Title: # Feasibility study of a floating system for extraction of wave energy	**Delivered:** 27.06.2011 **Availability:** PDF file at department
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Abstract:

In the foreseeable future our world will be in dire need of more sustainable energy sources than the current fossil-based energy regime.

This thesis proposes a novel idea toconvert ocean wave energy to electric energy. The principle is an enclosed barge-like floating device with an internal fluid volume. The device, being moored offshore, is excited by ocean waves which in turn excite the internal fluid, forming internal waves in a sloshing motion. This motion together with internal ramps at each end, force the fluid upwards where some of it overtops the ramp. The fluid, now being at a higher level than the internal mean waterline, is led through a low-head hydro-power turbine, utilizing the height difference to produce electric energy, which in turn can be exported to shore in cables. The concept benefits from its simplicity and reliability, the only moving part is the turbine which in turn require little maintenance. Only one mooring point is required and installation at site is as simple as towing out and hooking up the mooring and cables.

Keyword:

Wave energy conversion,
Sloshing, Overtopping

Advisor:

Professor Sverre Steen

Preface

The project 'Feasibility study of a floating system for extraction of wave energy' was carried out during springtime of 2011 at Department of Marine Technology, Norwegian University of Science and Technology (NTNU) in Trondheim, Norway.

The author especially wish to thank Professor Sverre Steen for taking on this project as an advisor and for his highly valued inputs and opinions.

Also great thanks to Professor Odd M. Faltinsen for valuable thoughts on the concept and sloshing.

Thanks to staff engineer Torgeir Wahl for help during model testing at MCLab.

Oslo/Trondheim June 2011

Christian F. Grøner

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1 Scope

Feasibility study of a floating system for extraction of wave energy

To cover the increasing demand for energy, renewable energy from the oceans is an attractive option. Harnessing energy from the ocean waves is in many ways tempting; as the waves contain a lot of energy, and that energy is available close to the shorelines. However, developing robust, effective, and cost-effective devices have been found to be a great challenge.

For this project, the student has proposed a novel floating device, which contains a volume of water which the motions of the device will make to slosh up into higher chambers inside the device. A simple low-pressure water turbine can then be made to provide energy when the water is flowing back down to the “sump” of the device.

The objective of the Msc. thesis is to investigate if a system as outlined above is feasible, and if it seems to be an attractive concept – if it has the potential to produce power at a lower cost and/or with better reliability than other known concepts.

2 Summary

The idea of harnessing energy from the ocean waves is a seductive one, a limitless resource. But the road from idea to success is long and has been traveled by many, the great achievements are few and far between.

This thesis proposes a novel idea to convert ocean wave energy to electric energy. The principle is an enclosed barge-like floating device with an internal fluid volume. The device, being moored offshore, is excited by ocean waves which in turn excite the internal fluid, forming internal waves in a sloshing motion. This motion together with internal ramps at each end, force the fluid upwards where some of it overtops the ramp. The fluid, now being at a higher level than the internal mean waterline, is led through a low-head hydro-power turbine, utilizing the height difference to produce electric energy, which in turn can be exported to shore in cables. The concept benefits from its simplicity and reliability, the only moving part is the turbine which in turn require little maintenance. Only one mooring point is required and installation at site is as simple as towing out and hooking up the mooring and cables.

A numerical model was set up on the basis of ocean wave data at a position offshore west of the Norwegian shore. The results showed promise of an increase in the tanks free surface elevations at the end of the ramps, an increase which was a small magnitude larger than the incoming waves for a wide band of wave periods.

A model was built based on the geometrical model used in the numerical testing. Model testing was performed in a wave basin to provide the physical data needed to get information of the non-linear sloshing this concept relies on.

Results turned out to be dubious, but some few test data showed promise of the idea being interesting. There is an obvious need for more testing, with greater accuracy in both the numerical models and the physical test models.

3 Proposed concept for wave energy conversion

3.1 The concept

**tekst fra prosjektet, blant annet?
**inkludere et avsnitt om patentsøk
The proposed device is of a barge-like construction, floating in the ocean at its waterline as shown in figure 3.1, initially discussed in the authors project thesis (Grøner, 2010). From the front end exposed to the incoming waves, the device will be slack-moored to the seafloor, leaving it free to rotate after the waves so the front end always faces the incoming waves, though strong winds from a different direction than the waves may shift the heading of the vessel a bit. Inside the device is an internal volume of water that will assume a sloshing motion, primarily from the pitch and surge motions of the device in incoming ocean waves.

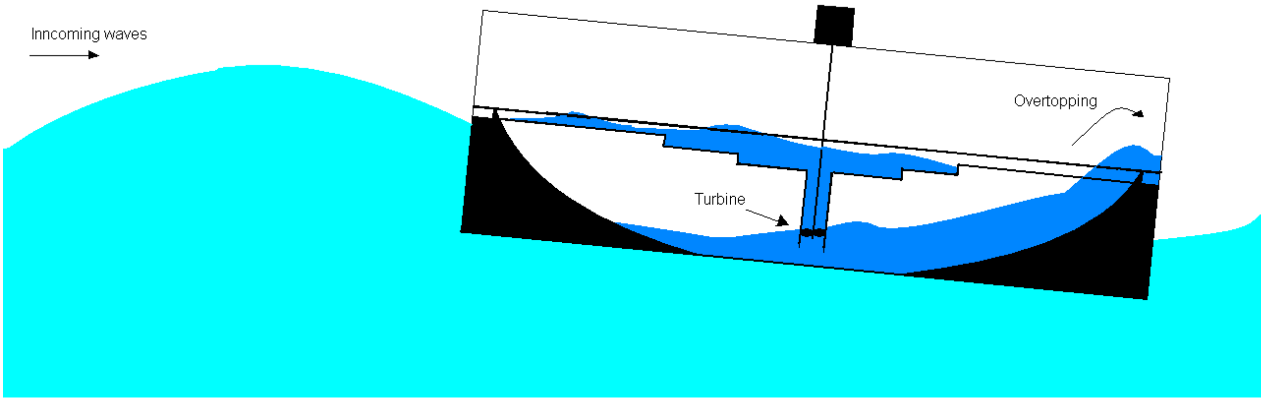

Figure 3.1 : Schematics of flows in proposed device

Inside the device there are ramps, drains and an upper basin as seen on figure 3.2. The sloshing motion of the internal water, is in the longitudinal direction of the device, and brings the water to overtop the ramps successively at each end.

When overtopping the ramps, water enters the drains that lead to the upper basin. A conventional low-head hydro-power turbine is situated in the shaft that leads water down from the upper basin to the main chamber of the device. The turbine is connected to an electrical generator on the top deck of the device. Electricity produced by the generator is sent to the land grid through cables down the mooring line and along the seafloor to shore. It is also possible to utilize electricity at site in a hydrogen gas production plant, if the site is too far offshore to economically lay electrical cables to land.

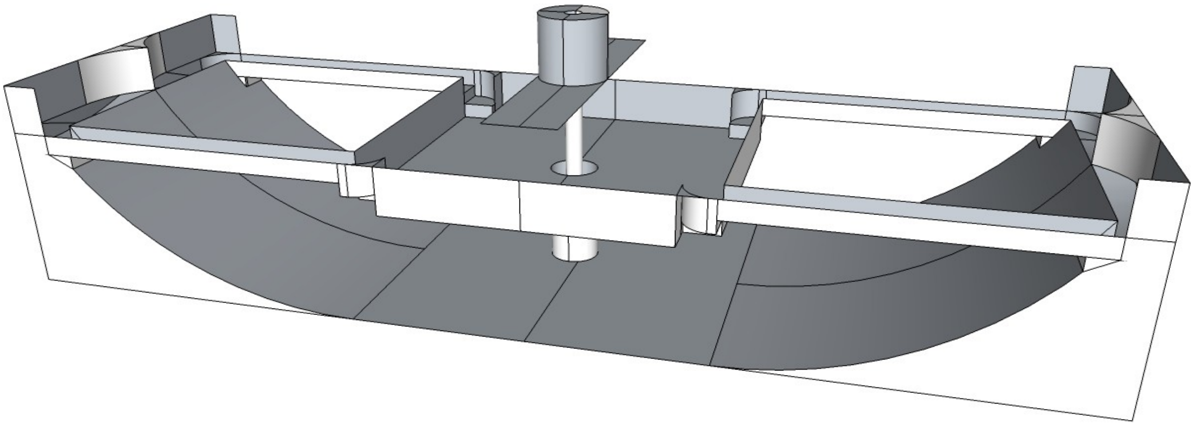

Figure 3.2 : Principle of internal arrangement of proposed device

3.2 Sloshing

Sloshing is a resonant free-surface flow in an enclosed space, partially filled with liquid. Most of the research in the area of sloshing has been done in relation to tanks aboard moving vessels. For ships this usually concerns ship motions in roll and sway, with internal rectangular tanks placed in traverse. This is partially transferable to the proposed designs motions in pitch and surge, since the design of the device is essentially a rectangular tank. The reason for the device to be rectangular is to keep the sloshing motion as two-dimensional as possible, avoiding internal cross-flow. This is initially to simplify the investigation into the concept of sloshing motion in energy harvesting. In vertically axisymmetric and square-base tanks, swirling wave motion may occur when the fluid is subjected to horizontal harmonic excitation of frequencies close to the lowest natural frequency (Faltinsen and Tymocha, 2009).

Sloshing occurs in all geometric tank shapes and a point to investigate further is whether a circular tank shape with a continuous ramp 360 degrees around might be a more effective design. A circular design would certainly provide a larger capture breadth per volume. It could exploit energy for different wave headings without turning, thus the mooring attachment could be centrally placed to further reduce mooring damping of the device in pitch and surge.

