Non Confidential version

Wave Dragon Prototype

Tilstandsvurdering **BILAG**

Energinet.dk projektnummer 6459

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BILAG

1. Oversigts-konstruktionstegninger, platform, vinger, turbiner og andre installationer på dækket samt plan for udstøbning af Leca beton på dækket
2. Relevante slides fra præsentationen Wave Dragon from demonstration to market -
3. AAU, Statusrapport Bygning af Wave Dragon, Nissum Bredning
4. AAU, Statusrapport Instrumentering af Wave Dragon, Nissum Bredning -Minus Appendix
5. AAU, Status report First offshore experiences, Wave Dragon, Nissum Bredning
6. AAU, Automatic Control of Freeboard and Turbine Operation. Wave Dragon
7. AAU, Hydraulic Response of the Wave Energy Converter Wave Dragon
8. Wave Dragon ApS, Rapport fase B af ENS projekt 51191/01-0033 for perioden fra 1. april 2003 til 31. december 2004
9. AAU, Report on damage in storm 05.01.08: Failure of moorings, drift a shore WD
10. TUM, Report on the refurbishment of the siphon turbine carried out 10.5. to 15.5.2004
11. TUM, Report on the condition of the cylinder gate turbines after the stranding of the Wave Dragon
12. HEMPEL A/S SPECIFICATION SHEET WAVE DRAGON Turbine Tunnels HEMPASIL HEMPASIL NEXUS 27302 & HEMPASIL 77500 påføring på Turbinerør for Wave Dragon, udført af Dan-Coat
13. TUM, Conference paper: Water Turbines for Overtopping Wave Energy Converters
14. TUM, The Hydro Turbines of the Wave Dragon Nissum Bredning Prototype after eight years at sea
15. FORCE Technology, Investigation of corrosion extent on samples from Wave Dragon
16. Wave Dragon ApS, Wave Dragon pilot plant - photos 2002 - 2012

Bilag angivet med rødt er ikke offentligt tilgængelige - kontakt evt. Wave Dragon

BILAG 1

Oversigts-konstruktionstegninger, platform, vinger, turbiner og andre installationer på dækket samt plan for udstøbning af Leca beton på dækket

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BILAG2

Relevante slides fra præsentationen Wave Dragon from demonstration to market -

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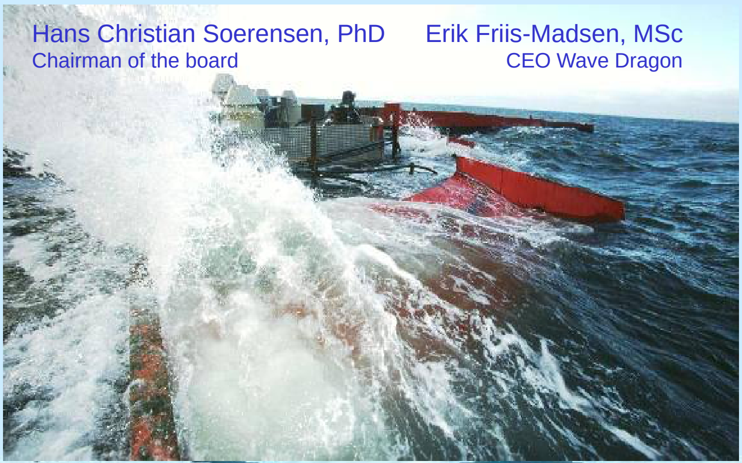
Wave Dragon
from demonstration to market

Hans Christian Soerensen, PhD
Chairman of the board

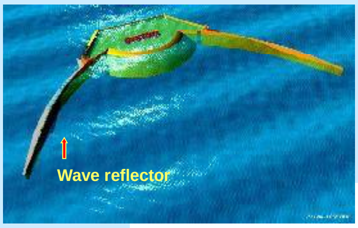
Erik Friis-Madsen, MSc
CEO Wave Dragon

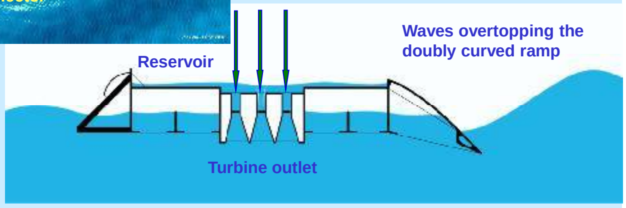


Wave Dragon principle

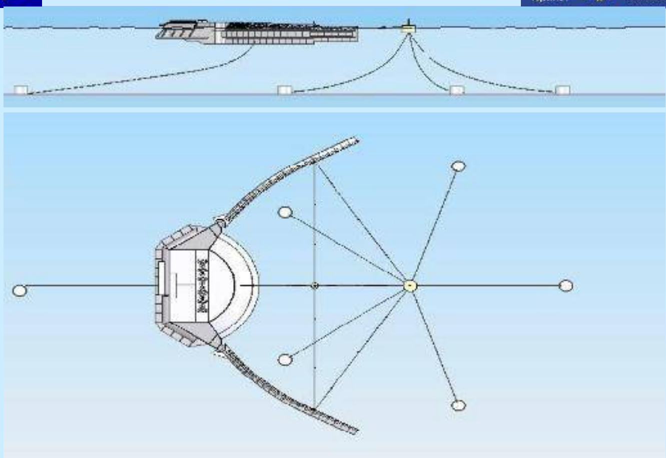
The *Wave Dragon* is a slack-moored wave energy converter that can be deployed alone or in parks wherever a sufficient wave climate and a water depth of more than15m is found.

Climate	Power	Yearly production
12 kW/m	1½ MW	4 GWh/y/unit
24 kW/m	4 MW	12 GWh/y/unit
36 kW/m	7 MW	20 GWh/y/unit
48 kW/m	12 MW	35 GWh/y/unit

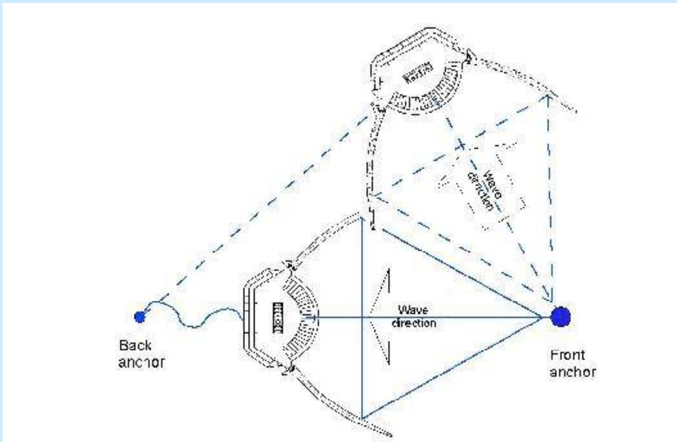




Mooring principle



Adjusting to the waves



20,000 hours production

- Real sea testing in scale 1:1 in a scale 1:5 sea state of the Atlantic
- Web cam 25 m/sec wind

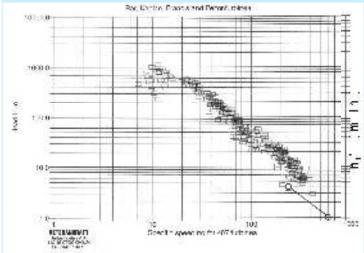
Wave Dragon
Development phases

#	Phase	To be obtained
1	Scale 1:50 Test in Wave tanks 1998 – 2002 1m€	Hydraulic behaviour Survivability Response different wave climates ENS & EU: 50%
2	Scale 1:1 in a real sea modelling the North Sea in 1:4.5 20kW 2002 – 2006 5m€	Power production, grid connection Operational management Model laws valid Survivability ENS, PSO, EU: 50%
3	Scale 1:1 in the Celtic Sea 7MW 2006 – 2010 25m€	Scaling feasibility Demonstration O&M CT, WAG, EU

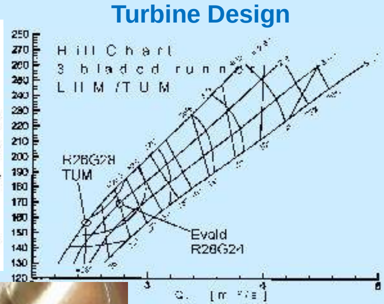
Tank testing Aalborg & Cork

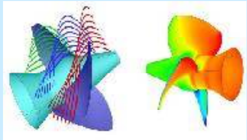
- Tank testing scale 1:50
  - Survivability
  - Hydraulic behaviour
  - Overtopping
- Feasibility
- Turbine design

Optimizing hydro turbine



Turbine Design





Operational Experience

Marine growth on structure and mooring lines below waterline: 5-10 cm

Marine growth in turbine outlet will reduce PTO. Testing non-toxic antifouling.

Operational Experience

Marine Growth

An option for the fishermen

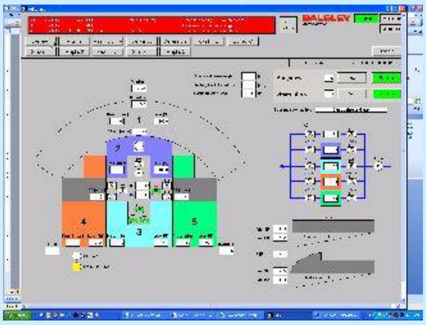
Operational Experience

Offshore Maintenance

Change in lubrication of bearings caused by marine growth

Operational Experience
redundancy

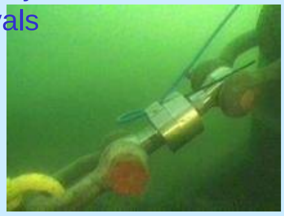
- Control system failure on Internet
- Power supply switch



Operational Experience
Maintenance intervals

- Moring cables
- Moring lines
- Redundancy
- Hydraulic systems
- Control and power electronic systems

Operational Experience
Moring lines, Redundancy and Maintenance intervals

Fatigue in a load cell

Operational Experience

Turbine Operation



Operationel experience


Avoid special vessels

Operational Experience

- Fatigue can be a problem
- The splash zone is special
- Don’t trust the offshore oil and gas suppliers

Operational Experience
avoid fatigue

Already in design
- For the turbines
- For the bulk heads


Operational Experience

Quality of components

Never trust the oil and gas sector – we are operating in the splash zone

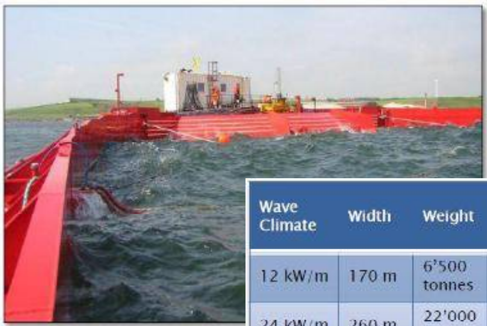
Solenoid valve

Operational Experience

Offshore Maintenance

It is possible

Wave Dragon device sizes

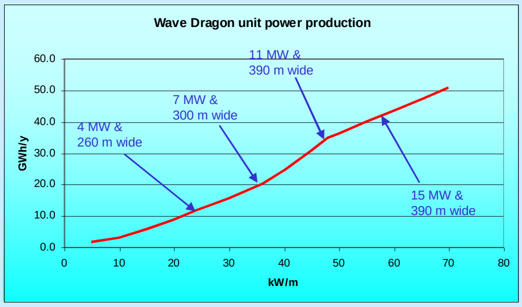


57 m wide 200 tonnes Wave Dragon prototype with 7 turbines deployed and connected to the grid in 2003 as worlds first floating WEC

Wave Climate	Width	Weight	Turb.	Rated Power	Yearly Production
12 kW/m	170 m	6'500 tonnes	8	1.5 MW	4 GWh
24 kW/m	260 m	22'000 tonnes	16	4 MW	12 GWh
36 kW/m	300 m	33'000 tonnes	16-20	7 MW	20 GWh
48 kW/m	390 m	54'000 tonnes	16-24	12 MW	35 GWh

Size dependant of sea state

Wave Dragon – published data



Wave climate	First device	After deployment of 100's
24 kW/m	0.11 €/kWh	0.054 €/kWh
36 kW/m	0.083 €/kWh	0.040 €/kWh
48 kW/m	0.061 €/kWh	0.030 €/kWh

Table 8.2: Wave Dragon expected cost in €/ kWh.

Wave climate	First device	After deployment of 100's
24 kW/m	4,000 €/kW	2,300 €/kW
36 kW/m	3,200 €/kW	1,875 €/kW
48 kW/m	2,700 €/kW	1,575 €/kW

Table 8.1: Wave Dragon expected capital cost in €/ kW price.

BILAG 3

AAU, STATUSRAPPORT BYGNING AF WAVE DRAGON, NISSUM BREDNING

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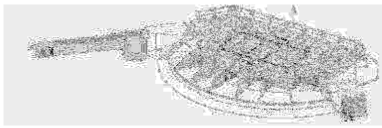


Statusrapport
-
Bygning af
Wave Dragon, Nissum Bredning

Projekt:

Bestemmelse af hydraulisk respons af bølgeenergiomsætteren Wave Dragon

iht. Samarbejdsaftale mellem
Wave Dragon Test Aps.
og
Aalborg Universitet, Institut for Vand, Jord og Miljøteknik.

Jens Peter Kofoed
Maj, 2003

Faggruppen for Hydraulik og Havnebygning
Instituttet for Vand, Jord og Miljøteknik - Sohngaardsholmsvej 57 - 9000 Aalborg - Telefon 9635 8080

Indholdsfortegnelse

Indledning

Nærværende statusrapport beskriver i ord og billeder tilblivelsen af Wave Dragon, Nissum Bredning modellen (WD-NB), i kronologisk orden. Konstruktionen af anlægget er foretaget af MT Højgaard, primært på deres stålværksted, Skydebanevej i Aalborg, under ledelse af projektleder Jens Præst.

Iht. samarbejdsaftalen mellem Wave Dragon Test Aps. (WDT) og Aalborg Universitet, Institut for Vand, Jord og Miljøteknik (AAU) har AAU løbende haft opsyn med arbejdet på værkstedet og deltaget i det løbende opfølgningsarbejde.

Siden projektets opstart er der løbende blevet publiceret materiale i form af billeder, video, notater og rapporter på websiden http://www.civil.auc.dk/~i5jpk/wd/wdnb.htm .

Bygning af WD-NB modellen

Oktober 2002

Svejsning af hovedforankringsbøtte.

Forankringsbøtte færdigsvejst.

November 2002

Reflektorelementer under opsvejsning.

Skulderender af reflektorer under opsvejsning.

Del af reflektor klar til samling.

December 2002

Reflektorer samlet.

Delelementer af reservoir under opbygning.

Del af rampe under opbygning.

Målecontainer beklædes indvendig.

Målecontainer forsynes med vinduer.

Januar 2003

Rampedel og reservoirdelelement samlet til en af fem hovedelementer af platform.

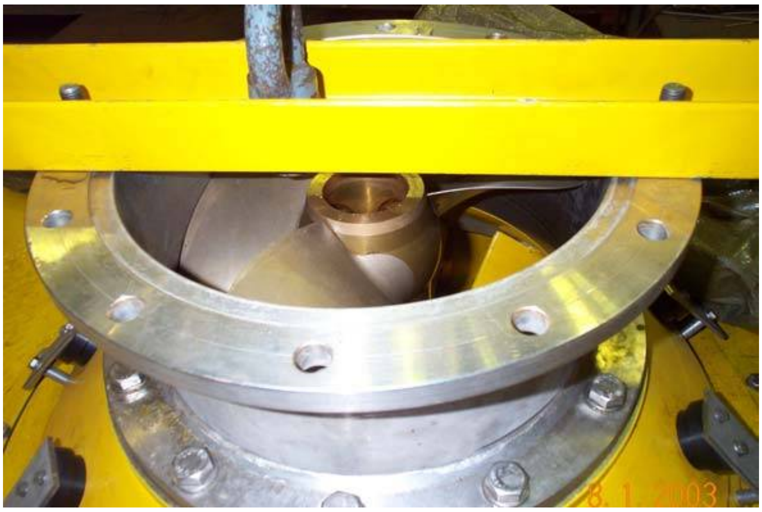
Reservoirdelelement med turbinehuller.

Skulderdelelementer under opbygning.

Sifonturbine ankommet fra München.

Sifon.

Runner.

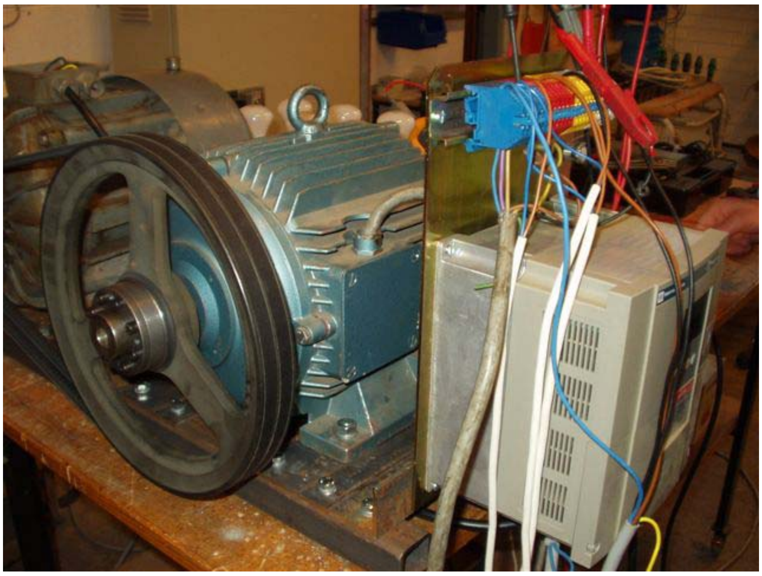


Midterdel af rampe under opsvejsning.

Detalje af sammenfatning af krumme plader på rampe.

Fendere til skulderforbindelsen.

Test af PMG hos West Control.



Et af fem hovedelementer af platformsdel flyttes til kaj, hvor samlingen af hovedelementerne samles.

Brønd til montering af Flygt pumpe.

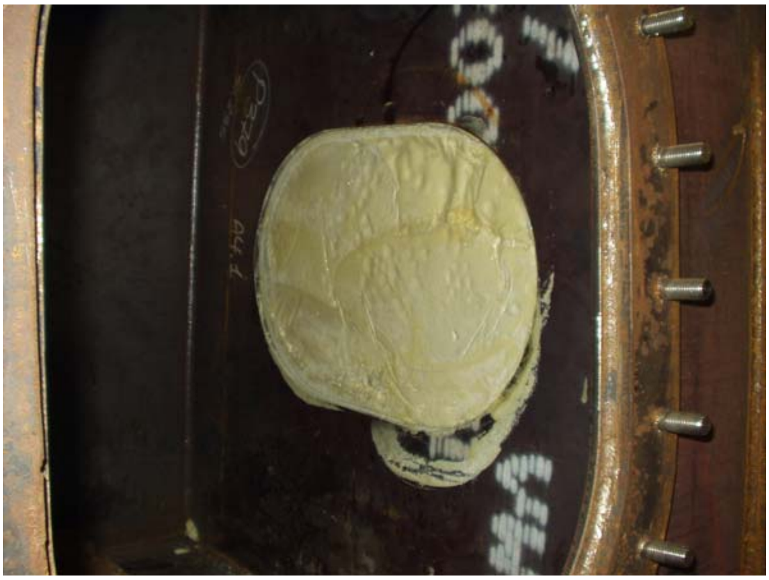
Centrale hoveddel af reservoir køres ud af værkstedshal.

Sifonturbine modificeret og samlet.

Samling af hovedelementer på kajpladsen.

Is i fjorden, der forhindrer slæbning.

Opskumning af reflektorer.



Februar 2003

Skulder elementer monteret

Ballastceller i reservoir under opbygning.

Reflektorer flyttes til kajpladsen

Afstivninger til målecontainer og ’canopy’ under opbygning.

PLC'er under installation.

Blæsere under installation.

Ilandføringskabel ankommet.

Flygtpumpe.

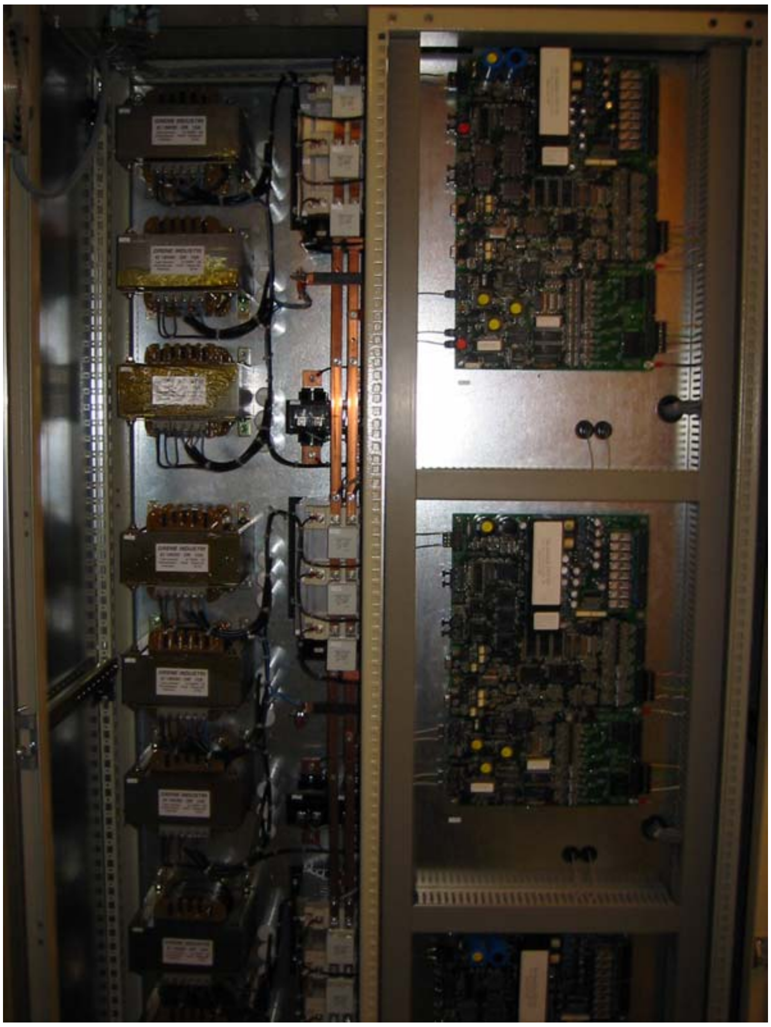
Frekvensomformer til styring af Flygtpumpe.

Dummyturbine under opbygning.

Målecontainer efter maling.

Baganker under opbygning.

West Control generator styringsenheder (frekvensomformere mv.) monteres i målecontainer.



Sandblæsning af reflektorer.

Sandblæsning af platform.

Dele af forankringssystem.

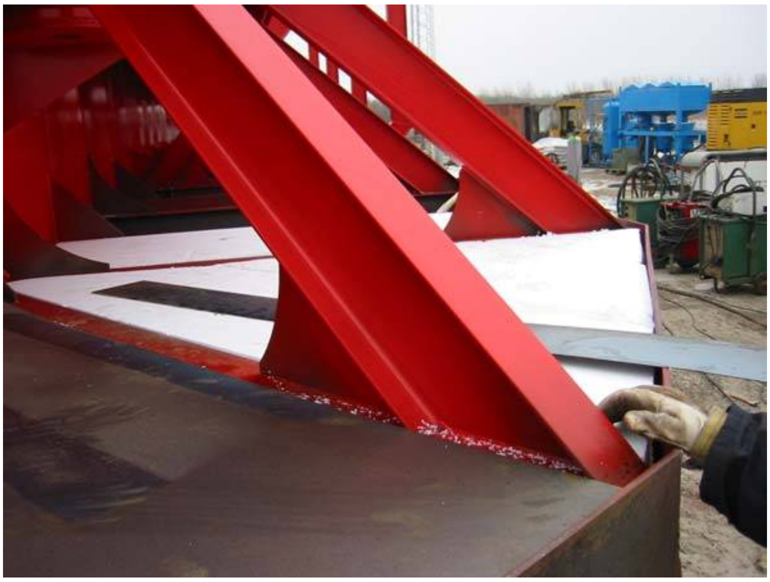
Maling af reflektorer.

Marts 2003

Maling af platform.

Opmærkning af manglende lufthuller mellem kamre.

Opdrift monteres på dæmpningsplade.



Modificering af turbine og forbindelse til generator.

Platform efter maling.

Reflektorer efter maling.

Fishtails.

Bolt til fastgørelse af fishtail.

Nederste fishtail monteret.

Fendersystem under montering.

Monteret fendersystem.

Opstregning af vandgangslinier.

000044

Montering af skilt.

Amtsborgmester Orla Hav taler ved søsætningen.

Søsætning under stor presseopmærksomhed.

Søsætningen.

000047

Ræk- og risteværk monteret.

Sifonturbine klar til montering.

Montering af dummyturbiner.

Montering af luftslanger.

000049

Montering af vandhydraulik.

Vandhydraulik monteret på dummyturbiner.

000050

Forankringsbøtter forlader værksted.

J-tube udgang i hovedforankringsbøtte.

Ankre til ilandføringskabelmarkeringsbøjer.

Hovedforankringsbøtte ankommer til test site 1 i Nissum Bredning.

Placering af hovedforankringsbøtte.

000053

Placering af baganker.

Dykkerkontrol af udførelse.

BILAG 4

AAU, Statusrapport Instrumentering af Wave Dragon, Nissum Bredning

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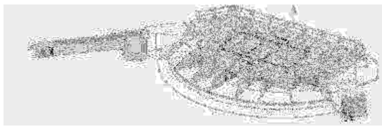
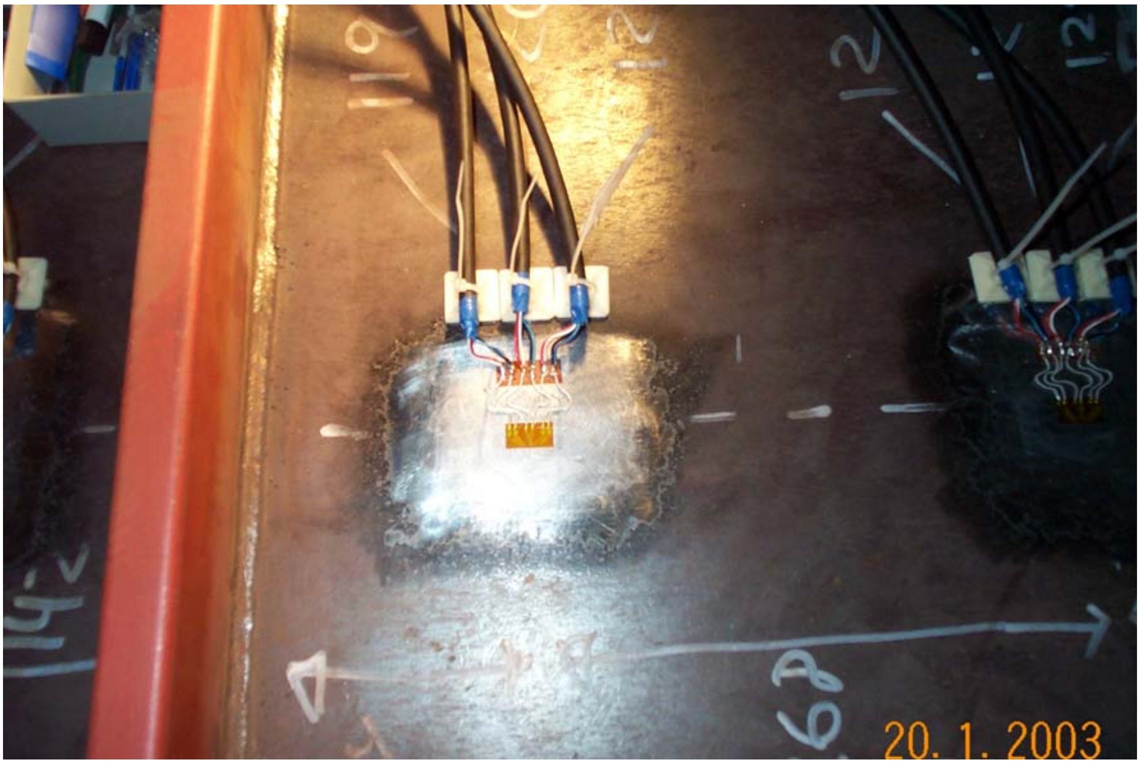


Statusrapport
–
Instrumentering af Wave Dragon, Nissum Bredning



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Indholdsfortegnelse

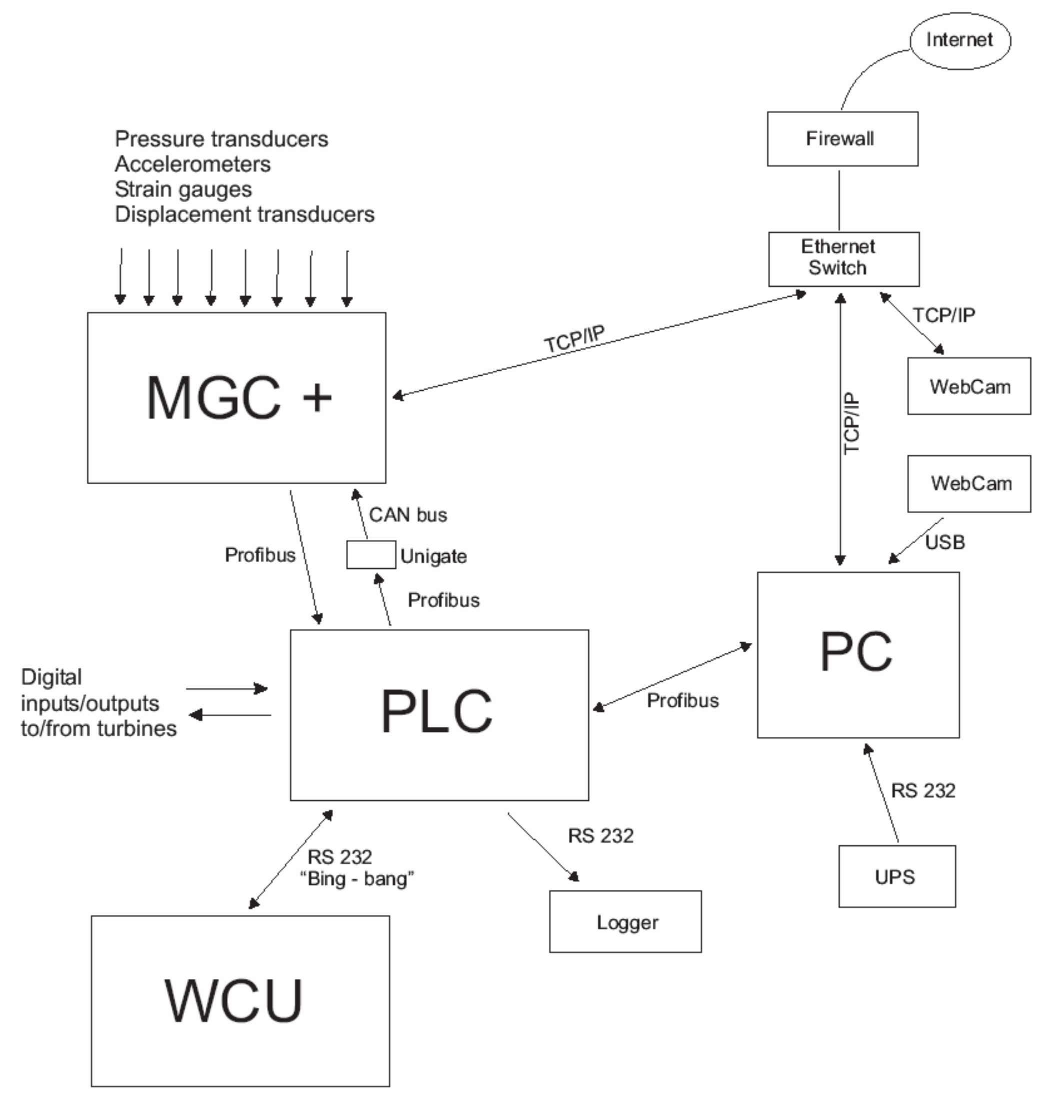
Indledning

Nærværende statusrapport beskriver i ord og billeder instrumenteringen af Wave Dragon, Nissum Bredning modellen (WD-NB). Instrumenteringen beskrevet i denne rapport er primært sket under konstruktionen af anlægget.

Siden projektets opstart er der løbende blevet publiceret materiale i form af billeder, video, notater og rapporter på websiden http://www.civil.auc.dk/~i5jpk/wd/wdnb.htm .

Måle- og reguleringssystem

Den principielle udformning af måle og reguleringssystemet ombord på WD er beskrevet i Appendix A. Systemet er løbende blevet tilrettet og justeret. Nedenstående diagram præsenterer status af systemets udformning.



Systemet tilpasses løbende.

Forbindelsen til WD via internettet udføres iht. Appendix C.

Instrumenter

WD udrustes med en række forskellige måleinstrumenter, således som det fremgår af appendix A.

I det følgende beskrives de enkelte komponenter i ord og billeder fra installationen.

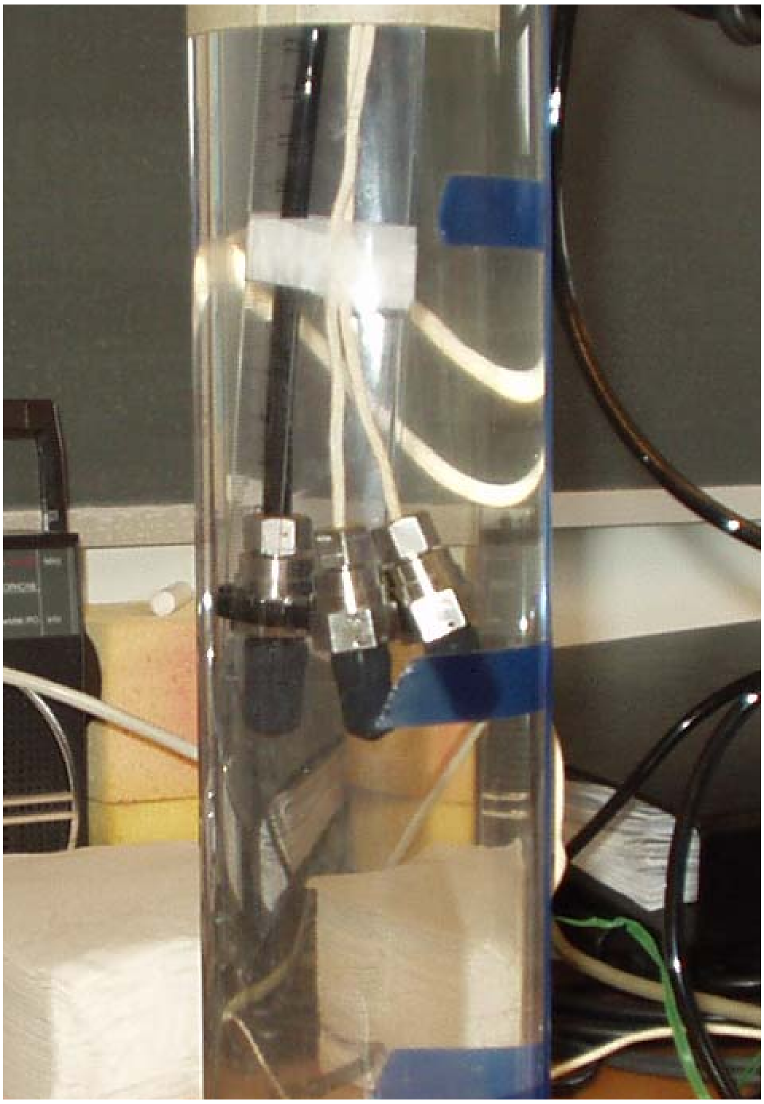
Tryktransducere

Markering af placering af tryktransducer (PRES_AC3 og PRES_R3).

Muffe til iskruning af tryktransducer.

Stander til junction box, hvori kabler fra de enkelte transducere samles med multikabler, der føre signalerne til målecontainer.

Afprøvning af tryktransducere inden montering.



Monteret tryktransducer. Transduceren er monteret i et specialfremstillet beskyttende hus.

Monteret tryktransducer, set fra den trykfølsomme side.

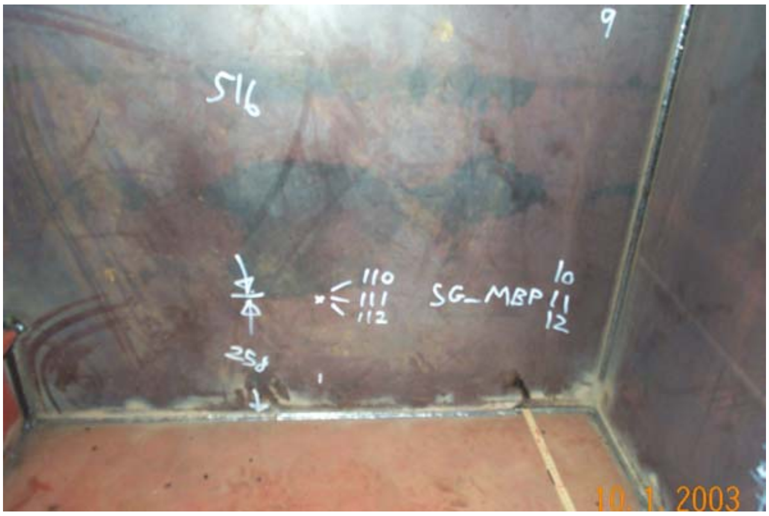
Kabler fra transducer og multikabler samles i junction box.

Tryktransducer, samt vandtæt ledningsgennemføring i reservoirdæk.

