Shear force X on shoulder.

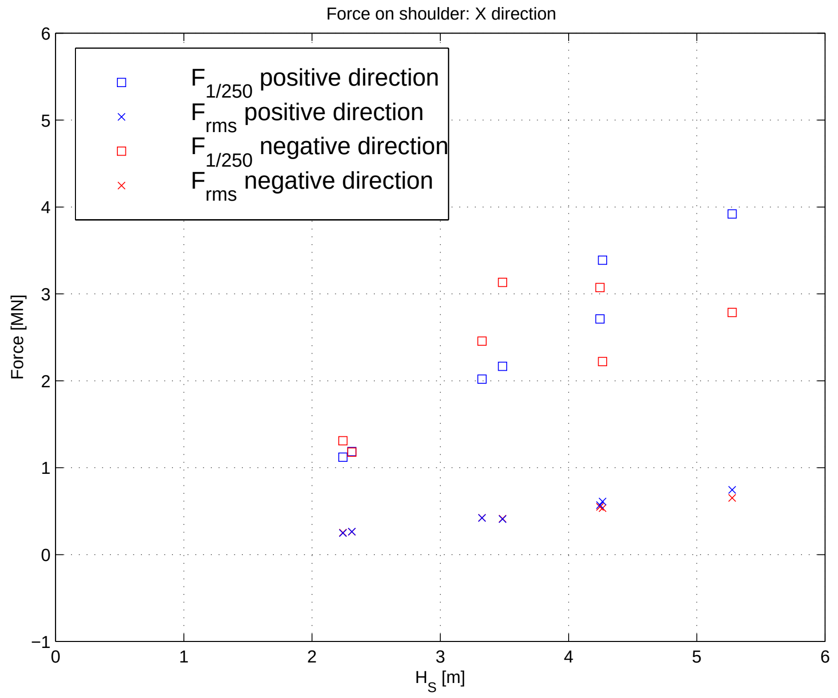


Figure D.4. Axial force Y on shoulder

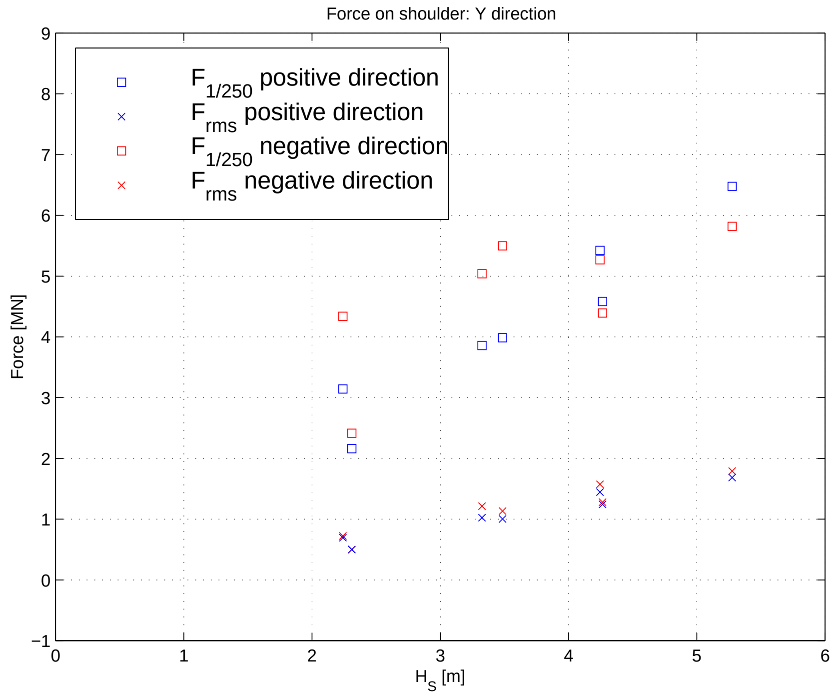


Figure D.5. Vertical force Z on shoulder.

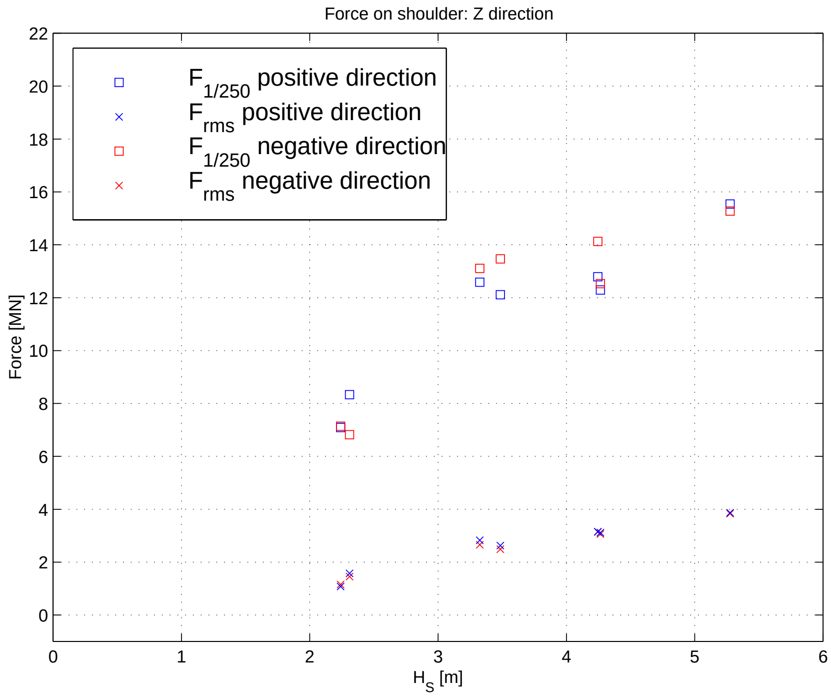


Figure D.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

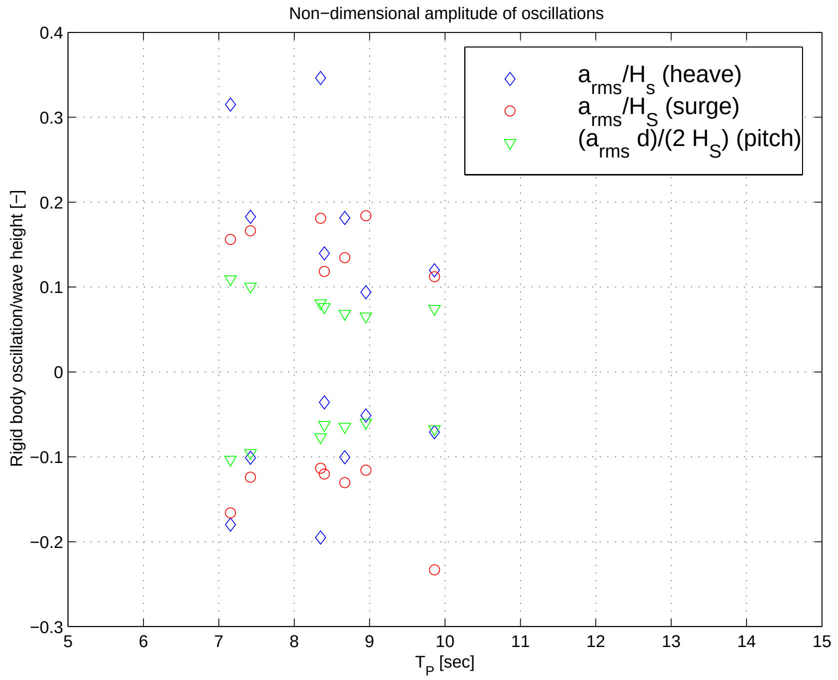


Figure D.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

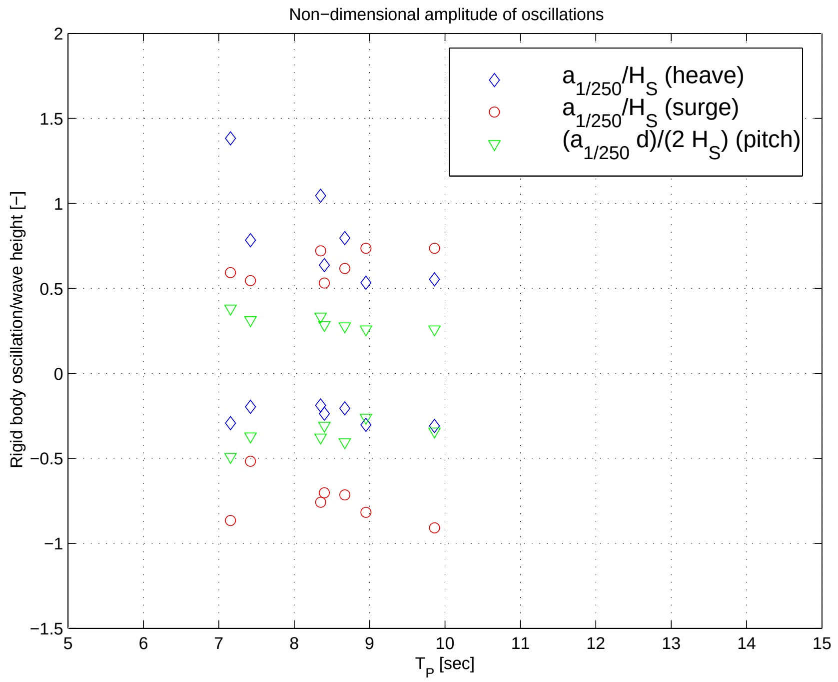
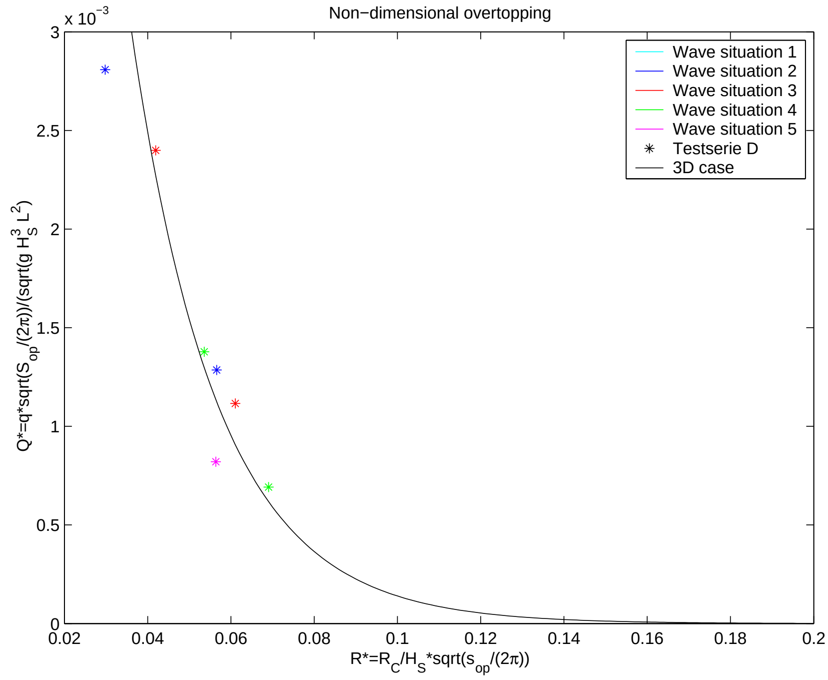


Figure D.8. Non-dimensional overtopping.



Testseries E

Effect of double-curved overtopping ramp

Figure E.1. Mooring force.

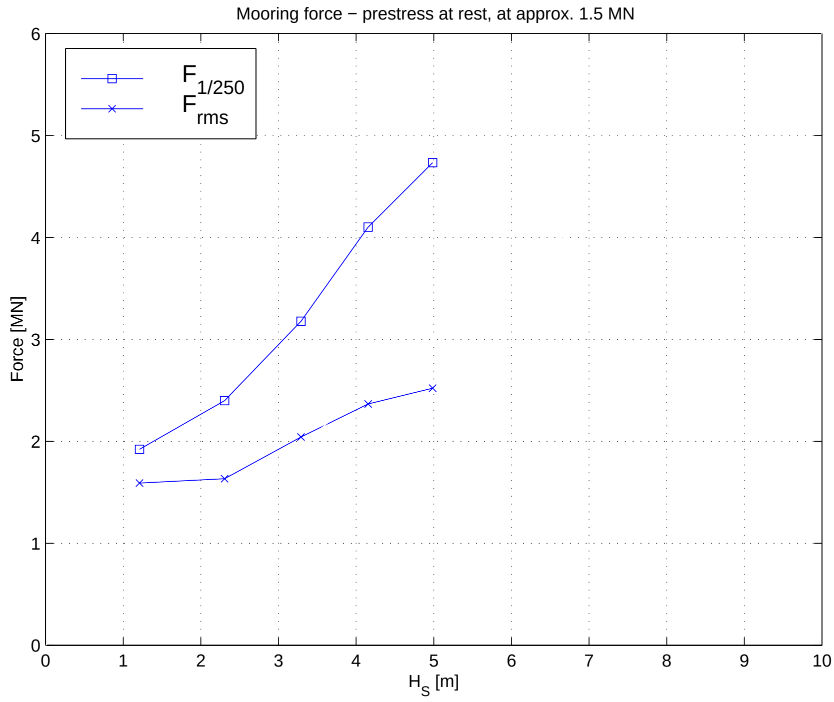


Figure E.2. Force along across cabel A

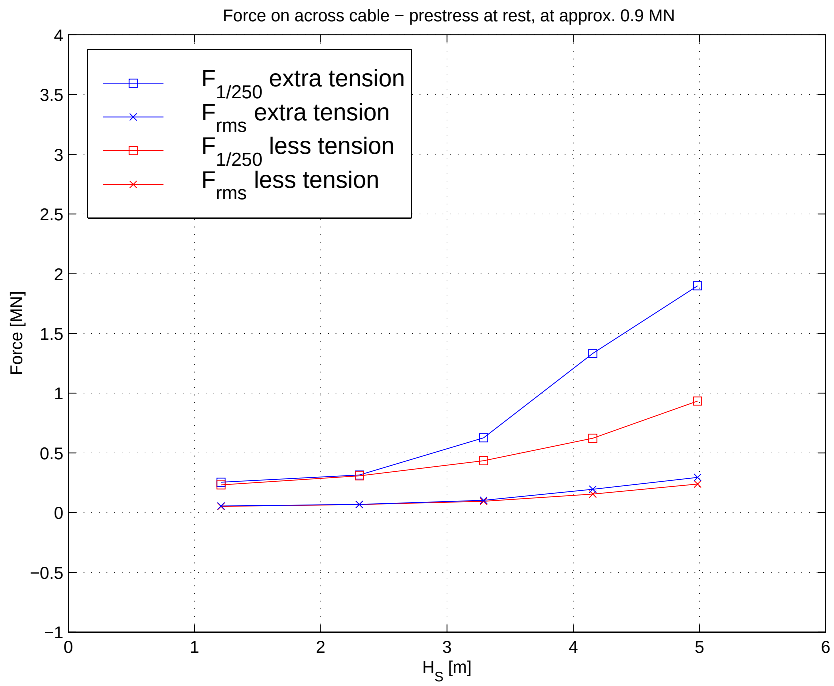


Figure E.3. Shear force X on shoulder.