3.3 Potential

To say anything about the potential energy output of the device at this stage, one would have to look at other devices with resembling power take-off systems, like the Wave Dragon. This device is designed to operate at a little above 20% efficiency in relation to wave energy density (WaveDragon, 2005).
Wave climate in the southern part of the Norwegian sea, level with Stadt, has a yearly averaged wave energy potential of about 50 kWh/crest-meter (WEC, 2010).
If we assume 15 meters as the breadth of the device, the energy output could be in the vicinity of: 50 kWh/m • 15 m • 20 % • 8760 h/year = 1,3 GWh/year per device.
This energy output value can only be used for indicative purposes, although the overtopping principle of the Wave Dragon is similar to that of the proposed device, the overtopping flow of the device is difficult to determine at this stage.

3.3.1 Conversion technology

One of the benefits of the proposed design is the use of ordinary low-head hydro-power turbines for electricity production. These have a well proven longevity of service life, need little maintenance and there exist well developed designs for vast ranges of use. For the range of the proposed device there are two turbine types that single out as fitting alternatives.

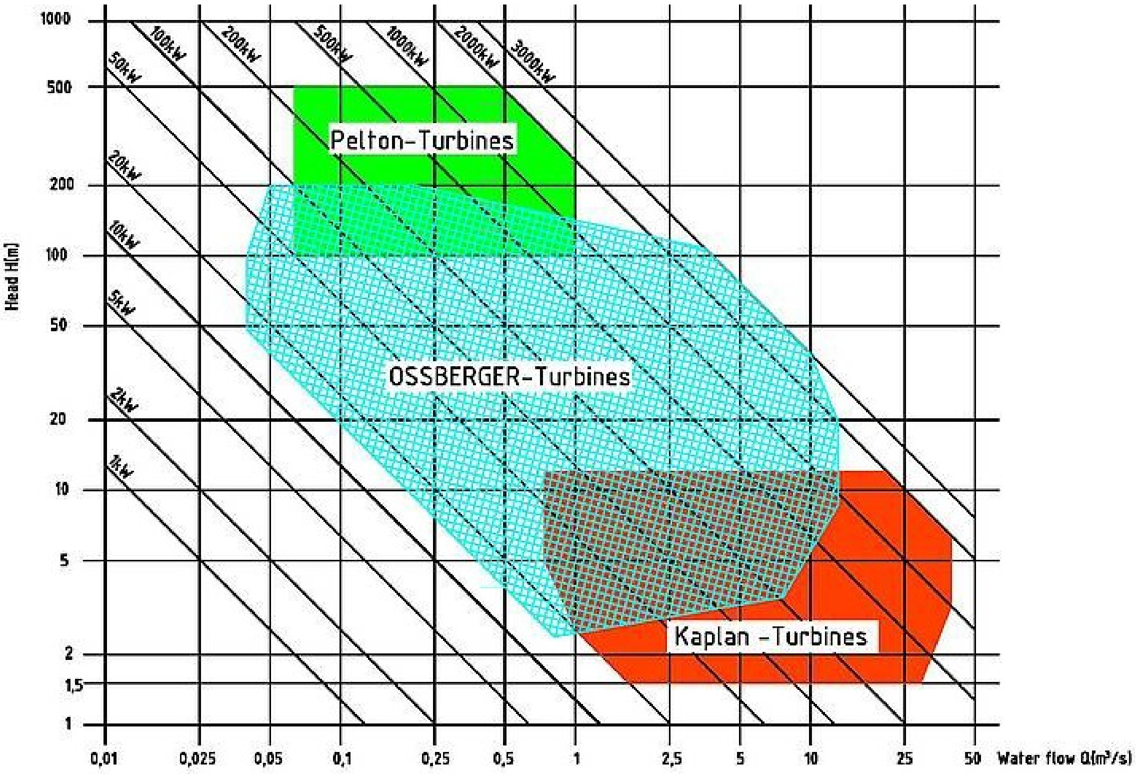

Figure 3.3 : Range of use of common turbine types (Ossberger, 2010)

Determining turbine type is mainly done by the two parameters head and flow.
As can be seen on figure 3.3 the Ossberger cross-flow turbines and Kaplan turbines fall into the low-head category.

There is also a question as to the rotational speed area of the turbine. The Ossbergers low specific speed makes for a larger turbine unit and the need of a gearbox to drive a generator efficiently. Due to the principle of the Ossberger it also has a 'lost head' of one turbine diameter (Cruz, 2008), and keeping as much head as possible is most important with the low heads in question. The Ossberger has an effective system of adapting the turbine to different flows by shielding off parts of the cross-flow turbine, the Kaplan turbine can also be implemented to cope with differences in flow by fitting it with adjustable guide vanes and runner blades.

4 Numerical model

To investigate how the proposed concept might work, a numerical model was set up as a forerunner to model testing. At this stage it was considered important to keep the design as simple as possible to make it easier to understand the working principle. Simplicity is also key to the concept, so the barge-like shape was kept, with some changes to the bow and stern, as it was meant to be the basis for model testing.

Due to the non-linear nature of sloshing, an exact numerical model would have to involve computational fluid dynamics to model the internal volume with coupling to the hull movements. This was considered to be too complex and labor-intensive as the means for investigating the concept at this still early stage. In discussions with Professor Odd M. Faltinsen it was therefore deemed that a linear method would be sufficient to determine the first sloshing modes as a basis for further investigation.

Carving out the dimensions proved to be quite a juggle between parameters. Several iterative rounds were performed to get the right compromise between performance in waves, structural weight, internal volume, internal free surface elevation and others.

Since the device needs to be designed and tuned according to the wave climate where it is placed, a location offshore off the west-coast of Norway was chosen. This area has several offshore oil-platforms which have had wave-monitoring equipment installed for many years, being a good source for wave-data. The 'eKlima' portal online (MET, 2011) give access to the climate database of the Norwegian Meteorological Institute, which include wave-data from platforms. The Troll A platform was chosen for its extensive records.

The Troll A total frequency distribution of wave height and period for the most recent eight years (with 84% data coverage) is included in appendix 9.2 and show an average wave height of 2,5m and average wave period of 9,3s (standard deviation 1,4 and 2,5 respectively).

At this stage it was believed that maximizing the pitch motion of the vessel would be the most effective way to trigger sloshing behavior.

As seen on figure 4.1 a large portion of the waves have periods at 7,1s – 8,0s, a great deal below the average 9,3s. To be sure that the vessel would pick up on the shorter periods, the waterline was chosen to be about half a wavelength of a 7,5s wave (λ~88m). And the bow and stern were given a 45 degree angle to smooth out the vessels wave response.

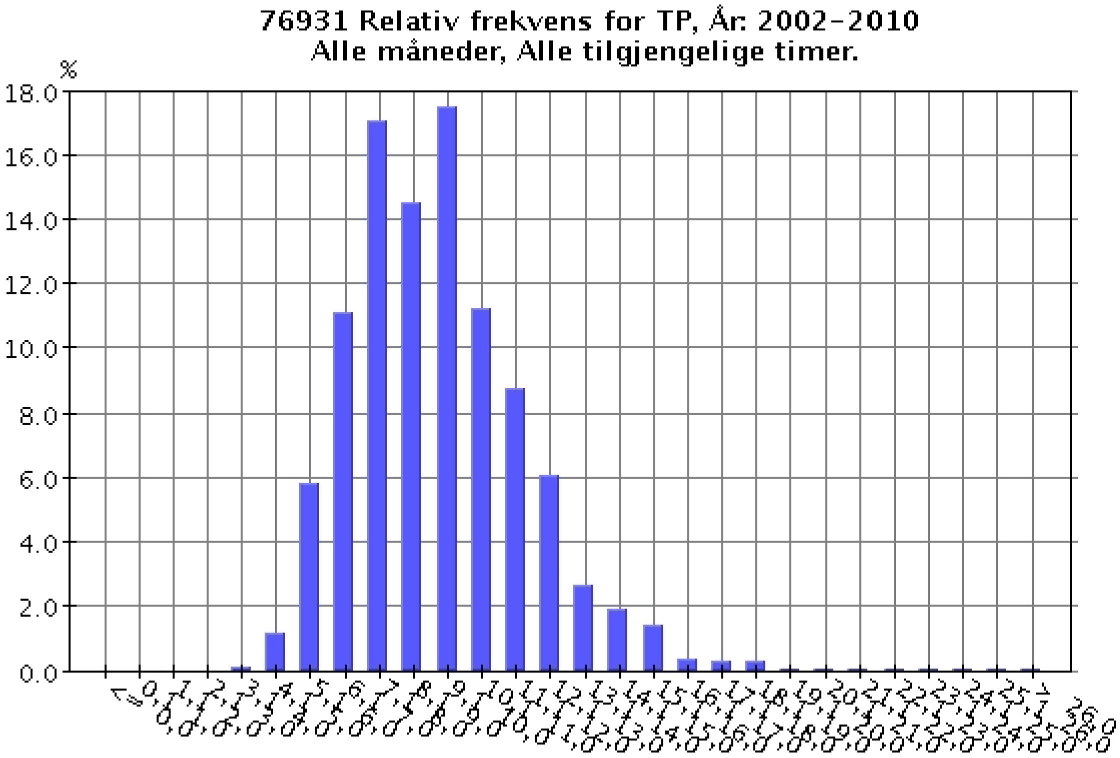

Figure 4.1 : Troll A, accumulated relative wave periods, year 2002-2010 (MET, 2011)

The depth-to-breadth ratio of a tank indicate the sloshing behavior of fluid in the tank (Faltinsen and Tymocha, 2009) and this was used for initial dimensioning of the tanks of the vessel.