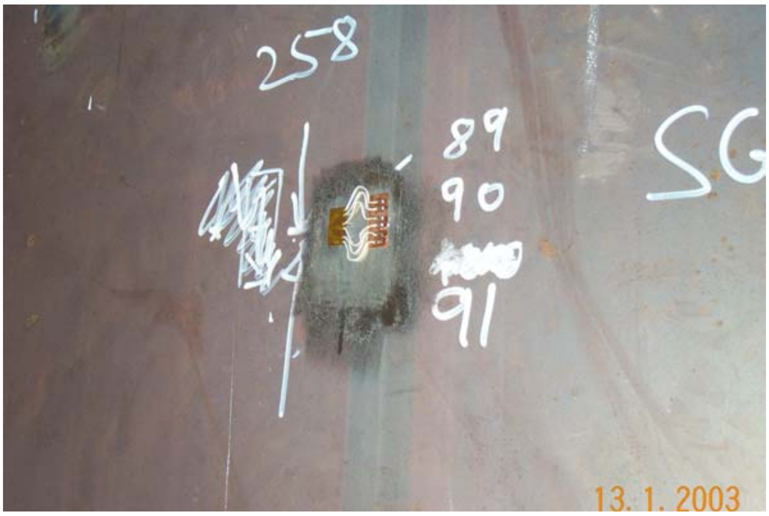
Tryktransducer placeret på pæl på hovedforankringsbøtte, anvendes til måling af bølger.

Strain gauges

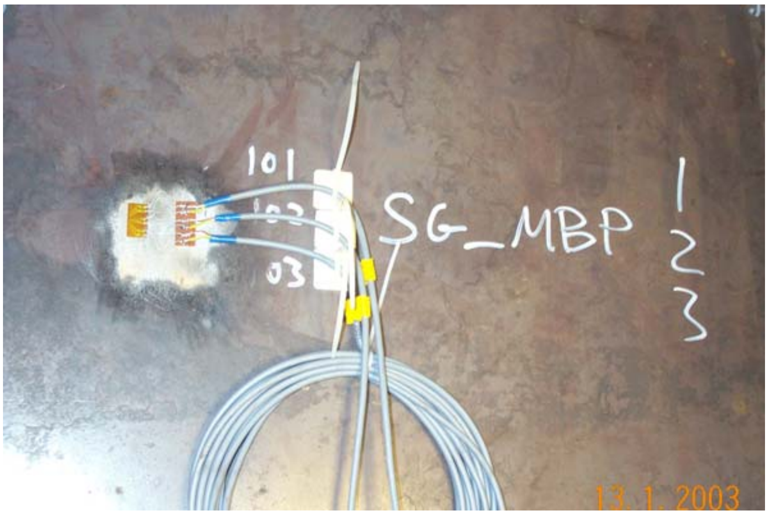
Opmærkning af placering af strain gauges (SG_MBP10-12).



Strain gauges (en rosette gauge bestående af 3 individuelle gauges) monteret, inden påsætning af kabler og og tætningsmaterialer.

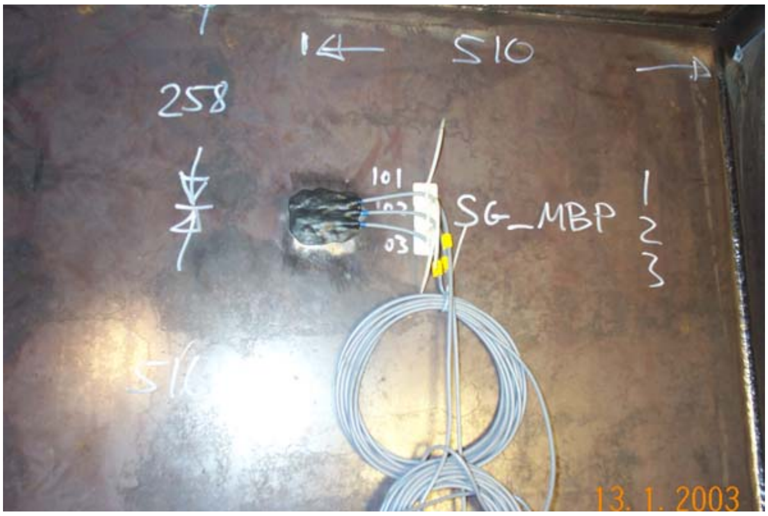


Kabler monteret på loddeterminal.

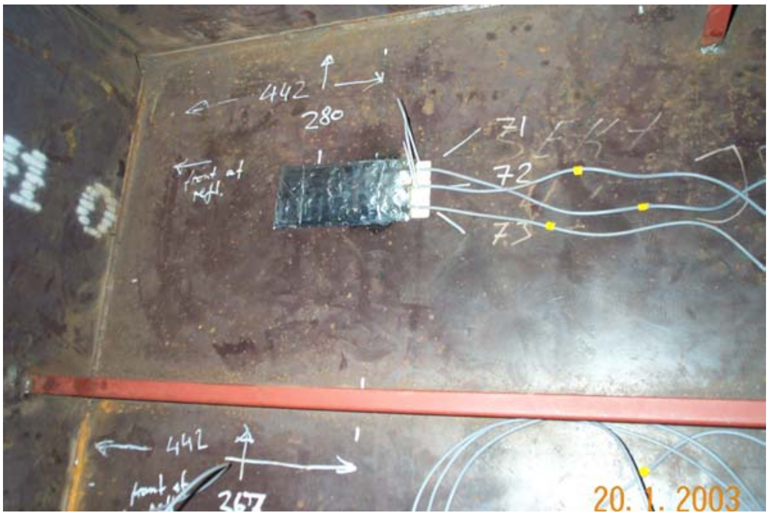


Strain gauges i hovedbjælken (i midten af platformen) inden tætning.

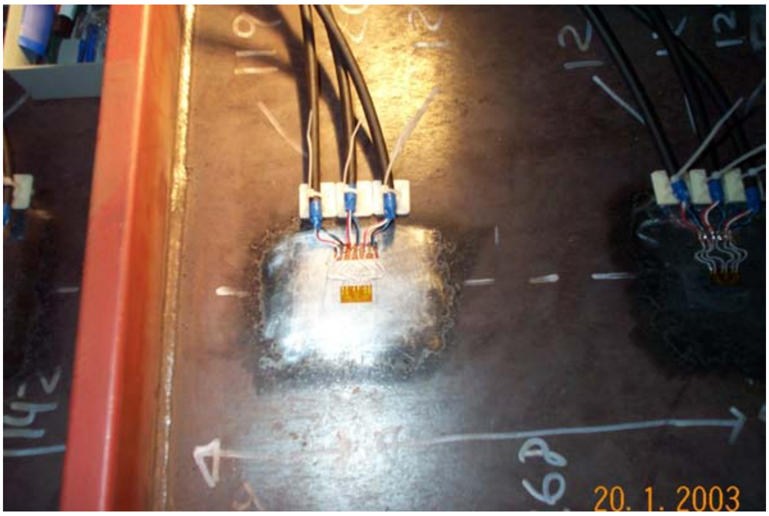
Tætning af selve rosette gaugen.



Rosette og loddeterminal tætnet.

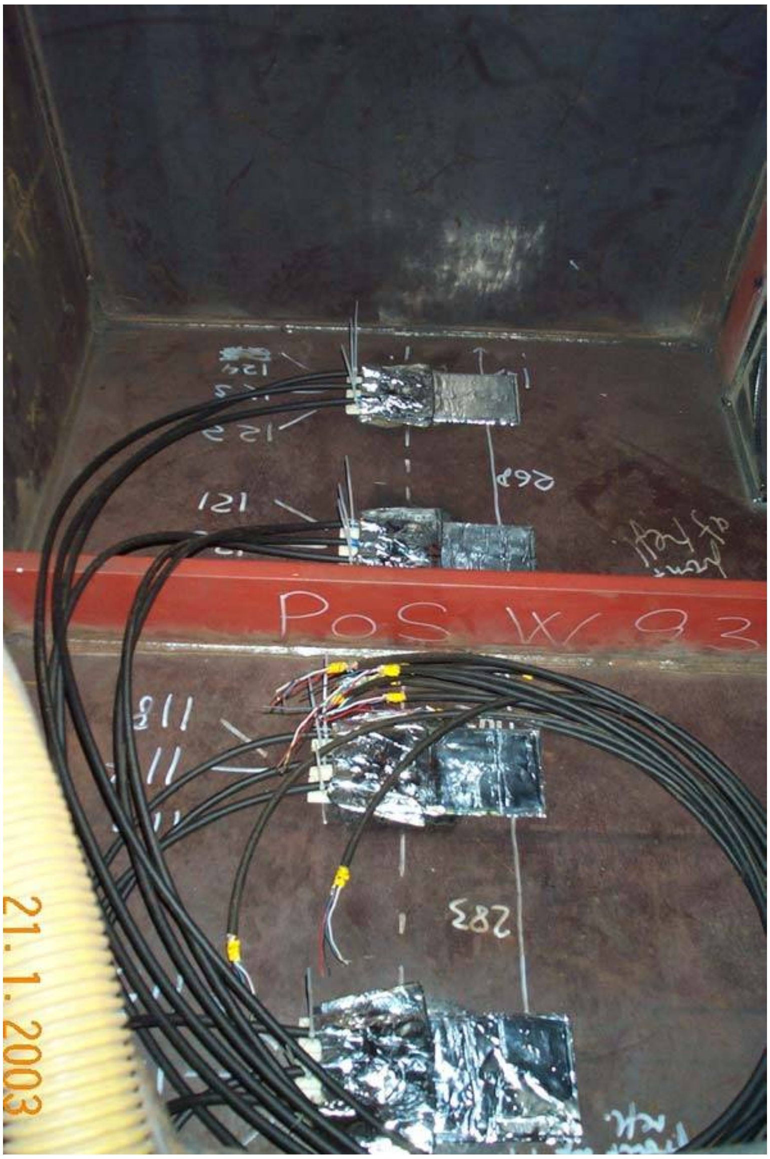


Rosette gauge i vandfyldt kammer. Her anvendes særlige vandbestandige siliconekabler.



Montagesituation.

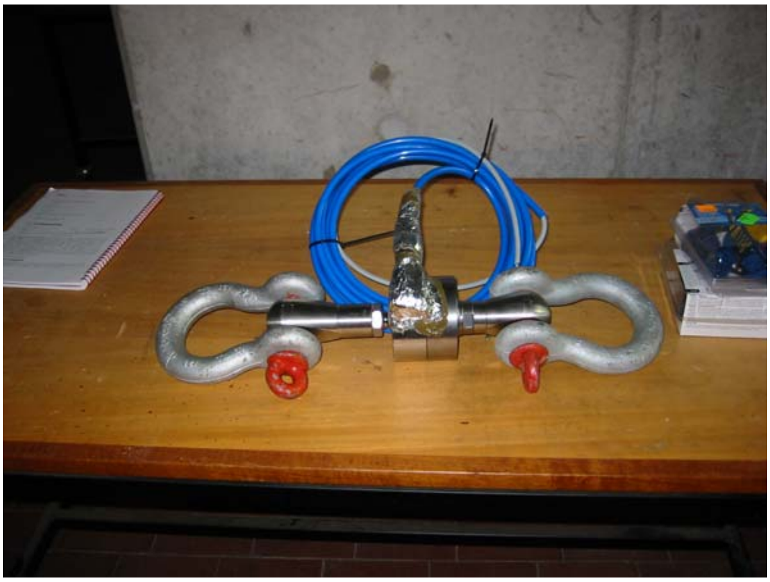
Færdigmonterede gauges i vandfyldt kammer.



Krafttransducere

Krafttransducer (100 kN) til måling af hovedforankringskraft, monteret på forankringsbøtte.

Krafttransducer (50 kN) til måling af kræfter i tværwire imellem reflektorer.

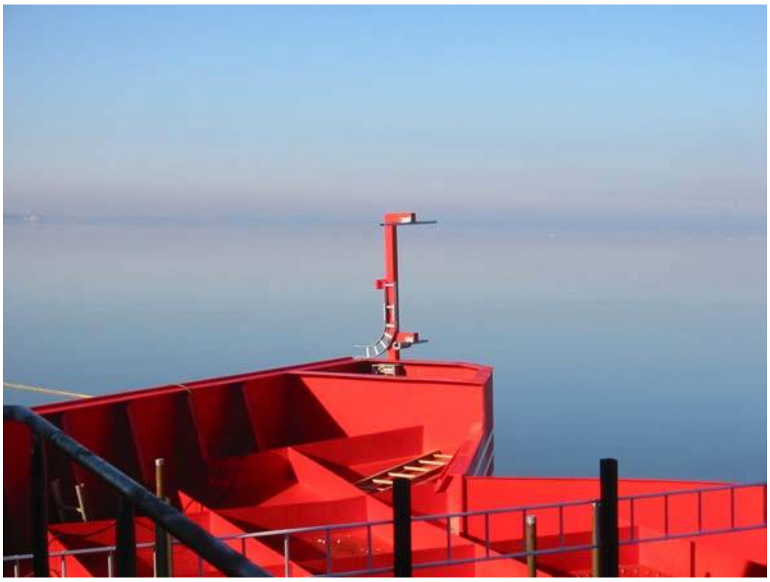


Flytningstransducere

Der monteres flytningstransducere i skulder forbindelsen mellem platform og den ene reflektor mhp. måling af deformation af fenderarrangementet i dette led.

Pæl til fastgørelse af den ene ende (reflektor) af flytningstranducer.

Pæl til fastgørelse af den anden ende (platform) af flytningstranducer. Disse pæle anvendes også til overførelse af multikabler fra reflektor til platform.



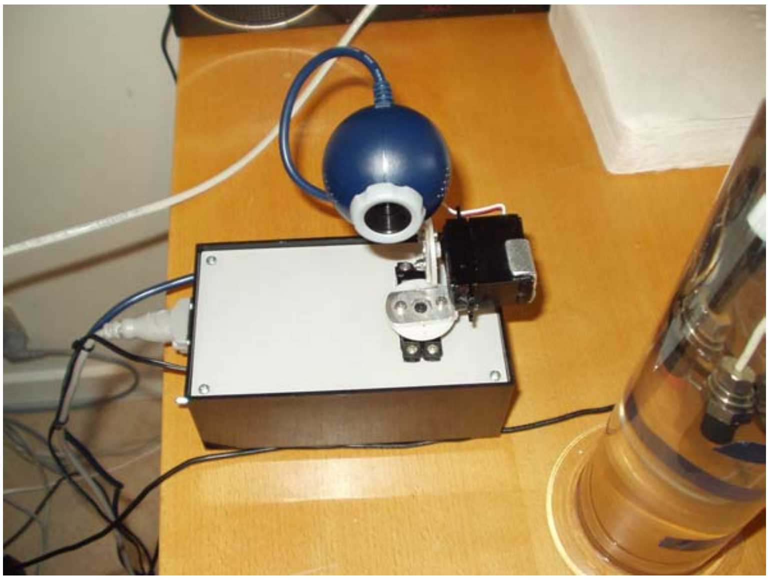
Accelerometre

Der monteres accelerometre på platform og arme til bestemmelse af disses bevægelser. På platformen placeres hhv. et vandret og et lodret i målecontaineren, samt et lodret på hver skylder. På den ene reflektor placeres et vandret og et lodret.

Pæl til montering af accelerometre på bagbord reflektor.

WebCam

WebCam med pan og tilt styring.



Appendix

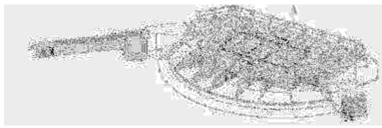
Appendix A: Setup of measuring and control system for Wave Dragon, Nissum Bredning model, DEA + EU project.

Appendix B: Details for installation of transducers and description of interfaces.

Appendix C: Funktionskrav til netværk og internetforbindelse på WD-NS.

BILAG 5

AAU, Status report First offshore experiences, Wave Dragon, Nissum Bredning



Status report
–
First offshore experiences, Wave Dragon, Nissum Bredning

Project:

Evaluation of hydraulic response of the wave energy converter, Wave Dragon,

according to Cooperation agreement between
Wave Dragon Test Aps.
and
Aalborg University, Department of Civil Engineering

Jens Peter Kofoed & Eoin O'Donovan
September, 2003

The Hydraulics and Coastal Engineering Group
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Table of contents

Introduction

This status report describes in words and pictures the first offshore experiences with Wave Dragon, Nissum Bredning model (WD-NB), after its deployment (28.03.2003) up to the present (approx. 6 months).

The report is based on the activity log in Appendix A.

Since the start of the project, material in terms of pictures, video, notes and reports have continually been published at the website http://www.civil.auc.dk/~i5jpk/wd/wdnb.htm.

The experiences so far have mainly been based on the following items:

- PLC/SCADA System
- Measuring Equipment
- Turbine Operation
- Mooring Lines
- Shoulder Connection
- Offshore Operation & Initial Testing
- Experimental Stress Analysis
- Marine Life & Growth

In the following these items are treated individually.

1. PLC/SCADA System

The running-in of the PLC/SCADA system has been on going over the period from system power up - 07.04.2003 until 01.06.2003, when the reflectors were re-mounted. During this period the basic control systems (primarily for regulating the floating level and controlling the turbines) were setup.

Fig. 1.1 Connection of WD to the grid

By the end of the period both the floating level and the turbine control systems were running in automatic mode. However, there were still items to solve, as the automatic control systems were often stopped because alarm conditions were activated e.g. due to a stuck valve.

Screen dumps from the SCADA system and pictures from the running-in of the system are presented here.

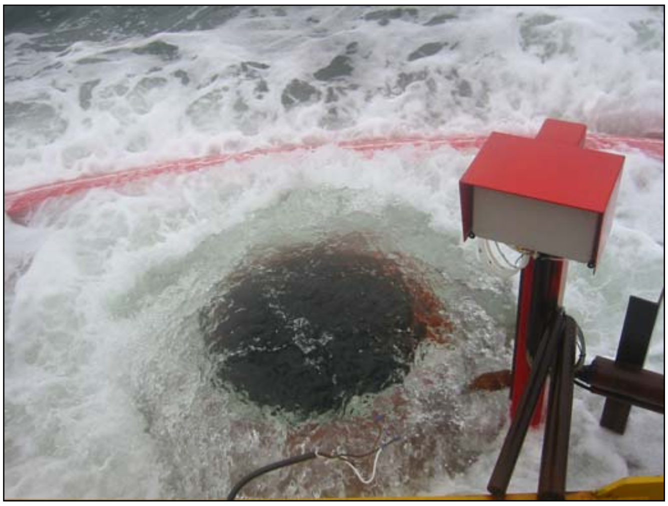

Fig. 1.2 The Flygt pump in operation

Fig. 1.2 shows the Flygt pump running which pumps water to the reservoir in the case of no incoming waves. This is incorporated in the SCADA system.

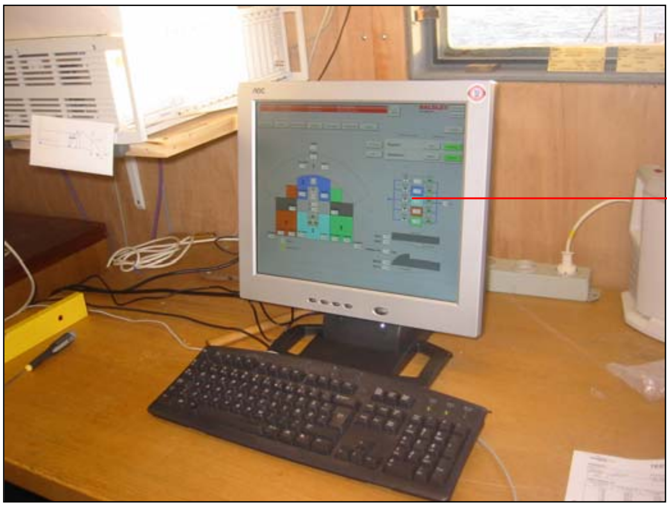

Fig. 1.3 PC screen and supporting equipment for the SCADA system

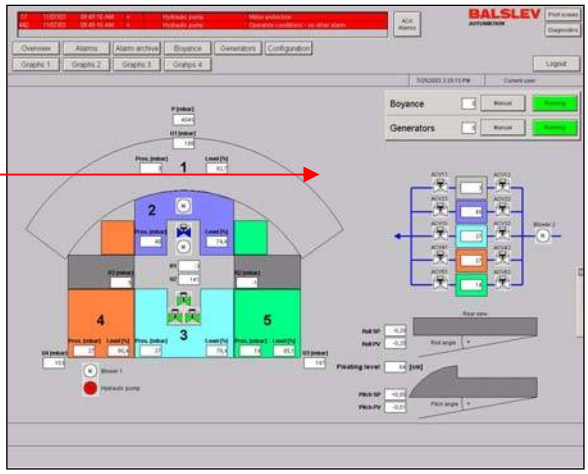

Fig. 1.4 SCADA control system main page

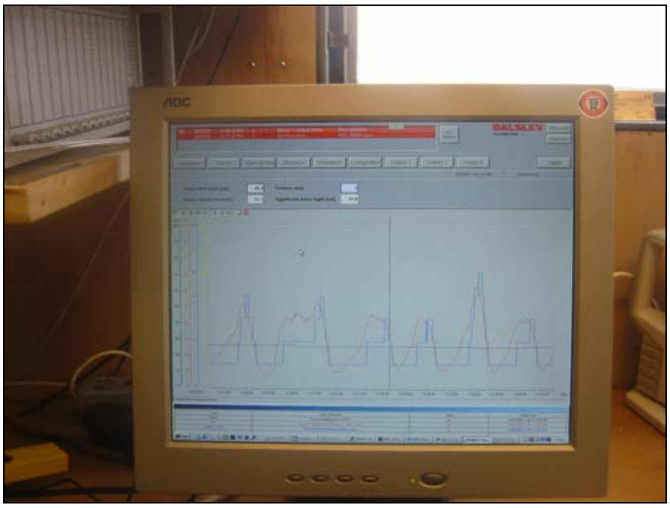

Fig. 1.5 Graphs (turbine step and water level in reservoir) from the SCADA system

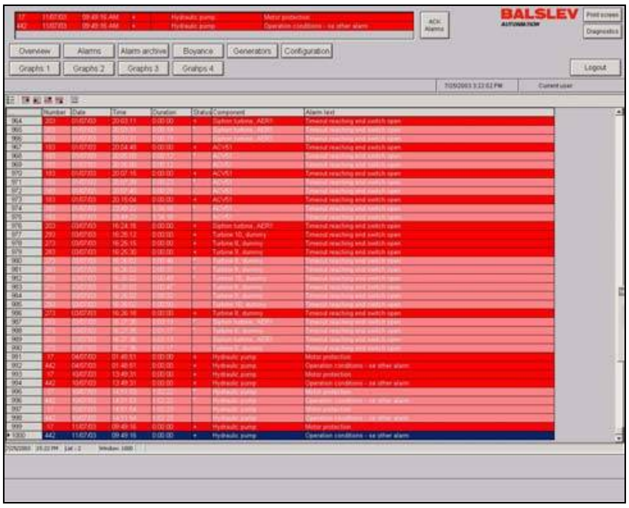

Fig. 1.6 Example of alarms from SCADA system

For further information on the PLC/SCADA system, please refer to Users Manual by Morten Nimskov, Balslev.

2. Measuring Equipment

Generally, the installed measuring equipment is described in the report 'Status report - Instrumentation of the Wave Dragon, Nissum Bredning' (in Danish). In the following additional notes on the experiences with this equipment is given, and added equipment is described.

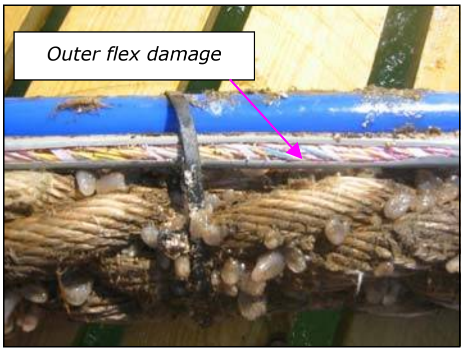

Fig. 2.1 Damaged original signal cable

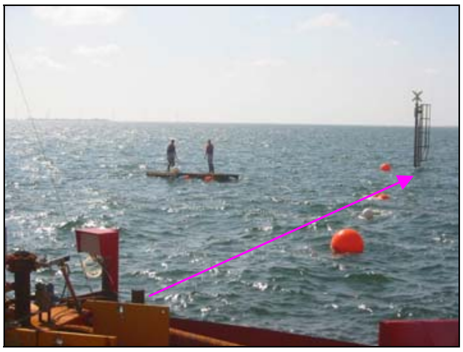

Fig. 2.2 Signal cable path

A new signal cable from the main body of WD to the mooring pile was installed (06.08.03) in light of the excessive damage to the original cable as can be seen in Fig. 2.1. The complete cable under water has been mounted in a PEL pipe for extra protection.

A weather staption (Oregon Scientific WMR-968, with wireless sensors) has been installed. The station measures:

(a) Wind speed and direction (sensor mounted on top of mooring pile, approximately 5 m above sea level, see Fig. 2.3).

Fig. 2.3 Wind vane mounted on mooring pile

Fig. 2.4 Rain-fall sensor

(b) Rain-fall (sensor placed on top of container, see Fig. 2.4).
(c) Outdoor temperature and humidity (sensor placed underneath container, see Fig. 2.5).
(d) indoor temperature, humidity and air pressure (sensor placed inside container, see Fig. 2.6).

Fig. 2.5 Outdoor temperature & humidity sensor

Fig. 2.6 Indoor temperature/humidity/air pressure sensor/panel

The data is collected from the sensors by the control panel. The control panel is connected to a PC via RS-232. On the PC the software package Weather View 32, prof. ed., is installed. The software stores the data, and puts selected data on the web in graphical form with updates every five minutes (see www.civil.auc.dk/~i5jpk/wd/wdnb.html or www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=IHURUPTH1).

In addition, a daily report of the Met data for the previous day is uploaded at twelve midnight. Daily e-mail with Met conditions are also sent to selected project partners.

Some problems, however, were met in installing the weather station. Turbulence from the mooring pile was found to influence wind direction measurements. This was remedied by raising the height of the wind vane using some steel piping. Realignment of the wind vane followed with care being taken to minimize the influence of the high voltage cable and steel pipe on compass readings.
Additionally, wind vane alignment should be validated in terms of known direction (fixed point on the horizon) or possibly the use of GPS.

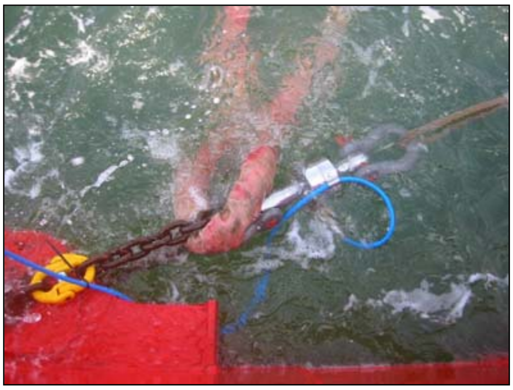

Fig. 2.7 Force transducer as originally installed

A force transducer was installed in the wire between the reflectors at the time of re-installation of the same (see Fig. 2.7). However, despite efforts to protect the force transducer wiring with a tube, the wire was broken within two months of installation (see Fig's 2.8 & 2.9). The transducer has since been repaired.

Fig. 2.8 Force transducer tube damage

Fig. 2.9 Force transducer wire failure

- It was also reported (05.08.03) that some of the pressure transducers under the structure gave strange readings, excessive marine growth being cited as a possible cause. The fault with the pressure transducer at the mooring pile was investigated and it was found that two of the connection wires in the electrical system panel were not secured in their appropriate terminals. These were promptly secured with the transducer giving pressure readings of the order anticipated.

- In addition, the transducers should be cleaned the next time the diver visits. Pipes are being installed on the main body of WD for ease of maintenance on the transducers.

3. Turbine Operation

Initial operation of the turbines highlighted the need for some adjustments including:

- Water level switches required for identifying water in aeration tube (see Fig. 3.1) and lubricating water in siphon turbine (See Fig. 3.2).

Fig. 3.1 Aeration tube water level switch installation

Fig. 3.2 Siphon turbine water level switch

- Large diameter pipe in aeration tube to avoid water in the vacuum pump (See Fig. 3.3).
- Debris collecting at the dummy turbines in cases of heavy overtopping, preventing operation of same. This problem will be eliminated with the planned inclusion of mesh fence to be placed all around the turbine area prior to the start of operation of the cylinder gate turbines.

Fig. 3.3 Large diameter pipe installed in aeration tube

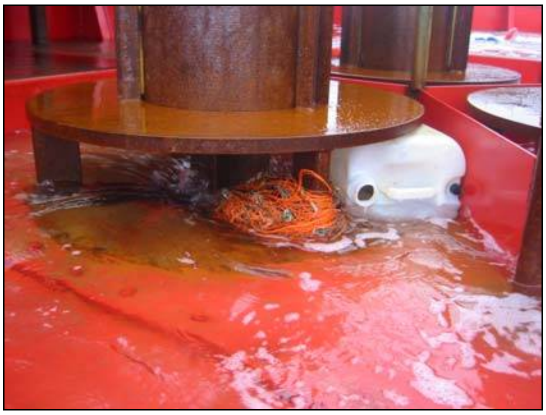

Fig. 3.4 Debris collecting at the dummy turbine cylinder gate

- Intrusion of saltwater in solenoids controlling the hydraulic pistons in the turbines. This has on more than one occasion lead to malfunction of the pistons. Some kind of shielding of these units is necessary.
- Corrosion of black steel dummy turbines. More on that below.

Fig. 3.5 Saltwater corrosion of solenoid (23.06.03)

The adverse effects of sea conditions on the operational integrity of WD has nowhere been more noticeable than in the functioning of the dummy turbines. It is interesting to compare the depreciation of the turbine gate material (black steel) over the five month period at sea. Fig. 3.6 shows the dummy turbine shell after deployment in late March. In contrast, the severe erosion of the annular ring of the turbine gate through which the shell slides is clearly evident four ½ months later.

Fig. 3.6 Dummy turbine condition (31.03.03)

Fig. 3.7 Severe erosion of dummy turbine gate (11.08.03)

As a result of this erosion, two of the three dummy turbines jammed. In addition, the hydraulic cylinder in one of the turbines was damaged (bent) in the process of attempting to move it. The cylinder was removed and has since been repaired at the workshop.

In light of theses operational problems, dummy turbine re-conditioning work was carried out (15.09.03). All three turbine shells were extracted individually using the hoist shown in Fig. 3.8 before rust removal and treatment was carried out (Galvafroid and greased). The result is shown in Fig. 3.9.

Fig. 3.8 Hoist used for dummy turbine removal

Fig. 3.9 Dummy turbines following maintenance

This allowed the shells to open and close effectively. In addition, the re-conditioned hydraulic cylinder was installed in the appropriate turbine. All three turbines now operate satisfactorily. Doubts remain, however, as to the long term operating ability of same. Efforts need to be concentrated on improving the vertical guidance of the shells with a self-centering system preferred.

Another point of note involves the operation of the siphon turbine. It was reported (11.08.03) that the hydraulic cylinder for operating the aeration valve on the siphon turbine did not work. Without any corrective action in the interim, this valve was found to function on the visit dating 15.09.03. Despite this, it is planned to carry out inspection tests on all turbines (dummy and otherwise). A good opportunity to carry out this work may be to correspond with the installation of the systems on the six new Kössler turbines (Danfoss).

Turbine calibration data (screen-dump from SCADA system- see Fig. 3.10) comprising time plots of Turbine Rotational Speed (N), Turbine Power (P), Relative Basin Level (RBL) and Floating Level (FL) have been established for various values of Basin Work Span (BWS).

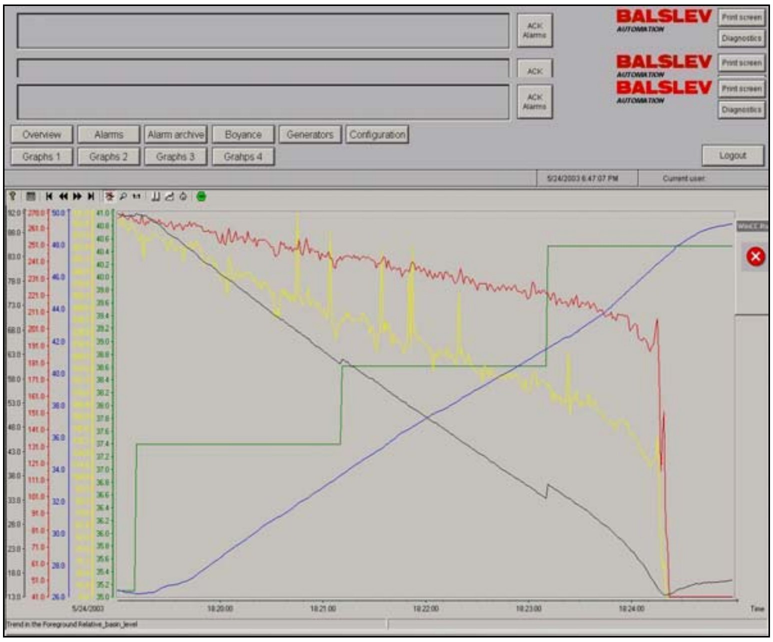

Fig. 3.10 Turbine calibration plot

This plot was used to estimate the Specific speed for the Siphon turbine in use on WD by carrying out the following steps:-

- Divide the plots into 20 second intervals, noting the values for N, P, RBL & FL at each interval.
- Calculate the Reservoir Area from the accompanying CAD drawing.
- Calculate the Basin Level (BL) = Crest Height – ((1-RBL)xBWS)
- Calculate Flowrate (Q) = (Reservoir Area x Change in BL)/Time Interval
- Calculate Head (H) = Average Floating Level – [(1-Average RBL)x BWS]
- Specific speed, $N_S = \dfrac{N\sqrt{Q}}{H^{0.75}}$

Crest Height = Vertical Distance from floor (turbine level) to the crest.

From such data a specific speed of 340.6 resulted.

On 12.09.03 the six cylinder gate turbines were installed. Below are some of the pictures from the process.

Fig. 3.11 Unloading of turbine centre section (runner & guide vanes)

Fig. 3.12 Installation of floor plates

Fig. 3.13 Draft tube & centre section assembly

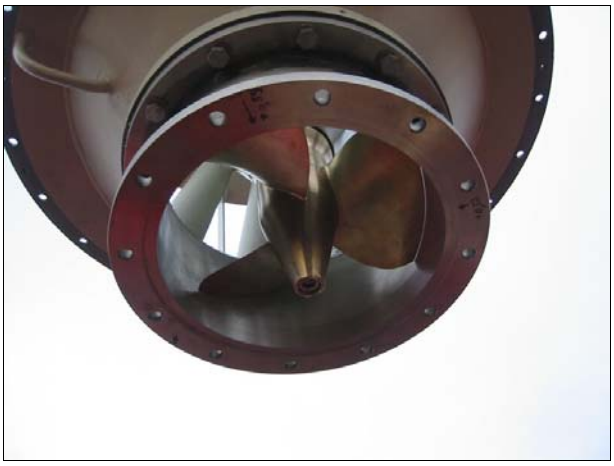

Fig. 3.14 Turbine Runner

Fig. 3.15 Installation of draft tube

Fig. 3.16 Installed turbines

4. Mooring Lines

Generally, mooring lines have proved to be a sensitive part of the plant. The experience of the first weekend after installation, which lead to the dislocation of the reflectors, underlined the importance of pre-tensioning of the mooring lines to keep the reflectors tightly into the shoulder connection. Thus, the uncertainty of the extension of nylon ropes under load has shown itself to be problematic.

Another area of concern involves the wear of certain mooring lines due to contact with edges of the WD structure. A case in point is the wear of the mooring lines from the rear of WD to both reflectors on rubbing against the base reinforcement gusset's. This problem has been remedied by attaching some guide brackets to the main structure to deflect the ropes from the gusset's as can be seen in Fig's 4.1 and 4.2.

Fig. 4.1 Mooring equipment for deflecting lines from rear of WD

Fig. 4.2 Installed mooring attachments

It is clear that, in the absence of appropriate mooring maintenance procedures, the stability of WD is severely jeopardised. Evidence of this has presented itself on more than one occasion. For example, it was noticed (19.08.03) that one of the ropes connecting to the main body (starboard side) had completely failed due to rubbing contact with the shoulder window on the main body.

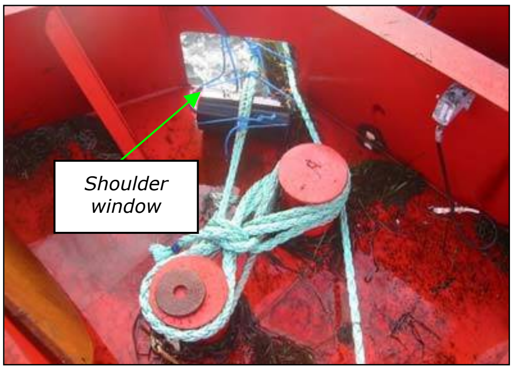

Fig. 4.3 Rubbing at shoulder window

Fig. 4.4 Cut mooring rope with resulting stability problems

Chain has now been used for the section, on both port and starboard shoulders, near the bollards, to prevent this type of failure again (see Fig. 4.5). Note: Rounded edges are to be installed on the lower edge of the shoulder window to prevent steel–steel wear.

Fig. 4.5 Chain section near shoulder

In addition, the mooring lines from the reflector tips to the mooring pile were shown to possess significant wear (29.08.03). This was especially true of the mooring line to the starboard reflector at the mooring pile end (See Fig.4.6).

Fig. 4.6 Significant wear on starboard reflector mooring line

Fig. 4.7 Improved mooring line protection

This was remedied by placing a shackle and thimble on the main rope from the body to the mooring pile (See Fig. 4.7). The shackle accommodates the thimbles on the ends of the mooring lines from the reflector (which were reversed). For completion and extra protection, thimbles have been placed on the opposite end of the reflector mooring lines. Both the fore mentioned mooring lines had their lengths modified to comply with the designated 42m.