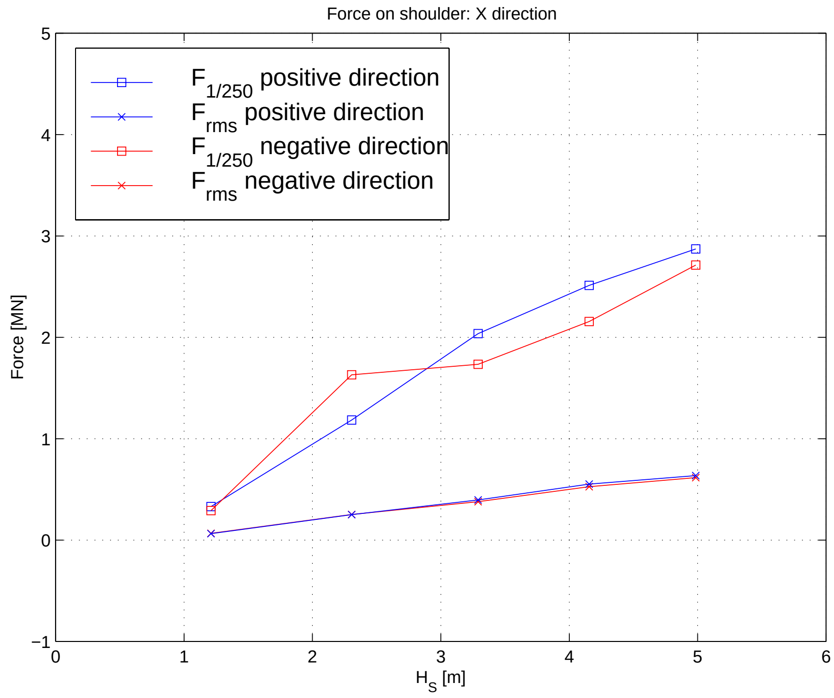


Figure E.4. Axial force Y on shoulder

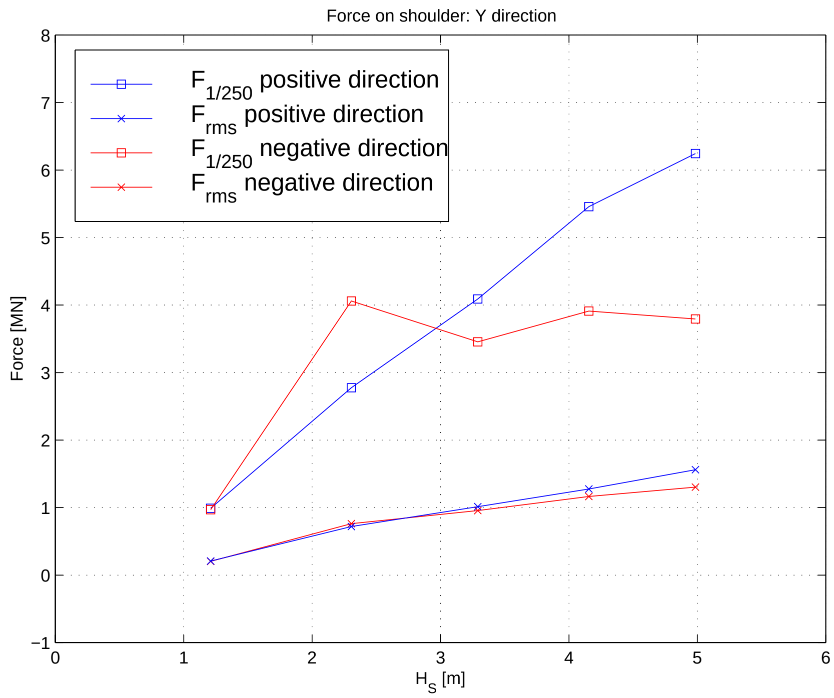


Figure E.5. Vertical force Z on shoulder.

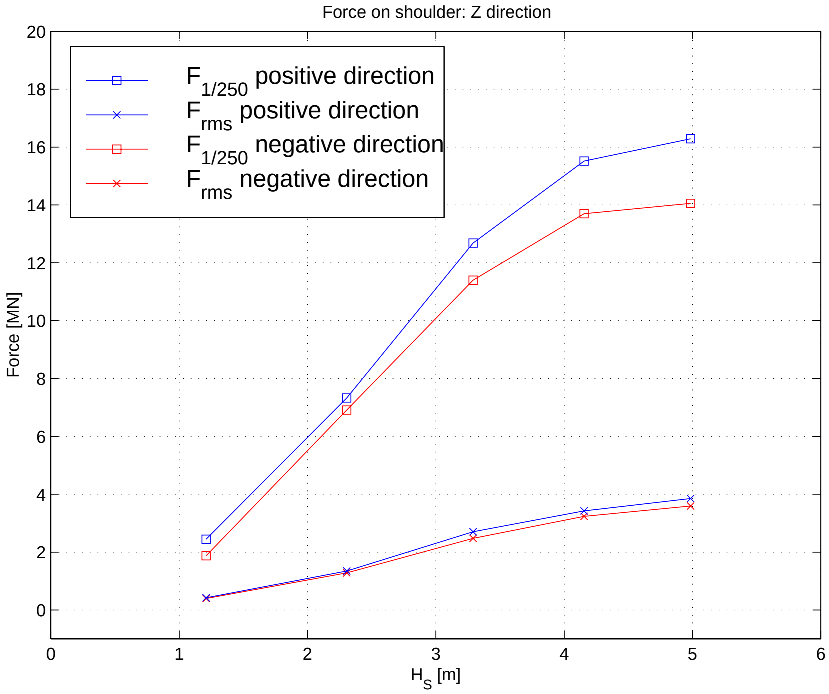


Figure E.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

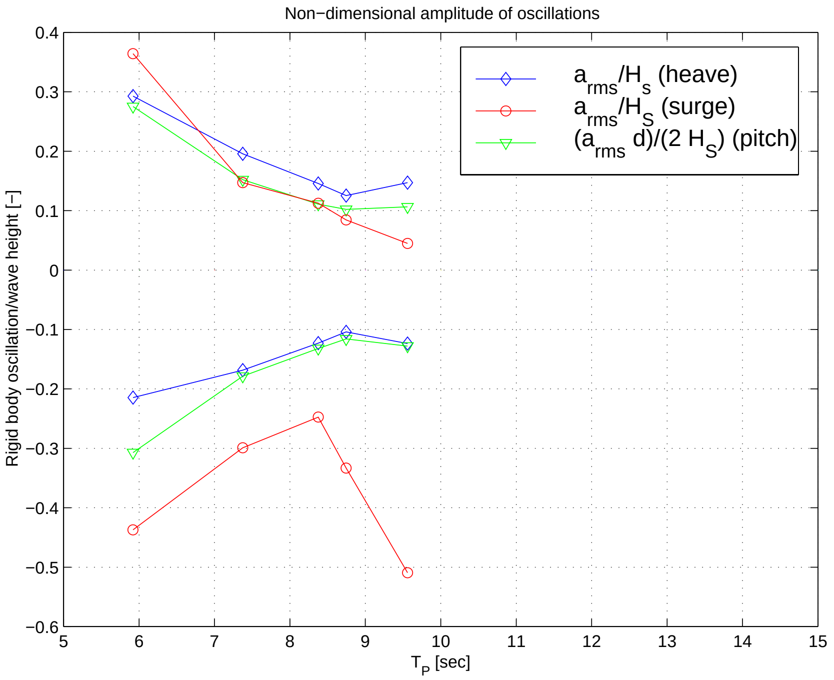


Figure E.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

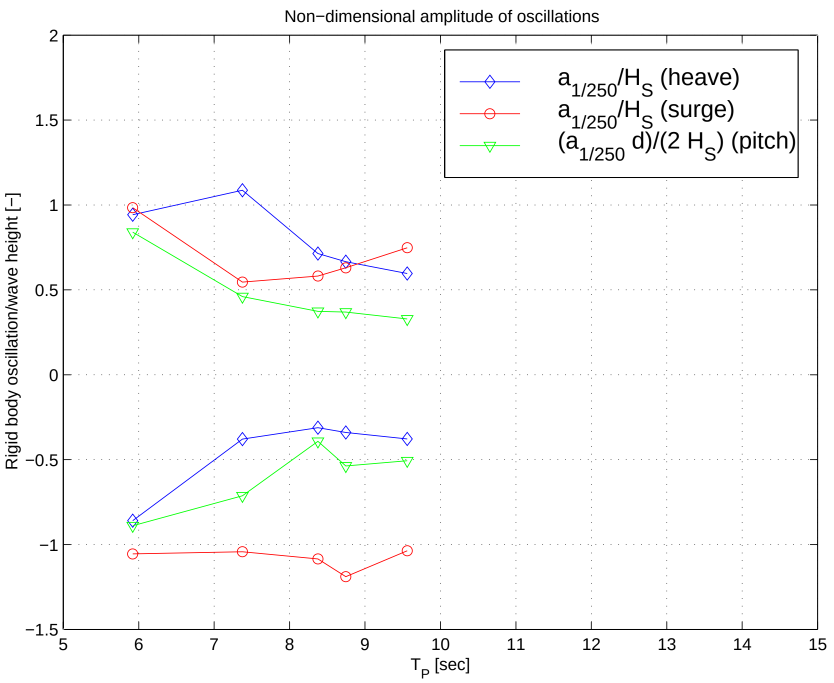


Figure E.8. Non-dimensional overtopping.

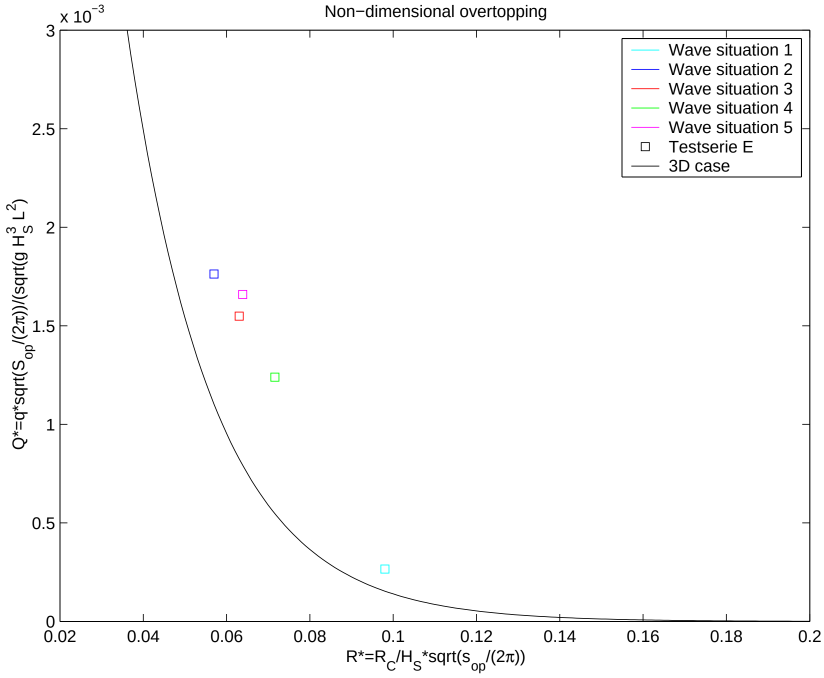


Figure E.9. Sample time series of mooring force in wave situation 5. Measures in scale 1:51.8.