A formula, based on linear potential theory, for the highest natural sloshing period for rectangular tanks is shown in (Faltinsen and Tymocha, 2009), the formula is shown below in F 4.1 and further exemplified in figure 4.2:

$$T_1 = \frac{2\pi}{g\pi\tanh\left(\frac{\pi h}{l}\right)/l}$$

F 4.1

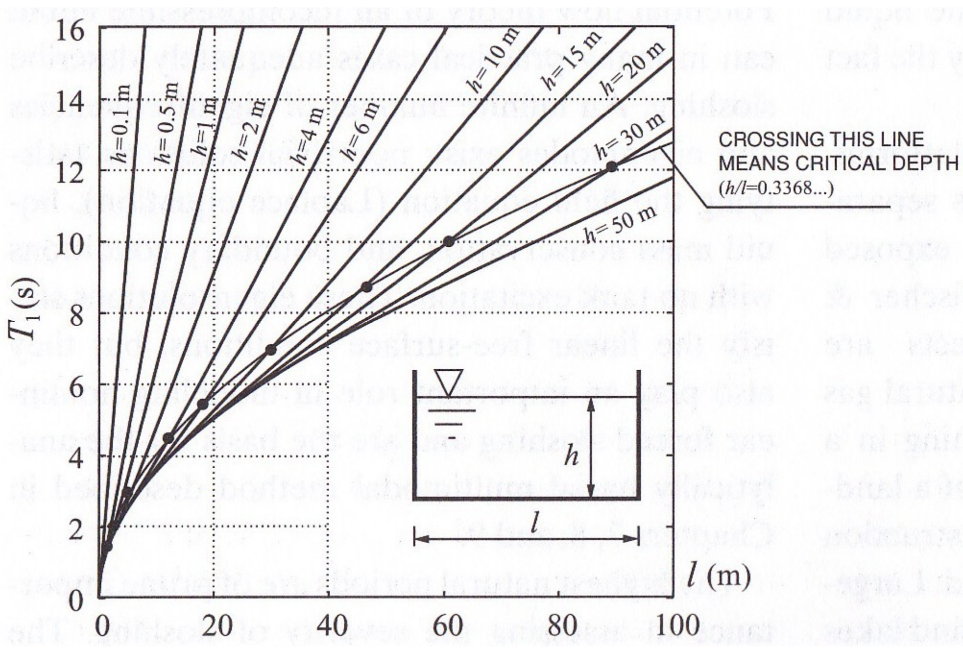

Figure 4.2 First-mode natural sloshing period for a two-dimensional rectangular tank vs. the tank breadth. The critical depth-to-breadth ratio is also indicated (Faltinsen and Tymocha, 2009)

In appendix 9.1 this is expanded and detailed to include an inner tank length of around 40 meters, which at around eight meters tank depth produce a first-mode natural sloshing period, for the fluid in the tank, between nine and ten seconds, right at the sweet-spot of the average wave period.

4.1 Geometrical model

The geometrical model for the analysis was drawn out in the CAD and marine design program Multisurf 7 from AeroHydro Inc. (aerohydro.com), because of its ability to produce geometry that can be directly interpreted (Lee et al., 2002) by the wave interaction analysis program WAMIT from WAMIT Inc. (wamit.com)

The Multisurf program is based on relational geometry and enables users to interactively define geometric surfaces accurately, the surfaces are in turn divided or collected in parametric patches according to the smoothness and continuance of the surfaces, and the patches then joined robustly by different techniques (Lee et al., 2002).

None of the chutes or drains were included in the numerical geometrical model as this would have added to much uncertainty and complexity. Water, from overtopping, flowing through the chutes and drains would also be sloshing back and forth and would probably have an effect on the vessel motions, but the amount of water and the position of the larger volumes
**bilde av modell I multisurf

4.2 Analysis

The numerical analysis was performed in WAMIT because of its ability to compute coupled motions between a hull in waves and free surfaces in internal tanks (Newman, 2005)

5 Model testing

To further investigate the behavior of the vessel in waves and the wave run-up over the ramps and to verify the numerical model, there was a need to perform model testing. The model was built on the basis of the numerical model geometrical shape 'civpi8h' mentioned previously **se til bilde og app.

The data to be obtained from the model testing was:

- position tracking to produce Response Amplitude Operators (RAO)
- internal wave run-up on the ramps
- water-flow from possible overtopping over the ramps
- general behavior of the vessel in waves

5.1 The model

Scaling the model was a compromise between wanting it as large as possible for observations and keeping it small enough to minimize the impact of wave reflections from the walls of the wave-basin, there was also a need to keep it small enough to be manageable to build. In discussions with Professor Sverre Steen it was decided that a width of about half a meter would be suitable. This resulted in a scale of 1:36. Scaling was done according to scaling laws in (Aarsnes, 2008).

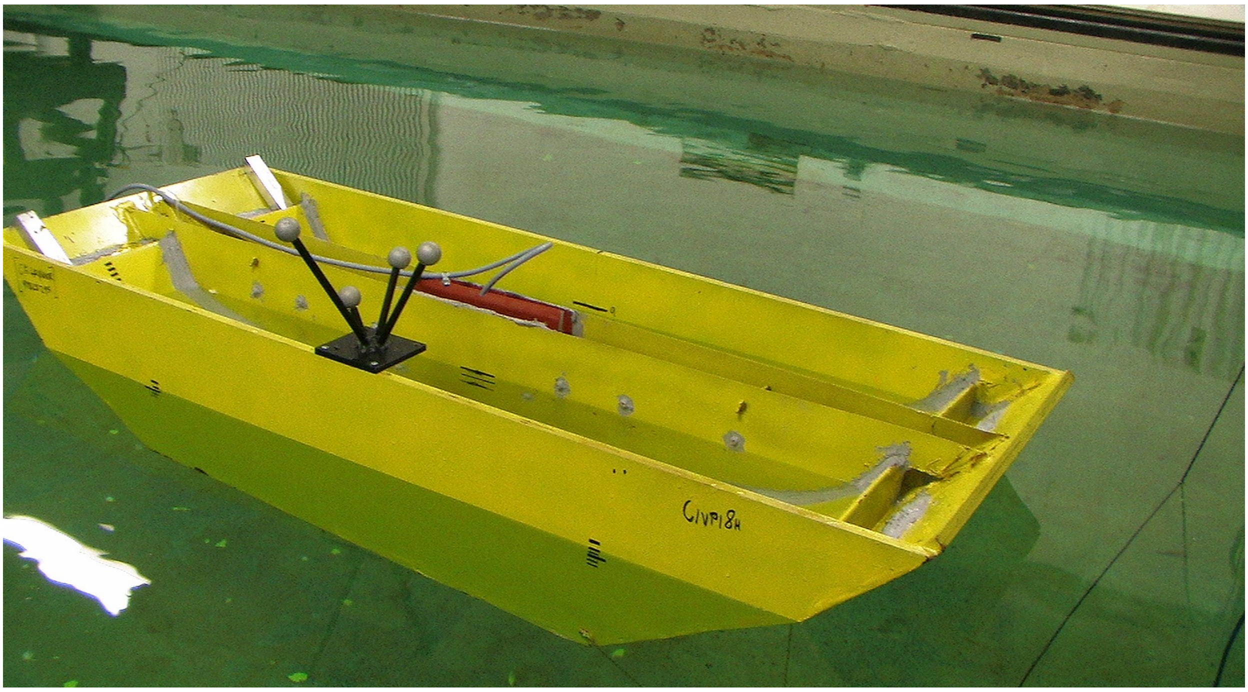

Figure 5.1 : Model in the basin, about 9m water filling

The model was built by the author, in a temporary workshop in the authors cellar storeroom, for lack of better facilities. This meant that although the model was built to the highest possible accuracy according to the geometrical model, under the circumstances it was not possible to make it completely exact. The main outer and inner dimensions are relatively precise, but it proved to be difficult to make the curvature of the ramps as uniform as wanted. It was also quite difficult to get the inner tanks, chutes and drains completely watertight, mainly because the large amount of water in the tanks tended to press the ramps a bit out of position causing the seals to split slightly, letting water into the structure. This was remedied by filling the cavities between the ramp substructures, under the ramps, with expanding foam insulation which added to the support of the ramps. All this also meant that the structures weight distribution did not end up as uniform as wanted, but the main faults in weight distribution would still be from the not quite uniform distribution of water in the tanks due to slightly skewed ramp curvature.

The hull of the model and substructures for the ramps was built up using 15mm foliated plywood sheets cut to shape, and joined with screws and waterproof jointing paste. All inner walls, ramps and chutes was made of 0,7 mm steel sheets cut to shape and joined by sheet-steel screws and more waterproof jointing paste. Sheet steel bending was done to produce chutes and overlapping ramp ends.

For visibility the model was coated in bright yellow. Several waterlines were marked in black for both inner and outer waterlines for visual confirmation. The run-up on the ramps was to be visually observed by digital video-camera so several run-up heights towards the top of the ramps were also marked in black.

Outer waterlines marked: 8 m (22 cm model scale), with grades both up and down.

Inner waterlines marked, with reference to full scale:

- 7 m (model scale 19,4 cm)
- 8 m design water filling (model scale 22 cm)
- 9 m (model scale 25 cm)

Run-up heights marked: 0 – 15 cm from top of the edge of the ramps. The angle of the ramps in the area of -15 cm to 0 is about 52 degrees.

Water-flow from possible overtopping was to be measured by two flow-meters, one for each internal tank. The flow-meters were mounted inline in drainpipes from the two center chutes, each pipe leading down to respective tanks. On figure 5.2 the area for the intake of the drainpipes can be seen as the red colored part of the middle of the chutes, the cable connecting the flow-meters to the totalizer/counter is exiting in between the two intakes.

Flow-meter set-up:

- Flow-meter: Gems Sensors FT-110 series 173940, flow range 2-30 l/min
- Totalizer: Kübler Codix 923 Electronic Preset Counter
- Armored cable connecting the flow-meters and the totalizer

The dry weight of the model was measured to a waterline of 8cm from the bottom, giving a weight of: 0,8dm * (7,5+0,8)dm * 6,1dm * 1,00kg/dm^3= 40,5 kg.