Fig. 4.8 Original reflector tip mooring arrangement

Fig. 4.9 Improved thimble/shackle mooring arrangement

Note: Initial installation of thimbles was carried out with the assistance of a representative from rope manufacturers *Randers Reb.*

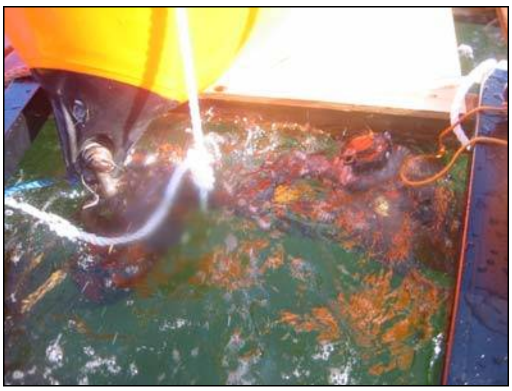

Fig. 4.10 Mounting of buoy using shackles (10.07.03)

Buoy mounting had also proved difficult. Rope attachment of same at mooring junctions has been insufficient with the ropes being cut. Instead shackles have been used as per Fig. 4.10.

5. Shoulder Connection

The first attempt to deploy the completed (reflectors attached) Wave Dragon at test site 1 in Nissum Bredning (27-28.03.2003) partly failed, as the reflectors were dislocated from the main platform during harsh wind conditions in the days (30.03.2003) after installation. Refer to Appendix B for details while pictures in the aftermath of the incident are provided below. In addition, Appendix C outlines details for reflector re-installation.

Fig. 5.1 Extreme heel of WD after reflector disaster

Fig. 5.2 Towing of reflectors to WD for re-installation (1.06.03)

Fig. 5.3 Rubber fender/fishtail plate being loaded on to WD

Fig. 5.4 Re-installation of fenders/fishtail plates at shoulder joint

Fig. 5.5 View of lower fishtail plate showing rings for chains

Fig. 5.6 Wave Dragon with reflectors re-installed

One of the most challenging aspects of the off-shore deployment of WD has undoubtedly been the on-going monitoring and improvement of the shoulder/reflector interface design. The latest episode of damage resulted from high winds (15.08.03). Peak wind speeds of 25 m/s were reported. Analysis of the damage showed that partial failure of the fender arrangement had occurred on both port and starboard sides of WD.

On the starboard shoulder, one of the nuts (inner most, see Fig. 5.7) securing the fender chains to the top fishtail plate had loosened completely allowing the fender and chain to fall out of the shoulder/reflector joint.

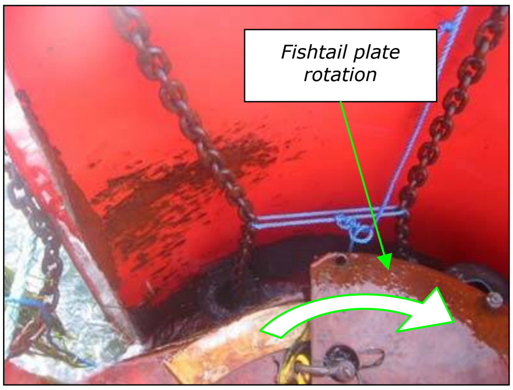

Fig. 5.7 Fender chain loosened and misplaced

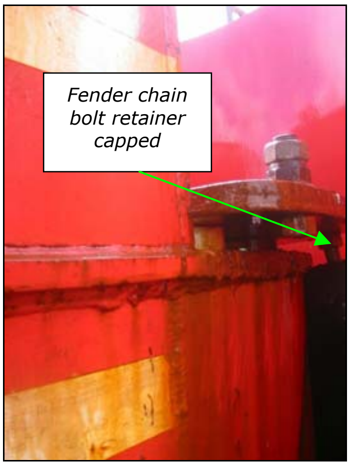

Fig. 5.8 (a) & (b)- Complete capping of outer fender retaining bolt

It is assumed that the subsequent transfer of forces to the remaining chains caused the failure of the outer fender chain bolt retainer on impact with the edge of the shoulder on the main body (see Figs. 5.8 (a) & (b)) as the upper fishtail plate was now more free to pivot about its centre.
It is also clear (Fig. 5.9) that the steel rods retaining the fishtail plates were not sufficient to oppose the excessive forces. The obvious resulting metal-metal contact was subsequently prevented (temporarily) by suspending two additional fenders by chain in the inner (wave side) annular gap left by the, now misplaced, original fenders.

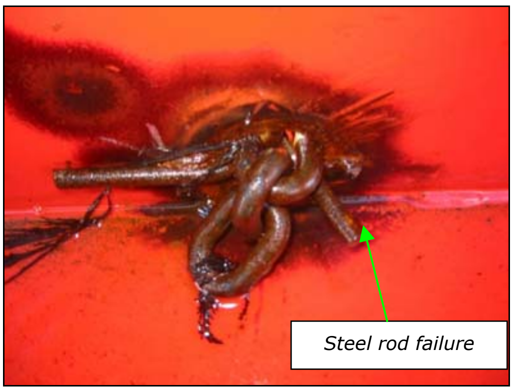

Fig. 5.9 Insufficient retaining of fish-tail plates

Fig. 5.10 Capping of port fender chain bolt retainer

On the port side, the three innermost fender chain retainer bolts had completely sheared, again on the threads at the lower side of the upper fishtail plate (see Fig. 5.10).
It is assumed that the chains were "pinched" by the misalignment of the floating level of the main body.

This misalignment, which may have, in part, occurred due the transfer of air from cells, especially with the high floating level of the main body, or, alternatively, due to improper operation of valves (not closing fully), caused the main body to pitch forward and reduce the gap between the upper fishtail plate and the reflector (see Fig. 5.11).

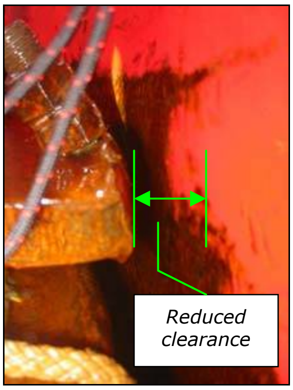

Fig. 5.11 Reduced distance between fishtail plate & reflector

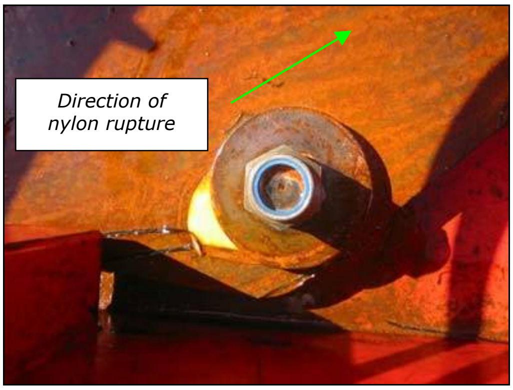

Fig. 5.12 Failure of nylon insert on fishtail plate

The natural movement of both the main body and reflector is likely to have generated enough impact force to cause failure of the nylon insert on the fishtail plate (see Fig. 5.12).

The resulting "play" in the fishtail plate meant that, on impact with the reflector, the chain bolts were pinched by the edge of the shoulder on the main body.

A similar course of action to that on the right hand side was employed here to prevent metal-metal contact.
The severity of the damage is well illustrated by examining the port shoulder as per Fig. 5.13.

Fig. 5.13 Damage to port shoulder

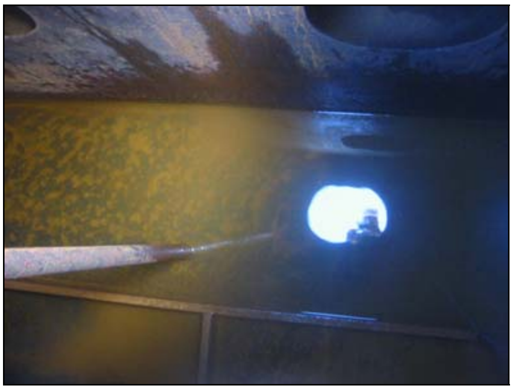

Fig. 5.14 Flooding of port shoulder

It is widely regarded that unexpected tilt in WD (port side) was in some way responsible for the capping of the fender chains on that side from the obvious reduction in clearance between fishtail plate and reflector. This tilt, which was present before the storm damage, was later identified to result mainly from water in one of the closed chambers in the port shoulder, not discounting the possible contribution from the earlier theories. As a result, this water was removed from the chamber using a submersible pump with depths of 1 meter reported in extreme sections (see Fig. 5.14)
Submersible pumps have now been installed in both port and starboard shoulders.

In an effort to combat the previous problems experienced at the shoulder connections, it was decided to permanently weld the upper fishtail plates to the shoulder.

This involved removing the outer lip of the fishtail plate (thus also preventing any further opportunity to "pinch" the fender chain bolts should the clearance between the plate and reflector be substantially reduced again). The inner bolting region of the fishtail plate was also surplus to requirements and likewise removed. (See Fig. 5.15)

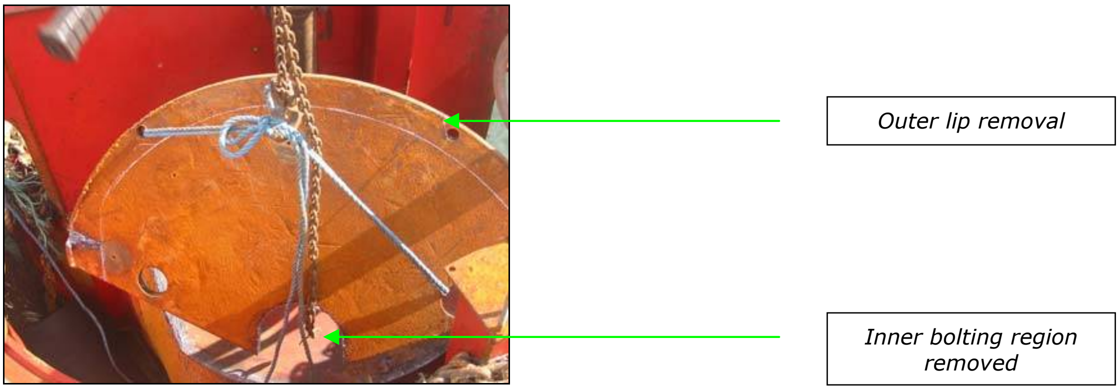

Fig. 5.15 Fishtail plate modification

The resulting welded fishtail plate is shown in Fig. 5.16 Note also that brackets (into which fits a support frame) have been added in the shoulder region to aid in the deployment of the rubber fenders at the interface.

Fig. 5.16 Modified fishtail plate

In place of threaded chain tensioners, rings have been welded to the fixed fishtail plate (See Fig. 5.17). These rings will suspend the vertical fender chains while being secured using chain-locks.

Fig. 5.17 Fishtail plate with chain rings welded

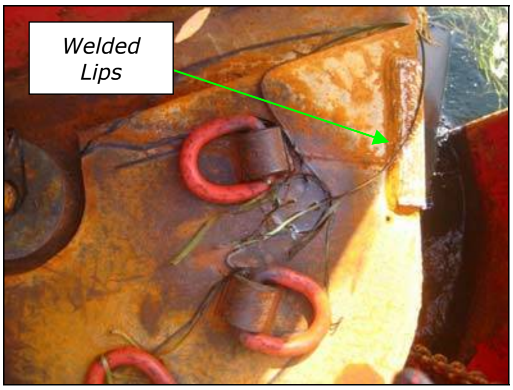

Fig. 5.18 Fishtail plate lips

Note also that five lips have been welded (See Fig. 5.18) at the shoulder edge to provide a smooth overhang for the vertical chains. Extra security is also being afforded at the shoulder connection with the inclusion of horizontal chains connecting the vertical fender chains, which will keep the latter equally spaced. Lost fenders have also been recovered from the sea bed while the chains have been located by attaching ropes to WD.

Fig. 5.19 clearly illustrates the severity of the forces at the reflector/shoulder interface.

Fig. 5.19 Rubber fender damage

Fig. 5.20 Lower fishtail plate (starboard) misplaced

During fender retrieval, it was noticed by the diver that the lower fishtail plate on the starboard side had the bolt and retaining nut capped off. The resulting overhang of the fishtail plate is clearly seen in Fig. 5.20. This problem, which has since been found to have also occurred on the port side, has been remedied by modifying (see Figs. 5.21 & 5.22) and restraining (see Fig. 5.23) the fishtail plate to the rear of the shoulder.

Fig. 5.21 Modified lower fishtail plate

Fig. 5.22 Point of restrainment of modified fishtail plate

Fig. 5.23 Tensioning of fishtail plate

Fig. 5.24 Original damage caused by fishtail plate bolt

6. Offshore Operation & Initial Testing

Generally, experience has shown that visits to WD test site 1, Nissum Bredning, especially for the purpose of structural maintenance work, are not recommended when the wind speed exceeds 10m/s and blowing in a direction ranging from South to North-West.
The following summarises some of the more abstract offshore behaviour of WD.

With a high floating level and in the case of larger waves, it has been observed that there is a tendency for air to escape from the foremost air compartments with the result being a heeling forward of the main body.
In addition, there has been greater instability in heel and trim movements with high floating levels.
Fig. 6.1, which depicts WD movements for given floating levels, is evidence of these instabilities.

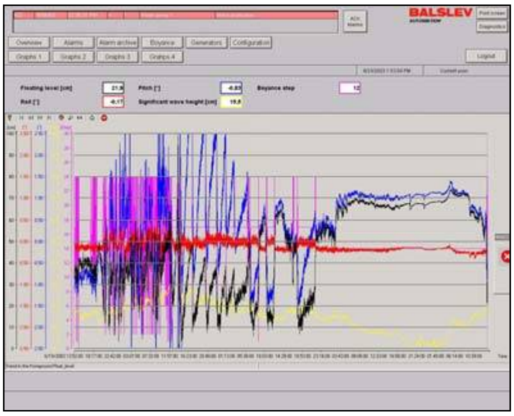

Fig. 6.1 Floating conditions in harsh wave climate

Much of the preliminary testing was carried out without the reflectors in place. An obvious initial test was to examine the floating ability of the main body. This involved evacuating the air chambers and flooding the reservoir. As observed from Fig. 6.2, WD showed no signs of sinking.

Fig. 6.2 Complete flooding of reservoir with no pressure in air chambers

Fig. 6.3 Extreme heel to the rear

It was also of interest to examine the behaviour of the main body in cases of significant heel to the front and rear. In the case of extreme heel to the rear it is obvious from Fig. 6.3 that there is no flooding of the container. Indeed there is an allowance of approx. 20cm from water level to container base.

In contrast, Fig. 6.4 shows WD with a heel of approx. 10° in the forward direction. A useful feature of forward heel is the ability to walk along the rear base-plate to carry out maintenance work (see Fig. 6.5)

Fig. 6.4 Heel of 10° to the front

Fig. 6.5 Base-plate uncovered

Turbine Performance Data

The specific speed, as obtained from turbine calibration data, was used in the evaluation of actual (overtopping) power production data (see Fig. 6.6). A similar approach to that used in the evaluation of the turbine calibration plot was adopted with time intervals of 10 seconds being used on this occasion to yield Flow V's Time performance series for WD as shown in Fig. 6.7.

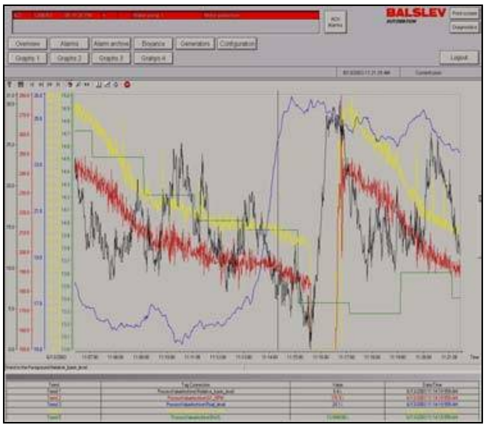

Fig. 6.6 Power production plot

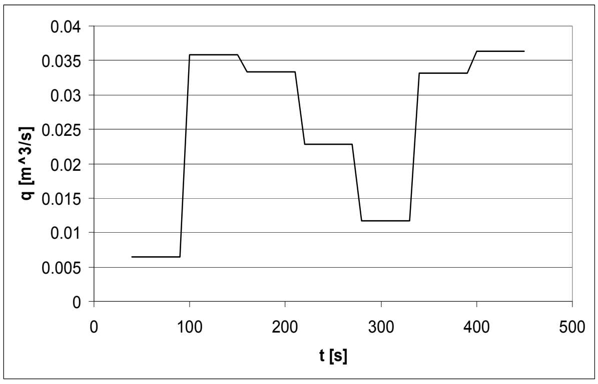

Fig. 6.7 Flow V's Time series

Furthermore, the discharge due to overtopping was evaluated from established relationships based on the doubly-curved overtopping ramp (ref. §5, "Forces and overtopping on second generation Wave Dragon for Nissum Bredning, Hald & Frigaard, 2001) and compared with experimental results from the second Generation WD model. Laboratory and calculated dimensionless overtopping discharge rates compared favourably here:) Calculated – 0.014 m^3/sec

Measured - 0.025 m^3/sec

In contrast, the power production as depicted by the SCADA system does not agree with the hydraulic power (i.e. mass flow rate x acceleration due to gravity x head).
Figures for average power production from SCADA and hydraulic power look like the following:-

SCADA power – 150 W
Hydraulic power – 10 W

Clearly, some further analysis must be afforded to this area in an effort to establish the reasons for disparity here.

1. Reflector arm

Generally, strain gauges are placed midway in between the reinforcement gusset's at three locations along the arm. It is desired to undertake an analysis of the cross sectional forces on the reflector with time.

A. Normal Force, N

Looking at a cross section of the reflector arm, we see something like the following:

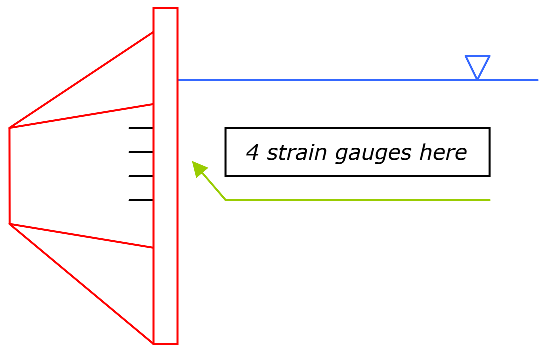

Fig. 7.1 Reflector cross section showing strain gauge placement

Normal force is the force into the plane of the page. Say we have a stress situation at a strain gauge like the following:

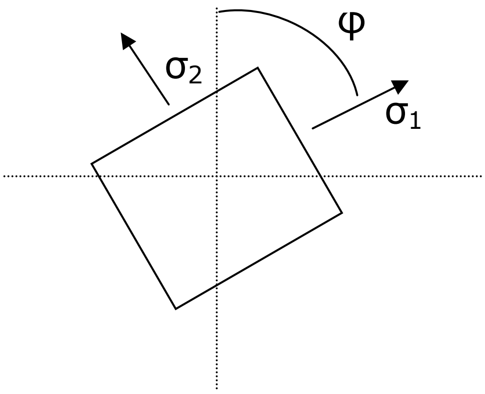

Fig. 7.2 Possible stress situation at a gauge

With $\sigma_{1,2}$ as the principle normal stresses and φ, the principle angle.

The *total* normal stress is σ_1 cosine(90-φ) & normal stress is (Normal force/Normal area) with Normal area equal to the area of the cross section.

Now the total Normal stress is = $\frac{N}{A} + \frac{My}{I}$ ....(i)

where M, Bending moment

y, Distance from the Neutral axis to particular strain gauge

I, Second moment of area of the section

Say we have a stress distribution (Linear) across the four strain gauges like that in Fig. 7.3,

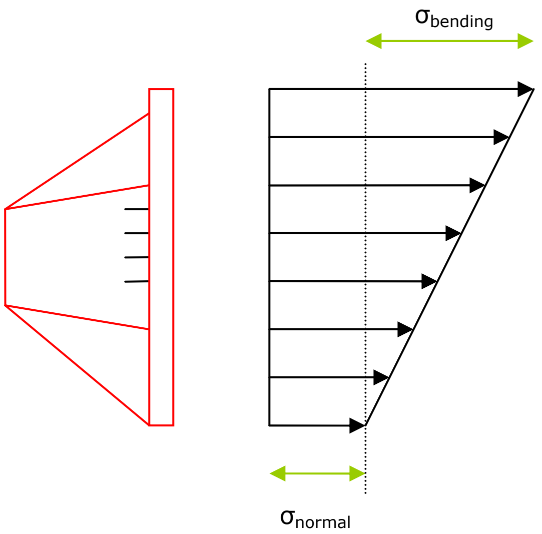

Fig. 7.3 Stress distribution across gauges

The four stress results can be extrapolated. The extrapolation to the lower part of the reflector gives the Normal stress equal to (Normal force/Normal area).
Knowing the normal area, the normal force, N, can be deduced.

B. Bending Moment, M

The only unknown in the equation (i) is the bending moment, M.
But since we have four points to produce the distribution, we can also curve fit a line to the data.

C. Shear force, Q

The maximum shear stress acting is $\frac{\sigma_1 - \sigma_2}{2}$

acting at 45° to the principle planes.
Since we know that the shear area is equal to the normal area then,

Shear force = shear stress (Q) x shear area (A)

This methodology needs to be implemented in the Catman® measurement data system on board WD.

In light of the fact that WD intends to stationed at test site 1, Nissum Bredning, for the foreseeable future, the online monitoring aspect of the project has taken on a much greater significance. The following deals with the more prominent aspects of same.

- It was established (26.08.03), on consulting with Torsten Bach (Siemens technical representative), that a signal for Fixed Wireless Access (FWA) for Internet connection could be established via Lemvig – thus avoiding the need to erect a tall, specialised mast, in the event of using a signal from Hurup, as was originally thought. In light of this, the existing roadside wooden pole, which supports the network cable interface as well as other electrical transmission features, has been made more secure with the addition of some wire-rope stabilisers to ground level as seen in Fig. 8.1.

Fig. 8.1 Wooden pole stabilised using wire rope

Fig. 8.2 Wooden pole with transmitter attached

- Additionally, The Firewall was opened up allowing access from outside with a NetOp host providing remote control of the PC on board Wave Dragon. Another, freely downloadable, remote control host, “TightVNC”, was installed.

- Measured meteorological data is now being published on the web in graphical form with updates every five minutes. In addition, a daily report of the Met data for the previous day is uploaded at 12 midnight. Daily e-mail with Met conditions are also intended to be sent to selected project partners.

- Work is progressing on a Network Management system that will allow an efficient monitoring of SCADA alarms in the WD control system. It is intended to send e-mails to selected project partners when alarms are activated,. e.g – low level of working fluid in pump.

- A Virtual Private Network (VPN) also intends to be set up

9. Marine Life & Growth at WD Test Site

It has been interesting to observe the various marine life at WD test site 1, Nissum Bredning. The prominent creatures as well as the various marine growth is illustrated below. Additionally, from a wildlife conservation perspective, no ducks have been cited at the test site.

Fig. 8.1 Early moss growth on damper plate

Fig. 8.2 Recent view of marine growth underneath the structure

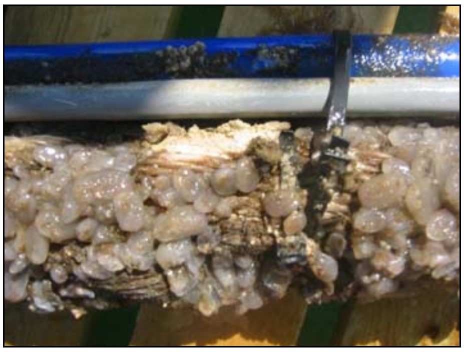

Fig. 8.3 Ascideans on rope to mooring pile

Fig. 8.4 Marine reeds growing near the force transducer

Fig. 8.5 Blue mussels seen growing around the structure

Fig. 8.6 Herring swim around the edge of WD

Fig. 8.7 A fiord-Tern sits on the reflector tip waiting for lunch

Fig. 8.8 The Herring in Fig. 8.6 more developed

Appendix A: Activity log

Date	*Description*	*At site*
03.03.27	Main body placed at test site 1.	JPK, NH (AAU), JP (MON), LC (SPOK), EFM (LOW)
03.03.28	Arms towed from Thyborøn to test site 1 and attached to main body.	JPK, NH (AAU), JP (MON), LC (SPOK), EFM (LOW)
03.03.30	Storm. Gusts of over 25 m/s. Arms are dislocated. Port arm capsized.	BP (FC)
03.03.31	Arms removed from main body and towed to Thyborøn. Electrical work at site started.	JPK ND (AAU), Anders (LIN)
03.04.07	Grid connection is established. Power is on the system.	JPK (AAU), LC (SPOK), JP (MON), Anders (LIN), Surveyer (Insurance)
03.04.08	PLC is started up. (Balslev)	Anders (LIN), MON (BAL)
03.04.09	Pressure transducers offset and cal., SCADA installed.	MON (BAL), JPK (AAU)
03.04.11	Wiring, floating level tests, oil in turbine. Severe wave conditions - not suitable for visit! Landing on beach necessary.	JPK, NH (AAU)
03.04.23	Ballasting of front tanks. Starboard, front (small) tank filled with 2.88523 m^3. Aft, front (small) tank filled with 2.63739 m^3. Turb10 (dummy) stuck. Greased with oil, driven a few times, then ok.	JPK, 4 Italians (AAU)
03.04.29	Severe wave conditions - not suitable for visit! Landing on beach necessary. 8 - 10 m/s from SW, Hs ~ 0.50 m (see 03042901.mea). Floating tests performed (for Sune & Jesper - and us).	JPK, NH (AAU), Sune, Jesper (AAU stud., B10K)
03.05.03	Demonstration.	JPK (AAU), EFM (LOW)
03.05.04	Demonstration.	EFM (LOW) + guests from 'bølgetræf'
03.05.07	PLC testing, installation of 'U'-tube, level switches. Siphon turbine tested. Flygt pump tested.	MON (BAL), JPK (AAU) Per, Morten (AAU stud.) Henrik (Lindpro)
03.05.08	Good waves! Automatic control of turbines tested - works, with minor problems! Steady tests run in Hs (p+ at pile) 0,35 - 0,5 m, floating level 0,5 - 0,6 m. Evacuation of siphon turbine results in water in blower. Piping taken to shore to be altered. Problems with Belimo valves - they easily get stuck. MON notebook wet - not working!	MON (BAL), JPK (AAU) EFM (LOW), JP (MTH), partly
03.05.19	Hs (p+ at pile) 0,14 m. Dummy turbine 10 out of order, hydraulic problem. 110 mm tube mounted on siphon turbine. Security equipment mounted.	MON (BAL), JPK & NH (AAU)
03.05.20	New tube on siphon turbine. Tests with extreme heel.	MON (BAL), JPK (AAU)
03.05.21	Working on PLC/SCADA. Making wire connections for strain gauges.	MON (BAL), NH (AAU)
03.05.22	Working on PLC/SCADA.	MON (BAL), EFM (LOW)
03.05.23	Project partners visiting.	JPK (AAU), EU meeting
03.05.24	Turbine calibration	JPK, WF & SR (TUM)

03.06.01-05	Preparation of installation of reflectors. Motor protection failure on BLOWER 2, 03.05.29 corrected manually	JPK (AAU), EFM (LOW), JP, Leif + 1 (MTH)
03.06.12-13	Work with reflectors	
03.06.16	Working re-establishing signal cable connections from port reflector to container.	Anders & apprentice (LIN)
03.06.17	Working re-establishing signal cable connections from port reflector to container. Approval from Shipping Administration.	Anders & apprentice (LIN), Peter Madsen (Søfartsstyrelsen)
03.06.18	Working re-establishing signal cable connections from port reflector to container.	Anders & apprentice (LIN)
03.06.23	Italian invasion. Problems with hydraulic cylinder for siphon. Cylinder gate dummy turbines blocked by debris. Debries in all dummy turbines. Steel to steel contact in shoulder connections.	JPK, PF, Luca, Paolo, Andrea (AAU)
03.07.01-02	Repair of port shoulder/fender arrangement Port top fishtail plate fallen down During temporary reparation one of the bouys where punctured, signal cable probably damaged	JPK (AAU), EFM (LOW), JP (MTH)
03.07.10	Raft construction and bouy mounting. Signal cable in port shoulder damaged. Signal cable at force transducer in cross wire damaged	JPK, PF, ND & KSS (AAU) + EFM (LOW)
03.07.15	Jens & Morten visiting	JPK, PF, JJ & MA (AAU)
03.07.25	Inspection of mooring lines, shoulder connections - ok. Wire to pile checked - shortcuts between some of the conductors. No visible problems on pile. ACC_P1 and ACC_P2 installed and calibrated. Crane on raft lubricated and protected by plastic bag. Wire to pile checked - shortcuts between some of the contuctors. No visible problems on pile. ACC_P1 and ACC_P2 installed and calibrated. Crane on raft lubricated and protected by plastic bag.	JPK, NH (AAU)
03.08.04-06	Installation of new fishtail plates and rubber fenders. Installation of thimbles on mooring lines D and I. Port D still needs to be turned around, as the thimbles have been put on the platform end of the line. This also goes for the I lines. New E lines with thimbles where supplied. Have not been installed yet due to too heavy weather. New signal cable to pile was installed. The complete cable under water has been mounted in a PEL pipe for protection. It seems that some of the pressure transducers under the structure gives strange readings. This is most likely due to marine growth, as it is evident that there is a lot of that under the waterline. This needs to be investigated. WDRT.MDB file put on CD to give to MON (BAL) to see what data can be recovered from the SCADA system.	JPK, Eoin (AAU), Leif, René (MTH (Promecon)), EFM (LOW), Anders + lærling (LIN), Bendy (FC)
03.08.07	Working with fenders.	BP (FC)
03.08.08	Adjusting valves, stabilizing the device.	BP (FC)
03.08.11	Installation of weather station. Check of new signal cable to pile. Force transducer FORCE_M seems ok, no signal from pressure transducer PRES_P. Two out of three dummy turbines stuck. The piston in one of the hydraulic cylinders were damaged (bent) in the attempt to make the dummy turbines move. The cylinder was taken off and brought back to the workshop. This problem seems to be due to massive corrion of the	JP, Eoin (AAU), Nicolai + Casper Holk

	the cylinder gates, as this is (or at least was) black steel. It seems absolutely necesary to overhaul the dummy turbines and paint them. The hydraulic cylinder for aeration valve for siphon turbine does not work.	
03.08.13	Excursion for Dep. of Civil Eng. AAU visiting	~25 persons, JPK, PF
03.08.14-15	Harsh wind conditions, 18 - 19 m/s average, >25 m/s in peaks.	
03.08.16	Pumped air in chamber. Stabilizing the device.	BP (FC)
03.08.19	After Storm. Damage on shoulder. Fenders lost. Repair of damage to dummy turbines. See '030819, Progress Report.pdf'.	JPK, Eoin (AAU), BP (FC)
03.08.21-22	Tightening of mooring lines, re-mounting of fenders - temp. Preparing for next high winds.	BP (FC)
03.08.24	Re-mounting of fenders.	Leif, René (MTH), Niels (Diver), BP (FC)
03.08.25	Repair of hole in port shoulder, temp. fenders mounted.	Leif, René (MTH), BP (FC)
03.08.26	'Line of sight' estimation for FWA. Damage on shoulder, fenders mounted. Harsh wind conditions, up to 20 m/s average.	JPK, Eoin (AAU), BP (FC)
03.08.27	Stay mounted on mast by electrical cabinet on shore for mounting FWA antenna. Inspection, fender adjustment, reboot of PC.	BP(FC)
03.08.28	Welding on of the fishtail plates. Attempt to drain port shoulder compartment.	Leif, René (MTH), BP (FC)
03.08.29	Adjusting weather station. Welding on of the fishtail plates.	JPK, Eoin (AAU), BP (FC), Leif, René (MTH)
01.09.03	Upgrading weather station software. Welding on of the fishtail plates.	JPK, Eoin (AAU), BP (FC), Leif, René (MTH)

Appendix B: Reflector Failure During Installation On Wave Dragon, Nissum Bredning, Test Site 1

by
Jens Peter Kofoed, AAU
Erik Friis-Madsen, LOW

Introduction

The initial attempt to install the Wave Dragon at test site 1 in Nissum Bredning (27-28.03.2003) partly failed, as the reflectors were dislocated from the main platform during harsh wind conditions in the days (30.03.2003) after installation.

Damage

In summary, the following damage was caused:

1. Starboard reflector was dislocated. The reflector part of the shoulder connection ended up on the back side of the starboard platform part of the shoulder connection.
2. Inner reflector part of shoulder connection superficially damaged due to steel contact with fishtail plate.
3. Bolt fixing the starboard top fishtail plate broke.
4. Fishtail plate, and fender arrangement along with it, fell down.
5. Damage to pipes for electrical wire on both shoulders.
6. Electrical wire for accelerometer on starboard shoulder cut.
7. Wires E damaged.
8. Aft reflector was dislocated and capsized. The reflector part of the shoulder connection ended up on the back side of the aft platform part of the shoulder connection.
9. Electrical wires for accelerometer and displacement sensors on aft shoulder damaged and possibly cut.
10. Junction boxes on aft reflector possibly water filled, as they have been under water for a longer period.
11. Nuts holding the chains fixing the fender elements to the shoulder were gone. Thus, the chains fell down and the fender elements were lost.
12. The aft reflector, upside down, was stuck on the aft bottom fishtail plate, as one of the cross steel wires in the shoulder connection was caught by one of the chain colts. Thus, this steel wire was cut when removing the reflector.
13. Mooring lines were generally tangled.

The starboard reflector was towed to Thyborøn 31.03.2003 by Martha Lerche (Thyborøn Redningstjeneste). The aft reflector had to be cut loose from the lower aft fishtail plate before it could be towed to Thyborøn. This was done by divers and assisting vessels the night between 31.03.2003 and 01.04.2003.

Cause of failure

Based on inspections on the structure and underwater video inspection, it is fairly well understood what caused the failure:

1. The nuts on the stretching screws were not tightened/secured – the chains and screws did not break. The nuts on aft shoulder, top fishtail plate, are all missing.
2. The mooring lines, intended to keep the reflectors tightly connected to the platform in the shoulder connection, was not properly tightened. From previous laboratory model tests it has been seen that the reflectors are dislocated when the mooring lines are not properly tightened. Furthermore, the mooring lines (polyester, nylon etc.) were not 'worked' prior to installation. Thus, the harsh wave conditions further loosened the moorings.
3. On the starboard shoulder, two out of the three fender elements in one of five fender lines were already missing when the starboard reflector was attached.
4. There was not the prescribed amount of ballast in the reflectors, which means they were not in the appropriate floating position. Furthermore, no additional ballast was applied in the closed compartments in the platform. Thus, the platform had a tendency to lean backwards, resulting in an angle in, and thereby weakening of, the shoulder connection.
5. The backward leaning of the platform was enhanced by the fact that the pressure in the air chambers was very close to atmospheric, as only the outlet air valves were closed. Thus, the air escaped through the blower.
6. The backward leaning of the platform was furthermore enhanced by the fact that the dummy valves were closed, meaning that the water accumulated in the reservoir and stemmed up against the reservoir back wall.
7. The fishtail plates were by mistake produced according to an old version of the construction drawings, meaning they were 65 mm too large. Thus, the reflectors hit the fishtail plates before the fenders where compressed, allowing heavy steel to steel contact. This lead to the failure of the top bolt holding the fishtail plate on the starboard shoulder, and the top fishtail plate and the fenders subsequently dropped below the structure. This allowed room for the reflector to dislocate.

Appendix C: Procedure for Installation of Reflectors

Based on the experience during the reflector failure during the initial installation of the reflectors on the Wave Dragon, it has been concluded that it is of paramount importance that a detailed work plan is worked out prior to the re-installation of the reflectors, and that it is followed very accurately and the structure is not left on its own until the outlined work has been completed.
Work plan

In the following this work plan is lined out.

Preparation of the platform prior to arrival of the reflectors:

1. Ballasting of the platform so a horizontal floating position can be maintained during installation.
2. Exchange top fishtail bolt on starboard shoulder.
3. Produce new fishtail plates according to updated drawings.
4. Assemble fender arrangements (consisting of fishtails, chains, fender elements etc.) for both shoulders on land. Lock and contra nuts must be used securing the chains in the fishtail plates. Two ropes should be attached to each of the lower fishtail plates enabling adjustments to the position of the fender arrangements after they have been installed.
5. Mounting of fender arrangements on shoulders. This requires diver assistance and a vessel with crane (e.g. Multisund). It is assessed that this operation can only be carried out in wind speeds of up to 3 – 5 m/s if the wind direction is between S and NW.
6. Prepare attachment points for extra security wire/chain. 20 t chains should be attached to lifting points on the reflectors close to the shoulder connection. The chains should be connected to the pulley by ropes of the same type as wires D. Make sure the ropes stay inside the pulley area.
7. 'Un-denting' of stair case shield on mooring pile.
8. Check and re-establish/prepare mooring lines where necessary:
    a. Exchange wires E. Randers Reb ø48 mm, breaking load 42 t.
    b. Exchange wires I. 41.5 m each, breaking load 10 t. These wires should be 'worked' to 50 % of the breaking load prior to installation.
    c. Exchange wires D. Randers Reb ø28 mm, breaking load 15 t.
    d. Check that wires C are steel wires. Breaking load 34 t. Check lengths, especially for the one with the force transducer (~1m should be left for the transducer).
    e. One of the cross steel wires (4 in total) in shoulder connection must be replaced (destroyed in detaching aft reflector after damage).
    f. Additional security wires/chains in shoulder connections.