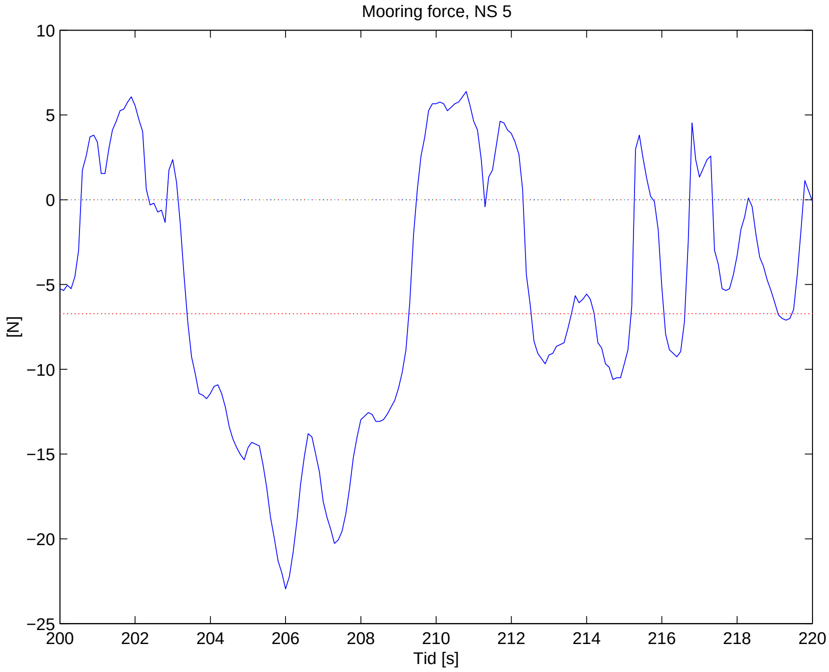


Figure E.10. Sample time series of cable force in wave situation 5. Measures in scale 1:51.8.

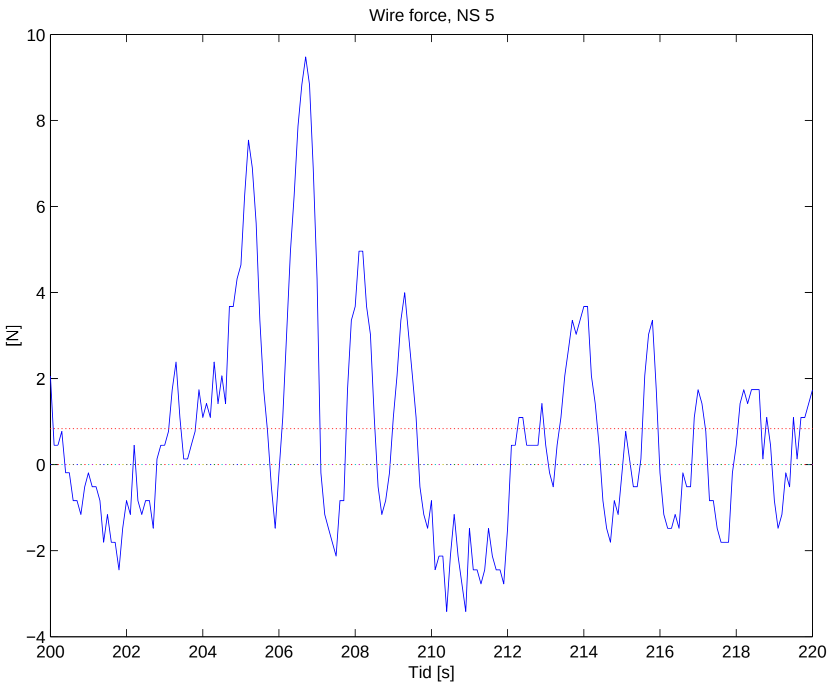


Figure E.11. Sample time series of shear force X in wave situation 5. Measures in scale 1:51.8.

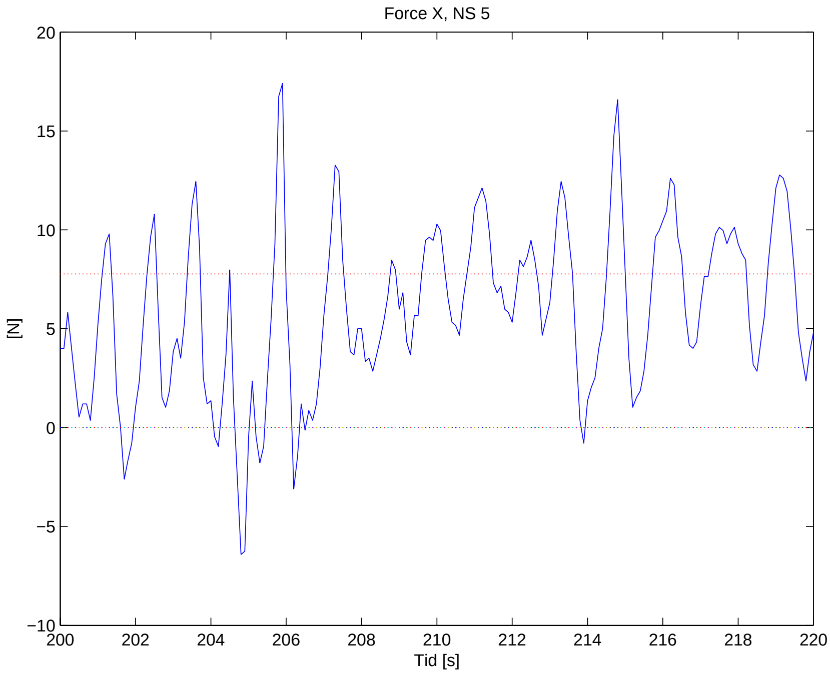


Figure E.12. Sample time series of axial force Y in wave situation 5. Measures in scale 1:51.8.

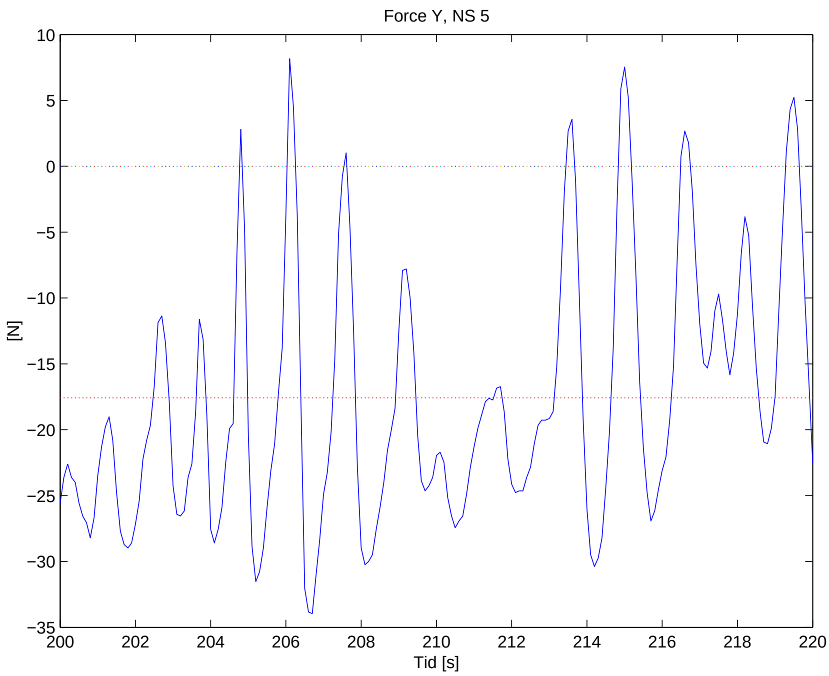
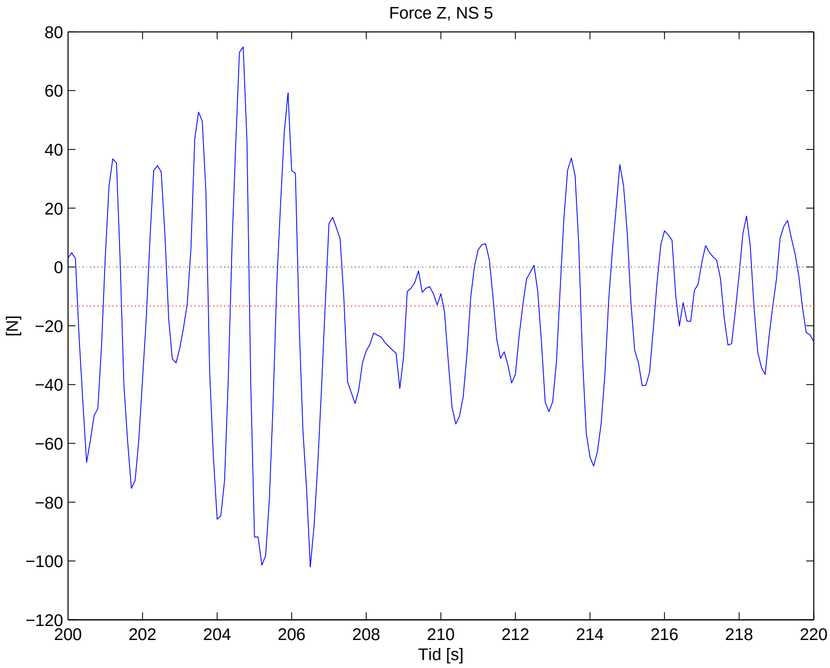


Figure E.13. Sample time series of vertical force Z in wave situation 5. Measures in scale 1:51.8.



Testseries F

Effect of double-walled wave damper in reservoir

Figure F.1. Mooring force.

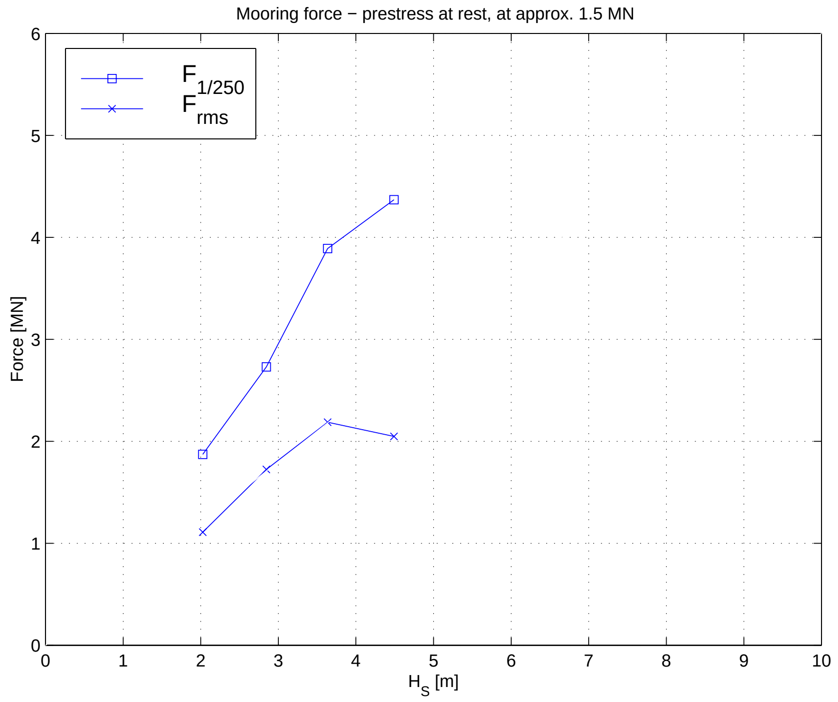


Figure F.2. Force along across cabel A

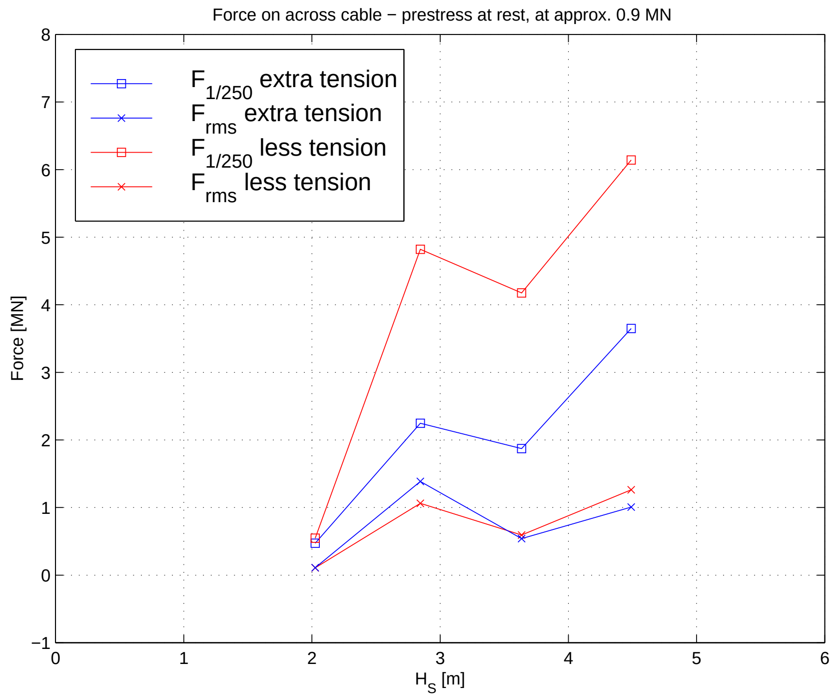


Figure F.3. Shear force X on shoulder.