	Model 1:36	**Full size**
Overall length	1,50 m	54 m
Overall breadth and waterline breadth	0,61 m	22 m
Waterline length	1,19 m	43 m
Design draught (with 8m tank filling)	0,22 m	8 m
Tank inner waterline length	1,14 m	41 m
Tank breadth (one tank)	0,25 m	9 m
Tank design filling depth	0,22 m	8 m
Total tank volume at design filling depth	95 liters	4417 m^3
Submerged volume at design draught	132 liters	6160 m^3
Design dry weight	37 kg	1743 tonnes
Measured dry weight	40,5 kg	-

Table 1 : Model design dimensions

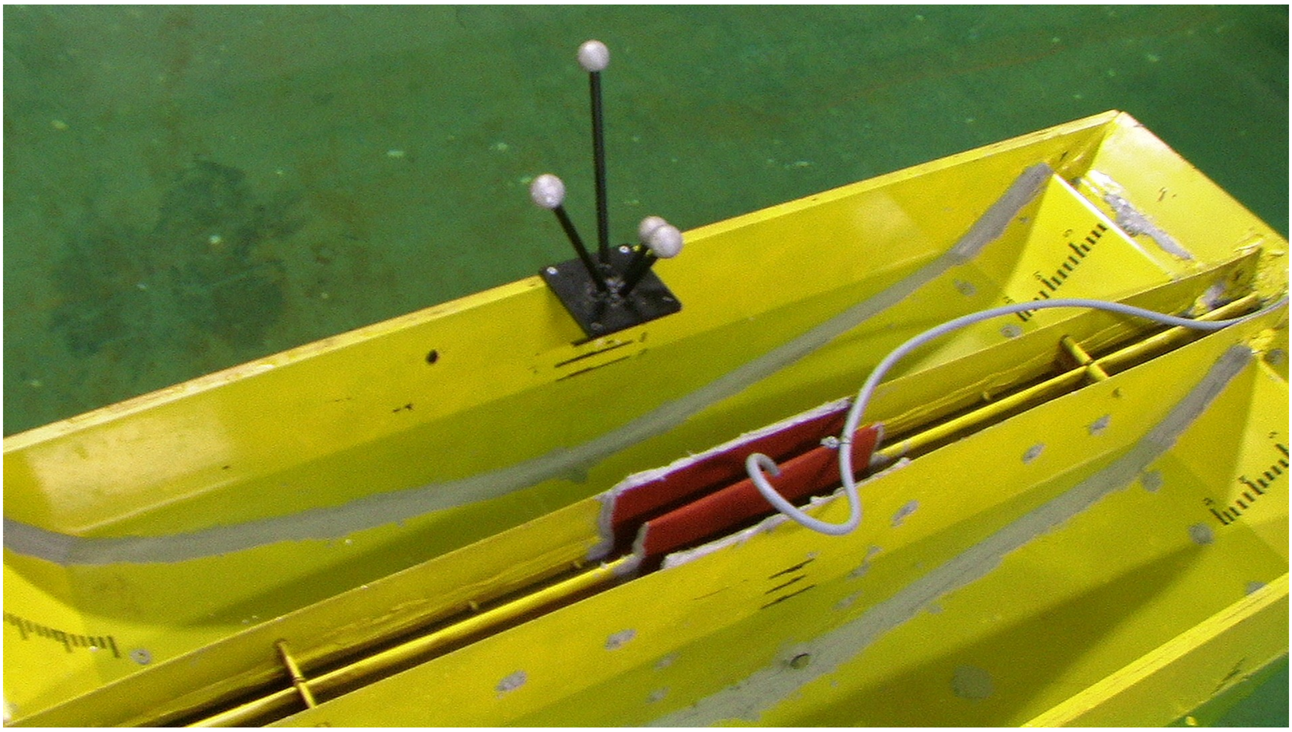

Figure 5.2 : Detail of the model, about 7m water filling

5.2 Test set-up

Model testing was performed in the Marine Cybernetics Laboratory (MCLab), a small wave basin operated by the Department of Marine Technology at NTNU.

Length	40 m
Breadth	6,45 m
Depth	1,5 m
Typical scaling ratios	I = 50 - 150
Typical ship model lengths	1-3 m

Table 2 : MCLab data (NTNU, 2011)

The lab is equipped with a real-time positioning system (NTNU, 2011) from Qualisys Motion Capture Systems AB (qualisys.com) and this was used to track the vessel under different wave conditions. Motion capture data was recorded with the Qualisys Track Manager software (QTM) which internally computes vessel motions in six degrees of freedom (6DOF), and this was later exported to Matlab files. The whole motion capture system had been calibrated by the lab staff.

A single paddle wave maker is installed in the basin, to generates waves computed by the wave synthesizer.

Paddle width	6 m
Active Wave Absorption Control System	AWACS 2
DHI Wave Synthesizer	Regular and irregular waves
Regular waves	H < 0.25, T = 0.3 – 3 s
Irregular waves	Hs < 0.15 m, T = 0.6 – 1.5 s
Stroke length on actuator	590 mm
Speed limit	1,2 m/s

Table 3 : Wave maker data (NTNU, 2011)

The model was moored to a single point, a heavy iron weight, on the basin bottom as can be seen in figure 15. A thin low-elastic string combined with a soft spring, made up the mooring line. The spring was used to smooth out the mooring forces and so mimic a longer slack mooring. Coming up to the model the mooring was attached to the model with a crowfoot, this was done to minimize the models tendency to oscillate from side to side, as was experienced in the pre-tests.

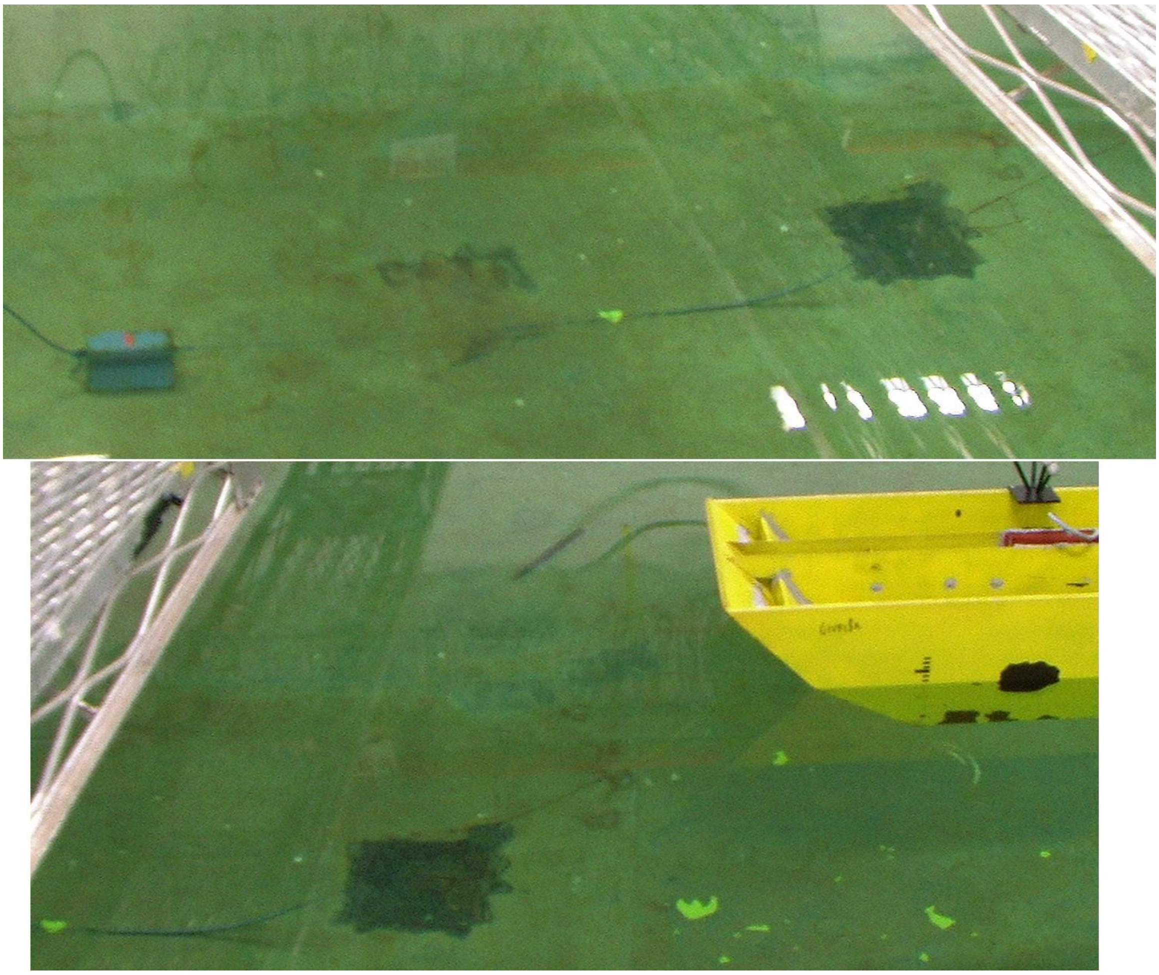

Figure 5.3 : First mooring arrangement

A second mooring arrangement was also tested. This was done to try to shift the vessel motion, reducing the pitch and increasing the surge. In this set-up the mooring line was considerably shorter and the line angle steeper as can be seen in figure 5.4. The line was also pre-tensioned, using the same soft spring as in the first mooring.

Figure 5.4 : Second mooring arrangement

6 Model test results and analysis

Some of the position data series captured with QTM were initially not complete enough to compute 6DOF data. To remedy this the 'bone length tolerance' was increased to 17mm for the QTM software to be able to compute corrupt series (Qualisys AB, 2010) . This could somewhat decrease the accuracy of those data series.