As there is very limited time windows allowing for the sea operations, it is not recommended to use the same vessel for both installing the fender arrangements on the platform and towing the reflectors to test site 1. It is suggested that e.g. Multisund is installing the fender arrangements, while the reflectors are towed to the site by another vessel, e.g. Martha Lerche (Thyborøn Redningstjeneste). It might be necessary/reasonable to do the towing as soon as the weather permits, and anchor the reflectors in the neighborhood, e.g. using the back gravity anchor as main anchoring point and some temporary back anchor (or maybe a line connected to the piles under the test site platform / 'kravlegården'). This is also emphasized by the experience from the previous tow of the reflectors from Thyborøn by Multisund and Skansund. During this operation the towing velocity was as low as 1 knot when going against the current. Thus, Multisund alone will not be able to do the towing against the current.

Preparation of reflectors in harbor:

1. Ballasting of the reflectors.
2. Drilling of holes allowing complete filling of ballast chambers.
3. Inspection of junction boxes for water.
4. Check of signal cables for entrained water.

Installation of the reflectors:

The installation procedure can probably not be carried out in wind speeds exceeding 3 m/s if the wind direction is between S and NW or wave heights exceeding 0.10 m.

For the operation two electrical winches, preferable 2 t each, should be available. These can be used for 'working' the mooring lines. The final tension to 2 t can be done using the already available hand driven winches.

To check the tension in various lines a dynamometer should be available. This is not a water proof unit, so some proofing is necessary. This could be done by putting the unit inside a transparent rubber hose that can be closed at the ends around a shaft.

1. Place starboard reflector in position and connect cross wires and extra security wires (not tight) in shoulder connection.
2. Connect aft wire E.
3. Connect force transducer to mooring point on aft reflector.
4. Place aft reflector in position and connect cross wires and extra security wires (not tight) in shoulder connection.
5. Connect starboard wire E.
6. Connect wires C.
7. Connect wires D. Mount electrical and manual winches and dynamometer to tighten and loosen wires D.
8. Place fender arrangements centrally using ropes connected to lower fishtail plates.
9. Tighten wires E manually with reflectors in correct position, refer to drawing (distance 56.6 m, inner side).
10. Tighten wires D with electrical winch as much as possible or until reflector ends are parallel, refer to drawing.
11. Loosen wires D until reflectors are a little wider than the correct position, refer to drawing.
12. Tighten wires E manually.
13. Tighten wires D with electrical winch until correct position is obtained, refer to drawing (distance 56.6 m, inside). The tension in wires D should be roughly 0.5 t. If this is not obtained, loosen wires D, tighten or loosen wires E, tighten D with electrical winch. Repeat until correct position is obtained with a tension of 0.5t
14. Ballast reflectors.
15. Tighten wires D by pulling in 0.5 m.
16. Connect wires G.
17. Connect wires I.
18. Tighten security chains/wires manually.

After completed installation:

1. Loosen back anchor chain again, to allow free movement (+/- 60 deg.).
2. Connect electrical wire for force transducer in wire C in junction box on aft reflector.

Additional to do's, not directly connected to the re-installation of the reflectors:

1. Re-establish cut signal cable on starboard shoulder, and move cable tube to less vulnerable location.
2. Check damaged signal cable on aft shoulder, re-establish if necessary, and move cable tube to less vulnerable location.
3. Water tight closing of wire entries into container (Brattberg).
4. Closing of holes in ballast cells left of platform centerline, near container.
5. Closing of holes around siphon turbine outlet.
6. Outside sealing of wooden container floor.
7. Check for missing and too long bolts in connection between main gravity anchor and pile/column on top.
8. Installation of CO2 fire fighting equipment in electrical boards.
9. Check level of filling material in gravity bucket anchors.
10. Install pins on upper fishtail plates to register max. fender compression.

BILAG 6

AAU, Automatic Control of Freeboard and Turbine Operation. Wave Dragon

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AALBORG UNIVERSITY

Automatic Control of Freeboard and Turbine Operation – Wave Dragon, Nissum Bredning

Project:

Sea Testing and Optimization of Power Production on a Scale 1:4.5 Test Rig of the Offshore Wave Energy Converter Wave Dragon

according to EU ENERGIE contract no. ENK5-CT-2002-00603

Jens Peter Kofoed & Peter Frigaard, Aalborg University
Erik Friis-Madsen, Wave Dragon Aps
Morten Nimskov, Balslev

February, 2004

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BILAG 7

AAU, Hydraulic Response of the Wave Energy Converter Wave Dragon

Hydraulic Response of the Wave Energy Converter Wave Dragon in Nissum Bredning

Project:

Determination of Hydraulic Response of the Wave Energy Converter Wave Dragon placed in Nissum Bredning

according to Co-operation agreement between Wave Dragon Aps and Aalborg University, Dept. of Civil Engineering

Jens Peter Kofoed & Peter Frigaard, Aalborg University

December, 2004

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Hydraulic Response of the Wave Energy Converter Wave Dragon in Nissum Bredning

by

Jens Peter Kofoed & Peter Frigaard, Aalborg University

December, 2004

Table of contents

1. Introduction

This report deals with the hydraulic performance of the Wave Dragon, Nissum Bredning (WD-NB) prototype.

Six reports describing the progress of the work on WD-NB project has been issued by Dept. of Civil eng, Aalborg University. These are:

- Kofoed, J. P.: *Status rapport - Bygning af Wave Dragon, Nissum Bredning*. Hydraulics & Coastal Engineering Laboratory, Aalborg University, May 2003. In Danish. (Title in english: *Status report - Building of the Wave Dragon, Nissum Bredning*.)
- Kofoed, J. P.: *Status rapport - Instrumentering af Wave Dragon, Nissum Bredning*. Hydraulics & Coastal Engineering Laboratory, Aalborg University, May 2003. In Danish. (Title in english: *Status report - Instrumentation of the Wave Dragon, Nissum Bredning*.)
- Kofoed, J. P. and O'Donovan, E.: *Status report - First offshore experiences, Wave Dragon, Nissum bredning*. Hydraulics & Coastal Engineering Laboratory, Aalborg University, September 2003.
- Kofoed, J. P., Frigaard, P., Friis-Madsen, E., and Nimskov, M..: *Automatic Control of Freeboard and Turbine Operation - Wave Dragon, Nissum Bredning*. Hydraulics and Coastal Engineering No. 1, ISSN: 1603-9874, Dep. of Civil Eng., Aalborg University, February 2004.
- Kofoed, J. P., Riemann, S. and Knapp, W.: *Calibration and Validation of Measurement System - Wave Dragon, Nissum Bredning*. Hydraulics and Coastal Engineering No. 2, ISSN: 1603-9874, Dep. of Civil Eng., Aalborg University, March 2004.

Kramer, M. & Kofoed, J. P.: *Placering af trykmåler til bølgemåling - Wave Dragon, Nissum Bredning*. Hydraulics and Coastal Engineering No. 6, ISSN: 1603-9874, August 2004. In Danish. (Title in English: *Placement of pressure transducer for wave measurements - Wave Dragon, Nissum Bredning.*)

The current report aims at providing the latest available information on the hydraulic response of WD-NB up November 2004. This mainly includes:

- Wave measurements.
- Evaluation of turbine performance.
- Evaluation of overtopping rates.
- Forces in moorings.
- Wave induced motions.
- Connections between platform and reflectors.

These items are dealt with in individual chapters in the following.

2. Wave measurements

Instrumentation

The task of carrying out continuous wave measurements in a real sea environment is by no means trivial. As already stated in Kofoed et al, 2004b, the cabling from the control room on board WD-NB to the pile where the pressure gauge, responsible for the wave measurements, is situated has been broken on more than one occasion. The cable was replaced with a robust offshore sea cable (supplied by Hydro Cable, Scotland)in the summer 2004. It was then discovered that the pressure gauge it self was malfunctioning and a replacement was put in place. Again, due to not too good experiences with the existing type of instrument, a different component was selected and installed. The new pressure gauge (PSL 4.1.1) is supplied by H. F. Jensen, Denmark.

Furthermore, a numerical study was performed in order to estimate the influence of the presence of the mooring caisson and pile on the wave measurements, and to study if less influence could be obtained by changing the location of the pressure gauge. It was found that less influence could be obtained by moving the pressure gauge further away from the pile (to 1 m horizontally from the center of the pile), but maintaining the level (4.03 m above the seabed). In this case the influence is max. 10 %, and typically less than 5 % in typical conditions. Furthermore, corrections factors to take the presence of the mooring caisson and pile into account into account have been found. See Kramer & Kofoed, 2004.

The new wave measuring equipment was ready ultimo Sept. 2004 and has been acquiring data continuously since then.

Figure 2.1: New pressure gauge on frame prior to installation on mooring pile.

Data analysis

The data selected for this analysis covers the period 01.10.2004 to 24.11.2004. The data is selected from a much larger data material, and has been chosen as continuous data is available from a large number of the deployed instruments and the encountered wave conditions spans the relevant range of wave parameters.

The data is organized in half hour records with data sampled at 10 Hz, i.e. each record consists of 18,000 data samples from the pressure gauge. A total of 2,459 half hour records have been collected and processed from the period considered here. The period consists of a total of 2,582 half hours, i.e. the recorded data covers 95.2 % of the period.

The analyses of the wave data have been performed using the time series analysis tool in the in-house developed WaveLab 2.68 software (http://hydrosoft.civil.aau.dk/wavelab/). The transformation from measured pressures at the gauge placed 4.03 m above the seabed to surface elevations is taken care of by the software, using a density of water of 1,025 kg/m^3 and a cut-off of the transfer function when the value gets above 10 (in order to avoid artificial amplification of high frequency noise). A bandpass filter, using the limits 0.333 f_p (peak frequency) and 3 f_p, has been applied to the surface elevation time series prior to the further analyses. Both a frequency and time domain analysis have been performed on each data record. In the frequency domain analyses at least 30 FFT sub blocks have been used, also using a taper width and overlap of 20 %.

No corrections have been done to take into account the presence of the mooring caisson. Furthermore, no wave reflection from the WD structure towards the measuring point has been assumed. Both items bias the results towards slight overestimation of the wave heights.

The results of the analyses are given below in figure 2.2 for the frequency domain analyses and 2.3 for the time domain analyses.

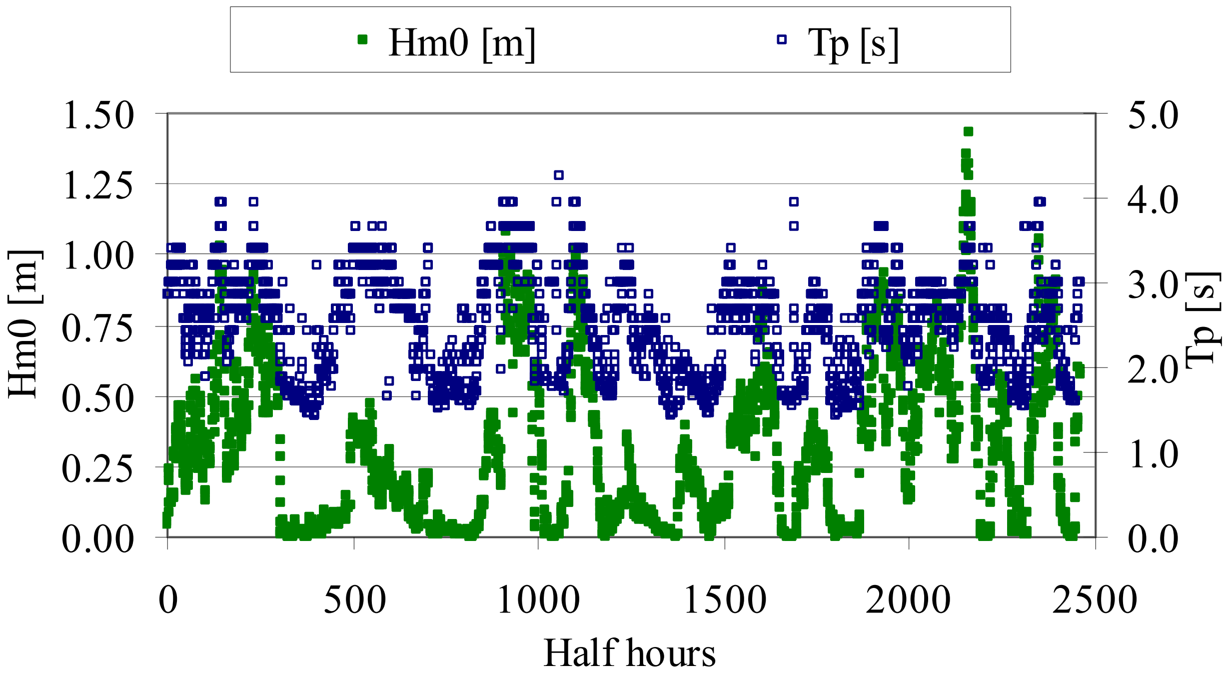


Figure 2.2. Results of the frequency domain analysis in terms of the frequency domain estimate of the significant wave height H_{m0} and the peak period T_p.

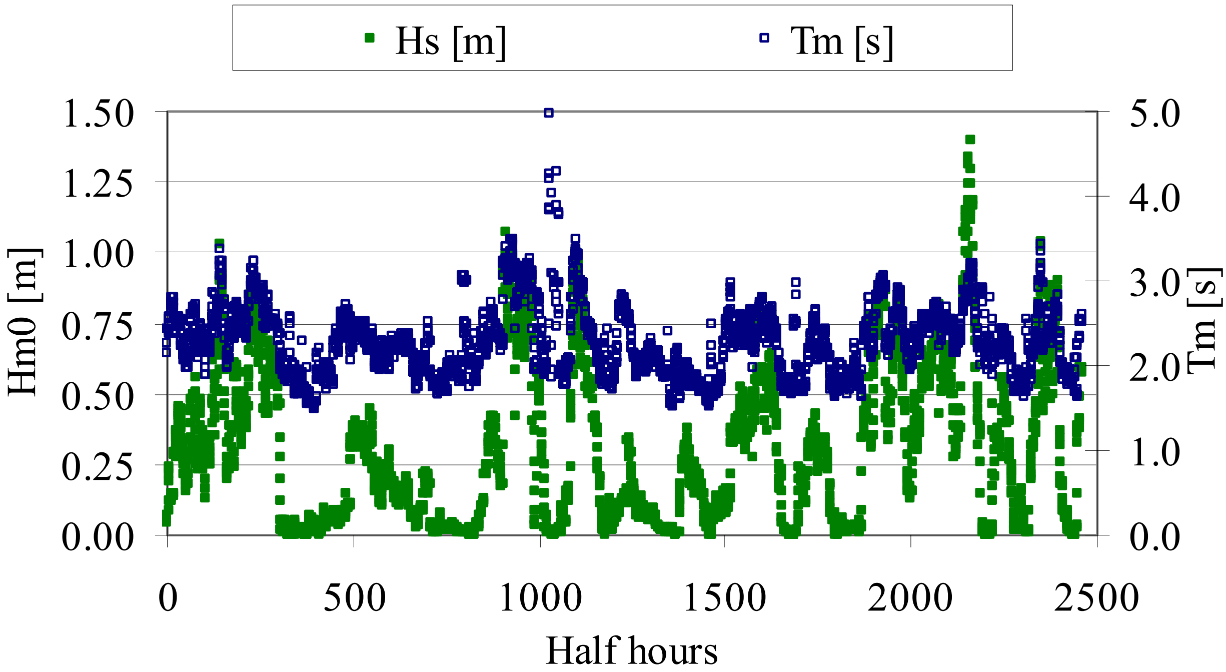


Figure 2.3. Results of the time domain analysis in terms of the significant wave height H_s and the mean period T_m.

In table 2.1 and figure 2.4 the wave data is given in the form of scatter table and diagram of the frequency domain parameters.

An analysis comparing the wave data to the North Sea wave conditions defined by Bølgekraftudvalgets Sekretariat, 1999, has been performed. The results here of are given in table 2.2.

From here it is seen that the North Sea conditions in terms of wave heights scaled to Nissum Bredning are covered, but the corresponding wave periods generally are smaller.

Furthermore, the data has been compared to the calculated wave conditions at Helligsø Teglværk, Nissum Bredning, by Kerper and Jacobsen, 1998, see figure 2.4 and 2.5.

From this comparison it is seen that the WD data covers wave conditions exceeding the wave conditions calculated by Kerper and Jacobsen, 1998. One reason for this is that the WD cowers a limited period during one autumn, while the data by Kerper and Jacobsen, 1998, are overall average data. Since autumns generally are more windy than all year round averages it is not surprising the larger wave conditions are overrepresented in the WD data. However, the data by Kerper and Jacobsen, 1998, suggests that at a water depth of 5 m $H_s > 0.9$ m has almost zero probability, while the WD data shows that $H_s > 0.9$ m is almost frequently exceeded (> 3 %). As seen in figure 2.8 the water depths for the WD data are roughly 5 to 6 m.

Hs \ Tp	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	
0.05	0.0%	0.0%	3.3%	11.1%	6.6%	3.6%	2.4%	3.3%	0.8%	0.7%	0.7%	0.3%	0.1%	0.1%	0.1%	**33.2%**
0.15	0.0%	0.0%	0.0%	1.6%	2.2%	1.4%	0.6%	0.8%	1.4%	1.7%	1.5%	0.8%	0.4%	0.0%	0.0%	**12.4%**
0.25	0.0%	0.0%	0.0%	0.1%	1.3%	1.1%	1.6%	1.3%	0.4%	0.9%	0.5%	1.0%	0.7%	0.0%	0.0%	**8.8%**
0.35	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	1.3%	3.7%	1.6%	1.2%	0.7%	1.6%	1.6%	0.2%	0.0%	**12.7%**
0.45	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	2.6%	1.9%	1.9%	0.8%	0.4%	0.7%	0.1%	0.0%	**9.2%**
0.55	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	2.5%	1.3%	1.2%	0.5%	0.1%	0.0%	0.0%	**7.4%**
0.65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	1.1%	1.5%	1.0%	1.0%	0.3%	0.0%	0.0%	**5.1%**
0.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	1.3%	0.7%	1.8%	0.5%	0.0%	**4.7%**
0.85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.4%	0.3%	0.8%	1.4%	0.0%	**3.3%**
0.95	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.2%	0.6%	0.9%	**1.9%**
1.05	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.4%	0.0%	**0.7%**
1.15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.2%	0.0%	**0.4%**
1.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**
1.35	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	**0.2%**
1.45	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
	0.0%	**0.0%**	**3.3%**	**12.8%**	**10.1%**	**7.0%**	**6.7%**	**13.6%**	**9.8%**	**9.8%**	**8.3%**	**6.9%**	**7.0%**	**3.7%**	**1.1%**	

Table 2.1. Wave data presented as joint probability for given H_s and T_p's.

North Sea							
Hs [m]	<0.5	1	2	3	4	5	>5.5
Tp [s]		5.6	7.0	8.4	9.8	11.0	
Prob. [%]	15.6	47.6	21.4	9.6	4.1	1.3	0.4
Scaled to WD-NB (1:4.5 lengthscale)							
Hs [m]		0.22	0.44	0.67	0.89	1.11	
Tp [s]		2.64	3.30	3.96	4.62	5.19	
Measured data, WD-NB, test site 1, Oct. - Nov. 2004							
Tp [s]		2.55	2.81	3.05	3.45	3.60	
Prob. [%]	34.9	23.7	21.5	12.2	6.3	1.1	0.3

Table 2.2. Comparison of standard wave conditions in Danish sector of the North Sea (Bølgekraftudvalgets Sekretariat, 1999) compared to measurements at WD-NB test site 1.

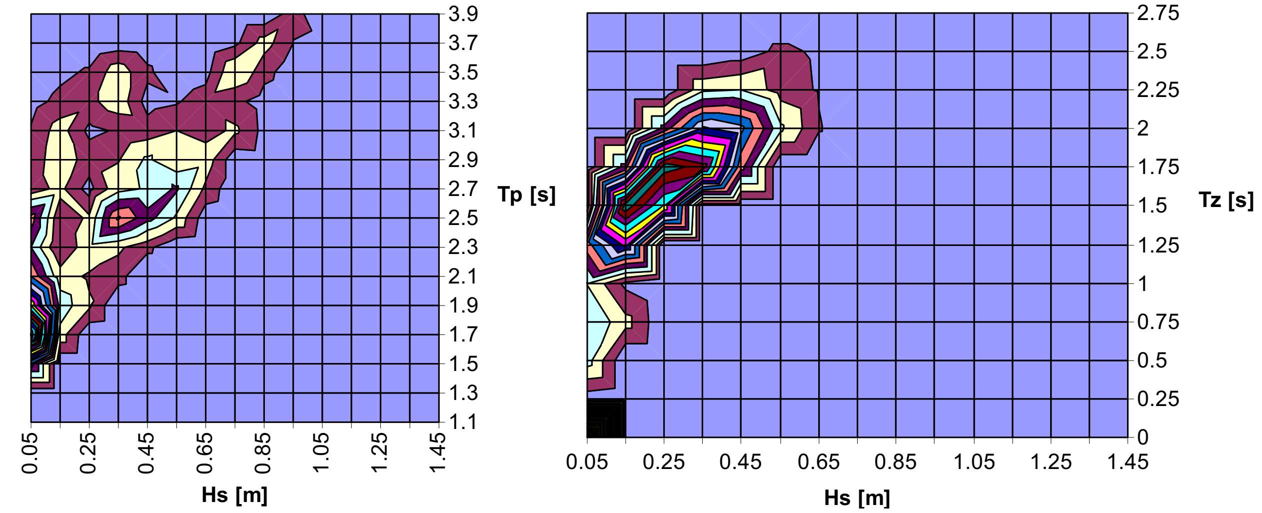


Figure 2.4. Left: Contour plot of the data given in table 2.1. Right: Results of calculation of wave conditions at 5 m water depth at Helligsø Teglværk, Kerper and Jacobsen, 1998 (T_z is the average time domain wave period, typical T_p / T_z ratio is ~1.25 for inner waters like Nissum Bredning).

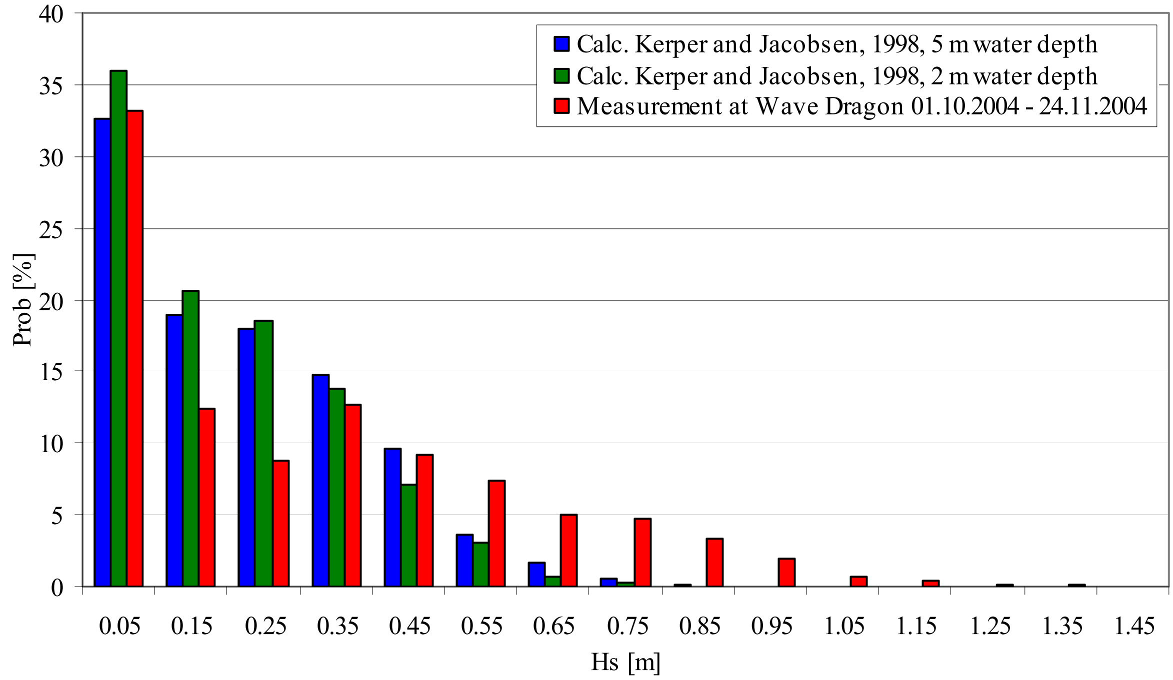


Figure 2.5. The wave height distribution for the wave conditions measured at WD and the calculated wave conditions at 5 and 2 m water depth at Helligsø Teglværk by Kerper and Jacobsen, 1998.

In figure 2.6 and 2.7 examples of measured wave spectra and wave height distributions are given. These shows reasonably shaped spectre and wave height distribution for a significant wave height of 1 m (no signs of significant wave breaking or higher order effects).

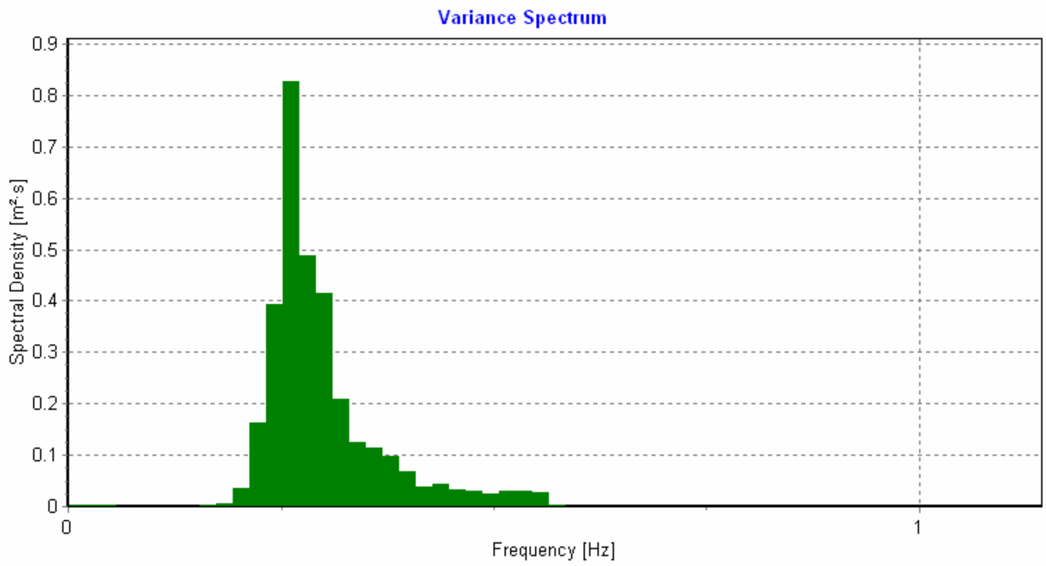


Figure 2.6. Variance spectrum for the measured waves from 25.10.2004 14.18-14.48. H_{m0} = 1.001 m, T_p = 3.94 s.

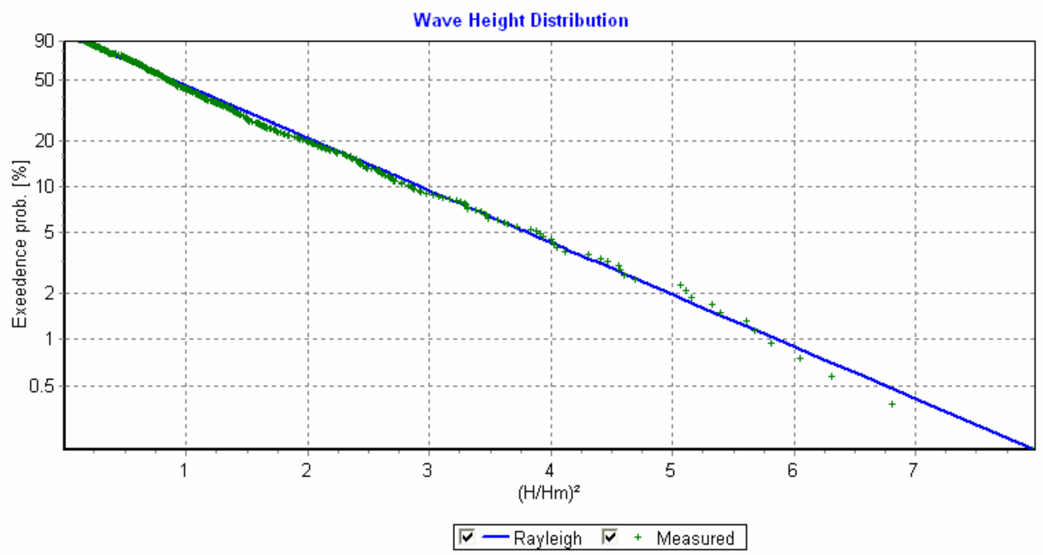


Figure 2.7. Wave height distribution for the measured waves from 25.10.2004 14.18-14.48. H_s = 0.992 m, T_m = 3.38 s.

Also the water level variations at the location of the mooring pile have been extracted from the wave records as half hour averages of the water elevation signal. These are given in figure 2.8.

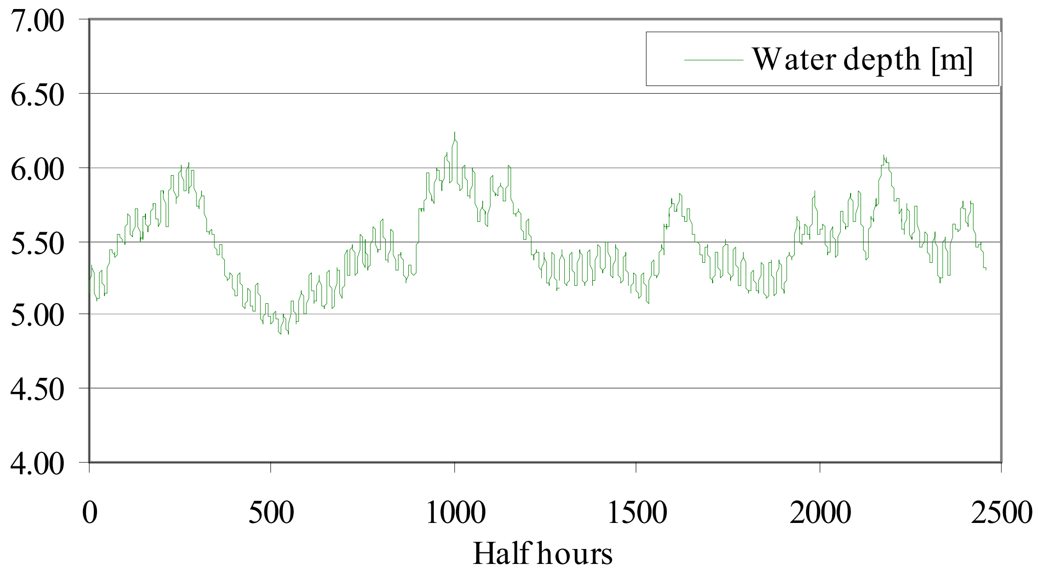


Figure 2.8. Water level variations at the location of the mooring pile during the period 01.10.2004 to 24.11.2004.

From these water level variations it is seen that the tide variation typically is up to 25 cm, while the larger variations (up to a little more than one meter) mainly is due to wind driven setup at the west coast, which enters into Nissum Bredning at Thyborøn.

3. Evaluation of turbine performance

Although turbine performance is not naturally a part of this report, it considered of importance to have a look at the subject, as the turbines are used as 'measuring devices' for the overtopping rates.

Before going into the details of the turbine performance a short overview of the evolvement of the turbine status:

The dummy turbines (TURB 8, 9, 10) were installed prior to the launch of WD-NB and have been working more or less since then. There have been, and still occasionally are, problems in opening and closing the turbines, as well as the adjustment of the end switches. The problems are mostly connected to the heavy corrosion of the dummy turbines, but with frequent treatment with grease they are kept running.

The siphon turbine (TURB 1) has also been in place from the beginning and was up and running in spring/summer 2003. However, at that time the automatic control system was not ready for continuous operation, and the turbine was only run when an operator was onboard. During the summer and autumn all attention was put on the structural problems, especially the problems with the fender systems in the connection between the reflectors and the platform, so serious attempts to run the turbine again did not happen until early 2004. At that time corrosion and ingress of salt water in the thrust bearing has made the turbine useless. The partners from TUM refurbished the turbine in May 2004 (see Knapp, 2004) and the turbine has been in an operational state since then. However, it has been experienced lately, that after longer time in standstill it needs a few manually forced turns to start running again. It is therefore important to operate the siphon frequently.

The cylinder gate turbines were installed autumn 2003, but the installation of the generators was not completed until February 2004, mostly due to bad weather conditions. When testing the turbines it was at first found there were problems with the electrical connection. Once this was sorted out it was found that the turbines did not deliver power as expected. Investigations later spring 2004 showed that there were severe problems with bearings in the cylinder gate turbines as well (see Knapp, 2004b). In July 2004 partners from TUM refurbished one of the cylinder gate turbines (TURB 5). In this process the thrust bearing was renovated, among other things (see Knapp, 2004c). This put TURB 5 in operational state. Based on the experiences from these refurbishment projects it was decided to refurbish the remaining 5 cylinder gate turbines. However, because of financial limitations this was split into two projects. It was also decided to discard the original thrust bearing design and install new bearings rather renovating the old ones. Refurbishment of TURB 2 and 4 was carried out in October 2004, and these turbines have been in an operational state since then (a report on this refurbishment is expected from TUM). The refurbishment of the remaining three cylinder gate turbines is currently postponed until the financial part of the problem has been solved.

The above means that real operational turbine data primarily exists in the period from last part of October 2004 to present (ultimo November 2004).

Power production

When looking at power production focus has been on a shorter period in time, in order to limit the data handling. During this period the turbines 1, 2, 4 and 5 plus dummies, were in operation. However, no data giving the operation of the dummies are currently available on the MGC+ (status signals are planned to be made available from the PLC to the MGC+ via the CAN-bus), so whatever goes though these are at first neglected. The half hour average power produced during the period (see figure 3.1) has been obtain using six different procedures:

- NETPOWER – The power put onto the grid as reported from the West Control unit (averaged over half hour periods).
- POWERSUM – The sum of the power produced by the individual turbines (averaged over half hours periods).

- POWRSUM – The sum of power the individual turbines would have produced if they were following the characteristics given by project partner Veteran Kraft AB (VKAB), see table 3.1, based on the revolutions per minute (n [RPM]) reported by the West Control unit (expression relating power (P [W]) to n: $P = 0.0000183 \cdot n^{3.022}$ [W], by curvefitting to table 3.1).
- POWHSUM – The sum of power the individual turbines would have produced if they were running at the optimal n at the given head, following the characteristics given in table 3.1, based on the turbine head (h [m]) as calculated by the PLC (function of pressures in reservoir and under platform, and heel) (expression relating power to head: $P = 1000 \cdot (1.1457 \cdot h^2 + 1.6072 \cdot h - 0.1455)$). The fact that a change in the turbine speed n will also change the flow rate q, and thereby also how often the turbines are running, is not considered. As the realized turbine speed typically is slightly lower than the optimal, POWHSUM will be slightly overestimating the power.
- HYDRTPOW - The power corresponding to the sum of the flow though the turbines and a turbine head as calculated by the PLC
- HYDRPOW – The power corresponding to the sum of the flow though the turbines and a head equal to the floating level as calculated by the PLC.

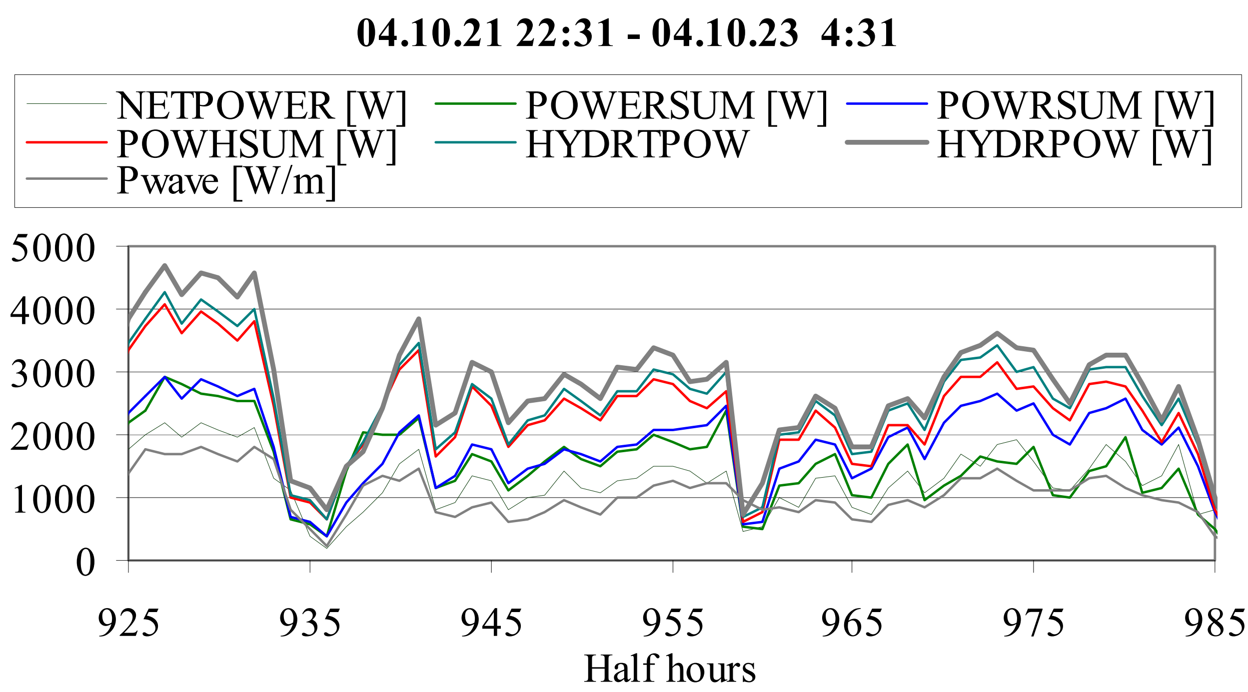


Figure 3.1. Power produced on board calculated in various manners.