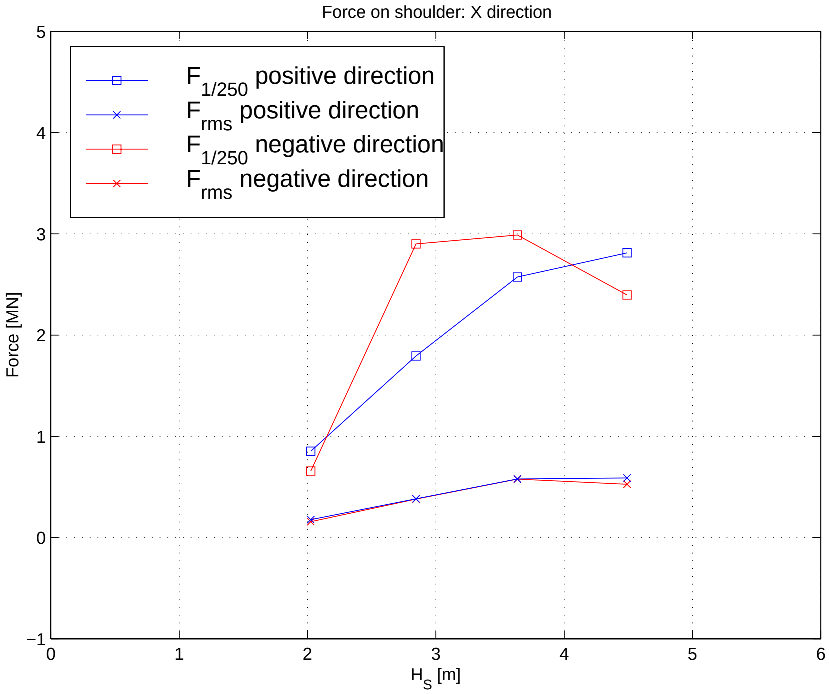


Figure F.4. Axial force Y on shoulder

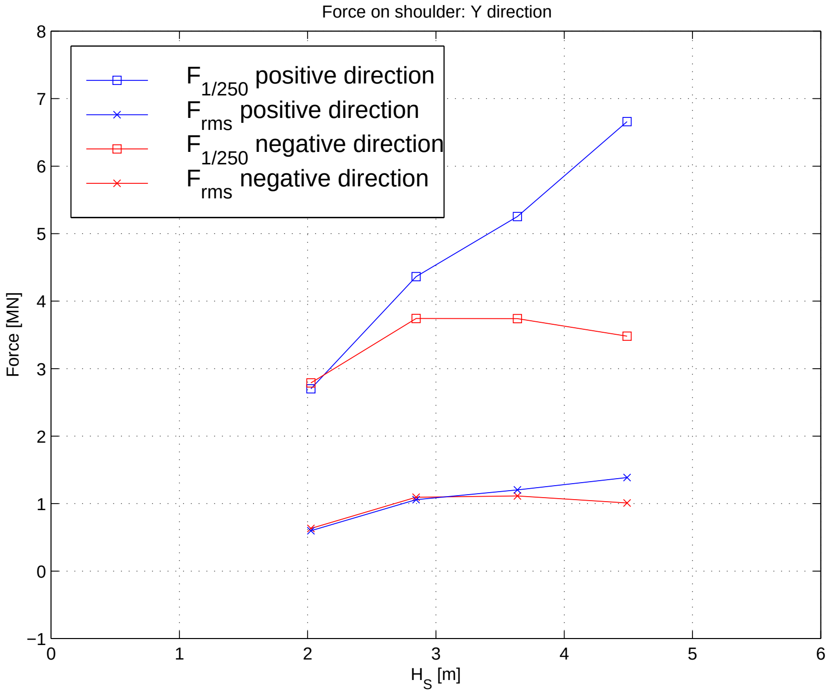


Figure F.5. Vertical force Z on shoulder.

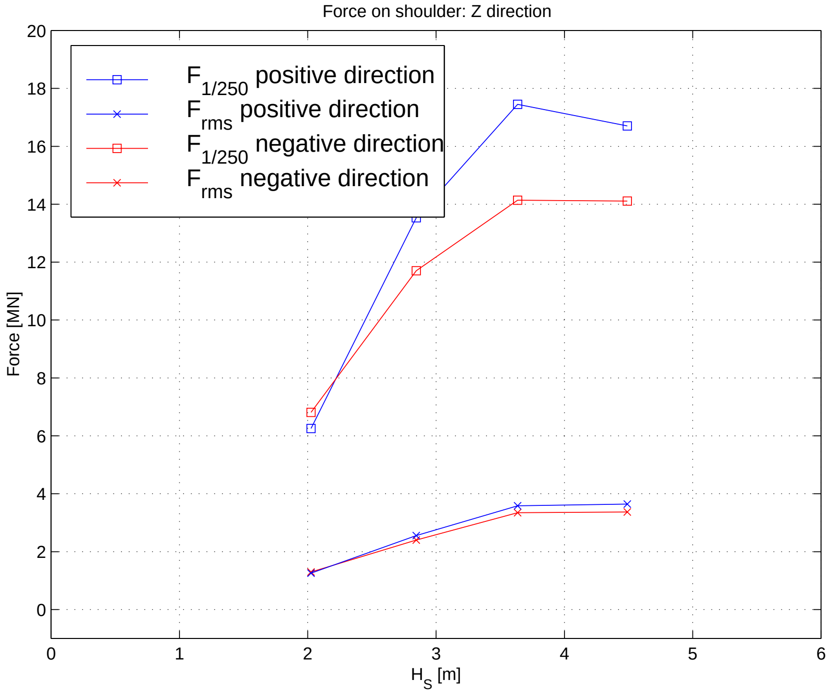


Figure F.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

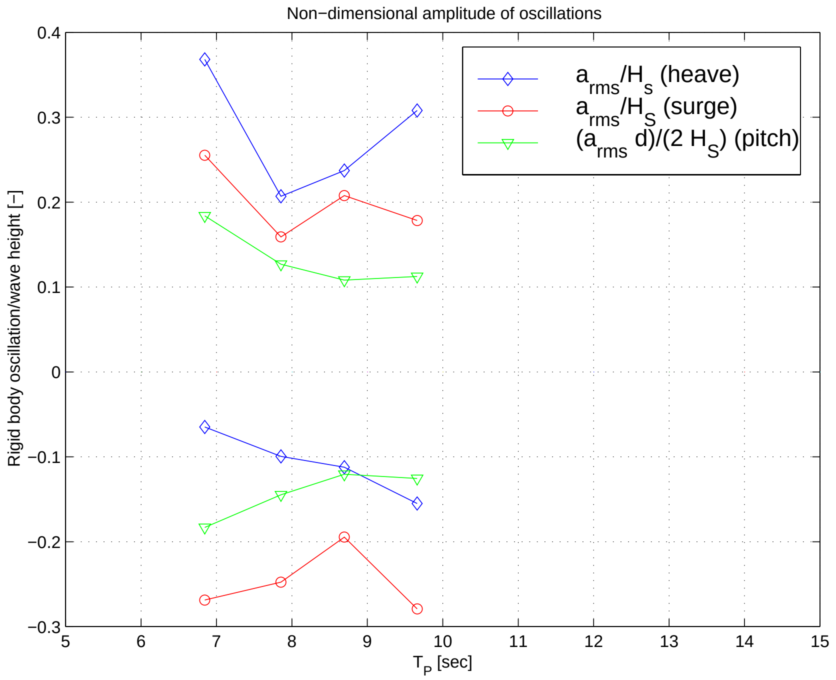


Figure F.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

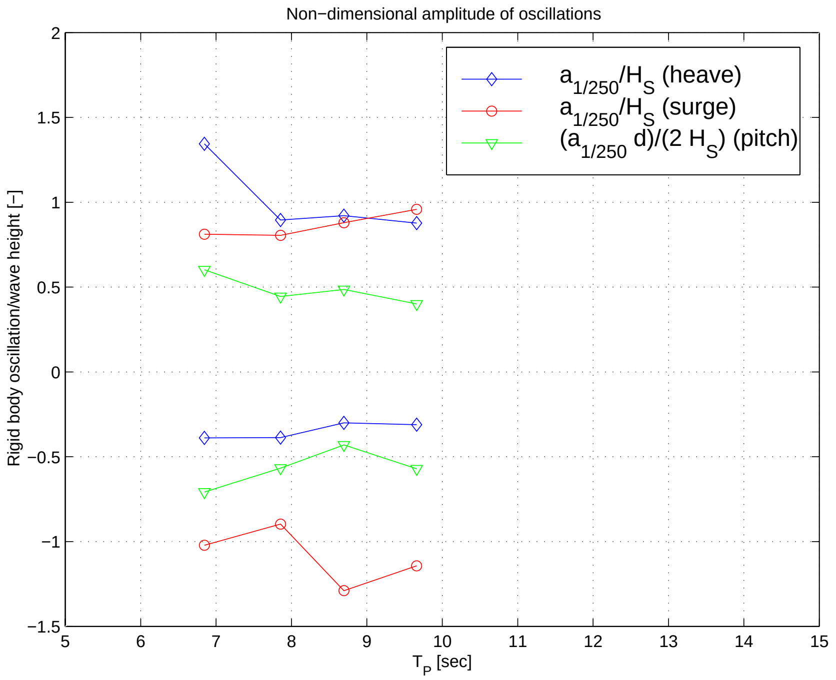
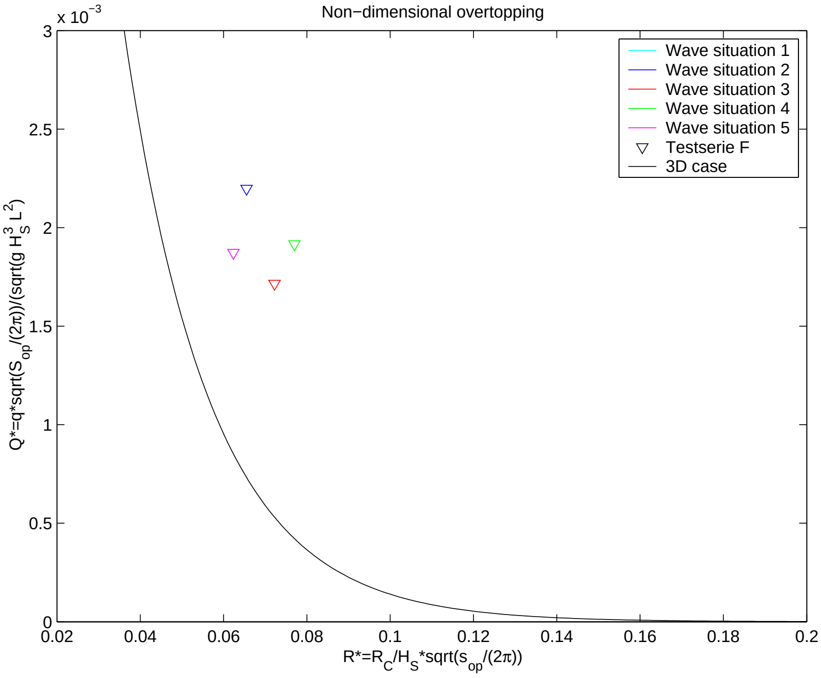


Figure F.8. Non-dimensional overtopping.



Testseries G

Effect of triming

Test conditions:

	Waves	Crest freeboard	
Trim 1	NS 2	Bow: 2m	Stern: 3m
Trim 2	NS 3	Bow: 3m	Stern: 4m
Trim 3	NS 4	Bow: 4m	Stern: 5m
Trim 4	NS 5	Bow: 4m	Stern: 5m

Figure G.1. Mooring force.

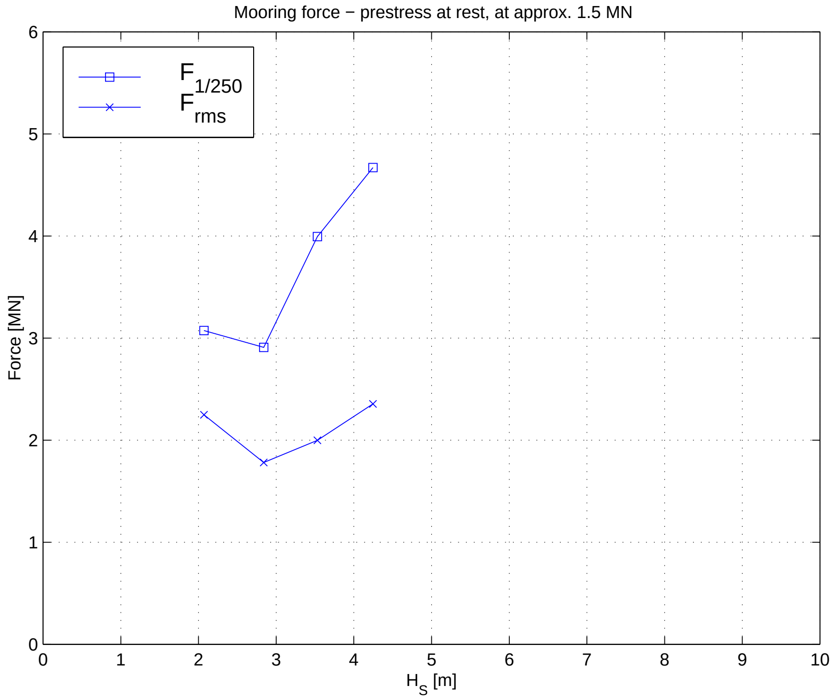


Figure G.3. Shear force X on shoulder.