The pitch and heave test RAOs for the design tank filling depth of 8m seem to be relatively coherent with the numerical results, as seen on figure 6.1 and 6.3. The surge test RAOs on the other hand had a somewhat different progression than the numerical, for the lower wave periods. A reduction rather than the numerical results increase, as seen on figure 6.2.

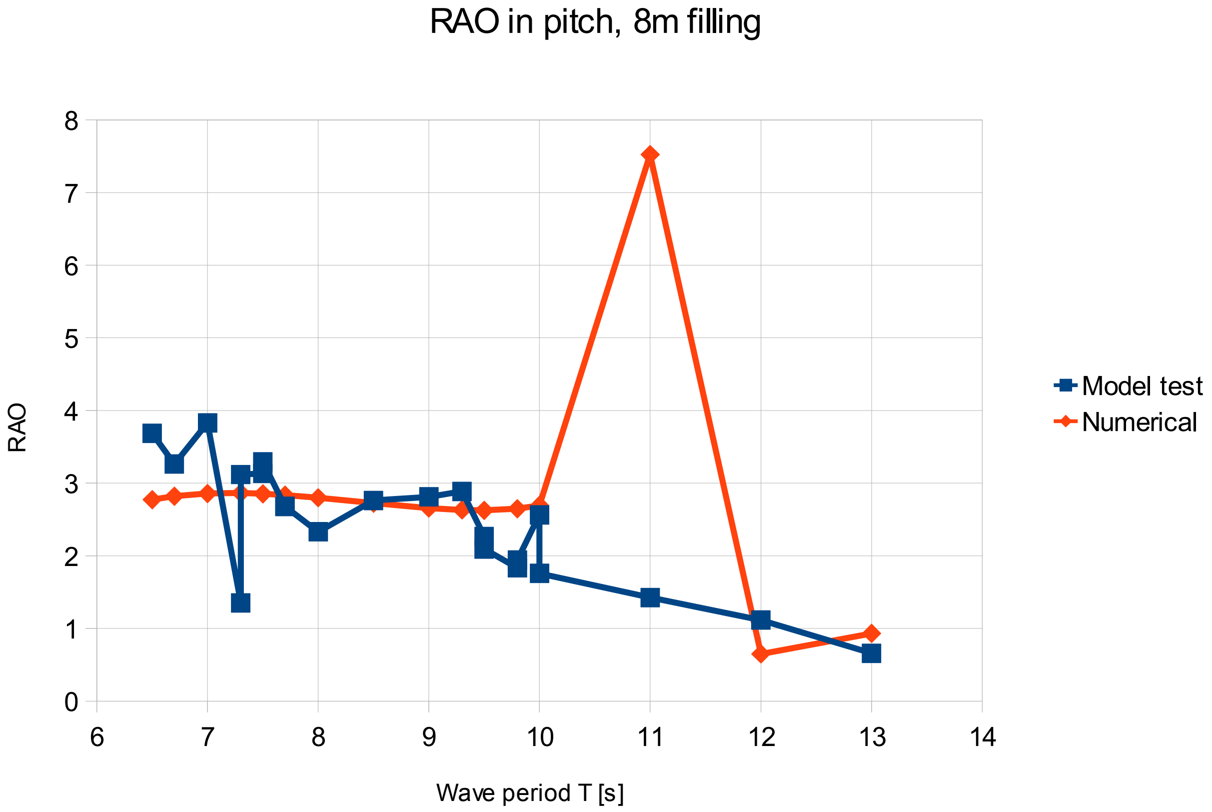

Figure 6.1 : RAO in pitch, 8m filling

Figure 6.2 : RAO in surge, 8m filling

Figure 6.3 : RAO in heave, 8m filling

Looking at the model test RAOs for tank filling of 7m, show much of the same results as for 8m filling, figure 6.4 and 6.5. But a much clearer picture of a peak at periods around 7 seconds, somewhat corresponding with the peak in free surface elevation seen on figure 6.7.

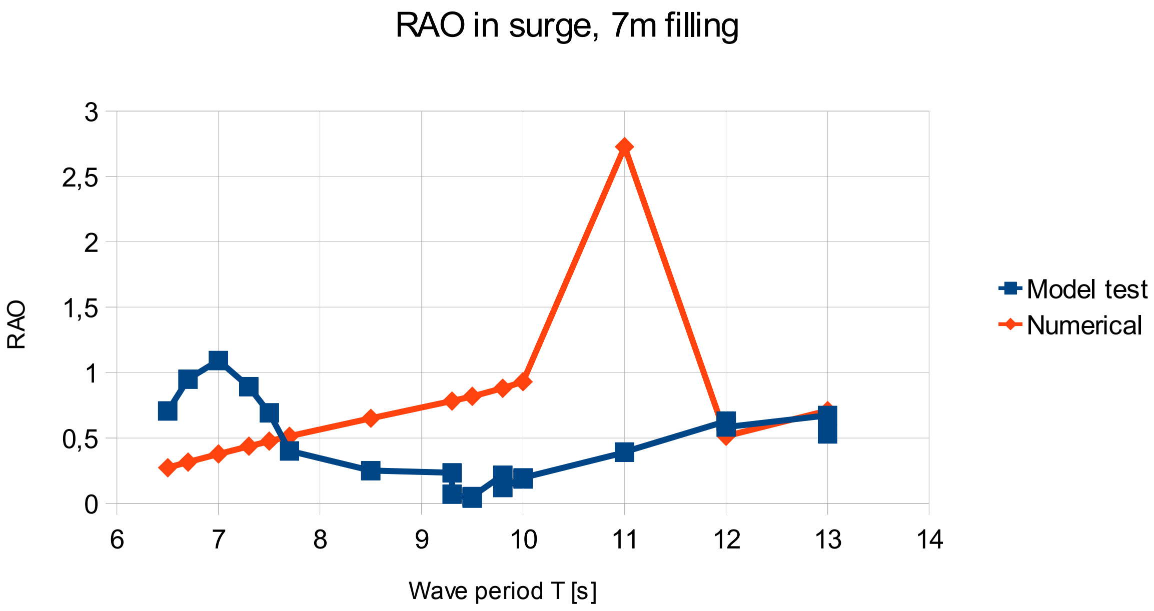

Figure 6.4 : RAO in surge, 7m filling

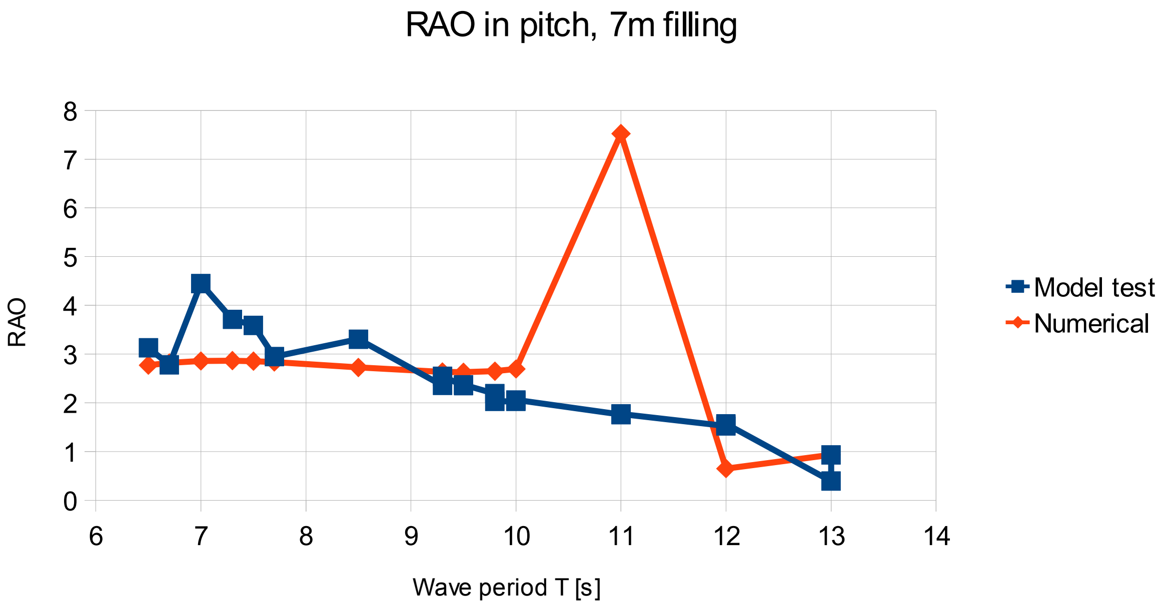

Figure 6.5 : RAO in pitch, 7m filling

The free surface elevation from the tests diverges to a large extent from the numerical results, as seen in figure 6.6 and 6.7. The elevation is given as a magnitude (Mod) of the amplitude of incoming waves.

Some of the discrepancies may be due to the numerical results being calculated for a freely floating vessel, while the model testing included a mooring arrangement. Differences in achieved weight for the model in comparison to the weights used in the numerical model, may also have a say in the much lower elevations experienced in the model testing.