Wave Dragon at Nissum Breding WAVDRNI1.wq1 STHLM 02-03-06

Speed-regulated on/off turbines: D = 0.34 m, Hn.max = 1. m
Working point: 4-bladed VKAB-runner, alfa=30 and gamma=18.5 deg.
3-bladed TUM-runner, alfa=28 and gamma=23.8 deg.
n11 = 170, Q11 = 2.75, Re-u-mod. = 5.2E6, Eta-mod = 89 %, t=10 grad C.

Model test at TU München: H=const.=3 m, D=0.34 m, t=20 grad C
Eta-elect. = 100 %.

Hn = Tot.head at guide vane inlet - Tot.head at draft tube outlet,
for which the used model test data is valid.
H-gross=Hg = Level in storage basin - Average water surface level

Hn m	n rpm	Q m3/s	Re-u*E-6	d-Eta %-unit	Eta-tur %	in/out- loss m	Eta-Hg %	P-out kW
1.600	632.5	0.40	2.9	-1.1	87.9	0.061	84.6	5.336
1.450	602.1	0.38	2.8	-1.2	87.8	0.055	84.5	4.599
1.300	570.1	0.36	2.7	-1.3	87.7	0.049	84.4	3.899
1.150	536.2	0.34	2.5	-1.4	87.6	0.044	84.3	3.240
1.000	500.0	0.32	2.3	-1.5	87.5	0.038	84.2	2.623
0.875	467.7	0.30	2.2	-1.6	87.4	0.033	84.0	2.144
0.750	433.0	0.28	2.0	-1.8	87.2	0.028	83.9	1.698
0.675	410.8	0.26	1.9	-1.9	87.1	0.026	83.8	1.448
0.500	353.6	0.22	1.6	-2.2	86.8	0.019	83.5	0.920
0.375	306.2	0.19	1.4	-2.5	86.5	0.014	83.2	0.596
0.250	250.0	0.16	1.2	-2.9	86.1	0.009	82.8	0.323
0.200	223.6	0.14	1.0	-3.2	85.8	0.008	82.6	0.230
0.150	193.6	0.12	0.9	-3.5	85.5	0.006	82.2	0.149

Table 3.1. Turbine characteristics for turbines onboard WD-NB as provided by VKAB.

Efficiencies

The corresponding efficiencies, based on the wave energy that passes between the reflector tips (width assumed to be 54 m) are given in figure 3.2.

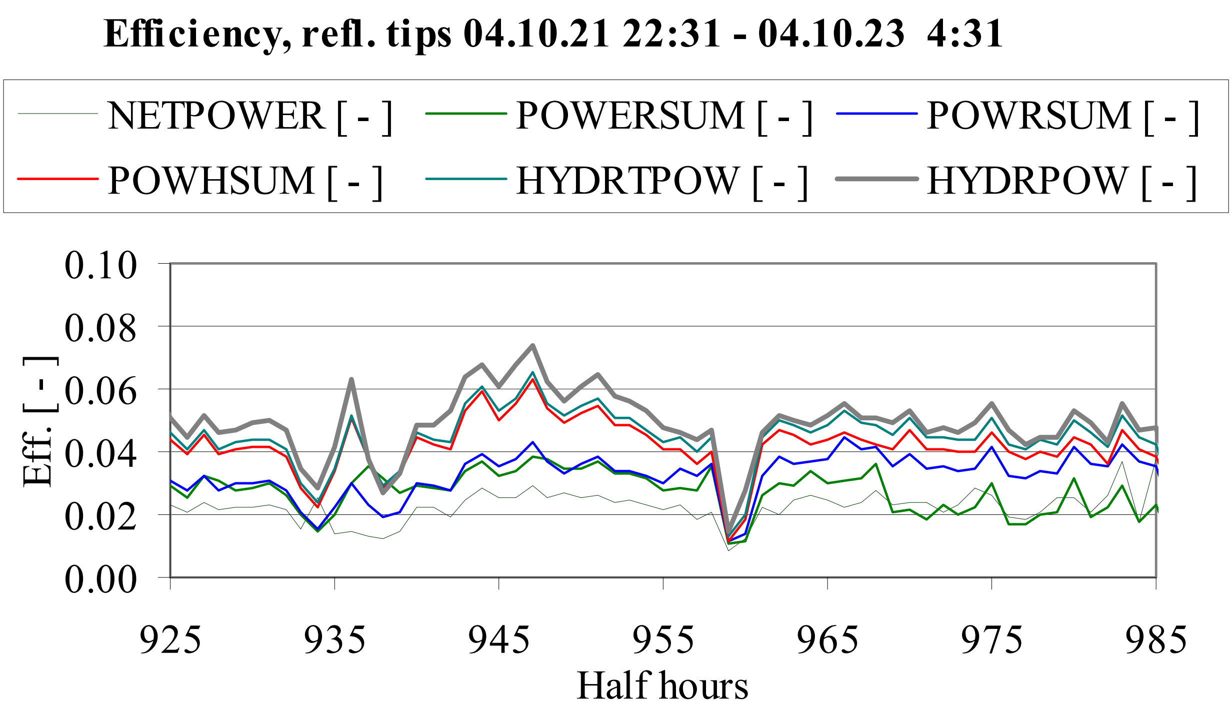


Figure 3.2. Efficiencies corresponding to the produced power given in figure 3.1.

Losses

The losses in the different steps in the power take off (PTO) has been calculated and shown in figure 3.3 for a selected range in the analyzed period.

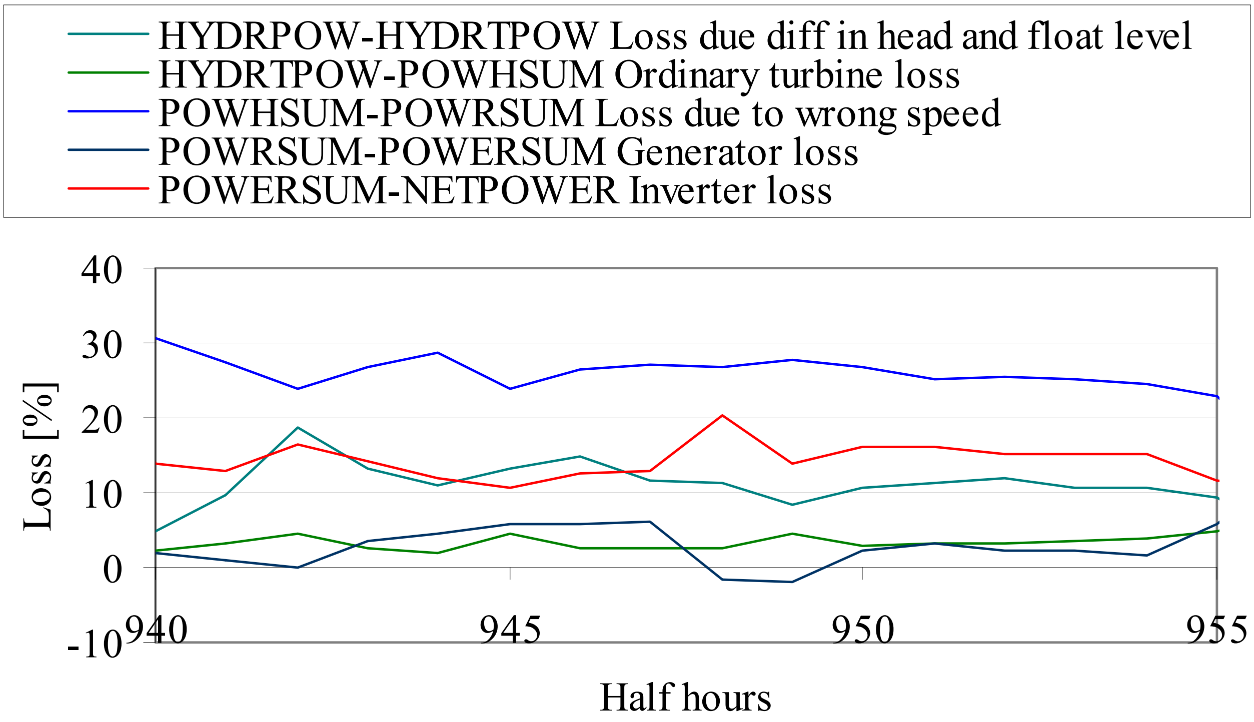


Figure 3.3. The various losses (in % of HYDRPOW) for a selected range of the analyzed period.

The average of the various losses (in % of HYDRPOW) in the selected range is given below:

- Loss due to difference in turbine head and floating level ((HYDRPOW-HYDRTPOW)/HYDRPOW): 11.4 %
- Ordinary turbine loss ((HYDRTPOW-POWHSUM)/HYDRPOW): 3.3 %
- Loss due to wrong speed ((POWHSUM-POWRSUM)/HYDRPOW): 26.2 %
- Generator loss((POWRSUM-POWERSUM)/HYDRPOW): 2.6 %
- Inverter loss ((POWERSUM-NETPOWER)/HYDRPOW): 14.3 %
- Total loss from HYDRPOW to NETPOWER: 57.8 %

It is seen that the losses due to the wrong speed of the turbines are the most severe ones, although figure 26.2 %, might be a little too high (for the above mentioned reason). This needs to be taken care of by modifications in the operation of the West Control unit. The ordinary turbine and generator losses seem to be too low – turbine losses around 10 %, and generator losses maybe down to 5 % at best, were anticipated. However, the given values are average values in a more or less arbitrarily selected range, so they should only be taken as rough estimates.

In figure 3.4 the half hour average values of the floating level (FLOATL), turbine head (TURBHEAD) and significant wave height (H_{m0}), as well as the ratio FLOATL/ H_{m0}, are given for the analyzed period.

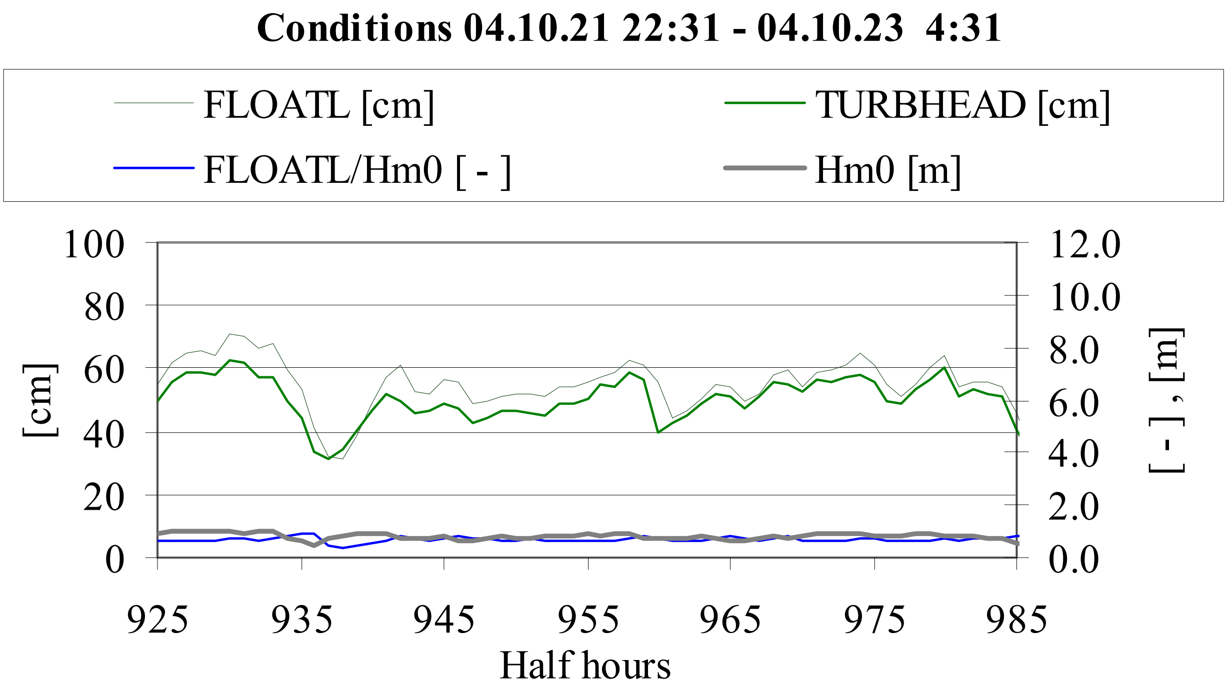
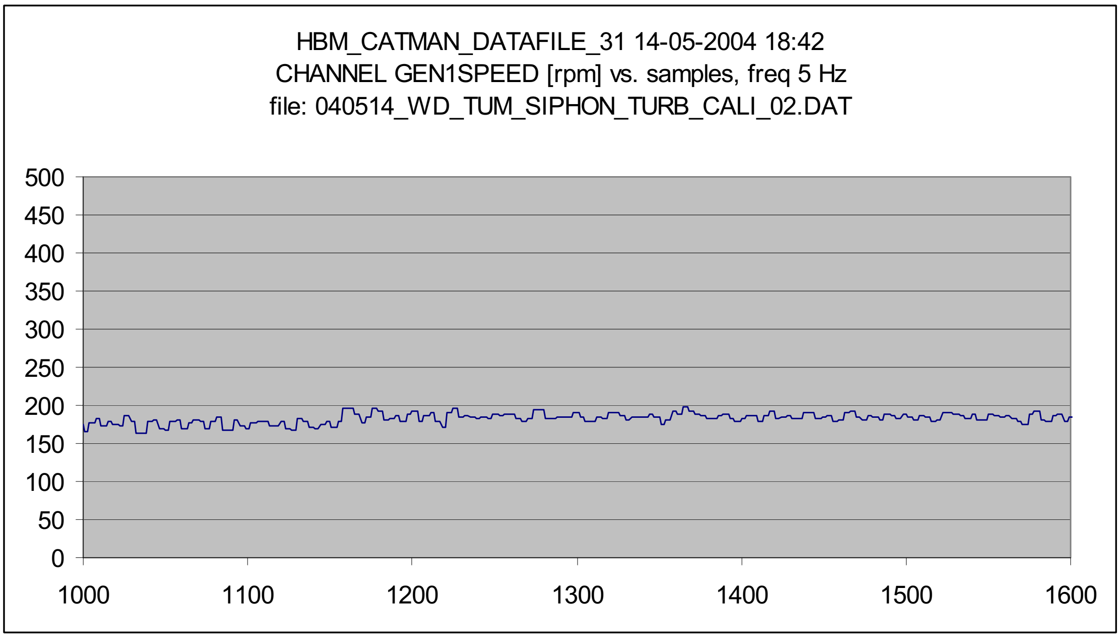


Figure 3.3. Important factors for the power production.

Oscillations in turbine speed

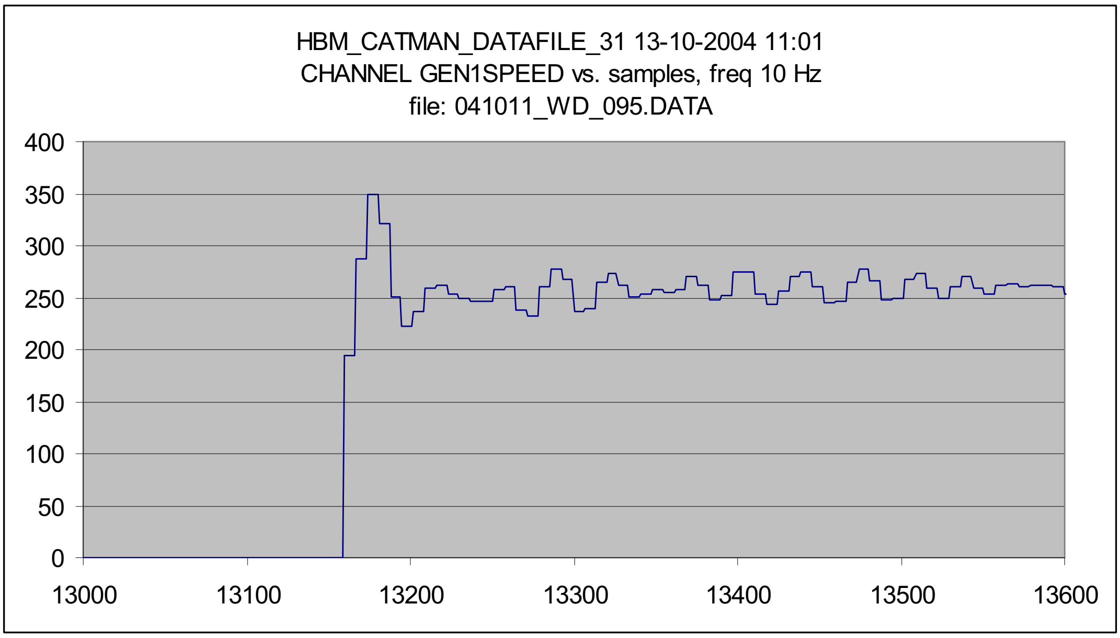
During the operation of the turbines after the refurbishments considerable oscillations in the turbines speeds has been seen. Below there are three figures with plots of turbine speed and pictures from the day.

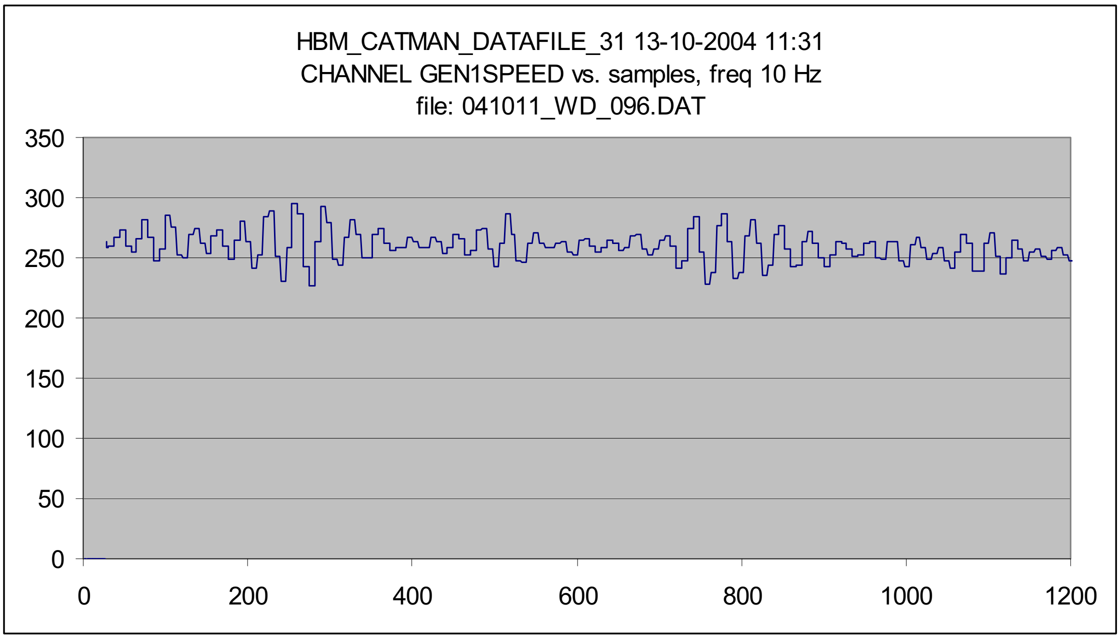


webcam3_20040514s172411835.jpg

webcam2_20040514173211000.jpg

Figure 3.4. Turbine calibration by TUM after restoration of TURB 1.

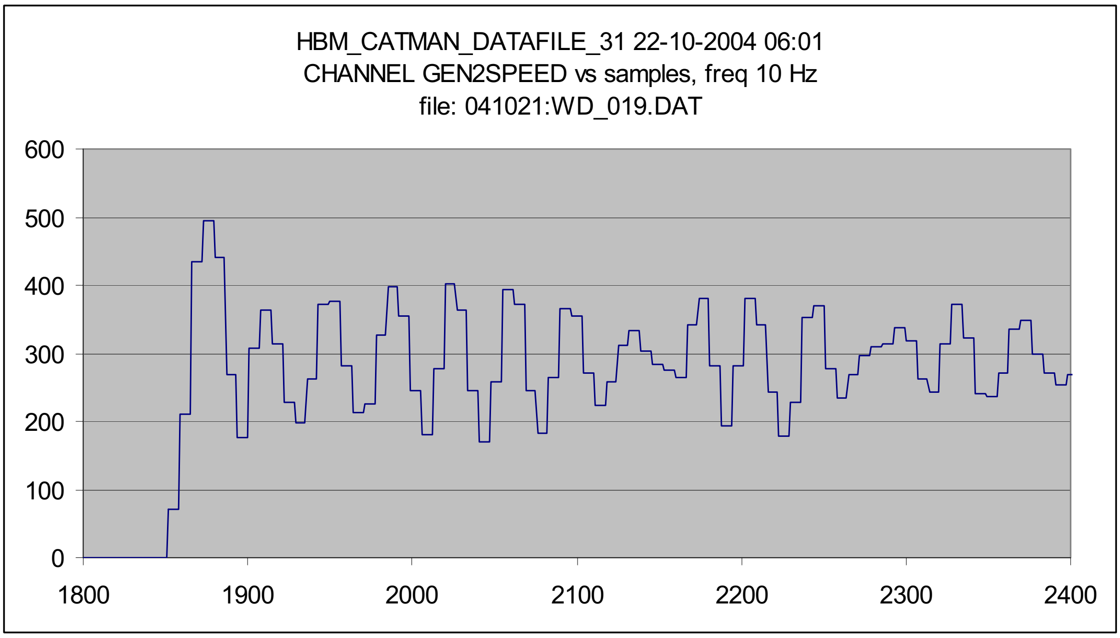


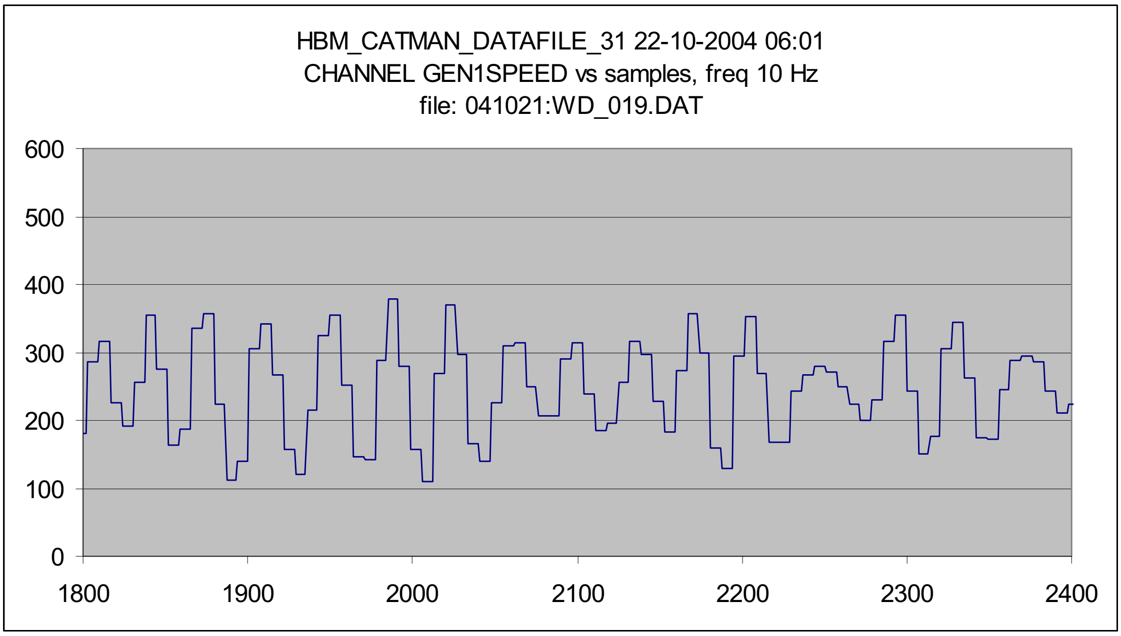


webcam3_20041013s110010757.jpg

webcam2_20041013120005500.jpg

Figure 3.5. Turbine testing by TUM after restoration of TURB 2 and 4.





webcam3_20041022s090010593.jpg

webcam2_20041022080005812.jpg

Figure 3.6. Turbines running in good wave and power production conditions.

The change in the turbine speed oscillations are pronounced from figure 3.4 to 3.5 and 3.6. The period of the oscillations are not far from the wave periods, for what reason it seems fair to say that the oscillations are tricked by the changing turbine head due to waves propagating under the platform. West Control was at WD-NB in July 2004 to change some burned IGBT's (transistors) and at this time the EEPROMS containing the West Control programming of the inverters was also replaced. A change in the programming might be responsible for the increased sensitivity to oscillations in the turbine head. This item is currently being investigated.

4. Evaluation of overtopping rates

Based on the calculated flow through the turbines non-dimensional overtopping rate (Q*) has been calculated as a function of the non-dimensional crest freeboard (R*), here the floating level has been used as freeboard, neglecting any heel or trim. The data is compared to the overtopping expression below by Hald & Frigaard, 2001 based on 1:50 scale model tests.

$Q^* = 0.025\exp(-40R^*)$ 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
T_p = Peak period
L = ramp width
R_c = Crest freeboard relative to MWL
s_{op} = wave steepness, $s_{op} = H_s/L_{op}$
L_{op} = deep water wave length, $L_{op} = \frac{g}{2\pi}T_p^2$

The results are shown in figure 4.1. From this figure it is clearly seen that, in opposition to previous findings, the overtopping rates falls significantly below the lab. results and the previous measurements on WD-NB. There can be a number of reasons for this:

- Dummies are not included in the overtopping rates in the new data. From graphs on the SCADA system (see figure 4.2 for the period corresponding to the power data given in figure 3.1, figure 4.3 the half hour period corresponding to the first data point in figure 3.1 and the red dots in figure 4.1) it can bee seen that there are quite frequent dummy turbine activity, and therefore significant amounts of water is 'lost' through these. For a single point, corresponding to the half hour shown in figure 4.3, the flow through the dummies are estimated to be 50 % of what goes through the other turbines (in average during the period).
- Spilling. From figure 4.2 - 4.3 it is also seen that the reservoir level is frequently above 100 %, ie. spilling occurs. Rough quantification of the spilling might be possible by calculation of the water level along the edges of the reservoir, comparing it to the crest height around along the edges, and then using an expression for the flow over an edge.
- Leaks. Earlier a leakage of up to 44 l/s has been seen, but this was primarily due to problems with the closing of the cylinder gates and recent observations shows fall of reservoir level of 6 – 10 cm an hour when no overtopping occurs, which corresponds to a leakage of 2.7 – 4.4 l/s (corresponding to 20 – 30 W at high floating level).
- Turbine calibration. In the calculations the original turbine characteristics have been used, as no other data is currently available. It is expected that TUM will provide updated turbine characteristics for the real turbines as well as the dummies. In the previous data set the characteristics from the first calibration tests of the dummies where used. These calibrations has later been questioned, as a later drain test showed as much as 30 % lower discharge, probably due to marine growth in the draft tubes.
- Bias in estimation of wave conditions. As mentioned in chapter 2 the presence of the mooring caisson and reflections from the WD structure towards the wave measuring point is not taken into account in the wave analyses. This will tend to result in slight overestimation of wave height, i.e. biasing the overtopping data points to fall below the prediction line.

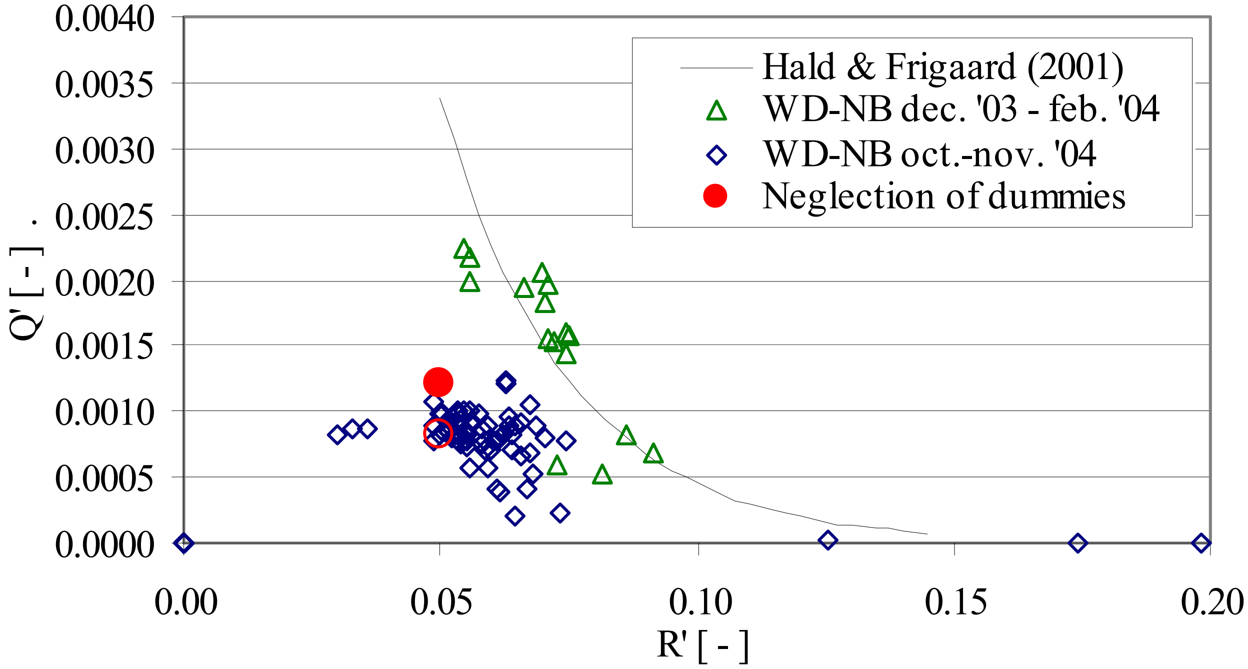


Figure 4.1. Non-dimensional overtopping rate as a function of the non-dimensional crest freeboard compared to lab. results and previous measurements at WD-NB. The effect of neglecting the dummy turbines exemplified in a single point based on observations in the SCADA system (all three dummies open 20 % of the time).

- Directionality of the waves. WD is able to align it self up against the waves as long as the wave direction is roughly +/- 60° from the middle position. Also the forcing from wind and current plays a role in the positioning of WD, and these are not always in line with the waves. Thus, although WD most of the time is facing towards the waves, this is not always the case and this then decrease the overtopping rate.
- Floating level used at crest freeboard. A different results might be achieved if the calculation was performed using the average position of the ramp, including heel, rather than the floating level, as the freeboard.
- The inclinometers measuring heel and trim have showed some drifting, which influences the position of the ramp and thereby the overtopping rate and the eventual spill back over the ramp.
- Uncertainty on floating level measurements. Some drifting in the measured pressures, used for the calculation of the floating level has been observed.

Furthermore, the overtopping process is highly non-linear and using an average over half an hour is therefore quite rough, taking into consideration the rather large motions, in especially heel, that typically occurs during such a half hour.

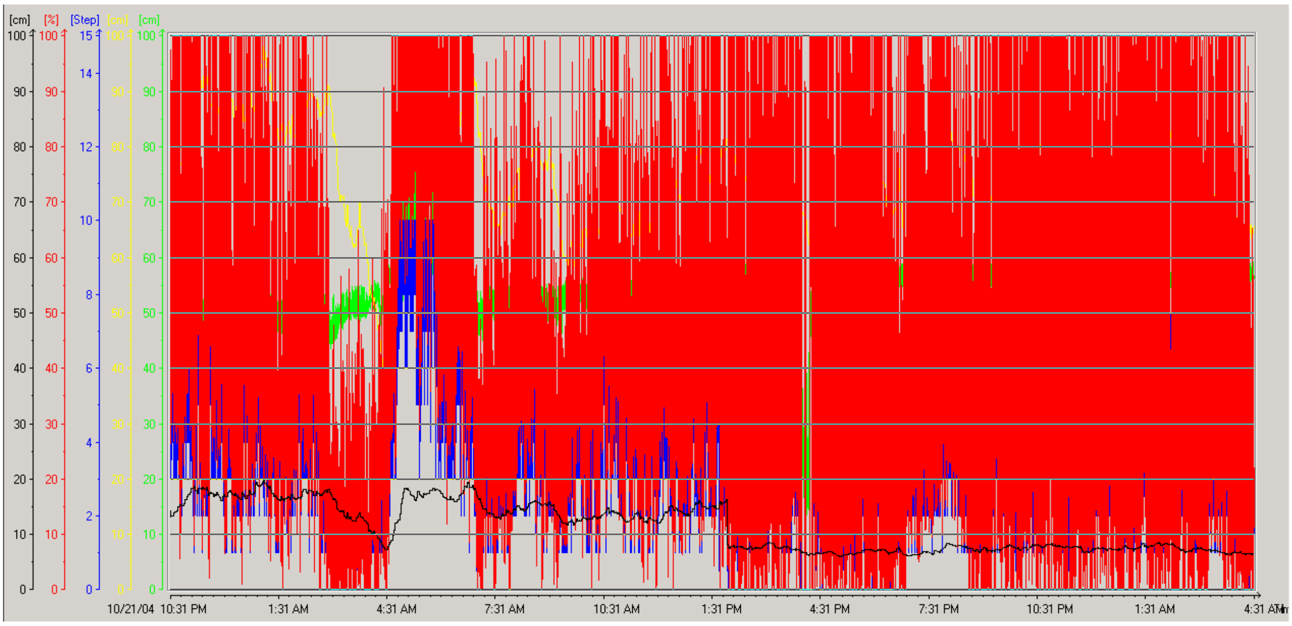


Figure 4.2. Screen dump from SCADA, graph 2, during the 30 hours period shown in figure 4.1.

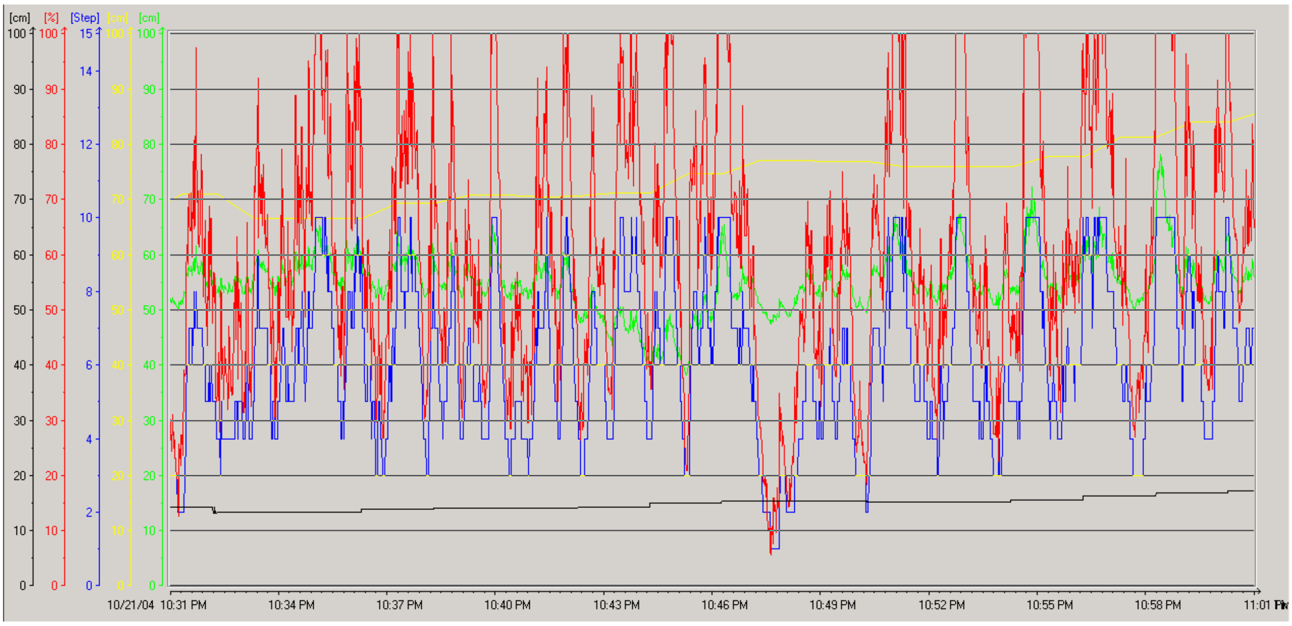


Figure 4.3. Zoom of figure 4.2, the first half hour.

An analysis of the overtopping rates, taking the heel into account, has also been performed, as described in Appendix B. The resulting overtopping rates are shown in figure 4.4. In these data the operation of the dummy turbines have been included.

Generally, as in figure 4.1 quite some scatter is seen and a large portion of the data points falls below the prediction line. The possible explanations for this are again the above mentioned points.