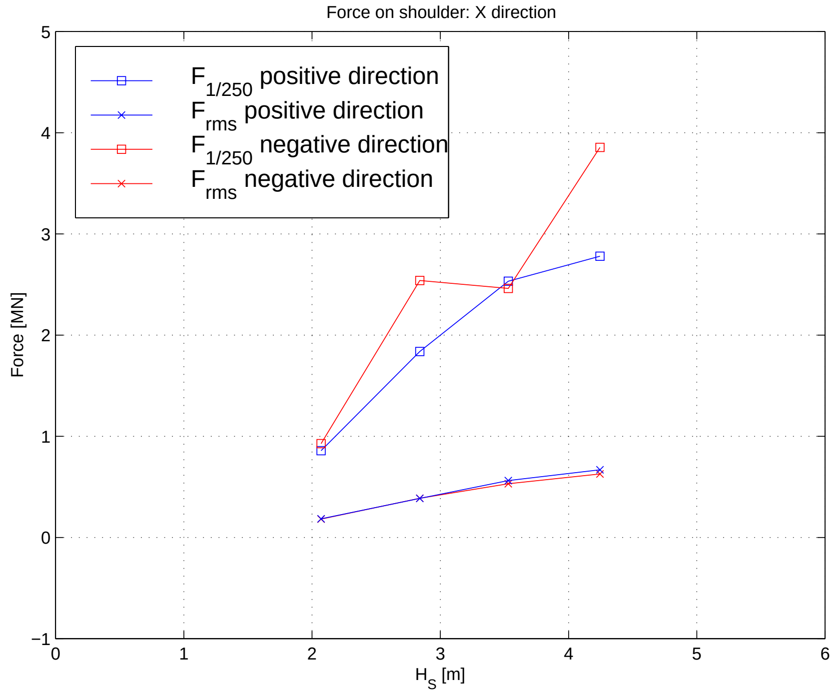


Figure G.4. Axial force Y on shoulder

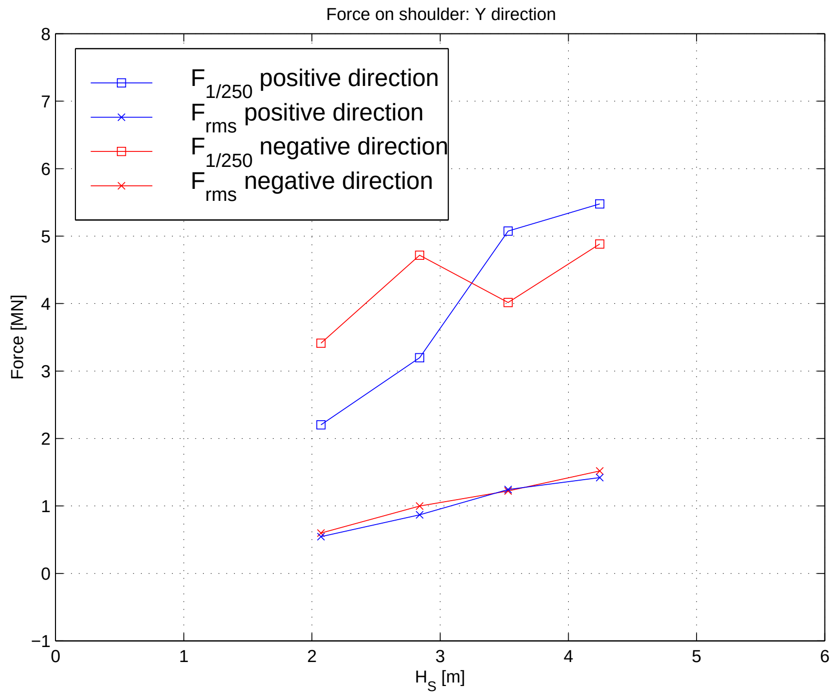


Figure G.5. Vertical force Z on shoulder.

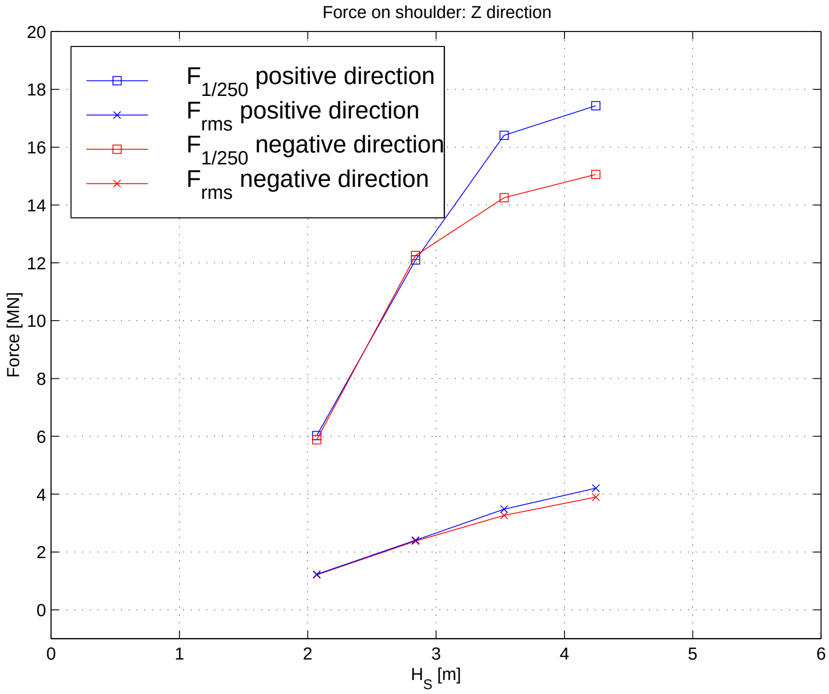


Figure G.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

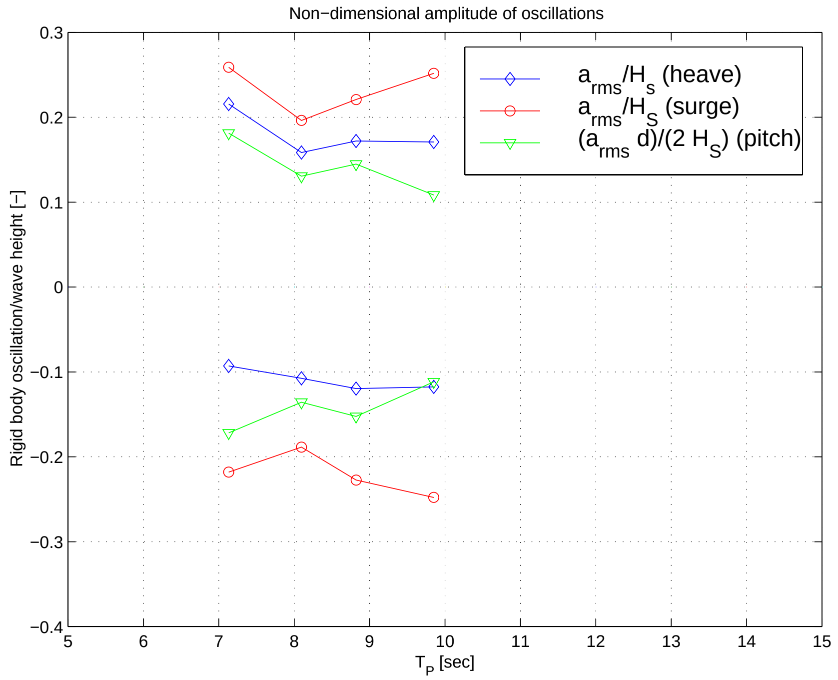


Figure G.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

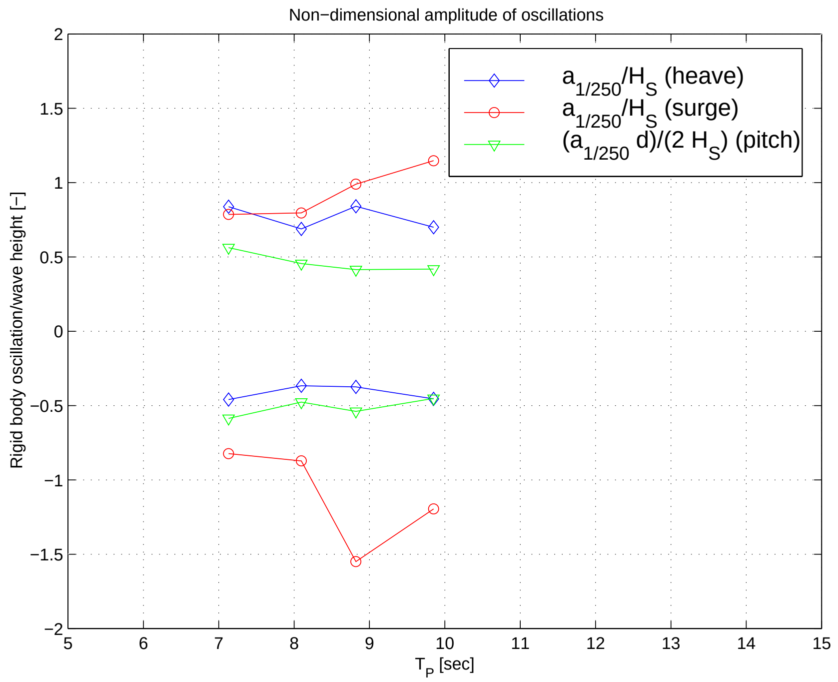


Figure G.8. Non-dimensional overtopping.

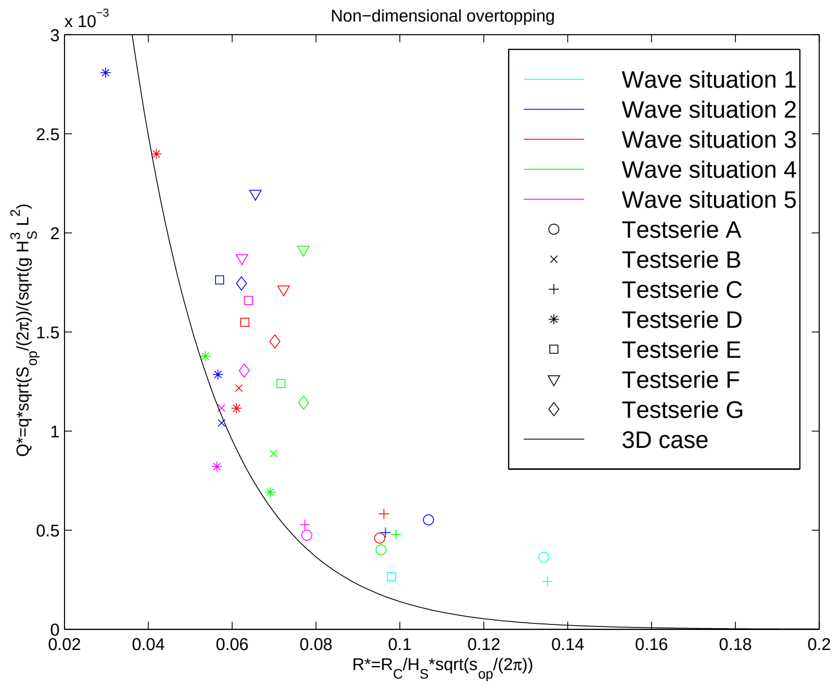
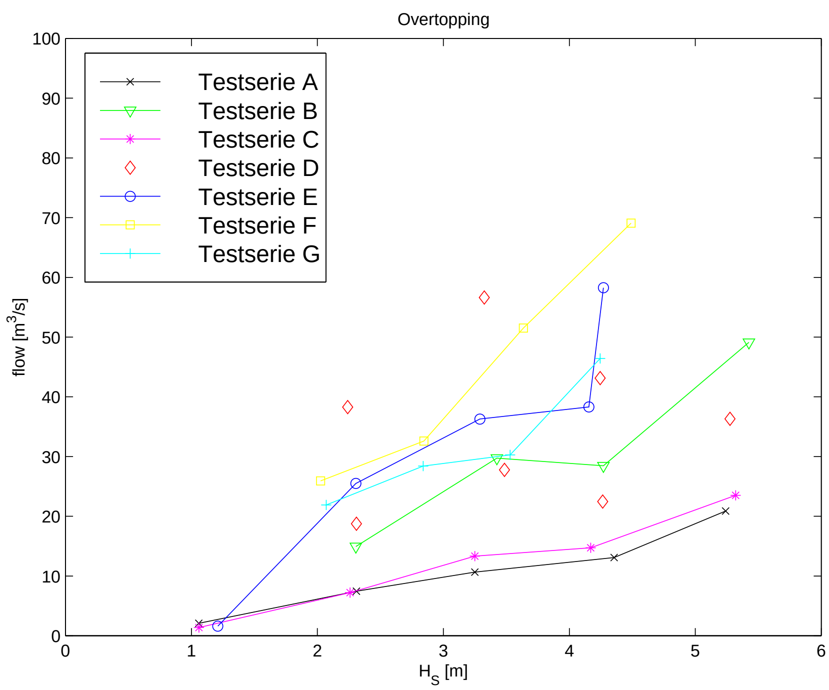


Figure G.9. Overtopping.