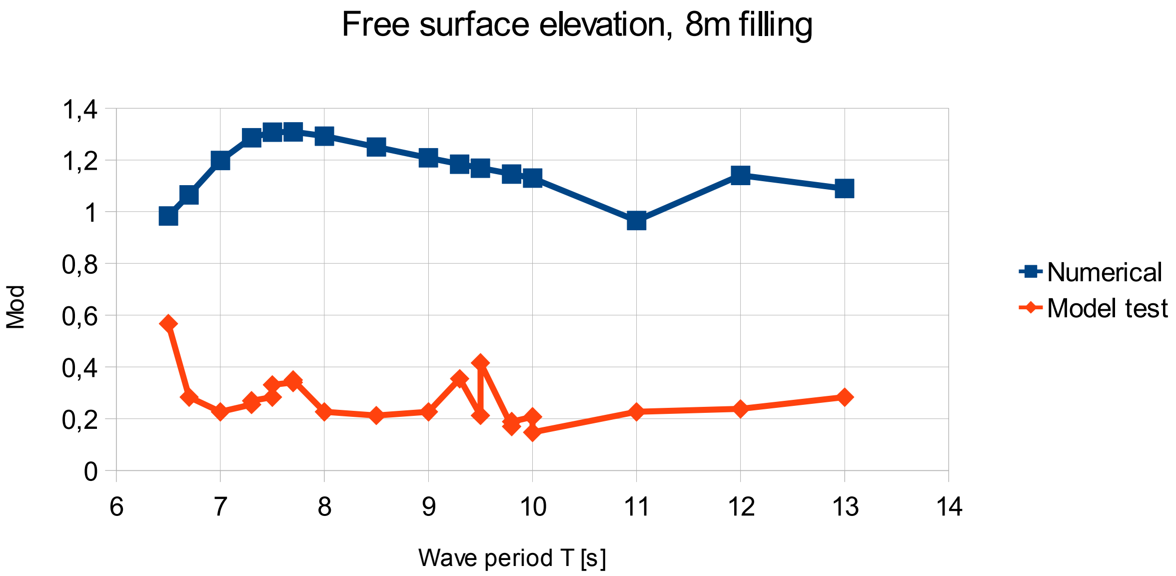

Figure 6.6 : Free surface elevation, 8m filling

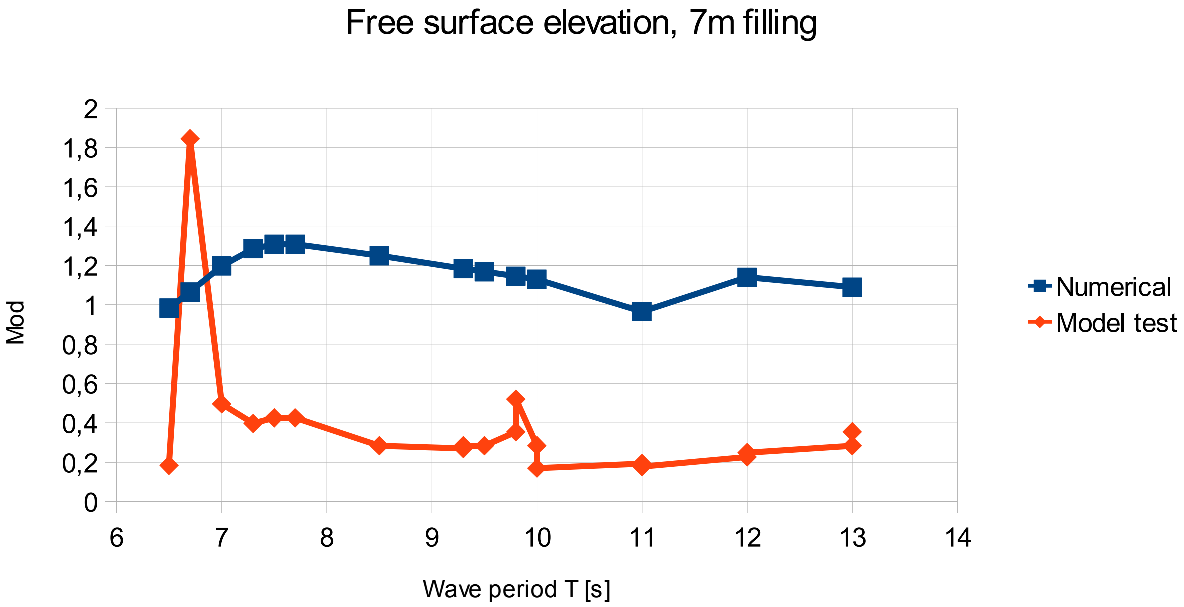

Figure 6.7 : Free surface elevation, 7m filling

When comparing the surge and pitch RAOs with the surface elevations for the design tank filling level of 8m, it is still possible to recognize that some of the peaks in the free surface elevation are related to peaks in surge and pitch.

At periods around 6,5s, 7,5s and 9,5s this is evident, but defining which of surge or pitch motion have the more impact is difficult.

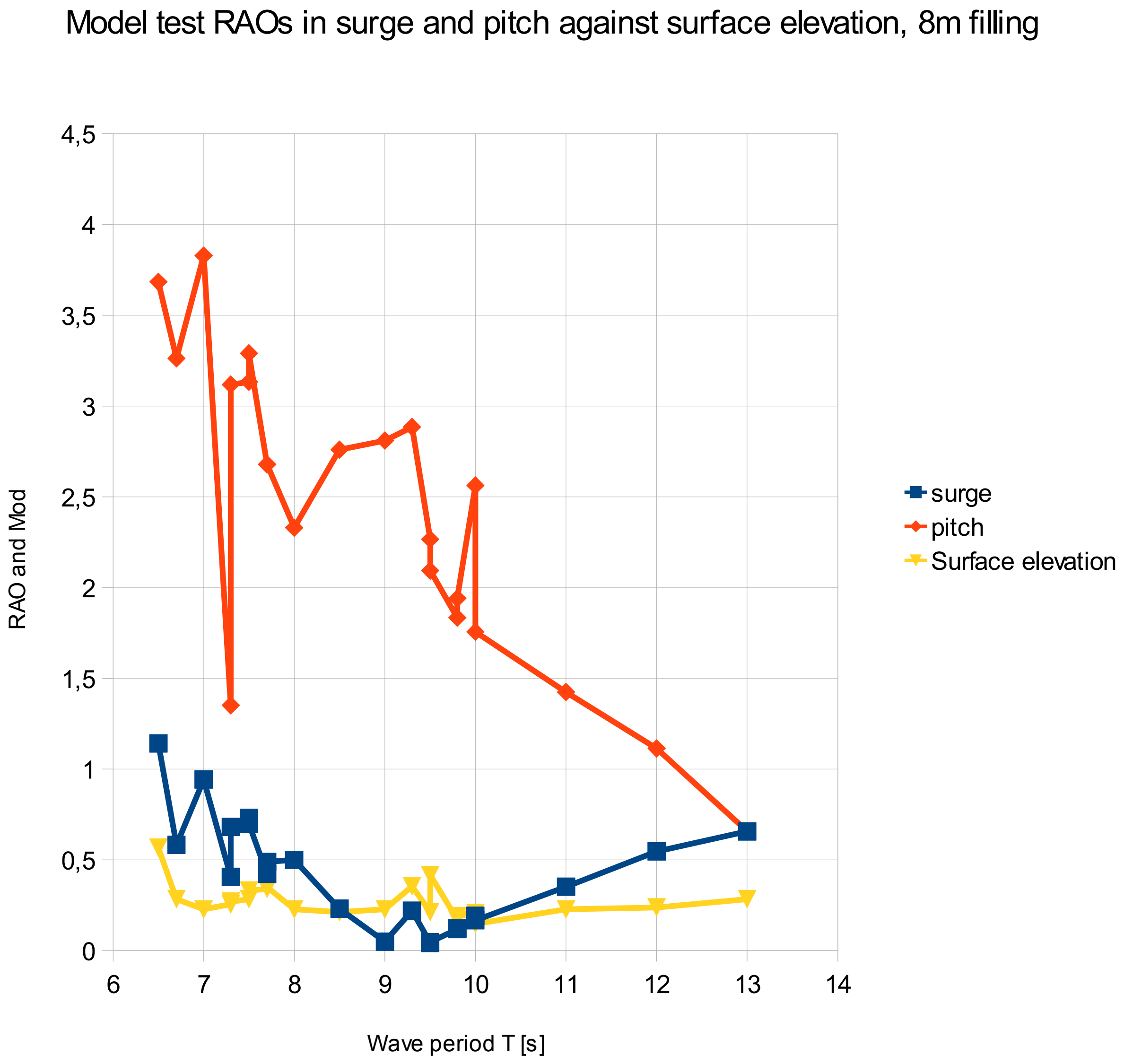

Figure 6.8 : Model test RAOs in surge and pitch against free surface elevation, 8m filling

7 Conclusions

The somewhat large incoherence between numerical results and model test results make it difficult to be categorical about the feasibility of the concept. One has to accept that the non-linear nature of sloshing demand an accuracy in the numerical and test models which is difficult to achieve.

There were examples of semi-strong non-linear sloshing responses at some of the periods and tank fillings tested, but not nearly as many or as powerful as expected. Those strong responses that were seen were marked by the fact that they took some time to manifest themselves and overcome the initial forcing given when starting a test. This time would sometimes overshoot the time-period of around 60s that was used to record position data, that was set to avoid wave reflections from the basin.

The conclusion must be that the results from this round of model testing was dubious and proved such a system is complex and difficult to tune, but some results show promise to the idea still being interesting. More numerical and model testing is needed.

8 Recommendations for further studies

A) Sloshing
  1. Establish ideal internal design to maximize sloshing
  2. Find possible overtopping flows
  3. Check performance for frequency ranges

B) Turbine
  1. Determine ideal turbine type and dimension according to flow.
  2. Investigate how exposing the turbine/shaft/generator system to pitching motion affects performance and service life.
  3. Check how oscillating back-pressure, from internal wave motion, in the downshaft from the upper-basin affects the turbine.
  4. Look into different designs of how to place the down-shaft, preferably out-of-way of the internal wave motion.
  5. Look into modularizing the turbine/shaft/generator system into one unit for ease of installation and maintenance/replacement.