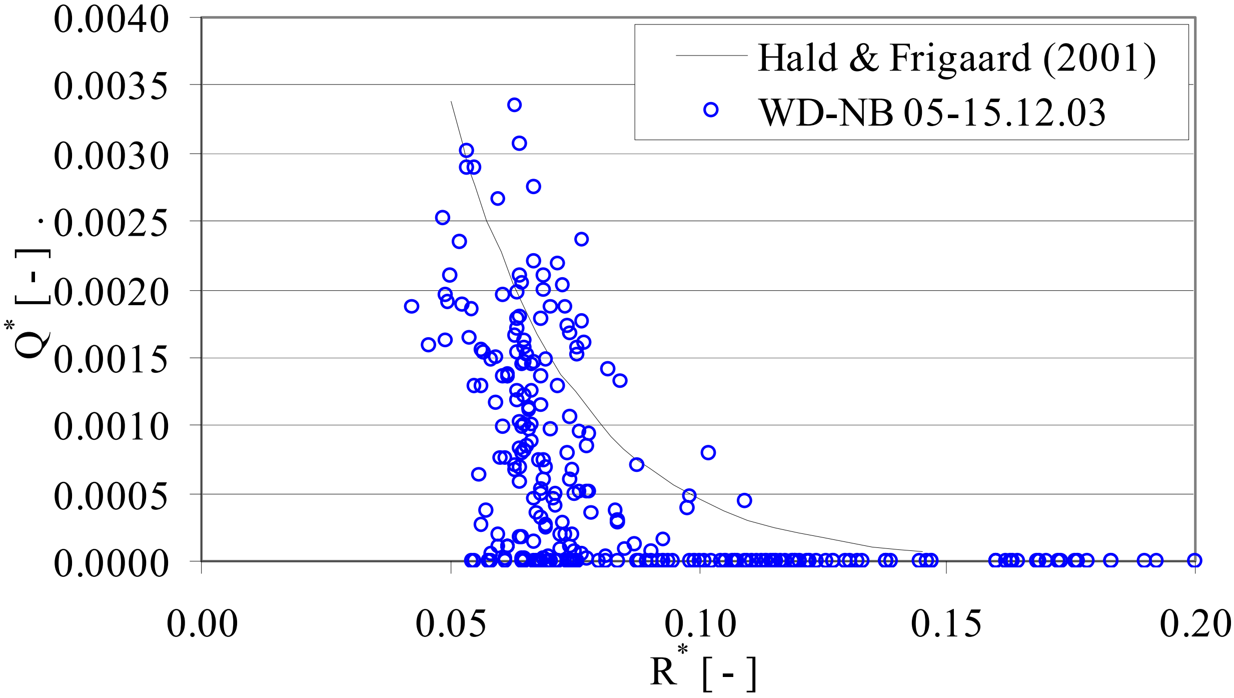


Figure 4.4: All the non-dimensional overtopping rates from Appendix B assembled in one graph. The data is also shown in figure 4.5.

In figure 4.5 the non-dimensional overtopping rates are plotted for one day at a time (6 days during the period 05-15.12.2003) along with half hour averages of the heel, crest freeboard (compensated using heel) and significant wave height. Below a few observations based on these graphs are given:

- Periods with heel close to 0 and R_c close to H_s seems to result in overtopping rates close to the prediction line.
- Significant oscillations in the heel seem to reduce the overtopping rates badly.

However, it is reassuring that some points are above the prediction line, as this could indicate that the overtopping expression under certain circumstances can be exceeded. Thus, the overall picture is that the overtopping expression is realistic in normal operation, i.e. the reservoir is level and not overflowed and WD is fairly aligned towards the waves.

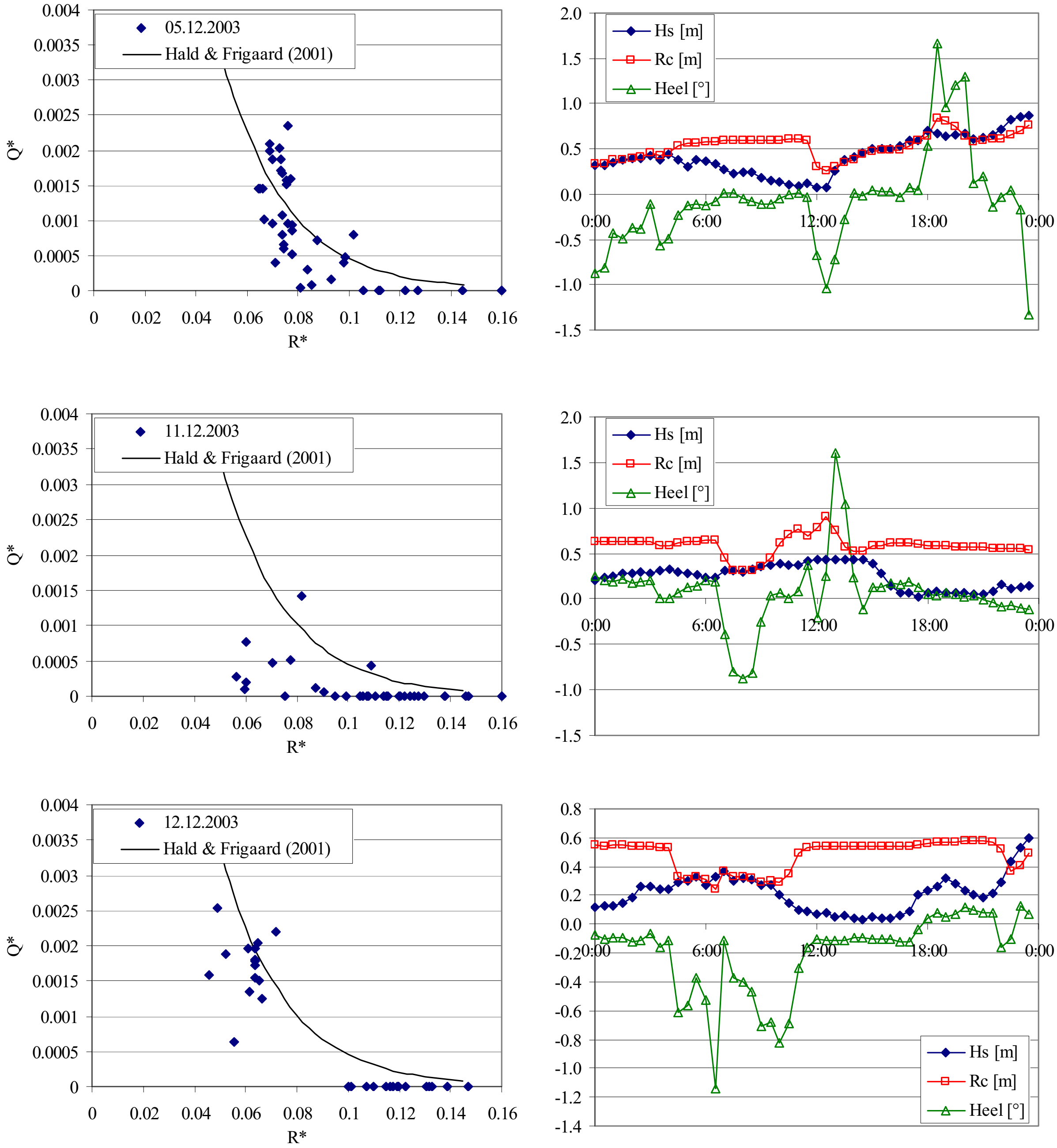


Figure 4.5a: Non-dimensional overtopping rates plotted for one day at a time (left) along with half hour averages of the heel, crest freeboard (compensated using heel) and significant wave height (right).

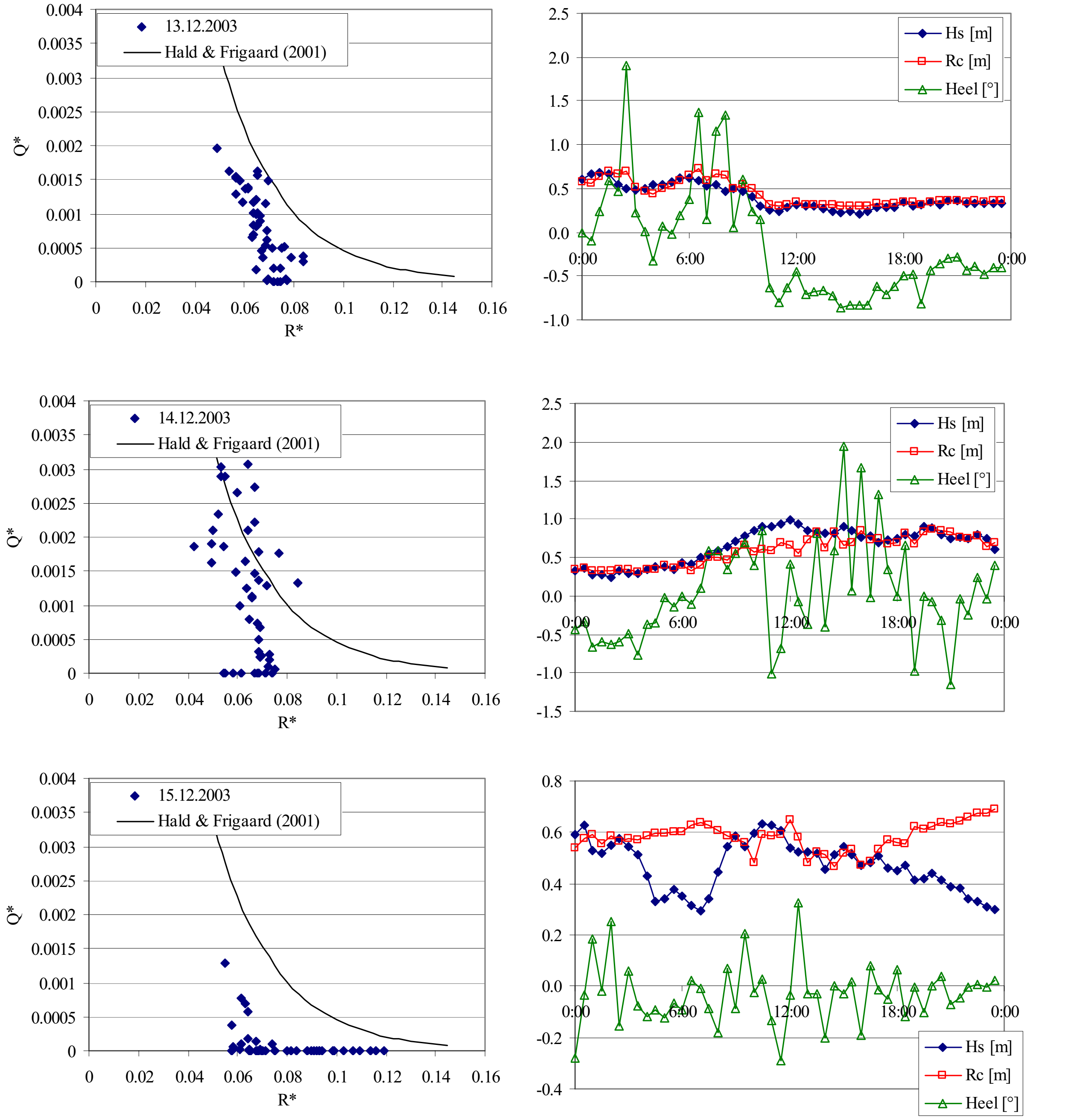


Figure 4.5b: Non-dimensional overtopping rates plotted for one day at a time (left) along with half hour averages of the heel, crest freeboard (compensated using heel) and significant wave height (right).

5. Forces in moorings

Instrumentation

WD-NB was originally equipped with two force transducers in the mooring arrangement. One in the attachment point at the mooring pile, of the main mooring line and one in the attachment point on the port reflector, of the cross mooring line between the reflectors. The first transducer has been performing well since WD-NB was installed at test site 1, providing reliable data except in the periods were the signal cable from the pile to the platform has been broken. The second transducer was already ruined during the dislocation of the reflectors the first weekend after installation.

An attempt has been made to repair the transducer by re-installing a new signal cable from the transducer to the junction box and heavily reinforcing the support for the cabling, but it seems so far that the effort has been in vain. The fact that the cable connection across the port shoulder to the reflector has been disrupted more than once has not made the job of putting equipment on the reflector any easier.

Thus, the analyses of the forces in the mooring system are so far limited to looking at the forces in the main mooring line.

Data analysis

The mooring forces in the main mooring line corresponding to the wave data given in chapter 2 are given in figure 5.1.

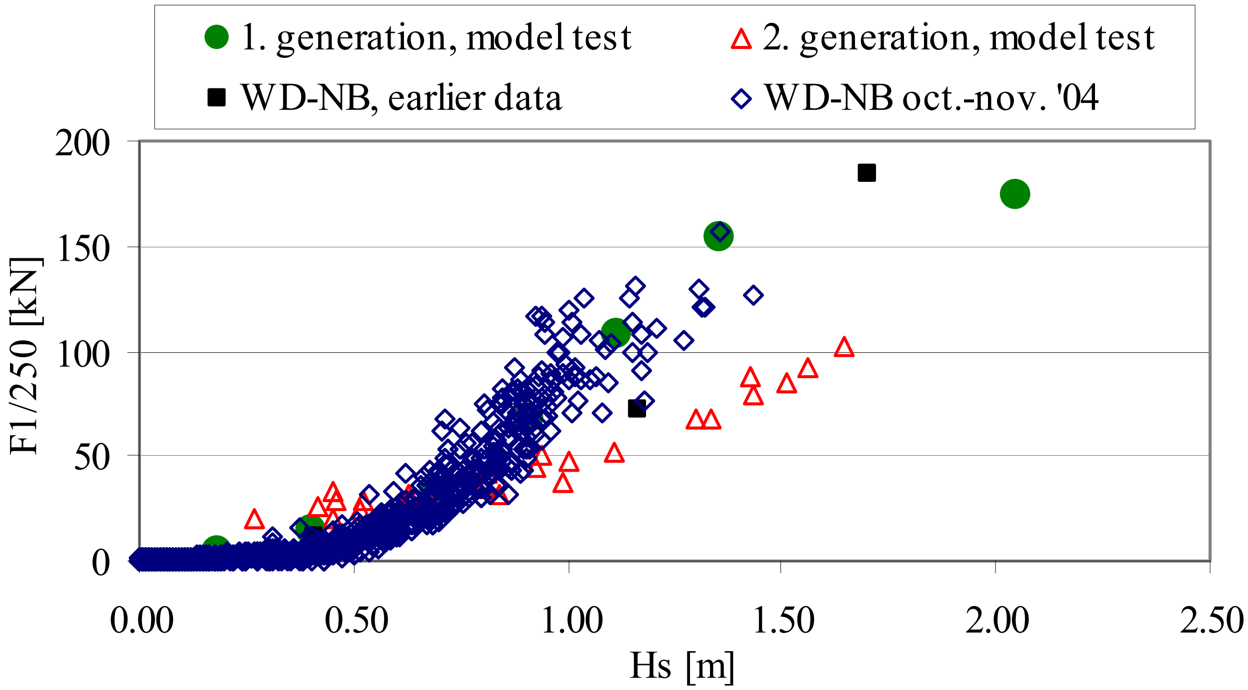


Figure 5.1. Mooring force in main mooring line attached to mooring pile in terms of $F_{1/250}$ (average of the 1/250 largest force peaks). The 'WD-NB, earlier data' is data observed at the SCADA system, ie. not really statistical data, but merely max points observed at the indicated single wave height.

From this figure it seems that the stiffness of the mooring system is too large – more like the situation as in the 1. generation model tests than in the 2.

6. Wave induced motions

Instrumentation

The planned measurements of movements using accelerometers have largely been disrupted by the dislocations of the shoulder connections on more than one occasion. The signal cables to the accelerometers on the shoulders and the port reflectors was cut during the first dislocation immediately after installation of WD-NB at test site 1. Fortunately, the accelerometers on the reflector were not yet installed, as they in that case probably would have been submerged and thereby damaged. The signal connection to the port reflector has been restored and destroyed more than once, see Kofoed et al., 2004b. The installation of the accelerometers on the port reflector is expected to be carried out when time and weather allows it. The accelerometers on the shoulders are currently being re-installed after an overhaul – exchange of signal cable etc. They are expected to be in operation within weeks.

Thus, until present only two accelerometers have been available for measurements. These are the two situated inside the container on the platform, measuring horizontal and vertical accelerations of the platform. Combined with the two accelerometers on the shoulders, these should have been providing heave, surge, pitch and roll time-series of the platform by double integration of the accelerations. However, as only the two accelerometers in the container have operational the following calculations and analyses have been performed.

Data analysis

The data from the accelerometers in the container on the platform have at first been integrated twice in order to obtain time-series of the motions of the points where they are placed. As an attempt to extract some information about the platforms motion in pitch and surge some assumptions have been made:

- LCG (longitudinal center of gravity) 5.509 m (forward from rear), given by Armstrong, 2003
- VCG (vertical center of gravity) 1.247 (above base), given by Armstrong, 2003
- ACC_P1: horizontal accelerometer in container, mounted on ceiling, on CL. Vertical distance to CG: roughly 3,5 m, depending of amount of water in reservoir.
- ACC_P2: vertical accelerometer in container, mounted on container wall towards reservoir, on CL. Horizontal distance to CG: roughly 5.5 m.
- If it is assumed the there is no heaving motion (probably not the case!) the pitch motion can be approximated as:
- pitch = arcsin(vertical motion from ACC_P2 / horizontal distance from ACC_P2 to CG).
- With a similar approach the motion in surge can be approximated as:
- surge = horizontal motion from ACC_P1 + sin(pitch)*vertical distance from ACC_P1 to CG.

Obviously these are rather rough assumptions and approximations which have to be kept in mind when evaluating the resulting data.

The results of these analyses for the period 04.10.20 17.50 - 04.10.24 22.01 are given in figure 6.1 and 6.2.

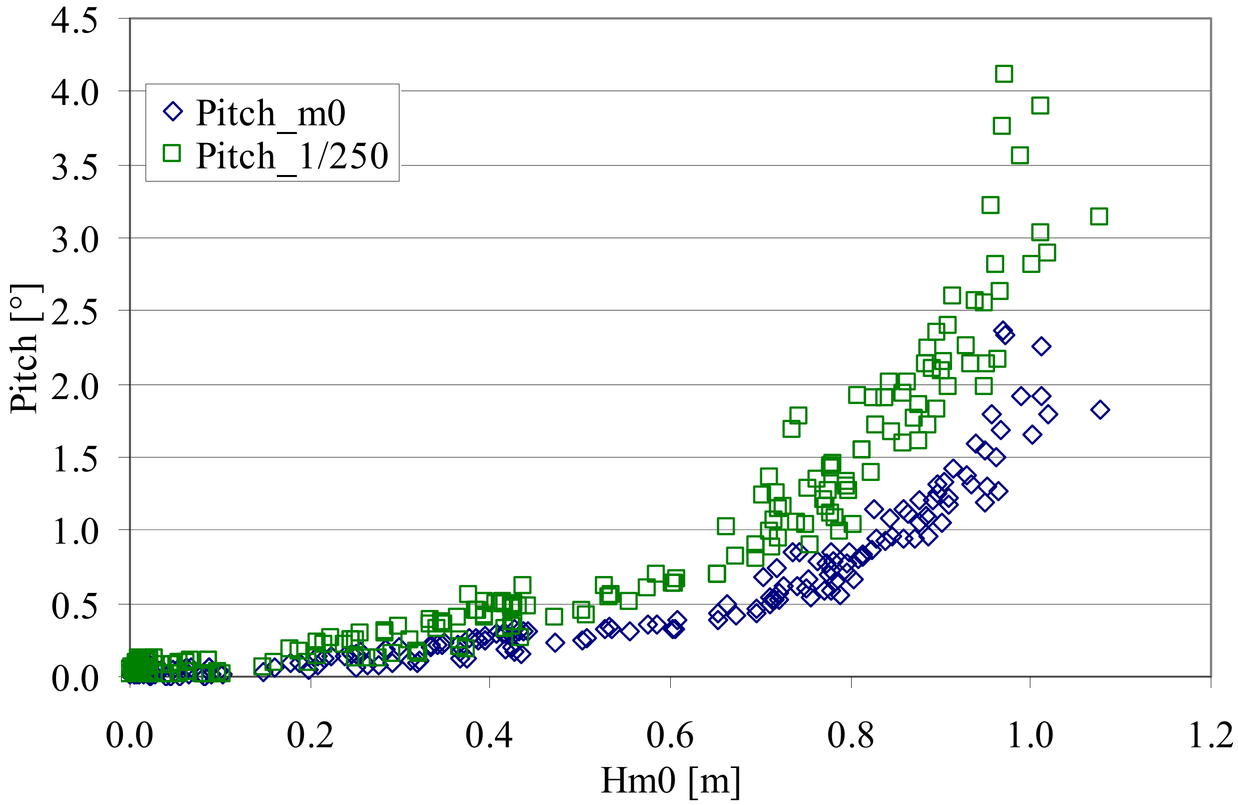


Figure 6.1. Motions in pitch, calculated corresponding to significant wave height (4 times the standard deviation), $pitch_{m0}$, and the mean of the 1/250th largest oscillations, $pitch_{1/250}$, both as a function of the significant wave height H_{m0}.

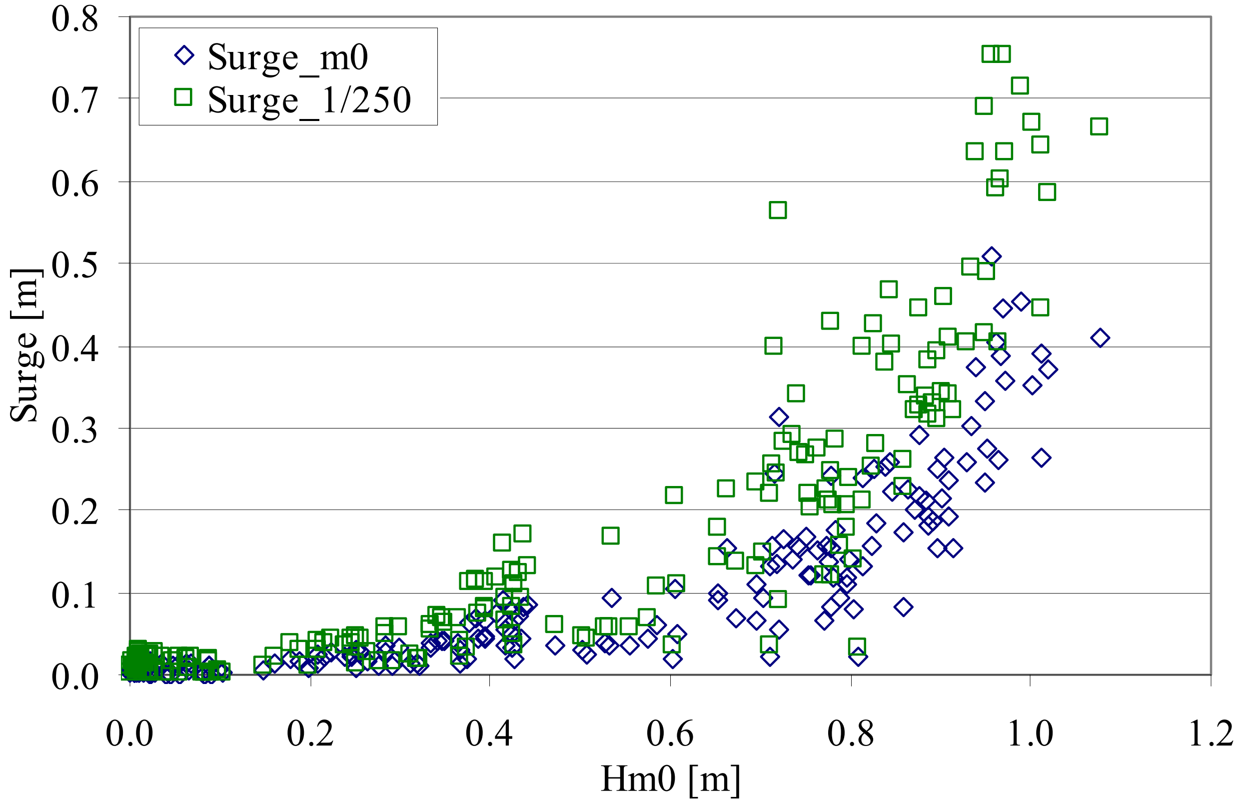


Figure 6.2. Motions in surge, calculated corresponding to significant wave height (4 times the standard deviation), $surge_{m0}$, and the mean of the 1/250th largest oscillations, $surge_{1/250}$, both as a function of the significant wave height H_{m0}.

7. Connection between platform and reflectors

Instrumentation

Prior to installation of WD-NB at test site 1 preparations were made to mount two displacement sensors in the port shoulder connections. Due to the problems and work on getting the fender arrangement in the shoulder connection to perform as initially intended these displacement sensors have not been installed until now. Instead a webcamera has been installed looking down on the fender arrangements allowing observations of the shoulder connection even in serious sea conditions where it is not safe to be on board.

Observations

In addition to work on the fender arrangement already mentioned by Kofoed and O'Donovan (2003) two major incidents during a little more than the last year:

Before repair of the port side fender arrangement planed in the autumn 2003 was carried out, heavy weather caused dislocation of the port reflector and consequently damage/puncture of the port side shoulder. This lead to flooding of a large buoyancy chamber. Further description is given in appendix A, date 03.10.08-09.

Between Christmas and New Year 2003 the starboard reflector was dislocated due failure of back rope between back of reflector and back corner of platform. The reflector was reinstalled the following day with calm weather, see figure 7.2.

webcam2_20040513090005585.jpg
webcam2_20040616170005773.jpg

webcam2_20040910120005484.jpg
webcam2_20040912160005390.jpg

Figure 7.1. Pictures captured by WebCam2 on the port shoulder.

Figure 7.2. Reinstallation of starboard reflector after dislocation, occurring between Christmas and New Year 2003.

Furthermore, the fenders and the chains holding them have continuously had problems. Both parts of the chains and fenders have been replaced in an attempt to maintain the connection. However, A durable long-term solution has not been found, and the layout of the connection most probably needs to be completely redesigned in order to obtain a solution that is applicable to a full-size structure.

Numerous problems with mooring lines have also been experienced, please refer to Appendix A for details.

8. Literature

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Kofoed, J. P., 2003b: *Status rapport - Instrumentering af Wave Dragon, Nissum Bredning*. Hydraulics & Coastal Engineering Laboratory, Aalborg University, May 2003. In Danish. (Title in english: *Status report - Instrumentation of the Wave Dragon, Nissum Bredning*.)

Kofoed, J. P. and O'Donovan, E., 2003: *Status report - First offshore experiences, Wave Dragon, Nissum bredning*. Hydraulics & Coastal Engineering Laboratory, Aalborg University, September 2003.

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Nimskov, M., 2003: *Wave Dragon SCADA interface, User manual*. Balslev, December 2003.

9. Appendix A: Activity log

In the following pages the activity log recorded since Sept. 2003 is shown. The log from before Sept. 2003 is given by Kofoed and O'Donovan (2003). The format of the log has changed slightly during the period, and some log entries refers to smaller visit reports. These reports are given after the log.

The logs and reports are given in raw and unedited text. In the logging it has been attempted to include as much as possible, but not all partners have used the log systematically, so in some respects it is incomplete. Furthermore, some parts of the text appear in Danish. The quite substantial work done on refurbishing the turbine are only mentioned briefly in the log but documented thoroughly by Knapp (2004, 2004b, 2004c).

Activity log

Last update 2003.11.20 by Jens Peter Kofoed

On this page the it is attempted to maintain an activity log of what has been going on at the Wave Dragon, i.e. who has ben there doing what. Please e-mail me if you have correction or additions.

Date	Description	At site
03.09.05	Fishing fenders. See '030905, Progress Report.pdf'	JPK, Eoin (AAU), BP (FC), Niels with father and brother (Diver)
03.09.09	Preparation of turbine installation. See '030909, Progress Report.pdf'	JPK, Eoin (AAU), BP (FC), Leif, René (MTH)
03.09.11-12	Installation of cylinder gate turbines.	JPK (AAU), Lars C (SPOK), EFM (LOW), BP (FC), JP, Leif, René (MTH), 2 on Multisund (NH Svendbord Bugser), German TV team (2 people)
03.09.15	Maintenance of dummy turbines. See '030915, Progress Report.pdf'	JPK, Eoin, Nik Flindt (AAU), Anders (Lindpro)
03.09.17-18	Moving pad eyes in shoulders, welding on walk way, putting in tubes for pressure trandsducers below structure.	Leif, René (MTH), BP (FC)
03.09.29	Preparation of fender mounting on port shoulder. See '030929, Progress Report.pdf'	JPK, Eoin (AAU), BP (FC), Leif, René (MTH)
03.10.07	Installation of webcam, chain on port side bottum of W. See '031007, Progress Report.pdf'	JPK, Eoin (AAU)
03.10.09	Rescue operation, port side damaged. See '031009, Progress Report.pdf'	JPK, Eoin (AAU), BP & Niels (FC), Leif, other (MTH)
03.10.12-17	Repair after damages. Installation of hydraulics for cylinder gate turbines. See '031017, Progress Report.pdf'	JPK, Eoin (AAU), BP & Niels (FC), Leif, René (MTH), Anders, apprentice (Lindpro), Torben (Danfoss), MN (Balslev), Niels (Diver), 3 persons (JH Dyk)
03.10.30-31	New steel wire ropes. (In Danish) d. 30 Oktober 1. Vi har afprøvet løftegalgen der skal bruges ved rep. af turbiner, Taljen skal understøttes for at kunne bære vægten af kappen . 2. Ny bagtros er monteret i venstre side. 3. Begge bagtrosse i begge sider er strammet op med 1,5 tons talje, d. 31 Oktober 1. Nye H trosse er monteret 2. Nye inderste C trosse er monteret til knudepunkt i midten, højre trosse er også monteret til knudepunkt ved pullert. Venstre er ikke monteret til knudepunkt ved pullert, men er fastgjort med tov til arm. 3. Rigningen er strammet op som det var før monteringen af nye wire. 4. Alle øverste kuglehaner er indjusteret til næsten fuld åbning	BP (FC), Leif, Torben (MTH)

Appendix A

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	Skal udføres hurtigst muligt. 1. Begge bagtrosse skal beskyttes for gnavning mod IPE bjælke bag på platform. Platform må ikke sænkes før det er udført 2. Venstre C tros skal monteres færdig 3. Nye C trosse til midt på arm skal monteres. 4. Efter at C kæderne er monteret er det blevet meget svært at løfte rigningen ud af vandet, så der skal monteres flere olietønder på tømmerflåden. 5. Montering af styr på turbiner 6. Der mangler 5 stk. 30 mm sjækler for at kunne montere de sidste wire, hullet i kovsen på de nye wire er ikke stor nok til at de kan sættes på de store sjækler i knudepunkterne.	
03.11.03	Registration of hydraulic behavior, 031103, EFM WD-hydraulisk opforsel SCADA.pdf (in Danish)	EFM (LOW), JPK (AAU)
03.11.05	New boat, securing mooring line. (In Danish): - ny gummibåd leveret og fastgørelsessted på strand ved teglværk. Etableret. - snørre bagtrosse. Gjort! - dreje skulderkamera. Gjort! - rekalibrere tryktransducere. Gjort! - hænge hylde op. Gjort! - sætte tønder op. Gjort! - tage billeder. Gjort! - pudse kameralinser. Gjort! - checke om cyl gate turbiner er HELT lukkede. Gjort! Det er de. - prøve at ansuge siphonturbinen. Slangen er IKKE forbundet! Kan ikke finde fittings. - smøre dummyturbiner. Gjort med "entreprenørsmkinefedt". - generatorkoblinger med retur. Er nu på vores værksted. - strømforsyning til webcams. Etableret. - pudse kameralinser. Gjort!	JPK, ND (AAU)
03.11.07	Guides mounted on cyl. gate turbines, GPS installed. (In Danish) GPS installeret. Fixpunkter indmålt. - Hovedanker 56°41'24,27" 8°20'35,15" - Baganker 56°41'25,77" 8°20'39,53" - Testsite, platform 56°41'31,31" 8°20'44,63" - Testsite, bro/strand 56°41'34,56" 8°20'50,70" Checke at cyl. gate turbiner er HELT lukkede. Gjort - det ser de ud til at være! Luftslange er IKKE forbundet forbundet til sifonturbine - skal gøres ved først givne lejlighed. Tryktransducere rekalibreret (offset justeret), se billede. HUSK til næste gang: - WD40 - Pagaj - Skævbidder	JPK (AAU), Leif, René (MTH)

	- Opdrift til kamera - Gardiner/persienner 70 x 70 cm - Polysturenkugler eller andet opdriftsmiddel til 6 olietønder - 750 kg talje fra HN - vandtæt box til GPS - USB forlængerledning samt repeater	
03.11.12	Remote controlled testing. Bouyance and generators have now been running in automatic mode for several days without problems. The wave height has been low today, the reservoir has therefore a number of times been filled by use of the pump. Serious leaks in the reservoir have revealed themselves, as the volume of water in the reservoir falls about 20 m3 pr hour with all turbines stopped. The turbine gates are probably responsible for most of the leaks. It is necessary to mount some kind of soft gaskets on the gates. During the day it has been verified that the lowest possible floating level with full reservoir is around 37 cm. This means that we 'lack' 37 - 22 = 15 cm. It is proposed to fill 2 x 10 m3 into the two watertight compartments (WTC2 P & S) in the center of the platform. This should bring the min. floating level down to app. 26 cm, which again means, that a heel around -0.5 degrees will lead to an average ramp freeboard of app 22 cm. This is OK for the moment - additional ballast should only be added, when the winter season is over. To test the dummies setpoints of heel , work span etc. has been changed during the day. The setpoints are now: TFL A: 1,00 TFL B: 0.00 TFL Min.: 37 cm TFL Max.: 89 cm BWS factor: 0,20 Turbine 8 step 1 Turbine 9 step 3 Turbine 10 step 5 See also picture/screendump from tests. To be modified in SCADA by MON: - Correct spelling of 'Buoyancy'. - Specify BWS on the form Ax+B as it is done for TFL. - Make it possible to adjust the time axis, or remove seconds and/or AM/PM - use 24 hours time format. - Include automatic daily motioning of dummy turbines if they have not been used. Furthermore, a list of what is done in the different buoyancy steps would be very welcome.	EFM (LOW), LC (SPOK), JPK (AAU)
03.11.19	Intro of Per and Martin (the new maintenance team;-)), repair of dummy turbines. See '031119, Progress Report.pdf'	Per, Martin, Eoin, JPK (AAU)
03.11.20	Remote controlled leak test performed, see 031120, EFM Leak test.pdf (in Danish)	EFM (LOW), JPK (AAU)

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YAHOO! Groups

Table Name: Activity log

Table Description: Log of activities onboard WD

Date / time	Comment	User	Attention	Acknowledged	Category
999999	IMPORTANT! Please use the following format when entering log entries: YY.MM.DD HH.MM. And please use '.' and not '-' or anything else as the seperators. This will help the sorting of the log a lot!	JPK	ALL		Admin
03.11.18 15:20	Test, app. 3 h with heel = -1,0 and short periods with propellerpump in order to fill reservoir - turbine no. 9 is stuck in open position.	EFM			Testing
03.11.19 12:00	There seems to be a programmed upper limit to the TFL at 100 cm (in addition to the TFL max). This should be removed or set to 200.	JPK	MON	Done! 03.11.19	SCADA
03.11.19 19.00	The login functions are now operational on the SCADA, users must use their login.	Morten			SCADA
03.11.26	Siphon turbine checked, light installed, raft modified, Oddesund harbour visited. See Files, Visit reports	JPK, Eoin (AAU)			Work on board
03.11.26 10.00	New alarm class introduced. The colour is blue and these alarms does not need nor can they be acknowledged	Morten			SCADA
03.11.26 12:00	UPS fault: mains rect. fault. Reset pressed.	JPK			Fault
03.11.26 12:00	Water pump 1 causes HPFI relay fallout on shore.	JPK			Fault
03.11.26 17:00	The new turbines are now activated (except no. 4 and 6) to keep the gates closed by the hydraulic cylinders. The turbines will however not operate untill step 10 - which at the present configuration most likely will not happen.	EFM + Morten			SCADA
03.11.26 17:00	It is possibel to switch the new 150 W lighs on/off by means of the SCADA system - Morten will tell JPK which contact to use.	EFM + Morten	JPK	JPK, connection 5.30	Work on board
03.11.26 18.30	BWS A and BWS B now operational	Morten			SCADA
03.11.28	Steel ropes mounted, see Files, Visit reports	JPK, Eoin			Work on board

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		(AAU)		
03.12.04	Connected inclinometers, pump fault resolved. See Visit report in Files section.	JPK & Eoin (AAU)		Work on board
03.12.05 17:00	Good wave conditions. Running in automatic mode. Only two dummy turbines enabled. Hs ~ 0.60 m	JPK & EFM		Testing
03.12.05 23.50	Heavy conditions Hs ~ 0.90 m, WS ~ 20-21 m/s in Thyborøn. Hydraulic pump fault caused by heavy negative heel. Critical condition. See note in Files section.	JPK	EFM	Testing
03.12.08 11:00	TURB 4 (cyl. gate) half way open again. I have activated it and set it to run in step 10 in the generator control, in order to activly keeping it closed. To minimize the probability of of opening of it I have set BWS B has been changed from 0,0 to 0,1.	JPK		SCADA
03.12.11	Siphon turbine repaired, End stops on cyl. gate turbines adjusted. See report for visit in the Files section.	JPK & Eoin (AAU)		Work on board
03.12.12 11:00	The syphon turbine is not running even if it's set as turbine step. A manual start activates the water flow through the turbine, but there is no recording of the generator producing power.	EFM		SCADA
03.12.12 12:00	TFL MAX is set to 67 cm to avoid unstability in high floating levels. When the regulation is fine tuned, the lmax level should be 87 cm.	EFM		SCADA
03.12.12 14:25	Solenoids replaced in Dummy turb. 9, Siphon turb non-return valve cleaned & oiled, Oil changed in lub. bearing, end stops adj. in cyl. gate turb 4 & 6, coarse heel & trim inclinometer adj.	Eoin		Work on board
03.12.14	Storm conditions with average WS up to 24 m/s. Problems with low water level in hydraulics. Does NOT seem to be cause by heavy backward heel. All dummy turbines opened and generator control switched to manual. Dummy turbine 10 can not close.	JPK	EFM, MON, LC	Testing
03.12.14 22.50	It seems that the buoyancy steps have been altered. However, it also seems like it is not done as suggested by EFM & JPK, see Excel sheet in Files, JPK notes. Please tell us what have been done.	JPK	MON	SCADA
03.12.15 10:00	Generators set in automatic mode. TURB10 can still not reach close end stop (has been closed as much as possible), so only TURB 8 & 9 are operating. Wave are coming almost directly from north. This induces heave movements of especially the port shoulder	JPK		Testing