Testseries H

Effect of guiding walls on ramp and
single-walled wave damper in reservoir

Figure H.1. Mooring force.

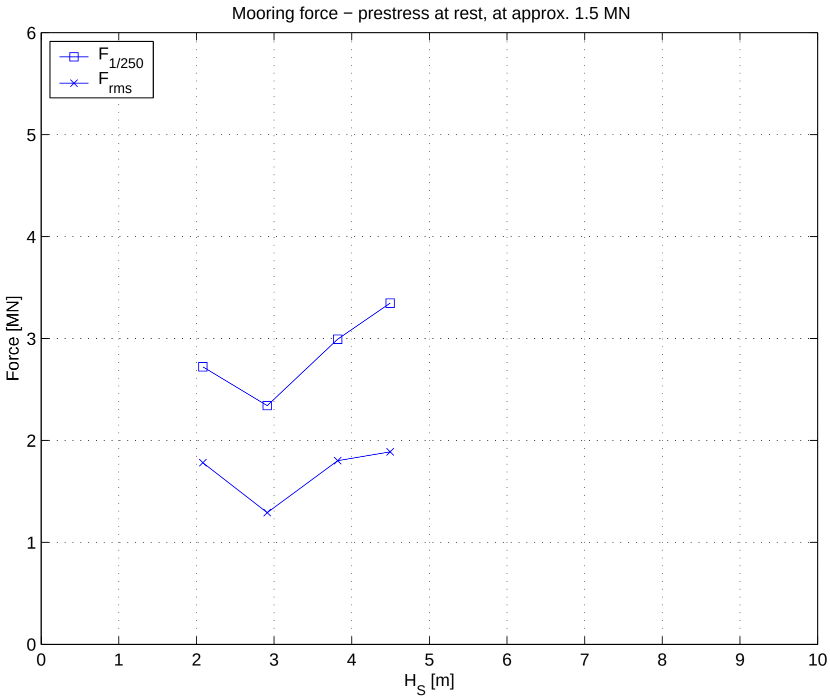


Figure H.3. Shear force X on shoulder.

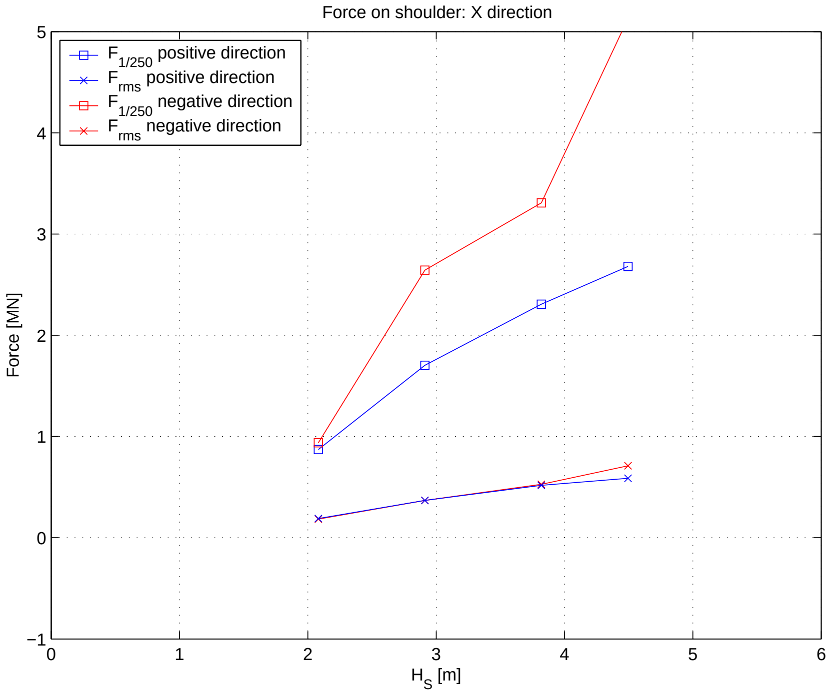


Figure H.4. Axial force Y on shoulder

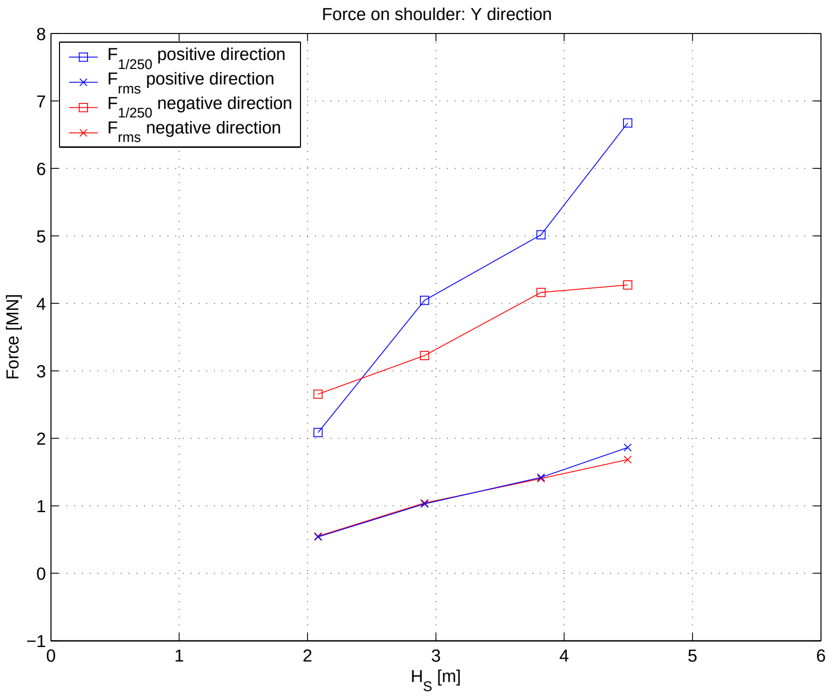


Figure H.5. Vertical force Z on shoulder.

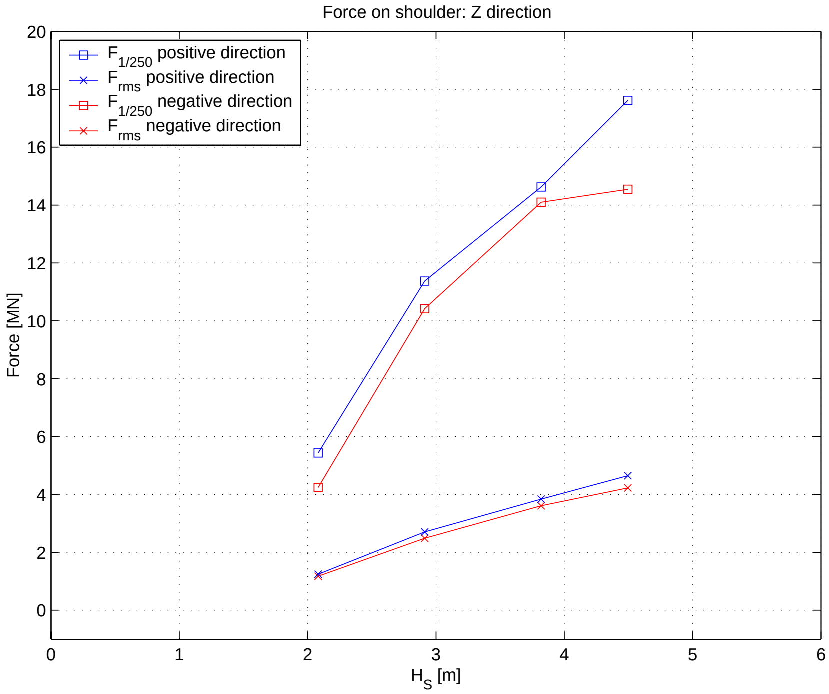


Figure H.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

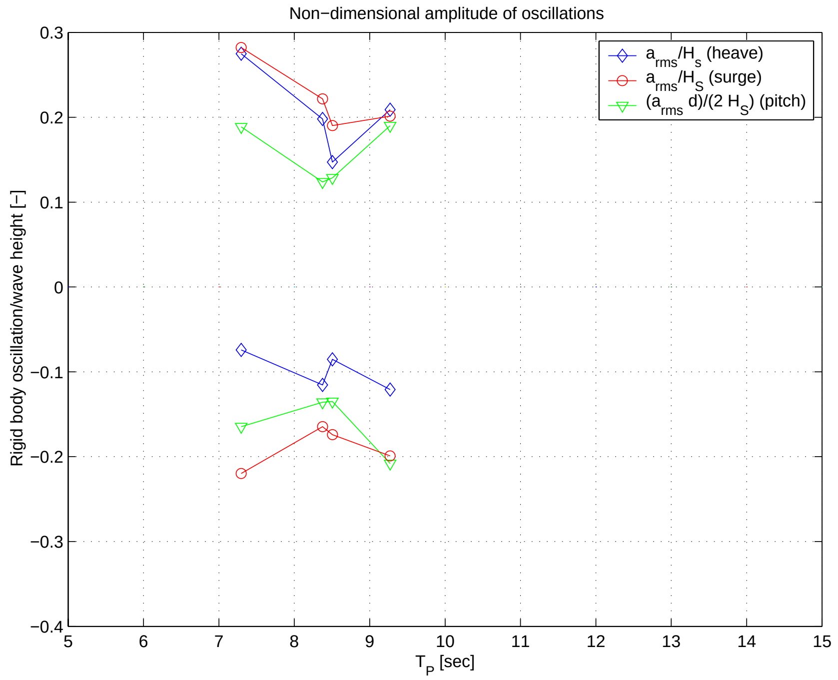


Figure H.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

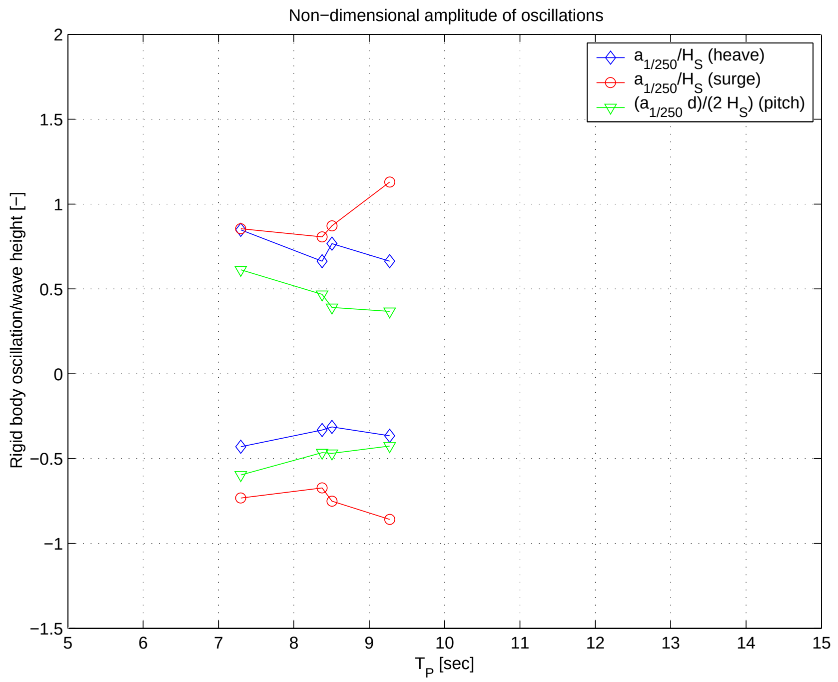


Figure H.8. Non-dimensional overtopping.

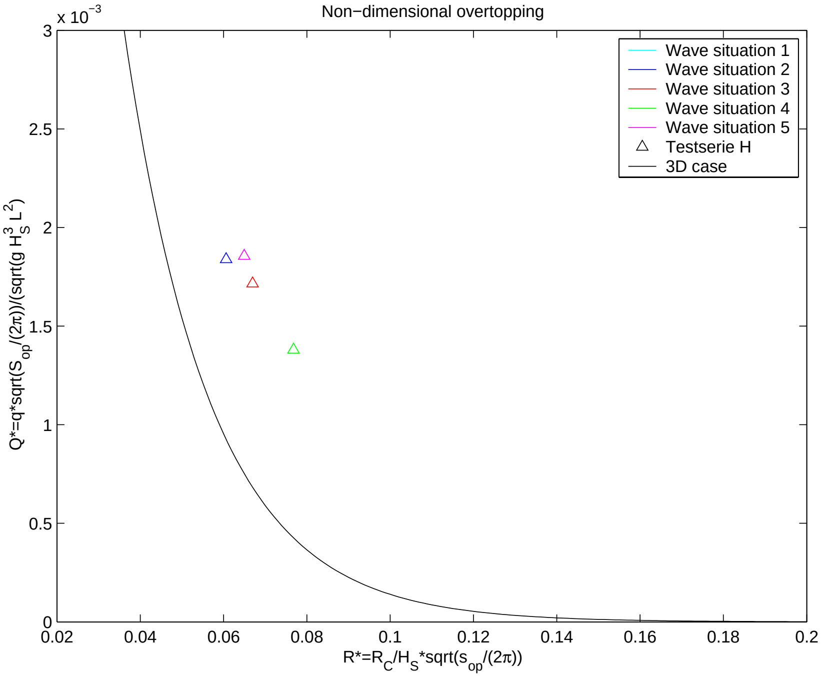


Figure H.9. Overtopping.