C) Design
  1. Look into if rectangular form is ideal or perhaps circular is better
  2. Optimize submerged hull for pitch and surge

9 Appendices

9.1 Appendix: First-mode natural sloshing period

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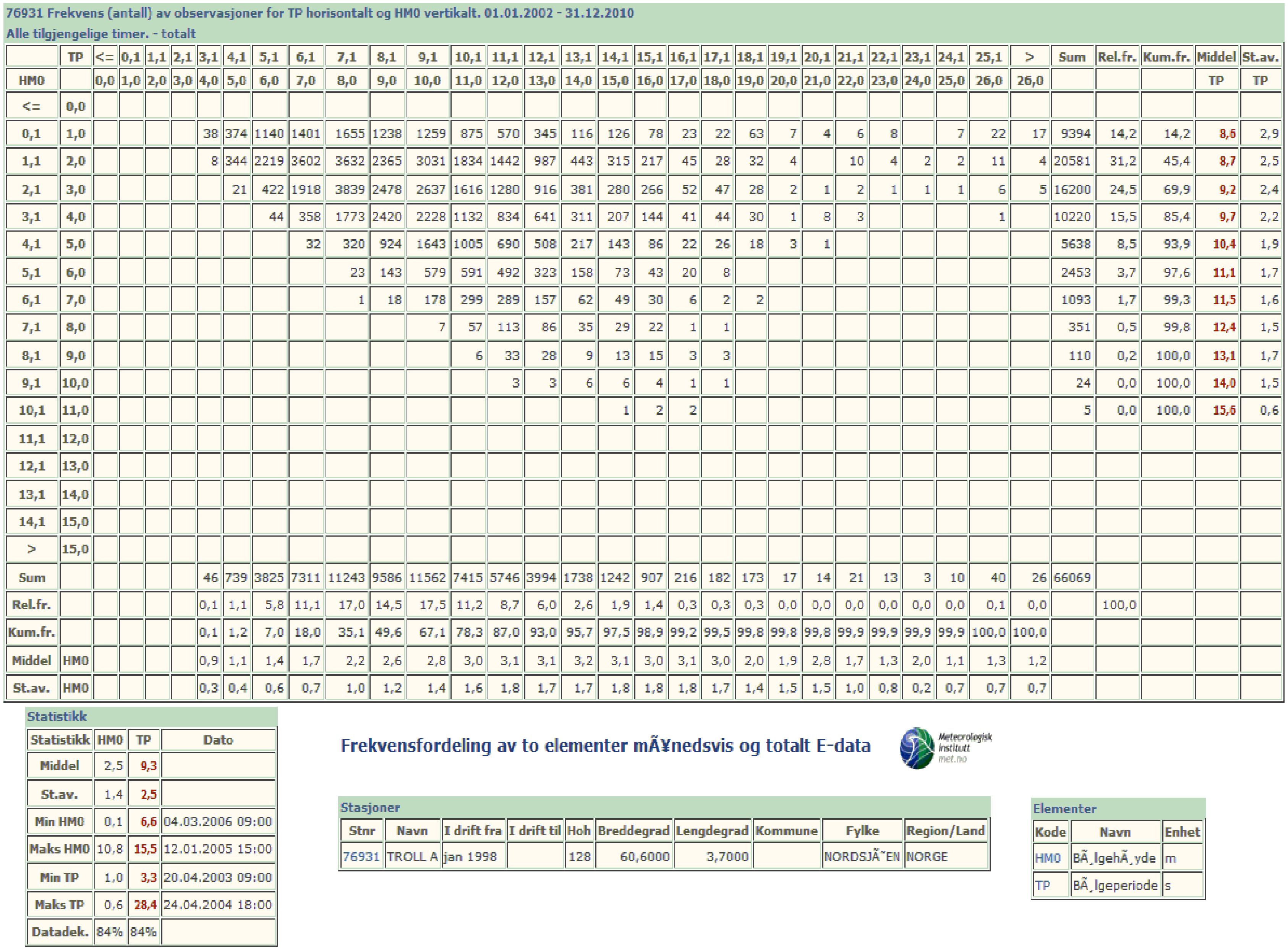
L	**0,5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
0,5	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
1	1,18	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13	1,13
2	1,98	1,67	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
3	2,83	2,22	1,99	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96	1,96
4	3,7	2,8	2,36	2,28	2,27	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26	2,26
5	4,59	3,39	2,74	2,59	2,55	2,54	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53	2,53
6	5,48	4	3,14	2,89	2,81	2,79	2,78	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77	2,77
7	6,37	4,62	3,54	3,2	3,08	3,03	3,01	3	3	3	2,99	2,99	2,99	2,99	2,99	2,99	2,99	2,99	2,99	2,99	2,99
8	7,27	5,24	3,95	3,52	3,34	3,26	3,23	3,21	3,21	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2
9	8,17	5,86	4,37	3,84	3,61	3,5	3,45	3,42	3,41	3,4	3,4	3,4	3,4	3,4	3,4	3,4	3,4	3,4	3,4	3,4	3,4
10	9,07	6,49	4,8	4,17	3,88	3,74	3,66	3,62	3,6	3,59	3,59	3,58	3,58	3,58	3,58	3,58	3,58	3,58	3,58	3,58	3,58
11	9,97	7,12	5,22	4,5	4,16	3,98	3,88	3,82	3,79	3,78	3,77	3,76	3,76	3,76	3,76	3,75	3,75	3,75	3,75	3,75	3,75
12	10,87	7,75	5,66	4,84	4,44	4,22	4,09	4,02	3,98	3,96	3,94	3,93	3,93	3,93	3,92	3,92	3,92	3,92	3,92	3,92	3,92
13	11,77	8,38	6,09	5,18	4,72	4,46	4,31	4,22	4,17	4,13	4,11	4,1	4,09	4,09	4,09	4,08	4,08	4,08	4,08	4,08	4,08
14	12,67	9,01	6,53	5,53	5,01	4,71	4,53	4,42	4,35	4,31	4,28	4,27	4,25	4,25	4,24	4,24	4,24	4,24	4,24	4,24	4,24
15	13,57	9,65	6,97	5,87	5,3	4,96	4,75	4,62	4,54	4,49	4,45	4,43	4,41	4,4	4,4	4,39	4,39	4,39	4,39	4,38	4,38
16	14,47	10,28	7,41	6,22	5,59	5,21	4,98	4,83	4,73	4,66	4,62	4,59	4,57	4,55	4,55	4,54	4,54	4,53	4,53	4,53	4,53
17	15,37	10,92	7,85	6,57	5,89	5,47	5,21	5,03	4,92	4,84	4,78	4,75	4,72	4,7	4,69	4,68	4,68	4,68	4,67	4,67	4,67
18	16,28	11,55	8,29	6,93	6,18	5,73	5,43	5,24	5,11	5,01	4,95	4,91	4,88	4,85	4,84	4,83	4,82	4,81	4,81	4,81	4,81
19	17,18	12,19	8,73	7,28	6,48	5,99	5,67	5,45	5,3	5,19	5,12	5,06	5,03	5	4,98	4,97	4,96	4,95	4,95	4,94	4,94
20	18,08	12,82	9,18	7,64	6,78	6,25	5,9	5,66	5,49	5,37	5,29	5,22	5,18	5,15	5,12	5,11	5,09	5,09	5,08	5,07	5,07
21	18,98	13,46	9,62	7,99	7,08	6,51	6,13	5,87	5,68	5,55	5,45	5,38	5,33	5,29	5,27	5,25	5,23	5,22	5,21	5,2	5,2
22	19,88	14,1	10,07	8,35	7,39	6,78	6,37	6,08	5,88	5,73	5,62	5,54	5,48	5,44	5,41	5,38	5,36	5,35	5,34	5,33	5,33
23	20,79	14,73	10,51	8,71	7,69	7,05	6,61	6,3	6,08	5,91	5,79	5,7	5,64	5,59	5,55	5,52	5,5	5,48	5,47	5,46	5,45
24	21,69	15,37	10,96	9,07	8	7,31	6,85	6,52	6,28	6,1	5,97	5,87	5,79	5,73	5,69	5,66	5,63	5,61	5,59	5,58	5,57
25	22,59	16,01	11,41	9,43	8,31	7,58	7,09	6,73	6,48	6,28	6,14	6,03	5,94	5,88	5,83	5,79	5,76	5,74	5,72	5,71	5,7
26	23,49	16,64	11,85	9,79	8,61	7,85	7,33	6,95	6,68	6,47	6,31	6,19	6,1	6,03	5,97	5,93	5,89	5,87	5,85	5,83	5,82
27	24,4	17,28	12,3	10,15	8,92	8,12	7,57	7,17	6,88	6,66	6,49	6,35	6,25	6,17	6,11	6,06	6,02	5,99	5,97	5,95	5,94
28	25,3	17,92	12,75	10,51	9,23	8,4	7,82	7,4	7,08	6,84	6,66	6,52	6,41	6,32	6,25	6,2	6,16	6,12	6,1	6,07	6,06
29	26,2	18,55	13,2	10,88	9,54	8,67	8,06	7,62	7,29	7,03	6,84	6,69	6,57	6,47	6,4	6,34	6,29	6,25	6,22	6,2	6,18
30	27,1	19,19	13,64	11,24	9,85	8,94	8,31	7,84	7,49	7,22	7,02	6,85	6,72	6,62	6,54	6,47	6,42	6,38	6,34	6,32	6,29
31	28,01	19,83	14,09	11,6	10,16	9,22	8,55	8,07	7,7	7,42	7,19	7,02	6,88	6,77	6,68	6,61	6,55	6,51	6,47	6,44	6,41
32	28,91	20,47	14,54	11,97	10,47	9,49	8,8	8,29	7,91	7,61	7,37	7,19	7,04	6,92	6,83	6,75	6,69	6,63	6,59	6,56	6,53
33	29,81	21,1	14,99	12,33	10,79	9,77	9,05	8,52	8,11	7,8	7,55	7,36	7,2	7,07	6,97	6,89	6,82	6,76	6,72	6,68	6,65
34	30,71	21,74	15,44	12,69	11,1	10,04	9,3	8,74	8,32	8	7,74	7,53	7,36	7,23	7,12	7,03	6,95	6,89	6,84	6,8	6,77
35	31,62	22,38	15,89	13,06	11,41	10,32	9,55	8,97	8,53	8,19	7,92	7,7	7,52	7,38	7,26	7,17	7,09	7,02	6,97	6,92	6,88
36	32,52	23,02	16,34	13,42	11,72	10,6	9,8	9,2	8,74	8,39	8,1	7,87	7,69	7,53	7,41	7,31	7,22	7,15	7,09	7,04	7
37	33,42	23,65	16,79	13,79	12,04	10,88	10,05	9,43	8,95	8,58	8,28	8,04	7,85	7,69	7,56	7,45	7,36	7,28	7,22	7,16	7,12
38	34,33	24,29	17,24	14,15	12,35	11,15	10,3	9,66	9,17	8,78	8,47	8,22	8,01	7,84	7,7	7,59	7,49	7,41	7,34	7,29	7,24
39	35,23	24,93	17,69	14,52	12,66	11,43	10,55	9,89	9,38	8,98	8,65	8,39	8,18	8	7,85	7,73	7,63	7,54	7,47	7,41	7,36
40	36,13	25,57	18,13	14,88	12,98	11,71	10,8	10,12	9,59	9,17	8,84	8,57	8,34	8,16	8	7,87	7,76	7,67	7,59	7,53	7,47
41	37,03	26,21	18,58	15,25	13,29	11,99	11,05	10,35	9,81	9,37	9,03	8,74	8,51	8,31	8,15	8,02	7,9	7,8	7,72	7,65	7,59
42	37,94	26,84	19,03	15,61	13,61	12,27	11,31	10,58	10,02	9,57	9,21	8,92	8,67	8,47	8,3	8,16	8,04	7,94	7,85	7,78	7,71
43	38,84	27,48	19,48	15,98	13,92	12,55	11,56	10,81	10,23	9,77	9,4	9,09	8,84	8,63	8,45	8,3	8,18	8,07	7,98	7,9	7,83
44	39,74	28,12	19,93	16,34	14,24	12,83	11,81	11,05	10,45	9,97	9,59	9,27	9,01	8,79	8,6	8,45	8,31	8,2	8,11	8,02	7,95
45	40,65	28,76	20,38	16,71	14,55	13,11	12,07	11,28	10,66	10,17	9,78	9,45	9,18	8,95	8,76	8,59	8,45	8,34	8,23	8,15	8,07
46	41,55	29,4	20,83	17,08	14,87	13,39	12,32	11,51	10,88	10,38	9,96	9,63	9,34	9,11	8,91	8,74	8,59	8,47	8,36	8,27	8,19
47	42,45	30,03	21,28	17,44	15,18	13,67	12,57	11,74	11,1	10,58	10,15	9,8	9,51	9,27	9,06	8,88	8,73	8,6	8,49	8,4	8,31
48	43,35	30,67	21,73	17,81	15,5	13,95	12,83	11,98	11,31	10,78	10,34	9,98	9,68	9,43	9,21	9,03	8,87	8,74	8,62	8,52	8,44
49	44,26	31,31	22,19	18,18	15,81	14,23	13,08	12,21	11,53	10,98	10,53	10,16	9,85	9,59	9,37	9,18	9,02	8,88	8,75	8,65	8,56
50	45,16	31,95	22,64	18,54	16,13	14,51	13,34	12,45	11,75	11,18	10,72	10,34	10,02	9,75	9,52	9,33	9,16	9,01	8,88	8,78	8,68
51	46,06	32,59	23,09	18,91	16,45	14,79	13,59	12,68	11,96	11,39	10,92	10,52	10,19	9,92	9,68	9,47	9,3	9,15	9,02	8,9	8,8
52	46,97	33,22	23,54	19,28	16,76	15,07	13,85	12,91	12,18	11,59	11,11	10,7	10,37	10,08	9,83	9,62	9,44	9,28	9,15	9,03	8,93
53	47,87	33,86	23,99	19,64	17,08	15,35	14,1	13,15	12,4	11,79	11,3	10,88	10,54	10,24	9,99	9,77	9,58	9,42	9,28	9,16	9,05
54	48,77	34,5	24,44	20,01	17,4	15,64	14,36	13,38	12,62	12	11,49	11,07	10,71	10,41	10,15	9,92	9,73	9,56	9,41	9,28	9,17
55	49,67	35,14	24,89	20,38	17,71	15,92	14,61	13,62	12,84	12,2	11,68	11,25	10,88	10,57	10,3	10,07	9,87	9,7	9,55	9,41	9,3
56	50,58	35,78	25,34	20,74	18,03	16,2	14,87	13,86	13,05	12,41	11,87	11,43	11,05	10,73	10,46	10,22	10,02	9,84	9,68	9,54	9,42
57	51,48	36,42	25,79	21,11	18,35	16,48	15,13	14,09	13,27	12,61	12,07	11,61	11,23	10,9	10,62	10,37	10,16	9,97	9,81	9,67	9,55
58	52,38	37,05	26,24	21,48	18,66	16,76	15,38	14,33	13,49	12,82	12,26	11,79	11,4	11,06	10,77	10,52	10,3	10,11	9,95	9,8	9,67
59	53,29	37,69	26,69	21,84	18,98	17,05	15,64	14,56	13,71	13,02	12,45	11,98	11,57	11,23	10,93	10,67	10,45	10,25	10,08	9,93	9,8
60	54,19	38,33	27,14	22,21	19,3	17,33	15,89	14,8	13,93	13,23	12,65	12,16	11,75	11,39	11,09	10,83	10,6	10,39	10,22	10,06	9,92