03.12.19 13:50	Min floating level reset to 37 cm. To avoild "heeling":-) instabillity arising from constantly and fruitless attempts to adjust to high floating level . It worked.	Lars		
03.12.19 14:15	Changed MAX bassin level from 60 to 65 cm. It seemed as if bassin level was not calibrated; showing higher level than could be seen at the web cam.	lars &efm	mon, jpk	Calibrating
03.12.19 15:00	TFL MIN adjusted to 32 cm and Basin max level adjusted to 70 cm due to incorrect calibration.	EFM		SCADA/calibration
03.12.19 15:25	Trim SP changed to +0.5 due to mis calibration.	EFM		SCADA/calibration
03.12.22 15:45	At the moment the platform is almost level in trim, when the measured value is +1.70 degrees - thus the set point is now set to this value. The heel set point is adjusted to +0.40.	EFM	JPK, Morten, Lars	SCADA set points
03.12.23 13.43	HEY - I found it!! I'll post commets here from now on.	monbalslev	all	
03.12.23 13.44	Both Trim and Heel from the MGC+ inclinometers are now the ones used by the program.	monbalslev	JP EFM	
03.12.23 14.02	Now that Trim and Heeling meassurements are reliable, Trim and Heeling SP's are set at 0,0. Basin max level is set at 60cm.	monbalslev	EFM, JP	
03.12.23 14.30	Floating level is unreliable. TFL_B has been set at 44cm, to compensate. Reason: At the ramp, it looked as if water level was at 2. line from top (FL=44cm) but meassurement said 79cm.	monbalslev	EFM, JP	
03.12.23 14.30	UPS TFL_B = 35.....! Why can't I edit my own records??	monbalslev	EFM, JP	
03.12.23 14.30	Buoyancy sequence is now as suggested by JPK and EFM.	monbalslev	EFM, JP	
03.12.23 14.45	U4 is the problem for FL, so I've stopped using it for calculating FL. U3 is used instead.	monbalslev	EFM, JP	
03.12.23 15.00	TFL_MIN set at 45cm to prevent instability caused by inability to reach low FL.	monbalslev	EFM, JP	
03.12.24 09.20	Calculation of Hs has an error - it goes SKY high when waves are high. 999.0 is displayed in this case. I'll look into it later....	monbalslev	EFM, JP	
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17:20	Dummy turbine no 8 restart	lars	jpk, efm	Maintenance?
03.12.25 15:00	Dummy 8 can open, but not close totally	EFM	JPK, Morten, Lars	
03.12.26 00:30	Graph 4 looks awfull! It seems like the force transducer is no longer giving any usable results, and the Hs measurements seems to be affected as well. This indicates a problem in the signal cable from pile. Not good!	JPK	EFM, MON, LC	Fault
03.12.26 00:30	Dummy turbine 8 restarted, but no effect. Some debrise is probably stuck in the turbine.	JPK		Work on board
03.12.26 00:30	I5WDPC (the PC running the weather station etc.) seems to be down since the 23th (no uploads from it since then). I might try a remote reboot, but doing so also reboots the MGC+ and the WD_WINCC PC.	JPK	EFM, MON, LC	SCADA
03.12.26 00:55	Tried to reboot PC's and router via SMS. Got confirmation from unit that the PC's were turned back on, but never recieved confirmation on turning on the router. It seems that this has failed. This does VERY UNFORTUNATELY means we are without internetconnection from out there, and thus we can't see anything, I'm very sorry! I'll try and contact Bendy first thing tomorrow.	JPK	EFM, MON, LC	Fault
03.12.26 01:55	Confirmation for turning on router arrived. The router is up and running and so are the PCs.	JPK	EFM, MON, LC	Fault
03.12.26 02:25	What is ASP on the main page? Actual set point?	JPK	MON	SCADA
03.12.26 02:35	TFL changed from 1 to 0, TFL B set to 55. This is done as Hs changes from 2 to 999 just like that.	JPK	EFM, MON, LC	SCADA
03.12.27 10:00	Hydraulik pump restarted (water alarm). Dummy turrbines 8 and 10 cannot close due to stuck rubber fenders in the valves!!! I have sent a mail to Bendy in the hope that he can go out there today. The wave measurement seems to be o.k. at the moment so the floating level is set to follow the waveheigt. Constant floating level 55 cm will be set again when I leave the office around 16:00	Erik	JPK, Morten, Lars	SCADA set points and turbine alarms
03.12.27 24:00	Automatic regulation stopped due to sudden heavy negative heel. The stacked grids have moved around on the deck.	Erik/Morten	JPK, Lars	Regulation
		JPK, PF, Søren,		

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03.12.29	Emergency work carried out. Starboard reflector displaced and capsized the night before yesterday. Reflector re-erected and put in place again.	Martin (AAU), EFM (LOW), Bendy, Niels (FC)			Work on board
04-14.10.04	Restauration of CGT's. TUM will make a complete report on this operation.	Thomas, Sven (TUM), Manfred (Kössler), LC (SPOK), JPK (AAU), Bendy (FC)			Work on board
04.01.02 17.15	Buoyancy sequence changed according to EFM/JPK wishes. Excel sheet uploaded to this site. I've tested the changes as much as possible. Still, I'll look at the dragon the next hours to detect malfunctions...	monbalslev	EFM, JP		
04.01.02 22.40	ASP is "Artificial SetPoint" - the value the program aims for. The new version of the buoyancy program seems to work. I have "let it loose". Also I've set the generators in automatic running with T08-T10.	monbalslev	EFM, JPK		
04.01.02 22.41	OOPS, the buoyancy is NOT let loose, the Hs calculation still doesnt work. TFL is at 45cm.	monbalslev	EFM, JPK	JPK, signal cable to pile heavily damaged/weared. Repair scheduled, replacement under consideration.	
04.01.03 12.15	I wondered why we couldn't make the shphon turbine run, and I found that I for some reason had turned off the communication alarm for the WDC. Anyway, the alarm is standing - the PLC cannot send succesfully to the WDC, and no telegrams are recieved. Either the cable is broken or there is an error in the WDC...	monbalslev	EFM, JPK	This requires contact to West Control. Can you talk to them? Maybe we can try 'rebooting' their units? /JPK I'm not at the office until feb. 1st. during the day time, so perhaps you can talk to them yourself? /MON	Fault
04.01.04	Last night I disabled the alarm for endswitches on the dummy turbines.			What seems to be the problem - anything stuck? Or is re-adjustment needed? /JPK I couldn't see if anything was stuck. But the	

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19.45	They should be enabled once the end switches are reliable.	monbalslev	JPK	readjustment is carried out WAY too often - perhaps something else than adjustment is needed........? /MON	SCADA
04.01.05 16.00	ACV2.2 T og ACV3.2 T changed to 70 seconds to stabilise heel regulation - see files, screndumps	EFM			
04.01.05 21.15	I just took out U1 from the FL calculation and used U2 instead. Something has to be done about the transducer problems - otherwise we'll soon find ourselves without ANY way of regulating anything! ;o)	monbalslev	all	I'll make an effort to put in a new pressure transducer in the tube situated near the crest at the center line. This will be removable, and thereby maintainable. Hopefully this can will help us. /JPK 04.01.06 12.44	Fault
04.01.06 11.00	ACV2.2 T og ACV3.2 T changed back to 80 seconds as heel is pendling up to +- 2 degrees	efm			
04.01.06 23.40	I found the bug that caused the heavy heeling this afternoon. It affected steps 15 and 17 and is now fixed. Pr. request by EFM I have uploaded the source code for the buoyancy program to the board - feel free to have a look. Write me an email if you have any questions. For the programming nerds - the bugs were in lines 744 and 807, where it said "AN #EXH;" As you can see in the uploaded code the correct command is "O #EXH;"	monbalslev	EFM, JPK	Some of it seems to be understandable - at least the setting of the control of valves in the various steps. /JPK 04.01.07 10.15	SCADA
04.01.06 23.50	Three new configuration values has been added to the config picture. ASP Factor: ASP = SP - (SP-PV)*(1-ASP Factor). Ext. Heel = abs(Extensive Heeling limit) Ext. Trim = abs(Extensive Trim limit)	monbalslev	EFM, JPK		SCADA
04.01.06 23.55	I've had the buoyancy in automatic now for a while, and it looks as if the adjustable ASP Factor is a good idea. It's now at 0,3 but feel free to experiment (limits are 0,1-0,5). From my point of view it's OK to run in automatic again... but further test and verification would certainly be good.	monbalslev	EFM, JPK		Buoyancy
04.01.07	I5wdpc (the pc running the weather station, gps, mgc+ software) is ill and has been since christmas. A new pc has been ordered. Data recovery is in progress.	JPK			Work on board
				There does not seem to be	

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04.01.07 07.10	The hydraulic pump has tripped on high temperature during the night. Last night I saw that it started very often without any turbine action, this must be the reason for the high temp. At the next visit to WD the hydraulic system should be checked for leaks.....	monbalslev	EFM, JPK	any leaks - water level is almost at max mark. There must be a return valve that is leaking. /JPK 04.01.08 09.54 Have you called Danfoss? We won't be able to run the generators in automatic until this problem has been solved.... /MON 04.01.08 22.13	Water Hydraulic
04.01.07 10.15	I'm running the bouyancy control in automatic to test under supervision. Test sequence: TFL 50 -> 80 cm, reservoir empty. TFL 80 -> 44 cm, reservoir empty. Reservoir filled, TFL maintained at 44 cm (system recovered lost floating level). TFL 44 -> 88, reservoir filled.	JPK	MON		Testing
04.01.09	New mooring line 'E' installed to replace temporary ropes after last accident with loss of starboard reflector (between christmas and new year). New retractable pressure transducer mount in tube close to ramp crest and center line. Not yet connected. Once this is connected it should be use for the measurement of the freeboard, reporgramming of PLC needed. Light relay now connected, so light can be switched on from the SCADA software.	JPK & Nik, AAU	EFM, MON		Work on board
04.01.13 18.10	As pr. request a seperate ASP factor has been introduced for Trim, Heel and FL. Please check if it's working properly....	monbalslev	EFM, JPK		Buoyancy
04.01.15 12.00	Testing of generator control, WCU. Temp. wire for one generator at a time is installed. Two out of 7 controller boards in WCU damaged. New pressure transducer for freeboard measurement connected to junction box. Hoses for ventilation of junction boxes with pressure transducers blown empty of water. Junction box in middle of turbine area contained water. Additional sealing applied. Water is dripping from ceiling in container (hole for wire for light, port side of container). Starboard line 'E' (from back side of reflector to aft reservoir corner) tightened.	Armin (West Control), Bendy, Thøger (FC), JPK, Martin, Per (AAU)	EFM		Work on board
04.01.16 06.50	The generator data is now correct. I wonder why the values are not zero when the generators are not running....	monbalslev	EFM, JPK		Generators
04.01.16 19.00	JPK, could you please ask WestControl for a table explaining the values for: NETSTAT, NETFAULT, DRiveSTAT, DRiveFAULT... I haven't got the file from last year, and furthermore it seems to be outdated anyway.	monbalslev	JPK		

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04.01.18 18.00	ASP Trim changed from 0,20 to 0,15. ASP Heel changed rom 0,40 to 0,30 to minimize pendling. Due to alarm ACV52 the trim adjustment is not verey good. Float Hyst changed from 3 to 5 cm due to inaccurate float calculation (only U2 and U3 are used)	EFM	Morten, JPK		Configuration
04.01.18 23.00	ACV52 has been in alarm for not reaching end switch closed. At the next visit to WD the valve should be checked for adjustment and possibly lubricated	monbalslev	EFM, JPK		
04.01.19	Bendy, an electrician and Hilligsø, Danfoss is working with the turbines all day. The platform is in high floating position.	EFM			
04.01.21	New prints for WDU, turbine 1 and 7, installed. Testing of generator control attempted. Transistor in circuit for turbine 7 exploded. Repair needed before turbine 7 can be tested. Remaining turbines not tested because of internet connection down (tests needed to be remote controlled). New pressure transducer PRES_FL connected to MGC+ - calibration/offset adjustment still needed. Work on protection of under neath container initiated. Work on signal cable connection across port shoulder continued.	Armin (West Control), Bendy, Thøger (FC), Per, Martin (AAU). On remote: JPK (AAU), EFM (LÖW)			Work on board
04.01.22	Turbines 6 and 7 has been operating this aftenoon. The configuration is now changed back to the dummies - se screndump in 'Files'. The Heel and Trim has been recalibrated - setpoints are now 0,00.	EFM	JPK, Morten, Lars		SCADA set points
04.01.22	See visit report in 'Files' section.	Bendy (FC), Per, Morten & JPK (AAU)			Work on board
04.01.23 15.20	Buoyancy control modified so 'too' and 'much too' high/low floating level are all the same (all chambers are active).	JPK	MON, EFM		SCADA
04.01.23 18.00	The Heel Hyst has been changed from 0,10 to 0,20. The ext. Hell has been changed from 1,00 to 0,80. The ext. Trim should be lowered somewhat, but it is not possible due to the actual limit on this parameter - the limit should be lowered to 0,1.	EFM	JPK, Morten, Lars	The purpose of the Ext. limits are purely to be a safeguard. If the normal operation cannot handle the Trim precisely enough, changes should be made here - not to the "safety function" /MON	SCADA set points
	Analouge output PQW578 is now ready for testing. At the config picture it is now possible to select which value is sent to the output. When a power				

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04.01.26 22.00	signal is selected, the output is scaled from Value = 0-5000 => AO = 0-27648 and when a RPM signal is selected the output is scaled from Value = 0-1000 => AO = 0-27648. JPK: I haven't got the hardware drawings here, so I cannot tell you which terminals to connect to. When you are at WD or if you have a set of drawings give me a call.....	monbalslev	EFM, JPK		
04.02.02 02.00	PRES_P seems to work fine. We get reasonable wave measurements. I have therefore changed TFL A from 0 to 1, TFL B from 66 to 0, and TFL min from 22 to 55.	JPK	EFM	TFL B has been changed to 55 cm to avoid heavy overtopping, as the top of turbine 3 is dismantled	SCADA
04.02.03 17:00	Ext. Heel has been changed from 0,80 to 1,00. This should be o.k. as the regulation now seems to be quite stable. Turbine calibration test has shown that heel is varying app. 2 degrees when the water level in the reservoir is changing 25 cm i.e. during normat turbine operation.	EFM	JPK, Morten, Lars		SCADA set points
04.02.04 18:00	Trim SP changed to -0.5 - it is strange that the inclinometer has shifted 0.5 degree in 4 days. Trim Hyst raised from 0.1 to 0.15 and Heel Hyst raised from 0.2 to 0.3 to lower the number of regulation operations - for instance when changing the floating level. The floating level should ASAP be calculated from the measured value at the ramp crest to the center of the platform as it was before the trouble with some of the transducers. A screendump of the configuration sheet has been uploaded to 'Files'	EFM	Morten, JPK, Lars C.		SCADA set points
04.02.09 06.45	JPK, regarding the CAN com; if you look in DB112, you'll see the data send to the gateway. It is transmitted every 1 second. I've enabled the alarm, so you will be able to see when the PLC is error-free on the com.	monbalslev	JPK	Will the error mess. MGCplus DP send disappear once it transmit the data properly to the UNIGATE? Or how should this error mess. be interpreted? 04.02.11 JPK - The alarm is acknowledged, so it should dissapear once the communication is OK. /MON 2004-02-24	SCADA
04.02.10	AN attempt was done to get the Profi/CAN bus com. between PLC and MGC+ up and running. Not successfull so far, but the work is continued on remote. Furthermore, Loose bolts were fitted on the hood of the Flygt pump well (so the hood works as a non-return valve), so overtopping water is not	PF, JJ & JPK (AAU)			Work on board

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	lost into the well, but the pump can still be activated remotely.			
04.02.10 11.15	Power fall out (manual). Data in SCADA system seems to be bad a few hours back.	JPK	EFM	SCADA
04.02.20	Etablishing trash rag. WD placed in high floating level (automatic mode).	Lars		
04.02.21	Trash rag establishing continued. With WD in high floating level. Late afternoon: TFL A=1 & TFL B=0 & BWS A=0.25 & BWS B=5cm.	Lars		
04.02.23 13.45	Router/firewall reset by SMS. This seemed to remedy the VERY slow connection speed that has been seen the last days.	JPK		Internet connection
04.02.23 14.25	A small time syncronizing piece of software (World Clock 3.0) have been installed on the PC's on board. Thus, the PC clock should be syncronized with an atomic clock every hour (provided internet connection is available):	JPK	LOW, BAL, TUM	Work on board
04.02.24 11.00	Dummy turbine 9 seems to be malfunctioning. No alarms are seen, but it is not openend when the step that should activate it is reached. It works in manual mode. This has probably been the situation since 04.02.20 at least, Which means that the measurements of overtopping during the weekend probably cannot be trusted.	JPK	MON	SCADA
04.02.24 17.15	As agreed with JPK, the turbines will not stop in case of end switch alarm. Alarms are displayed and the "block" representing the end switches will be flashing red. Furthermore, the max basin level is now corrected for negative heeling. The value used by the program cannot be seen on the screen. Finally, the FL is also corrected for heeling and should now be the correct floating level at the center line. The raw value from P_FLOAT can be seen on the overview screen.	monbalslev	JP, EFM	SCADA and PLC
04.02.26 18.20	Visit to WD. Starting up cyl. gate turbines. See visit report in 'Files' section, under 'visit reports'	JPK, MKR (AAU)		Work on board.
04.02.26 9.15	Turbines taken out of operation, target FL set to 100 cm, target heel to -1 deg., for work on board.	JPK	EFM	Work on board
04.03.01 9:45	Hydraulics stopped during the night due to high temp. I tried restarting, but could hear that the security valve went of everytime the hydralic power pack was pumping. I think this valve needs to be adjusted before running the turbines in automatic again!	JPK	EFM, MON, LC	Fault
	WD has been without waves and set to try to obtain FL = Hs for two days. This means TFL has been 22 cm in this period. However, this cannot be			

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04.03.09 10.00	acheived, as we know - FL ends up around 66 cm. But anyway, it keeps trying, which leads to control induced oscillations in FL and heel, see uploaded screendump in 'files/SCADA' section. The pressure readings in the air chamber showed that there still is a little pressure in chamber 3 and quite some in chamber 1 (~32 mbar). I have now tried to take it out of automatic in bouyancy control, and opened all outlet valves to see how low it can go. I will then put i back into automatic to see if it then stabalizes at the same FL as before, or lower (which is what I exspect/hope). If the later is the case, maybe we need to put in some condition in the operation, that eg. when it has gone through 10 bouyancy adjustment cycles whitout getting as far down as wanted, it should open all outlet valves for 10 min. and then try again.	JPK	EFM, MON	SCADA
04.03.14 17.05	Wave measurements absurd - Basin work span and target floating level effected. I have set BWS to fixed value of 20 cm and TFL to a fixed value of 66 cm. No other changes.	JPK	EFM, MON, LC	SCADA / measurements
04.03.14 18:45	Jens Peter, you actually did'nt change BWS from 15 to 20 cm - I have left it as 15 cm because only 2 dummies are working. I have changed the turbine steps so now T8 is at step 2, T9 is at step8 and T10 is at step 5	EFM	JPK, Morten	
04.03.16 17.00	Visit to WD. Demonstration for international students from AAU. Setting up new PTZ webcam. See visit report in Files/Visit reports section.	JPK		Work on board
04.03.19	Heavy wave conditions. Measurements recorded by MGC+ but PRES_P not functioning properly.	JPK		Testing
04.03.22	Turbine 8 and 10 endstpo error. Tried to open and close dummy turbines. no 8 couldn't open or close. No 10 could open but not close.	LC		Turbien operation
04.03.24	Visit to WD, PTZ camera mounted on pile, see Visit Report in Files section	JPK		Work on board
04.03.28	Per & Martin working on WD during the weekend, rust/paint jobs etc., see Visit report in Files section	Per & Martin, AAU		Work on board
04.04.01	Pictures from the latest 4 visits to WD have been added to the partner site http://www.civil.auc.dk/~i5jpk/wd/partner/ pictures section	JPK		Admin
04.04.02	Visit to WD, Check of amplifiers, see Visit report in 'Files' section	JPK		Work on board
04.04.04	Rapid rise in wind/wave conditions at noon (from 4-6 m/s to 12-14 m/s from south within half an hour). Failure of hydraulics lead to VERY low floating level (9 - 12 cm). See picture in 'Photos'	JPK		Fault / testing

04.04.13-14	Meeting regarding EU WP 2.3 and 2.4 at WD. Minutes can be found in 'Files' section. Big problems getting out there, as outboard motors for boat was malfuntioning. Has been brought to Aalborg for repair.	Andreas and Tony, Niras, JPK, AAU		Work on board / meeting in summerhouse
04.04.19 1300	Visit to WD. Work on communication between PLC and WCU. See visit report in 'Files' section.	JPK (AAU), Armin (West Control)	Wilfried (TUM), EFM (LOW), MON (BAL)	Work on board.
04.04.21 15.00	FWA (broadband internet) connection down. Sonofon is informed and will send a technician ASAP.	JPK		Fault
04.04.21 15.45	FWA link up again. Sonofon will still send technician to check installation, thursday or friday.	JPK		Fault corrected
04.04.22	Problem with lubrication of rubber bearing in cylinder. See note in 'JPK notes' in 'Files' section.	JPK	EFM, Kössler	Fault
04.07.17	Visit to WD. See report in 'Files' section.	Thomas, Søren Krogh, JPK, AAU and Xavier, FC		Work on board
04.08.13	Visit to WD. Fan coil mounted, see Visit Report in 'Files' section.	EFM (LOW), JPK, Martin and Tim (AAU)		Work on board
04.08.21 12.55	Checked SCADA system. The generator system seemed to have been left in automatic mode unattended since yesterday. Alarms on all dummies and the hydraulic pump had set out due to high temp yesterday around 18.00. It seems from inside temperature curve that the cooloing system stopped between 16 and 17 yesterday. I have set the generators in manual and tried to open the dummies. They don't open completely, but from webcam1 I can see they are almost open.	JPK	LC, EFM	Fault
04.08.27 23.00	Sihon turbine has been running in automatic mode all afternoon, unmanned. That is a premier! There is a lot of starting and stopping, but the waves are not very high compared to the freeboard. I have now switched turbine 1 and 5 in the generator setup to let turbine 5 run for a while. Only very seldom	JPK		Testing

	does both turbines run at same time.			
04.08.30 12:00	I have reduced the target floating level TFLB from 66 to 44 cm. The siphon turbine was running for very shot intervals.	Lars		
04.08.30 13:45	Returned to TFLB = 66 cm. As the siphon turbine seems to have problems with the hydraulics, I have put turbine 5 in turbine step 1 and the siphon in step 5.	Lars		
04.09.09 11.25	Offset of PRES_FL adjusted. Chanfed from 381 to 396 mbar, ie. the floating level has been recorded as 15 cm lower than real.	JPK		Calibration
04.09.10	Reinstalled fender column on starbord shoulder. Added 30 cm small diameter fender in fender row on starbord shoulder. Replaced broken upper chain link in fender column number two. Hydraulics left off, due to leakage. Dummies open, rest closed. See Visit report in 'Files' section for further notes on activities at WD 04.09.08-10.	lch & efm		Maintenance
04.09.23	Visit to WD. See visit report in 'Files' section.	JPK & NH (AAU)		Work on board
04.09.25	Visit to WD. See visit report in 'Files' section.	TT Nautech, JPK (AAU)		Work on board
04.10.20 17.40	Offset of PRES_FL, PRES_R1-3 adjusted, -3.5, -2.0, -4.0 and -4.0.	JPK		Calibration
04.10.25 14.08	In order to avoid siphon turbine starting and stopping too frequently it is set at Step and Step 0->1 is set to 0.3 instead of 0.1. Thus, it will not start until step 4 is activated but stop is stil at Step 1->0 at 0.0.	JPK	EFM	SCADA
04.12.03 21.05	Trying out various CONSCALE values to get better generator/turbine performance. See note in 'Files' section.	JPK	EFM, WK (TUM)	Testing

Wave Dragon Progress Report VI

Date: 5/9/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: Jens Peter Kofoed, Eoin O'Donovan, Bendy Poulsen, Nils (Diver) & aides

Report:

On this particular visit to WD:

- Bendy finished installing the submersible pumps in both port and starboard shoulders.
- The GSM internet connection was put back up and running again.
- In carrying on the work from 29/08/03, the rope from the mooring pile to the port reflector tip was reversed with a thimble placed at the designated length of 42m from the mooring pile. In addition, a 3m length of chain was attached to the starboard reflector/mooring pile line to increase it to the 42m length.
- The diver came and retrieved fenders noting that the fishtail plate on the starboard side has the bolt and retaining nut capped off. Ropes have been attached to the loose chains so that they can be retrieved next week.
- Due to time constraints, the diver did not get the opportunity to clean the transducers.

Inventory of Fenders on WD

	Within shoulder/reflector interface	*Outside shoulder/reflector interface*
Port side	*4 Large* *1 Small* *1 ½*	*5 Large* *9 Small* *6 ½'s*
Starboard side	*5 Large* - *2 ½'s*	*5 large* *4 Small* *1 ½*

Appendix A

Wave Dragon Progress Report VII

Date: 9/9/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present:Jens Peter Kofoed, Eoin O'Donovan, Bendy Poulsen,Leif & Rene (Promecon)

Report:

On this particular visit to WD:

- Leif and Rene extended the floor bolts for the turbines and finished welding on the shoulder lips on the starboard side. Work is commencing on the lips on the port side.
- Leif cut up the old blinding plates to construct a pathway along the starboard of the main body.
- The Zywall 1 was replaced with a Zywall 10W Internet firewall.
- A method was agreed upon for installation of pipes for the pressure transducers under the structure.

Wave Dragon Progress Report VIII

Date: 15/9/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: Jens Peter Kofoed, Eoin O'Donovan & Nick (AAU), Anders (Lindpro)

Report:

- The main objective of Anders work was to make the Internet fiber connection operate correctly. As a result, the media converters that convert fiber to Ethernet communication were changed from 10 to 100 Megabit units. It is thought that the end filter installed by Siemens did not detect the 10 Megabit unit. In addition, the crossover cable between the media converter onshore and the filter installed by Siemens was changed.

- Some modifications were made to the web-cam settings and its online updating strategy. The Web-cam now updates at ~ 10 minute intervals and provides stationary shots illustrating conditions for the past ~ 2 hrs 40 mins. The online settings were also adjusted for compatibility with the broadband setup.

- The hydraulic cylinder that operates the Aer-ation valve is now operating again. However, all hydraulic cylinders, including those on the dummy turbines, need inspection (and most likely adjustment). A good opportunity to carry out this work may be to correspond with the installation of the systems on the 6 new Kössler turbines (Danefoss).

- Finally, some important maintenance work was carried out on the Dummy turbines. All 3 turbine shells were extracted individually before rust removal and treatment (Galvafroid and greased) was carried out. This allowed the shells to open and close effectively. In addition, the reconditioned hydraulic cylinder (bent ram) was installed on one of the dummy turbines. All 3 turbines now operate satisfactorily.

Wave Dragon Progress Report IX

Date: 29/9/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin O'Donovan(AAU), Bendy Poulsen(FC), Leif & Rene (Promecon)

Report:

- Leif and Rene proceeded to work on the port shoulder connection. On removing some of the fenders temporarily placed at the interface, it was noticed that the fishtail plate had been damaged in the same manner as the starboard side with the plate completely detached from the underside of the shoulder. On a more positive note, no more fenders or chains have been lost and all the material to carry out the modifications to the shoulder connection is available. The modifications to the port shoulder are due to be completed on 30/09/03.

- The buoy at the intersection of the mooring lines from the port shoulder and reflector, which had been ruptured on impact during high winds with an adjacent buoy, was also replaced.

- In other maintenance work, the dummy turbines were put operating again. However, despite recent treatment, two of the three turbines did not open/close properly. The root of the problem is, however, more related to the excessive "play" in the turbine shell causing it to be "off centre" than corrosion.
  Efforts need to be concentrated on improving the vertical guidance of the shells with a "self-centering" system preferred.

- As regards the on-line monitoring aspect, the Firewall was opened up allowing access from outside with a NetOp host providing remote control of the PC on board Wave Dragon. Another, freely downloadable, remote control host, "TightVNC", was installed.

- Finally, the fault with the pressure transducer was investigated and after some examination it was found that two of the connection wires in the electrical system panel were not secured in their appropriate terminals. These were promptly secured with the transducer giving pressure readings of the order anticipated.

Wave Dragon Progress Report X

Date: 7/10/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin O’Donovan(AAU)

Report:

On this particular visit to WD:

- The mooring line attached to the bollards on the port side was modified. 10 meters of chain was installed in place of the Nylon line to prevent wear at the shoulder window, which has been seen to be a problem. In turn, the Nylon rope was reduced to 8 meters to complete the mooring.

- Approx. $7m^3$ of water was pumped from the chamber in the port shoulder.

- In addition, a large rubber fender was placed in the port shoulder/reflector interface in view of the high winds expected over the coming days.

- A second (colour) webcam was placed on the left window of the container to monitor the port reflector. Currently, it only provides a black & white picture. The reason for this need to be investigated.

Wave Dragon Progress Report XI

Date: 9/10/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed (AAU), Bendy & Nils (FC), Leif & Assistant (Promecon)

Report:

Port Reflector disaster

In light of the damage caused to the port shoulder of WD on impact from the misplaced reflector, it was necessary to pressurize the now flooded shoulder compartment. This was achieved by taking the air pipe from the Siphon turbine to the compartment, moving the pipe from the intake to the output side of the blower. With the blower left running, this had the effect of reducing the trim from 5 to 2.5 degrees.
In addition, some rubber fenders were added to the port side to prevent any damage from possible impacts of the reflector.

Wave Dragon Progress Report XII

Date: 12 - 17/10/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin (AAU), Bendy & Niels (FC), Leif & Rene (Promecon), Anders & Apprentice (Lindpro), Torben (Danfoss), Morten (Balslev), Nils (Diver), JH DYK Diving

Report:

Shoulder/Reflector Interface

- On Sunday, 12th Oct, Niels (FC) and his son (diver) visited test site 1 and recovered three small and one large of the rubber fenders which toppled off the port reflector arm when misplaced. Five further large fenders were reclaimed on Monday by diver Niels.
- Damage to the top of the port shoulder was welded up (Promecon) at which point it was also noticed that some further damage had been caused to the shoulder below water level.
- Water was pumped from the shoulder compartment using a high capacity submersible pump.
- To limit the extent of any possible future flooding of the shoulder section of the main body, on Tuesday, man-hole covers were fitted to close off the front shoulder compartment.
- JH DYK diving welded up the underwater damage to the port shoulder, recovered further fenders before assisting in installing the lower fishtail plate. The Diver also confirmed Niels finding of a ill-fitted starboard lower fishtail plate. It is thought that one of the small rubber fenders became caught on the underside of the shoulder when initially tensioning the chains.
- This problem was remedied by jacking out the starboard reflector, thus affording more room at the interface, and shortening (gas cutting) links from the appropriate fender chains.
- On Wednesday, the rubber fenders were re-fitted on the port side before moving the reflector into place.
- On Thursday, some piping was welded to the lower edge of the shoulder window to cover up the sharp edge that existed there, thus providing a smooth contact surface for the mooring chains attached to the shoulder bollards. In addition, vertical piping was welded from the base of the window to the rim of the main body, thus sectioning the shoulder window in two, to deflect the mooring from wearing on rubbing against the edge of the reflector.
- It was also noticed that the sounding pipes (vertical pipes to airtight compartments) are heavily corroded and are thus not competent in the event of bring hit by heavy debris that may be included in some overtopping waves. It is intended to weld galvanized pipe on the outside of the sounding pipes to prevent any flooding of the compartments.

Appendix A

- In repairing the damage to the signal cable, from the reflector to the container, at the port pile, it was decided to install two junction boxes (one on the shoulder, the other on the reflector) and install new cable in between. This will be also more convenient for detaching the reflector when towing to the next test-site.

SCADA & Online Monitoring

- On Monday and Tuesday Morten Nimskov, from Balslev, installed a new PC for the SCADA system making some modifications to the SCADA setup in turn, i.e. including the new cylinder gate turbines into the system. SCADA has now been confined to the new PC as there is no Profi-bus card on the original system.
- Wireless remote controlled WebCams (2) were installed on the staircase outside the container and on the pile over the port shoulder with remote control operation being made available to project partners.
- On Wednesday, the Firewall was upgraded to solve the problem with the FTP, *viz*. blocking LAN to WAN.

Cylinder Gate Turbines

- On Monday, Torben from Danfoss began fitting pipes for the cylinder gate turbine hydraulic system.
- It later emerged that some mistakes had been made which meant that the installation was more difficult that anticipated. These problems are outlined below:

    - The width and height of the brackets for attaching the upper end of the hydraulic cylinders to the turbine shell was incorrect. This was a design error as the specification for the cylinders was recorded as 48 mm dia., with the distance between the brackets being equal to 48 mm. The old brackets were cut off with new brackets being welded with a distance of 52mm between them. Furthermore, the min. length from eye to eye of the hydraulic cylinders appeared to be 15 mm longer than given in the specifications. Thus the brackets was also made higher to accommodate this.
    - Additionally, accommodation of the hydraulic hose from the upper end of the cylinder was not allowed for in the design of the top section of the cover of the turbine shell. This was remedied by extending the opening by gas cutting out some material there.
    - Finally, the window on the side of the turbine shell cover had to be extended downwards to avoid the lower edge of the window catching the hydraulic hose from the top of the cylinder during operation.

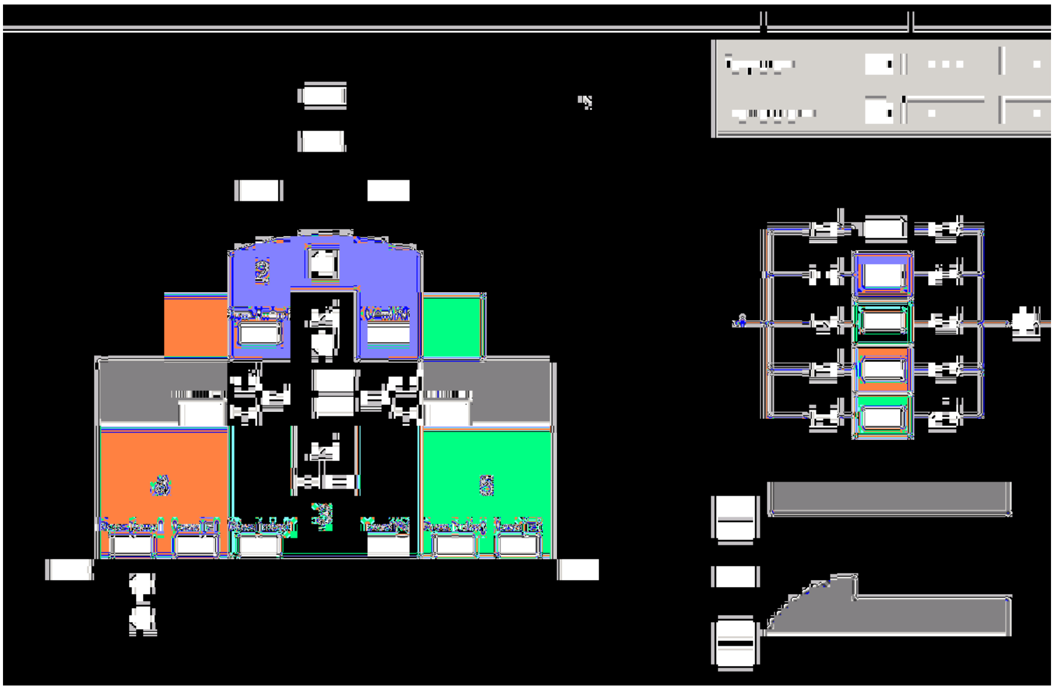
- On Thursday, Lindpro began installing the electrical system for the operation of the cylinder gate turbines.