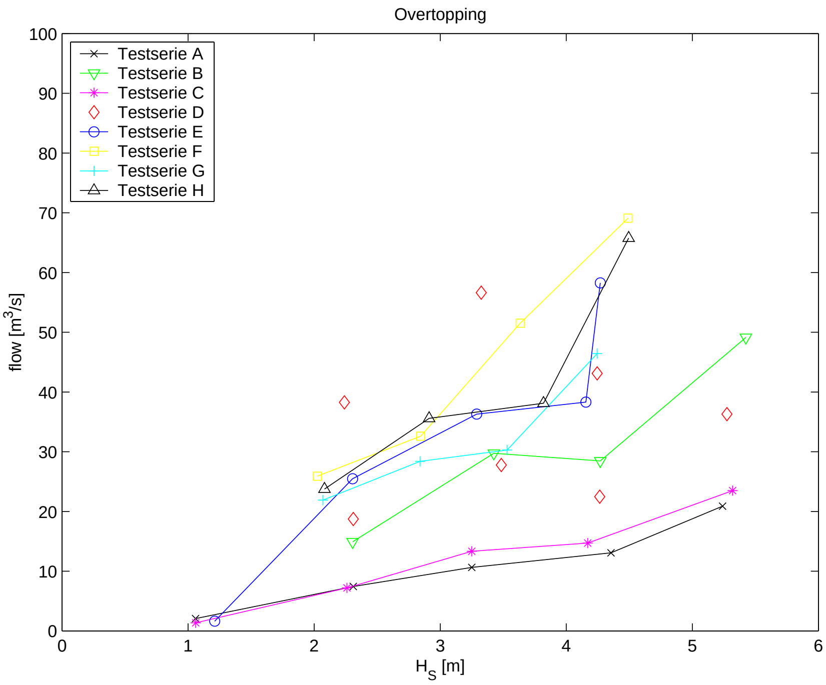


Figure H.10. Non-dimensional overtopping. All tests.

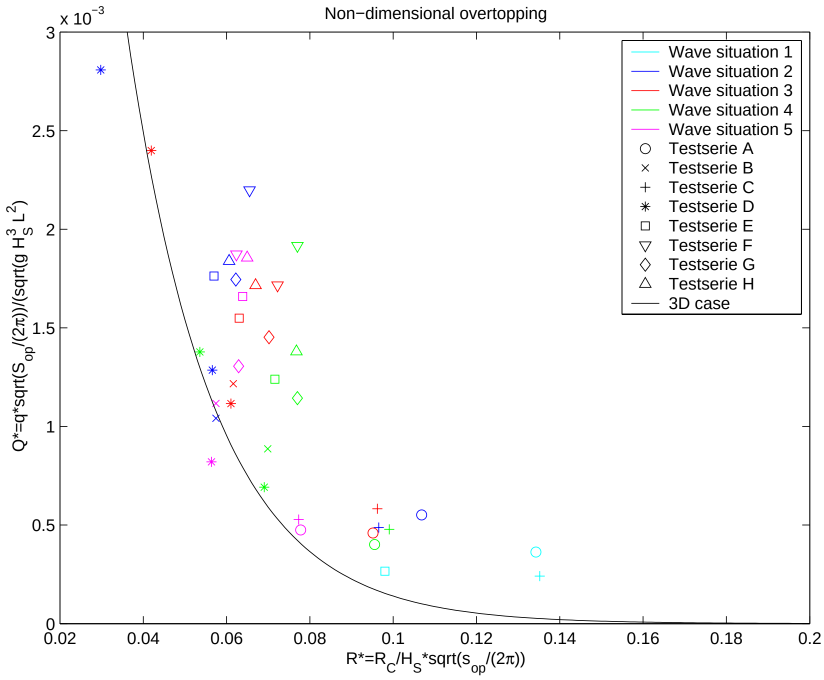
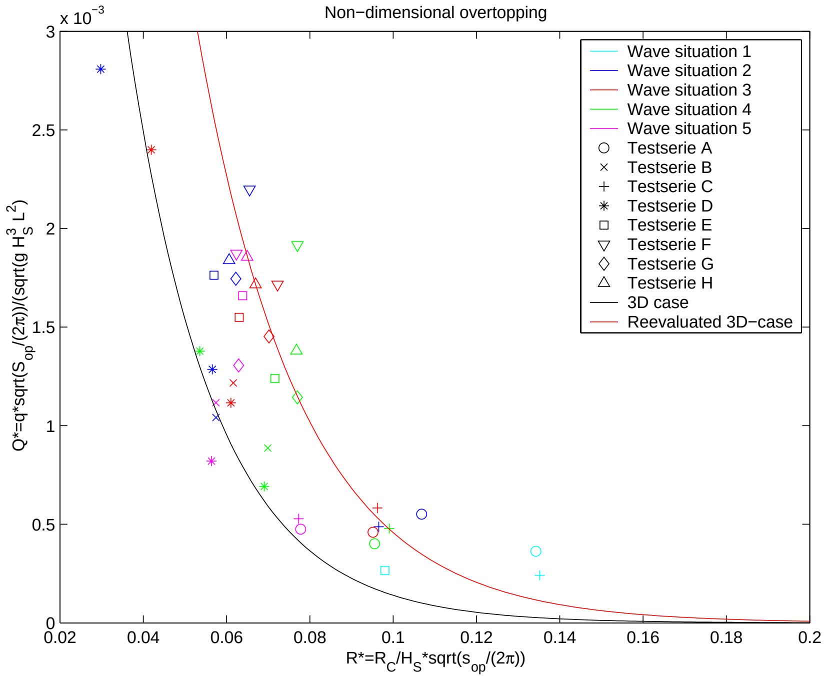


Figure H.11. Non-dimensional overtopping. All tests and reevaluated overtopping eq.



Testseries I

Effect of increasing height of guiding walls on ramp by +2 m
and adding ballst

Figure I.1. Mooring force.

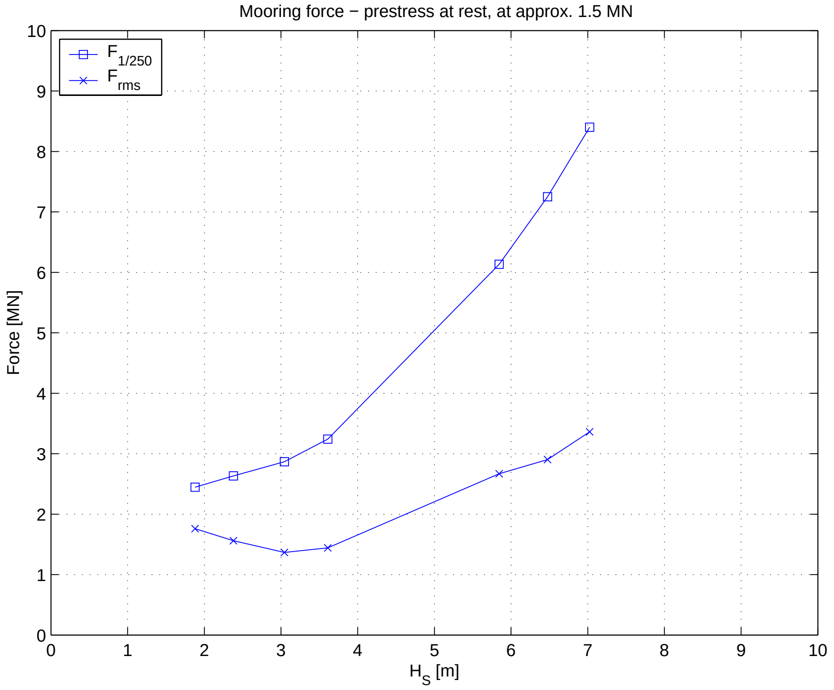


Figure I.3. Shear force X on shoulder.

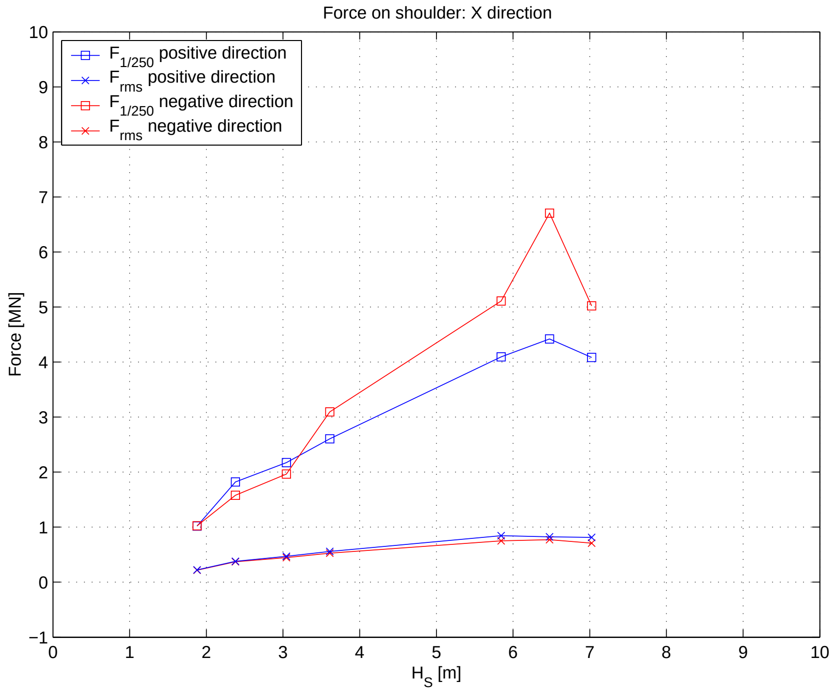


Figure I.4. Axial force Y on shoulder

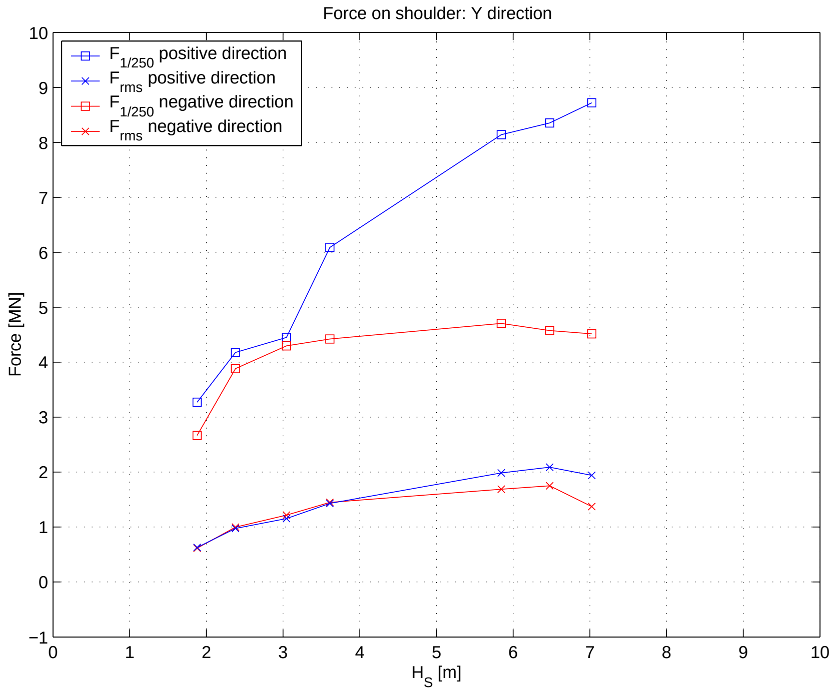


Figure I.5. Vertical force Z on shoulder.

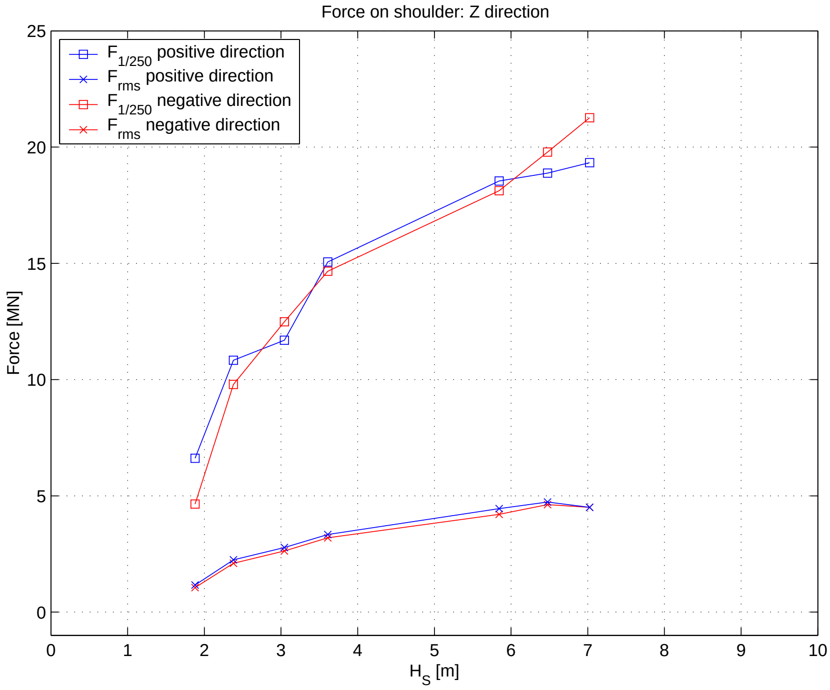


Figure I.6. Non-dimensional positive and negative rms amplitudes of heave, surge and pitch motions.