9.2 Appendix: MET eKlima data



76931 Frekvens (antall) av observasjoner for TP horisontalt og HM0 vertikalt. 01.01.2002 - 31.12.2010
Alle tilgjengelige timer. - totalt

	TP	<=	0,1	1,1	2,1	3,1	4,1	5,1	6,1	7,1	8,1	9,1	10,1	11,1	12,1	13,1	14,1	15,1	16,1	17,1	18,1	19,1	20,1	21,1	22,1	23,1	24,1	25,1	>	Sum	Rel.fr.	Kum.fr.	Middel	St.av.
HM0		0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0	25,0	26,0	26,0				TP	TP
<=	0,0																																	
0,1	1,0					38	374	1140	1401	1655	1238	1259	875	570	345	116	126	78	23	22	63	7	4	6	8		7	22	17	9394	14,2	14,2	8,6	2,9
1,1	2,0					8	344	2219	3602	3632	2365	3031	1834	1442	987	443	315	217	45	28	32	4		10	4	2	2	11	4	20581	31,2	45,4	8,7	2,5
2,1	3,0						21	422	1918	3839	2478	2637	1616	1280	916	381	280	266	52	47	28	2	1	2	1	1	1	6	5	16200	24,5	69,9	9,2	2,4
3,1	4,0							44	358	1773	2420	2228	1132	834	641	311	207	144	41	44	30	1	8	3				1		10220	15,5	85,4	9,7	2,2
4,1	5,0								32	320	924	1643	1005	690	508	217	143	86	22	26	18	3	1							5638	8,5	93,9	10,4	1,9
5,1	6,0									23	143	579	591	492	323	158	73	43	20	8										2453	3,7	97,6	11,1	1,7
6,1	7,0									1	18	178	299	289	157	62	49	30	6	2	2									1093	1,7	99,3	11,5	1,6
7,1	8,0											7	57	113	86	35	29	22	1	1										351	0,5	99,8	12,4	1,5
8,1	9,0												6	33	28	9	13	15	3	3										110	0,2	100,0	13,1	1,7
9,1	10,0													3	3	6	6	4	1	1										24	0,0	100,0	14,0	1,5
10,1	11,0																1	2	2											5	0,0	100,0	15,6	0,6
11,1	12,0																																	
12,1	13,0																																	
13,1	14,0																																	
14,1	15,0																																	
>	15,0																																	
Sum						46	739	3825	7311	11243	9586	11562	7415	5746	3994	1738	1242	907	216	182	173	17	14	21	13	3	10	40	26	66069				
Rel.fr.						0,1	1,1	5,8	11,1	17,0	14,5	17,5	11,2	8,7	6,0	2,6	1,9	1,4	0,3	0,3	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0		100,0			
Kum.fr.						0,1	1,2	7,0	18,0	35,1	49,6	67,1	78,3	87,0	93,0	95,7	97,5	98,9	99,2	99,5	99,8	99,8	99,8	99,9	99,9	99,9	99,9	100,0	100,0					
Middel	HM0					0,9	1,1	1,4	1,7	2,2	2,6	2,8	3,0	3,1	3,1	3,2	3,1	3,0	3,1	3,0	2,0	1,9	2,8	1,7	1,3	2,0	1,1	1,3	1,2					
St.av.	HM0					0,3	0,4	0,6	0,7	1,0	1,2	1,4	1,6	1,8	1,7	1,7	1,8	1,8	1,8	1,7	1,4	1,5	1,5	1,0	0,8	0,2	0,7	0,7	0,7					

Statistikk

Statistikk	HM0	TP	Dato
Middel	2,5	9,3	
St.av.	1,4	2,5	
Min HM0	0,1	6,6	04.03.2006 09:00
Maks HM0	10,8	15,5	12.01.2005 15:00
Min TP	1,0	3,3	20.04.2003 09:00
Maks TP	0,6	28,4	24.04.2004 18:00
Datadek.	84%	84%	

Frekvensfordeling av to elementer mÃ¥nedsvis og totalt E-data

Meteorologisk institutt
met.no

Stasjoner

Stnr	Navn	I drift fra	I drift til	Hoh	Breddegrad	Lengdegrad	Kommune	Fylke	Region/Land
76931	TROLL A	jan 1998		128	60,6000	3,7000		NORDSJÃ˜EN	NORGE

Elementer

Kode	Navn	Enhet
HM0	BÃ¸lgehÃ¸yde	m
TP	BÃ¸lgeperiode	s

9.3 Appendix: on file

Appendices to be found enclosed on file:

Wamit input files and output files, position data, visual observation data, Multisurf geometry file.

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