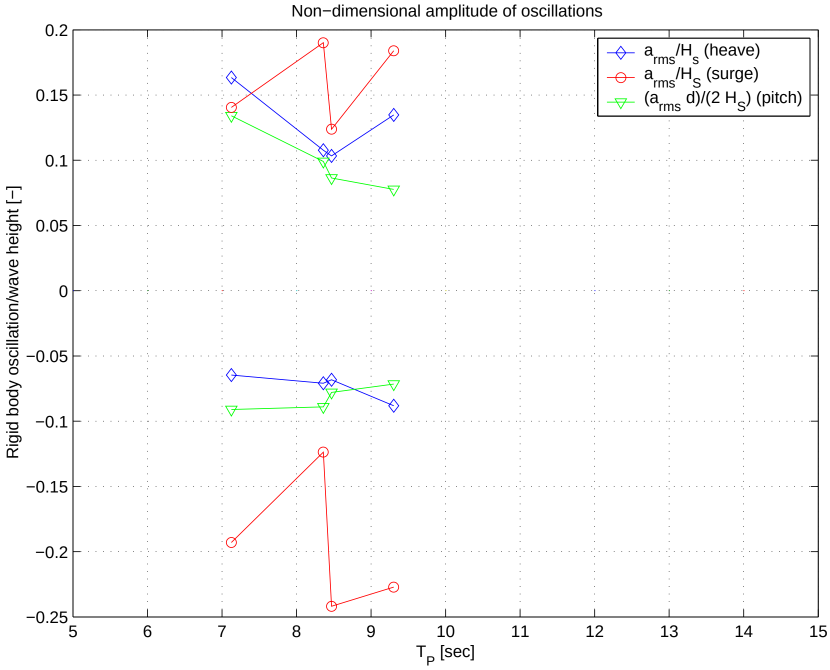


Figure I.7. Non-dimensional positive and negative peak amplitudes of heave, surge and pitch motions.

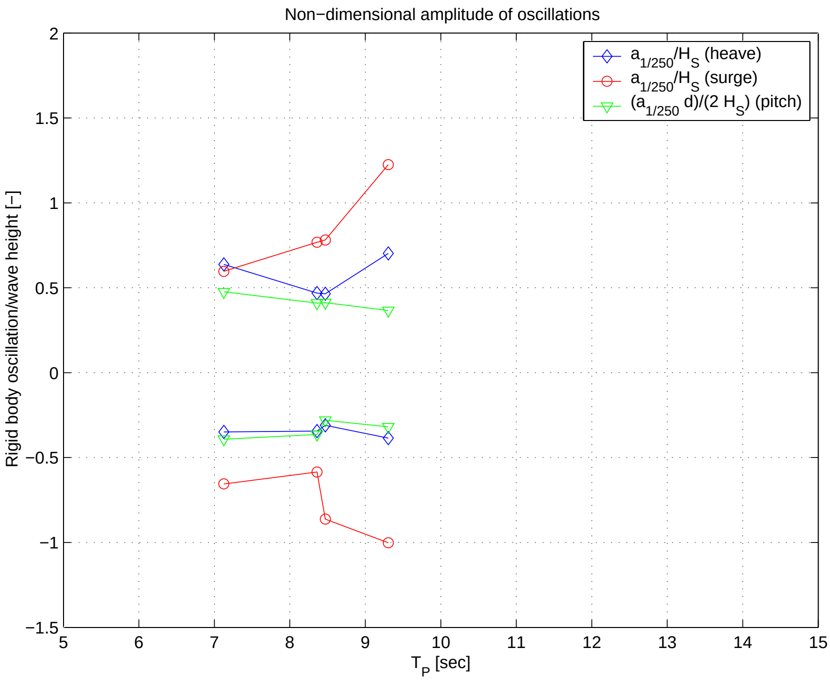


Figure I.8. Non-dimensional overtopping.

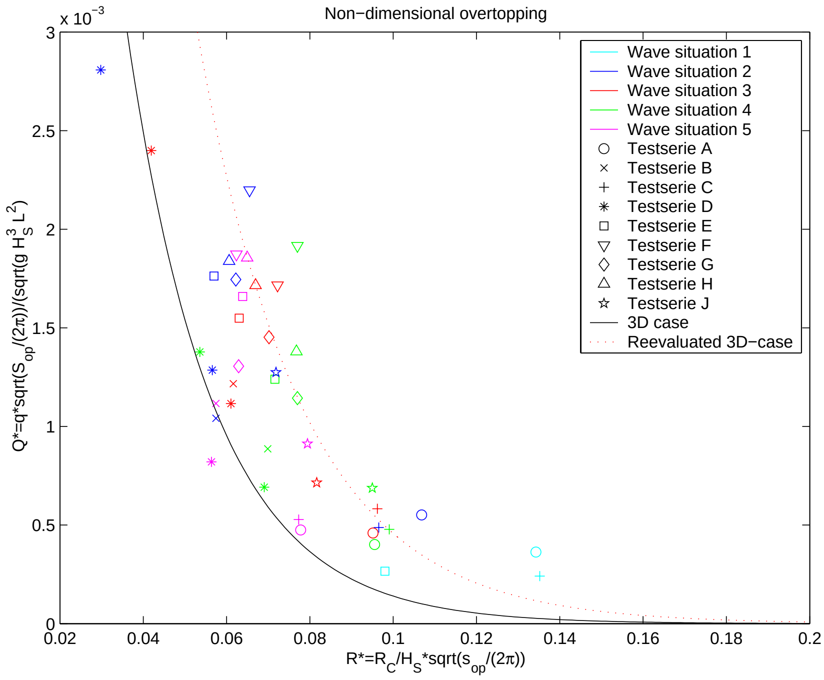
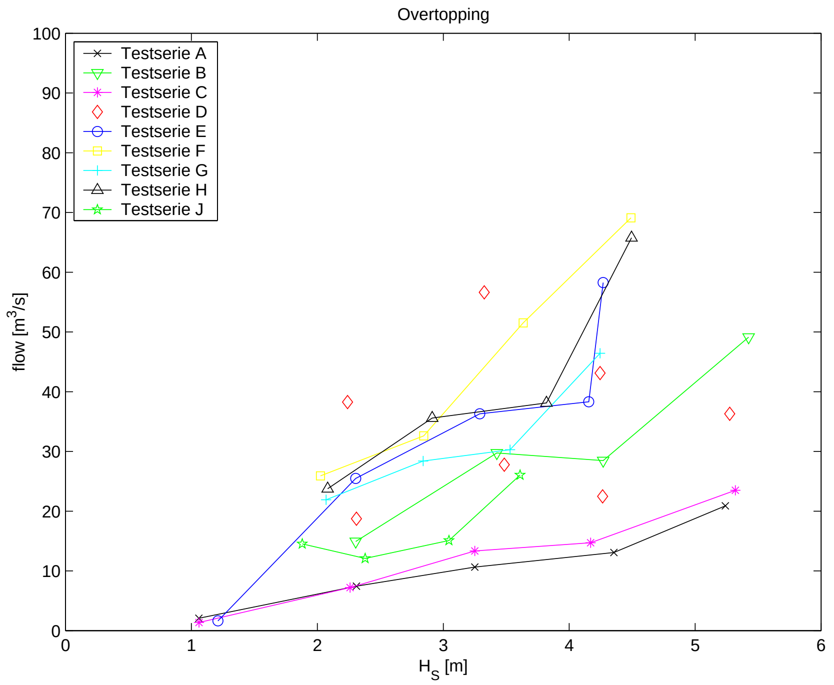


Figure I.9. Overtopping.



Testseries J

Effect of fixing reflector arms to shoulders

Figure J.1. Mooring force.

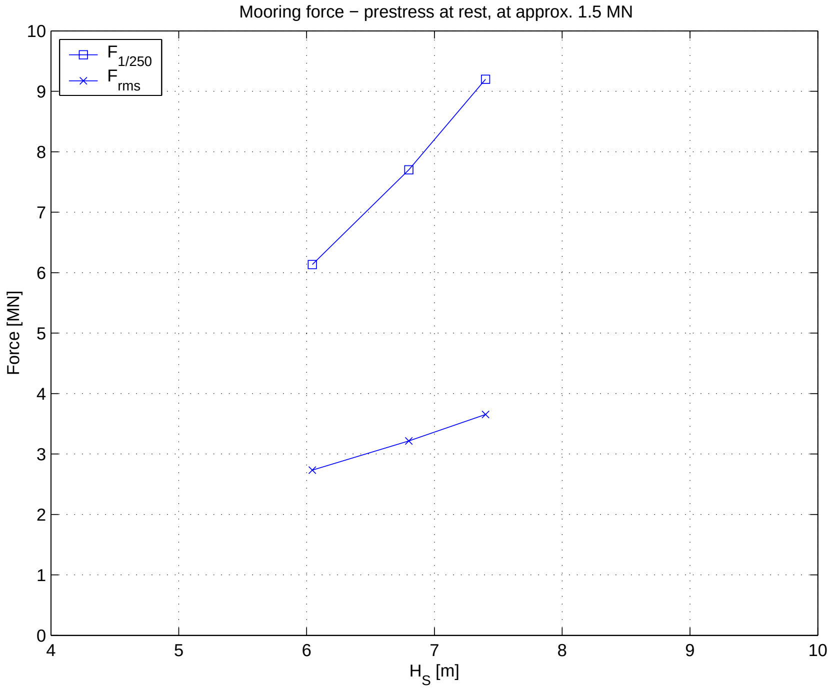


Figure J.3. Shear force X on shoulder.

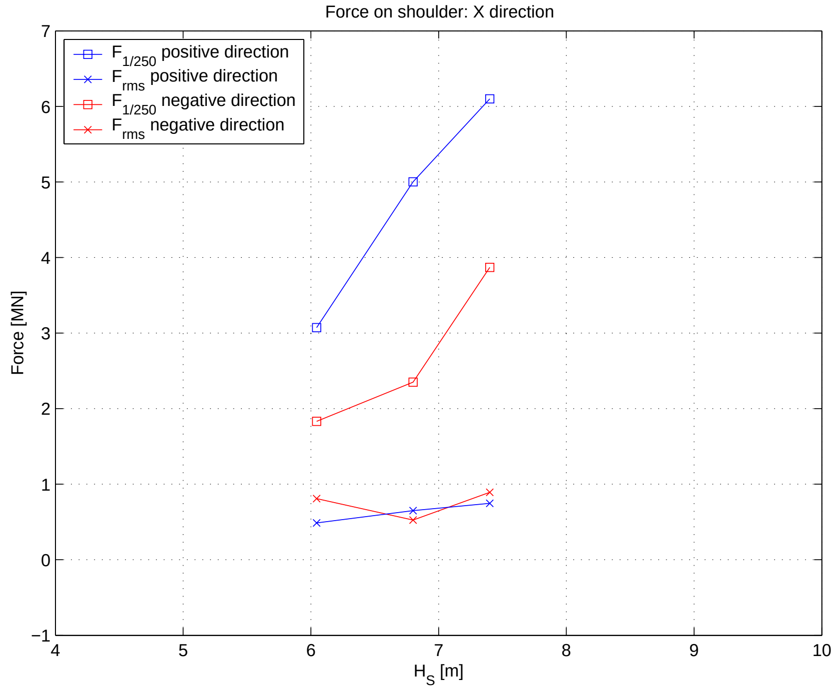


Figure J.4. Axial force Y on shoulder

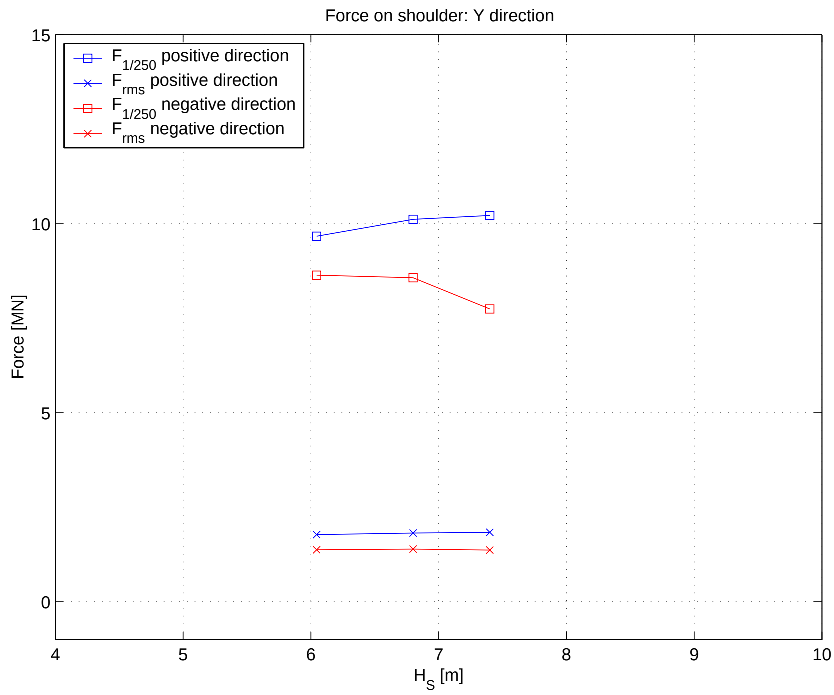


Figure J.5. Vertical force Z on shoulder.