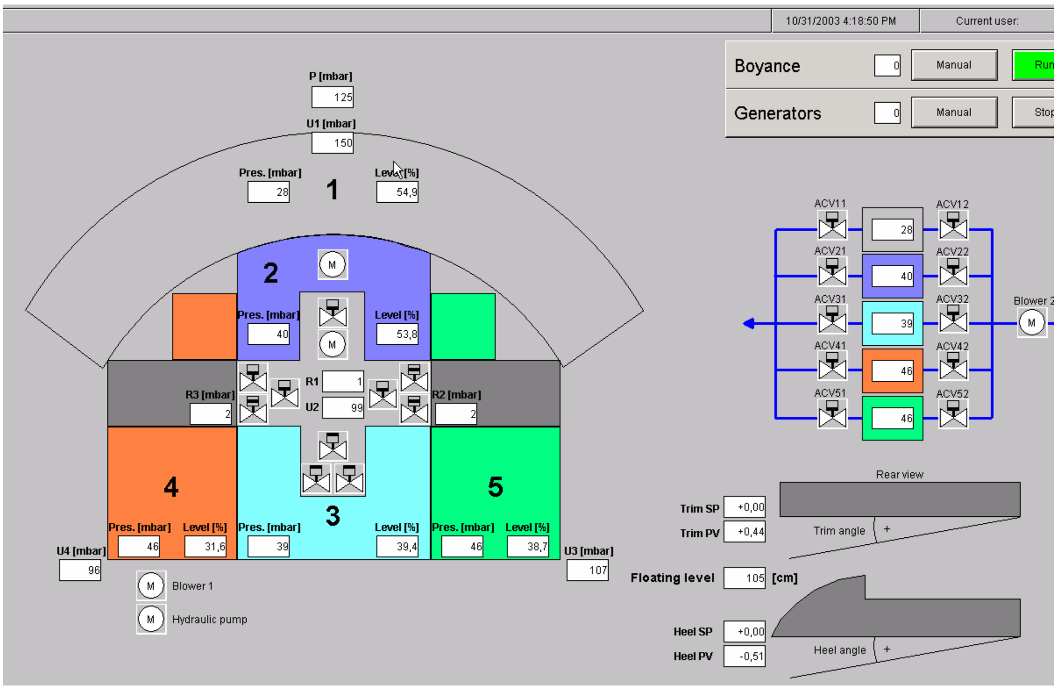
Mooring Lines

- Two pieces of 20 mm rope, each of length 26m, were prepared to attach from the centre of the 'W' to the tip of each reflector respectively using approx. 2.5m of chain from the tips, to maintain the geometry of the mooring lines in the case of no waves.
- In that operation, it was noticed that the wire rope mooring from the centre of the 'W' to the bottom of the 'W' on the starboard side was worn to ⅛ of the original diameter. To temporarily secure the line, a piece of chain was attached from the shackle and around the clasp forming the eye on the wire rope. New wire ropes with thimbles are necessary for the mooring comprising the 'W'.
- In the course of the port reflector disaster, the new shortened mooring line from the rear of WD to the reflector was cut from rubbing off the damper plate of the reflector when it was capsized. The older mooring line was still in place and has been shortened and reused.

Note:

On Wednesday, the Canon digital Camera (DIGITAL IXUS V^2) and water-proof casing were lost. Despite best efforts, the diver could not find it on the sea bed. He (Niels) did, however, find some more fenders and assisted installing the chain from bottom of the shoulder to the top of the port reflector (that prevents excessive vertical movement of the reflector).

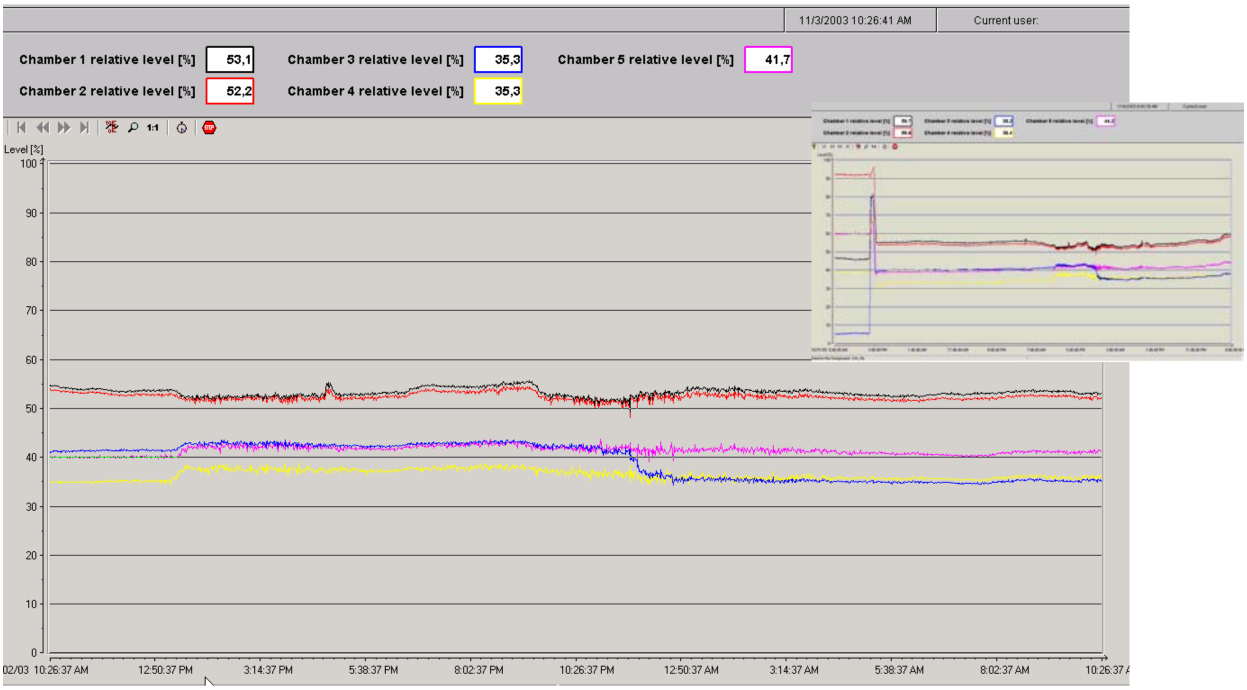


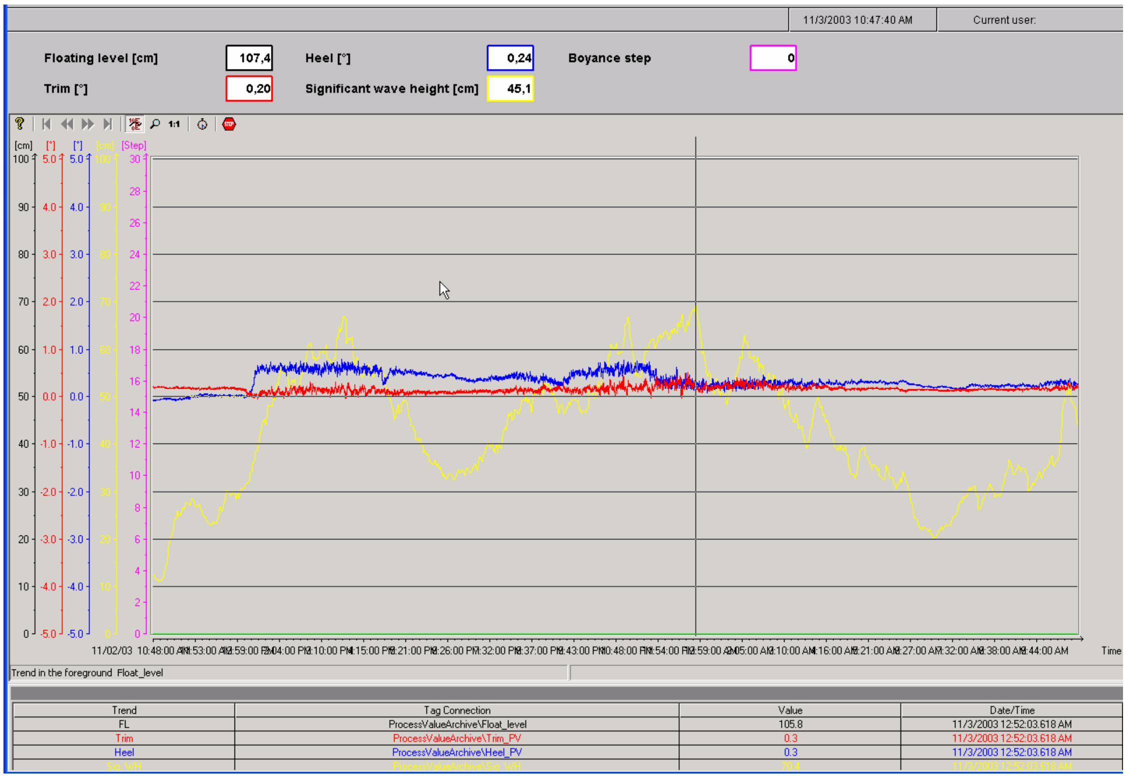


Automatikken har ikke været i drift i perioden mellem ovenstående screen dumps – d.v.s. i 65½ timer. Der har i perioden været bølgehøjder op til 0,7 m significant. Ved periodens start var ballastkamrene på dækket kun delvis fyldt, og der var væsentlig mere ballast i højre side.

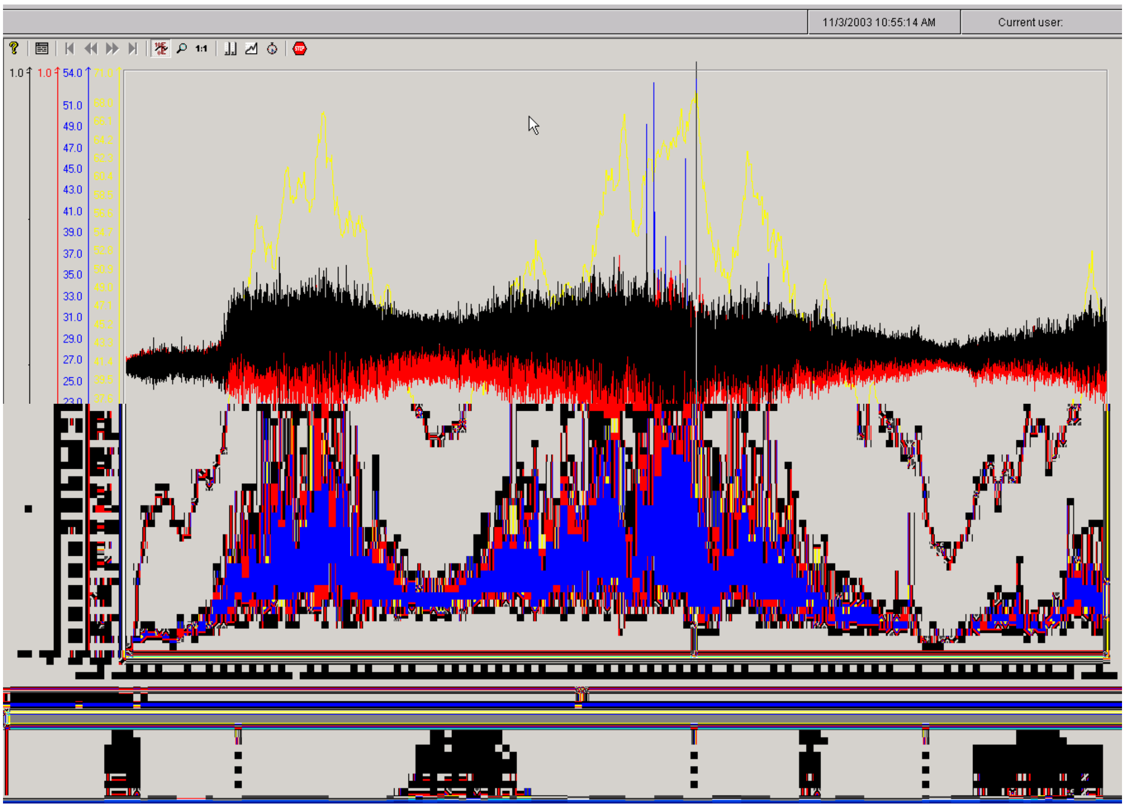
Det fremgår, at platformen i perioden er krænget 0,77° bagover (Heel), hvilket kan tilskrives fyldning af ballastkamrene på dækket. Samtidig ses det, at platformen har rettet sig o,3° op i tværretningen (Trim). Trykket i luftkamrene er ændret i god overensstemmelse hermed, d.v.s. luftmængderne i kamrene 1, 2 ,3 og 5 er stort set konstante. Imidlertid viser tryk-/level indikeringen, at der er tilført en vis luftmængde til kammer 3 - luftmængden er øget ca. 9%. Denne lufttilførsel kan kun stamme fra luft, der rives med i vandstrømmen gennem dummy turbinerne. Ved forholdsvis store opskylsmængder, som der her må have været tale om (på trods af, at flydehøjden har været 50% større end den største registrerede søtilstand) er der så stor inerti i vand-/luftblandingen, at noget af luften bevæger sig under skottene omkring dummyturbine-sektionen og op i kammer 3.

Appendix A



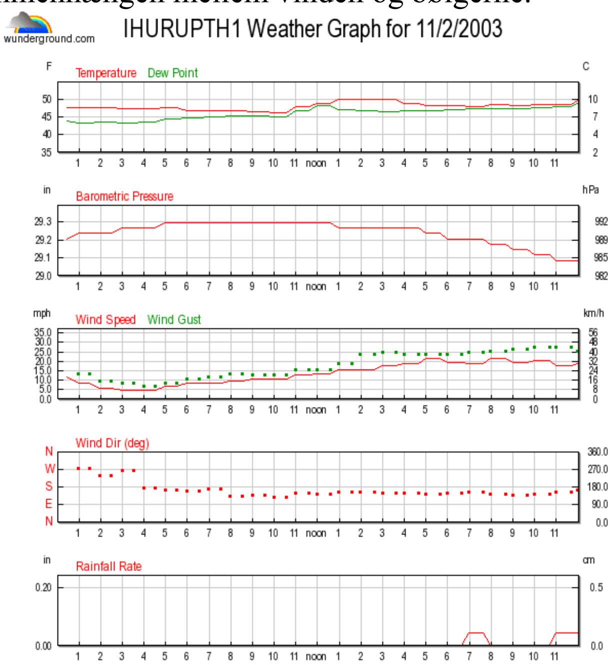


Det fremgår tydeligt af ovenstående skærm-dumps, at der ved den aktuelle flydehøjde bliver et så stort opskyl, når bølgehøjden overstiger ca. 0,3 m, at ballastkamrene fyldes og WD krænger lidt bagover. Denne krængning er en tilsigtet effekt af fyldningen af ballastkamrene/reservoiret og skyldes, at tyngdepunktet af vandet i reservoiret er placeret længere bagud end platformens tyngdepunkt. Det fremgår ligeledes, at den ovenfor omtalte tilførsel af luft til kammer 3 sker på et tidspunkt, hvor bølgehøjden er større end 0,6 m. I løbet af en halv time falder vandstanden i kammer 3 betydeligt, mens vandstanden og dermed luftmængden er næsten konstant i de øvrige kamre. Over en længere periode – her vist 4 døgn på det indsatte formindskede diagram – forsvinder ca. 10% af luftmængden i alle kamre bortset fra kammer 3. Denne reduktion svarer kun til halvdelen af iltindholdet i den friske luft. Det er således sandsynligt, at tabet af luft skyldes at en væsentlig del af ilten i luften forsvinder fra kamrene dels på grund af forrådnelsesprocesser dels på grund af korrosion af stålpladerne. Der bør foretages en iltmåling i kamrene for at få en bedre viden om dette forhold.



Denne skærm-dump viser accellerometrenes registreringer (platformens bevægelser) og kraften i ankertrossen. Det ses, at der er målt en kraft på 53 kN. Det skal bemærkes, at bølgehøjden beregnes ud fra målinger over et kvarter og derfor plottes senere end de tilhørende kraftmålinger etc.

Det er bemærkelsesværdigt, at der forekommer en markant stigning i bølgehøjden til mere end o,6 m significant med kulmination kl. ca 15.30, hvorefter bølgehøjden forholdsvis hurtigt igen falder. Registreringerne fra WD's vejrstation viser ikke en tilsvarende variation i vindhastigheden på dette tidspunkt, idet hastigheden var stigende indtil kl. 17.00. Derimod toppede den målte max, vindhastighed, "wind gust", allerede kl. 15.00. Vindretningen var næsten konstant. Sammenhængen mellem registreret vindhastighed og signifikant bølgehøjde er således ikke åbenbar. De målte vindhastigheder og vindretningen vil senere blive lagt ind i SCADA-systemet, hvilket skulle giver et bedre overblik over sammenhængen mellem vinden og bølgerne.



Appendix A

Wave Dragon Progress Report XIII

Date: 19/11/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed, Eoin O'Donovan, Martin & Per (AAU)

Report:

On this particular visit to Wave Dragon, the following tasks were carried out:

- The evacuation pipe, used to pump air to the port shoulder chamber in the time of storm damage (9.10.03), was reconnected to the siphon turbine.
- GPS receiver was moved from the container window to a fixed location on the roof with USB extension cord used to connect to the USB hub. This had the desired effect of attaining more satellites (currently a maximum of nine as opposed to five previously).
- As one of the dummy turbines had difficulty in operating, some examination revealed that the problem existed with one of the solenoids for activating the hydraulic piston. It seems that saltwater corrosion has caused this problem (previously experienced on 23.06.03). In response to this a solenoid switch was taken from the aeration valve with the siphon turbine operating satisfactorily again.
- Silicon was applied to the interface between the base of the centre section and the gate on one of the cylinder gate turbines (steel-steel contact) as a preliminary test to solve problems with leakage losses here. There is also a need to examine the possibility of reducing the closing/opening time for the cylinder gate turbines. Currently, there is a closing/opening time of 20-30 seconds, resulting in timeouts in the SCADA system.
- Blinds were installed on both container windows.
- Strain gauges on the port shoulder and the main beam of the main platform were connected to the MGC+. During this operation, it was also noticed that there are problems with the amplifier cards which must be examined further.
- The hole in the container floor, allowing for the exhaust from the evacuation pump for the siphon turbine, was sealed.
- The trace of the planned trash rack was checked for obstacles. Four problems was found, pictures taken.

Upcoming Tasks

- Re-align Weather station.
- Re-arrange pressure transducer (on pile) wiring.
- Clean pressure transducer.
- Treat underneath of container.
- General rust & paint job.
- Implement Network Management Project (Morten and Jens).
- Replace signal cable from platform to mooring pile.

Appendix A

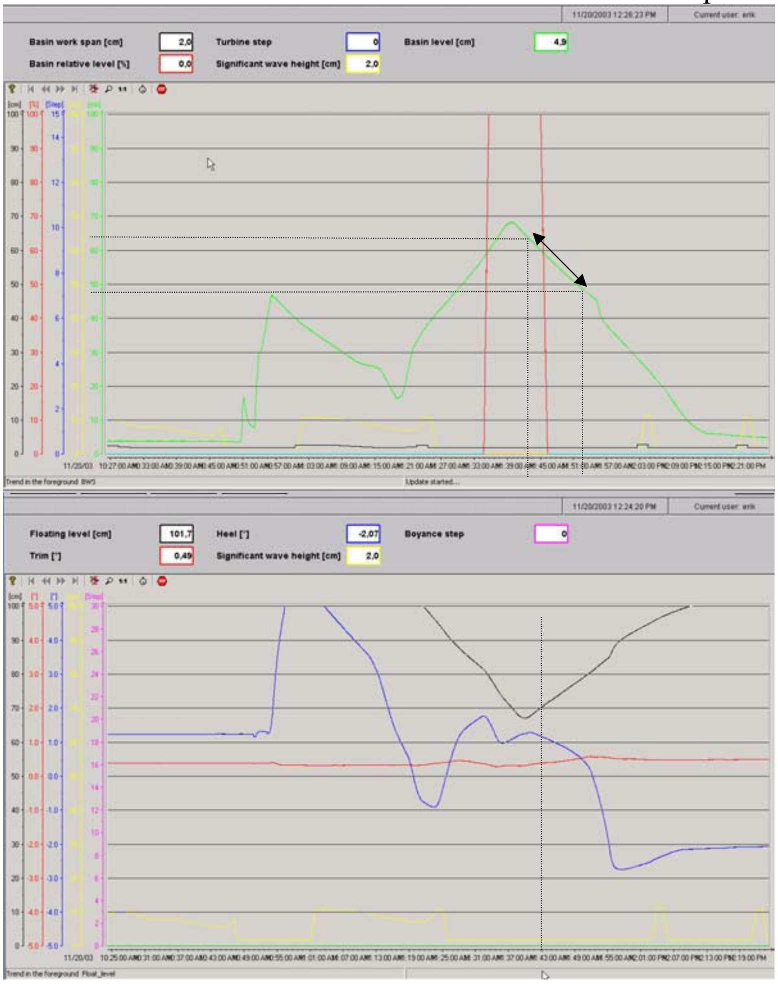
- Install accelerometers on port reflector.
- Install accelerometers on shoulders.
- Backup routines for data.
- Purchase some boxes for manuals.
- Organise electrical/hand tools more orderly in the container.
- Change the Belimo valves for air chamber or otherwise solve with stock valves.

SCADA system:

- Implement default maintenance operation of valves.

Læktest, 20. november 2003 **EFM**

Alle turbiner lukkede – en turbine tætnet med silicone på kanten af cylinderspjældet.



På 10 minutter (11:43 til 11:53) ses vandspejlet at falde med stort set konstant hastighed fra et niveau på 64 cm til 47,5 cm, d.v.s. 16,5 cm.

Idet netto bassinarealet er beregnet til at være 165,5 - 6 = 159,5 m^2 bliver læk tabet 2,63 m^3 svarende til 44 l/s eller en mistet elpoduktion på ca. 300 W ved højt flydeniveau.

Wave Dragon Progress Report XIV

Date: 26/11/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin O'Donovan (AAU)

Report:

On this particular visit to Wave Dragon, the following tasks were carried out:

- Efforts were made to turn the siphon turbine, however it seems that the lubricated bearing has been contaminated causing the oil in it to emulsify. This oil needs to be changed.
- Equipment manuals and project partner documents were filed separately and shelved.
- Some maintenance work was carried out on the raft with one of the drums moved from the rear to add buoyancy at the position of the hoist (front). Some of the timbers on the raft, which had become loose on hitting against WD, were also secured with extra screws.
- A halogen light was installed on the right container window to add visibility to the turbine area at night and also heat to the inside of the container. A second lamp will be installed in due course. A timer switch has been included in the operation of same.
- The remote controlled Web-cam's were cleaned and this will become part of the routine maintenance at each visit to WD.
- The pumps are activating the safety trip switch onshore. This problem needs to be investigated further.

Wave Dragon Progress Report XV

Date: 28/11/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin O'Donovan (AAU)

Report:

On this particular visit to Wave Dragon, the following tasks were carried out:

- The remaining modified wire rope mooring lines (with thimbles) of the 'W' were attached. These included the outer lines of the 'W' and the line on the port side of the centre of the 'W'.
- Force transducer was re-installed in the port cross-wire. In addition, some chain was included here to provide some additional security and prevent the transducer becoming the weakest link in the system. The latter needs to be wired to the junction box on the reflector arm.
- The weather station wind vane was re-calibrated based on GPS examination of WD location.
- Inclinometers to record heel and trim movements have been mounted on adjacent walls in the container. These need to be wired to the data acquisition port and power source respectively.

Wave Dragon Progress Report XVI

Date: 4/12/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin O'Donovan (AAU)

Report:

On this particular visit to Wave Dragon, the following tasks were carried out:

- A new bracket was mounted on the port shoulder pile for the remote Web-cam there.
- Work has begun on organizing the hand/electrical tools in the container. This job will be completed on the next visit to WD.
- Four plastic drums were delivered to the site for covering the valve chests for the siphon/cylinder gate/ dummy turbines. This work will be carried out at the next visit.
- The inclinometers for monitoring heel and trim were wired to the data acquisition ports and power source (24V) respectively. Some further calibration and examination needs to be carried out here to ensure readings are accurate and consistent.
- An electrician was called from Hurup Elektro to examine the problems experienced with the pumps (28/11/03). After some initial checks (for short circuits etc.), the pumps were activated and both were found to function without tripping the safety switch on-shore. Perhaps moisture in the junction box may have caused the problems initially. In light of this, some silicon gel should be applied to the junction box to absorb any moisture present.
  In any case, the small pump, for supplying water to the rubber bearing in the siphon turbine, was changed as a precautionary measure.

Wave Dragon Progress Report XVII

Date: 11/12/2003

Location: Wave Dragon Test Site 1 (Nissum Bredning)

Present: JP Kofoed & Eoin O'Donovan (AAU)

Report:

On this particular visit to Wave Dragon, the following tasks were carried out:

- Two Danfoss solenoids, which had shown significant saltwater corrosion and thus affected operation, were replaced in Dummy turbine 9.
- Checks were made to examine the fault with the siphon turbine. After careful examination, the non-return valve in the extension pipe was cited as the likely cause. The pipe was removed with the valve cleaned and oiled before checking the pipe for any blockages – none were found. The pipe was reassembled before flooding the reservoir and running the turbine. The latter was found to turn but at an extremely low rpm. However, it was noted previously (26/11/03) that the oil in the lubricated bearing had emulsified and needed changing. On draining the old oil from the bearing it was noticed that some swarf from cut threads has also contaminated the oil. This could be a serious obstruction to correct operation.
- The end stops were adjusted in cylinder gate turbines 4 and 6.
- Some further work was carried out in arranging the tools in the container. This will be completed by sorting the electrical tools on the far wall of same.
- In addition, some coarse zero adjustment of heel and trim was carried out on the inclinometers.

Appendix A

040122, Visit report

Bendy (FC), Per, Martin, JPK (AAU)

Wire from new pressure transducer Connected in PLC cabinet and to MGC+.
Repaired Dell PC (i5wdpc) setup and NetOp/VNC and Catman up and running. Re-install of weather station software needed.
Tried to install NetOp/VNC on new PC (i5wd2pc), but no success. The PC brought back home again.
Container treated under neath.
Worked signal wire connection via port shoulder.
Organized container.
Cleaned webcam lenses.
Checked temporary fix of signal cable to pile - look ok, but wave signal still ok.
Turbine 5 and 6 tested and put into operation. Was running fine and produced REAL wave energy for a couple of hours! Data from WCU regarding the power production, rpm etc. only arrives every few seconds - should be milliseconds.
Before departure the cylinder gate turbines was taken out of operation and the dummies activated. It is considered unsafe to have the generators running when WD is unmanned, as the automatic fire fighting system has not been installed yet.

040226, Visit report

TURB 9 sometimes stuck. Needs same treatment as TURB 8 by Wilfried et al. Not done today.

Growth in dummy turbine draft tubes. Moussels found on the lower 10-20 cm of draft tubes. Iron bar used for feeling the growth. Underwater cam with light needed for proper inspection.

Drilled holes in ballast cells filled with 'foam pipe' pieces - like ear plugs.

Testing of TURB 2, 3, 4 and 7. TURB 7 does not work - gives a DR_STAT=3. TURB 2 reports no RPM or Power, but by touching the runners with a small stick you could hear that the Runner on TURB 2 turned some thing doule as fast as TURB 3 (which works as expected - this also goes for TURB 4). This probably means that the generator in TURB 2 is not breaked at all.

It was also noted that no current was shown in the SCADA system for any of the turbines, although power was produced. By looking directly at the value coming from the WCU using Step7 it seemed that current values were transmitted from the WCU to the PLC.

It was observed that short wave period combined with high water level in NB resulted in extreme transfer values in the calculation of the Hs in the PLC. The matrix used needs to be checked.

'Struts' on back ropes. The struts produced in the workshop turned out to be made with a too small opening in the hook going through the hole in the knee. It is brought back to the workshop and will be modified.

Check measurering of trash rack. It was discovered that the reason for one of the rack plates seemed to be too short, as reported by Bendy, was actually caused by a mistake in the installation. The plate in front of the siphon turbine

New PC installed.

Solar cells for weather station inspected.

040304-05, Visit report

Present: JPK & Jens Jakobsen, AAU

Working on CAN-bus communication. New factory made cables connected, terminations checked, baud rates set. Found that MGC+, ML71 unit, works as expected. Detailed evaluation of signals on CAN-bus by using a scope. Do data, but network management data, from Unigate on CAN-bus. Verified through Step7 that data does arrived to the Unigate. However, no data is put on the CAN-bus by Unigate.

Work on the system entailed LARGE problems for the PLC. The profibus stopped working properly. Complete, simultanous close down of all units on the profibus necessary to get PLC and profibus up and running again.

Installation on PC's:
- GPS, Creative WebCam on i5wd2pc.
- Cyclic data acq. setup using Catman on i5wdpc.
- NetCam Watcher on i5wd2pc.

New strut on starboard back rope installed.

HC visited along with Taus and 3 potential investers friday at noon.

040306-07, Visit report

Visit by Per Bruun Madsen & Marting Thorsøe.

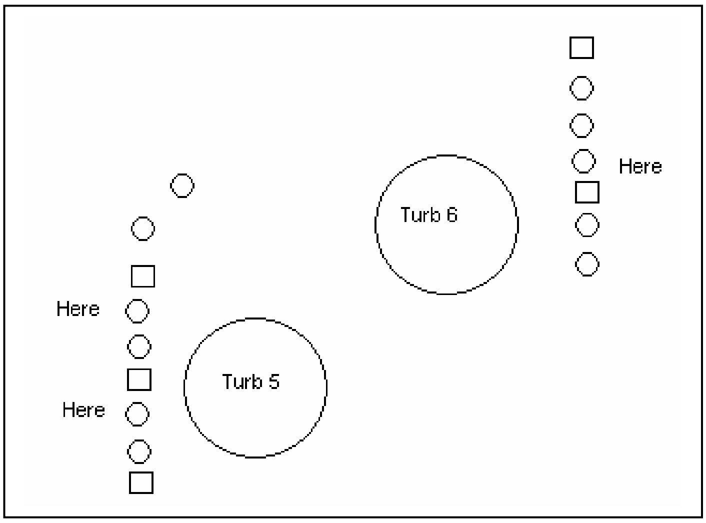
Painted the pipes on the platform and filled them with cement.
Modifyed TURB 9.
Exchanged halogen tube in starboard lamb on staircase.
Sealed leaks in reservoir.
Started rust and paint job at starboard side.

Log for the weekend 24-25 March

Saturday:
Sealed the holes in the fence round the turbine area using ion-mesh.
Removed pressure cylinder from turbine 8 and took it in for reappear.
Changed fittings for the turbines 9 and 10.

Removed white paint from pipes by ramp, the paint could be removed by rubbing. The pipes were painted last the 6/7 Marts 2004. Repainted the pipes with rust protecting paint.
Started to remove rust and paint at the fence around the container.

Sunday:
Tried to fill holes in the bottom of the turbine area, but had trouble making the filling stick in the holes. There was too much water in the turbine area. It is necessary to remove all the water from turbine area to be able to fill holes, but the wind was to strong to do so. Tree holes were filled as illustrated:



Moved box with chains and metal parts from the platform infront of the container to the roof of the container and secured it.
Removed rust and painted ventilation pipe by dummies in the turbine area.
Removed more rust and painted the fence around the container.

040402, Visit report

By JPK

Chain meant for keeping starboard reflector 'in the area' in case of joint failure, has failed (chain locks on reflector). Clearly it has not been long enough for low floating levels / large negative heel.

Endstop on TURB 9 closed adjusted.

SG amplifier boards in MGC+ checked. Only board 6 (boards 6 to 11 are SG amplifiers) are working.
- Back card (AP815's) 6 and 7 swapped, still only board 6 working - indicating the problem is not with the AP815's.
- Front boards (ML801's) 6 and 7 swapped, then slot 7 is working and 6 not. Indicates fault on ML801.
- ML801 from slot 5 (normally used with AP801 back card without problems) tested in slot 6 seems to work fine.
- ML815 from slot 8 tested in slot 6 - not working.
- ML815 from slot 6 tested in slot 8 - at first working, then not working.
- ML815 from slot 6 tested in slot 9 - not working.
- ML815 from slot 6 tested in slot 10 - not working.
- ML815 from slot 6 tested in slot 11 - not working.
- ML815 from slot 6 tested in slot 6 - not working. This work earlier. I'm afraid something is harming the ML801 cards! Could it be the the AP815's in slot 8 - 11?

ML801 in slot 1 - 5 are Hardware rev. 1.12, while 6 - 11 is rev 1.13. All have Software vers. P5.16.

All back and front cards in slots 6 - 11 are brought home to be send to supplier for repear.

Re-activation of CAN-bus after messing around with the MGC+ proved to be a little difficult. However, by the help of Jens J it is now working again. See mail from him for details on what to do.

I then tried to run the cyl gate turbines. Only TURB 3 seems to run without problems. By pushing the runner blades with a stick it was felt that the runners of TURB 4, 5, 6 are stuck. TURB 2 is not completly stuck but harder to turn than TURB 3 and 7.

TRIM zero adjusted in MGC+ by 0.07° - seems to be fine now. Target for trim set to 0 in SCADA.

Placement of fire fighting system. I think the only suitable place for both the bottle and electrical board is behind the entrance door. I will bring a wooden plate 1142 x 1398 mm for placing in the windows next to the door, so the tools can be moved to here.

Working log from Wave Dragon 17-18.04.04

This log was written by Per Bruun Madsen and Martin Thorsøe, after working on Wave Dragon the weekend of the 17-18 April 2004.

Saturday 17.04.04

- **We had a lot of problems this day**. When we arrived we didn’t have a key to unlock the boat and had to open it by force. When we got on the water the engine had a malfunction, to fix it we vent to a store in Agger. Therefore we didn’t start the work before 2 in the afternoon.

- **Painting Drum.** We cleaned the painting drum, on platform. It had apparently been tilted during a storm and there was paint all over.

- **Painting job.** Continued the rust and painting job on the fence round the container.

Sunday 18.04.04

- **Fixed the raft**. We checked all the oil drums for leaks, none was found. Added 2 drums to the opposite side of the crane on the raft. When checking the drums for leaks we found that some of the ropes keeping the drums in place were broken, they were replaced. The broken moorings were replaced with new mooring lines and the raft is now secured by 4 mooring lines.

- **Filled water on the hydraulic pump**. We filled the hydraulic pump with distilled water, because it had been running dry. This wasn’t enough to fix it though, so Bendy arrived and repaired it.

- **Put up antenna at bollard.** We in stored a new antenna at the pole (bollard) in front of the wave dragon, fastened the wire and connected the wire in the electrical box.

- **Painting job.** Continued the rust and painting job on the fence round the container.

For more information look at the pictures taken the weekend, they are located in the folder

040419 Visit report

By JPK

Out there: JPK (AAU), Armin (West Control)

Communication problem due to buffer overrun in WCU because hardware handshake not working.

Should not be a problem if data amount is reduced (from 48 to 17 bytes). This working fairly well. Data update rate 1.5 to 2 Hz.

Scale factor problem resolved. Was not enabled in WCU.
Test:

Scale	50	100	150
RPM	215	195	165
W	100	155	150

Mechanical problems with turbine 4, 5, 6 (not able to run, even in test mode). 4 and 6 could be turned by hand but very hard. 5 could not be turn by hand. 7 ended up running after som motioning by hand and running in test mode for a while.

Problem with hydraulics.

Solenoid on power pack failed. Permanent magnet used temporarely instead. TURB 2, 3, 9, 10 can not be operated.

A total of 13 old solenoids are on the valve blocks. They should be replaced by new model.

Measurements performed on siphon turbine for Wilfried. A+B = 350 mm, B = 31 mm, C = 16 mm.

040717, Visit report

Thomas, Søren Krogh, JPK (AAU) and Xavier (FC). Also 3 TUM working here, but not covered in this report.

Main mooring line inspected. Looks in good shape. New signal cable to pile attached to reserve main mooring line. New bouys attached as well. Steel wires from ramp inspected - no problems seen. New ropes from pile to tip of reflectors installed. Port side rope has a unworked length of 40 m, starboard side rope is 37 m plus 2 m of chain at reflector tip. Bouys have been attached to these ropes as well.

It was observed that the ropes previously installed from reflector tips to center bouy in front of ramp (to maintain geometry in periods with no loads) were there no more.

040813, Visit report

Present: JPK, Martin Thorsøe, Tim (AAU) and EFM (LOW).

Underwater inspections and video filming:
- Starboard lower fishtail not close to shoulder structure as it should be, approx. 25 cm room.
- Port side lower fishtail, port pad eye for chain holding the fishtail, broken off.
- Sandfill ind back and main anchors check. No significant change since last inspection (one year).
- Pressure transducer on pile dismounted. Tested by connecting directly in board in container, still not working. New pressure transducer ordered at H. F. Jensen (different type), shoulde arrive within 2-3 weeks.

Fan coil and pump for cooling installed. Not enough hose, so cooling on hydraulic power pack not installed yet, but both thermostats are in place.

Problem with hydraulic cylinder for activating butterfly valve on siphon turbine identified, pins in solenoid corroded. Sloenoid changed, problem fixed.

Similar problem for TURB8, should be fixed at next visit.

Wind anemometer and rain measuring device exchanged.

IP setting for wireless bridge at WebCam3 changed from 10.1.1.36 to 10.1.1.28 to get it out of the DHCP IP adress range.

Batteries in indoor thermometer exchanged.

New port side G rope mounted - however not in shackel at bouy, but in chain.

Distance from crest to pile checked in eastern wind (stretched back anchor chain) - 14.85 cm.

PRES_R2 checked - seems to be working ok. However, latter (040817 13.40) it was found not to working (constant value of -54).

Bring on next visit:
- 'Karabinhage' for boat.
- Plastic bags.
- Coffecups.
- Hobbyknifes.

WD Visit report, 04.08.24

Present: LC (SPOK), Tim, MKR, JPK (AAU)

Upgrade of LAN:
4 port 10 Mbit hub replaced by Linksys 8 port 100 Mbit switch.

WLAN access point integrated in ZyWall 10W disabled and replaced by Linksys WAP11 WLAN access point with external antenna. Antenna placed on container roof, point towards mooring pile. Loss of connection to WebCam3 should thus not happen anymore.

Wind anemometer:
Lately the wind speed has not been measured, although wind direction is. Various attempts to fix this were done by exchanging anemometer and/or transmitter – however, without success. Unfortunately, it seems like the equipment is not good enough for the rough conditions, so **a new instrument is needed**.

Reprogramming of level switch logic in siphon turbine:
Together with René Arnskov, Balslev (on remote access), the level switch logic in siphon turbine control was corrected. Now the lubrication pump starts when the siphon turbine is asked to start and the generator is not released until water is present at the level switch. If water is no longer present at the level switch the generator will brake after 60 s. However, the aeration valve does not open and as soon as there is water at the level switch again, the generator is released again. **It needs to be considered if the turbine should be completely shot down (the alarm then needs to be acknowledged manually before it starts again), or the very slow rotation (5-10 rpm) in braked mode is ok for the rubber bearing?**

Dummy turbines:
One solenoid for turbine 8 was malfunctioning. Getting it of was quite a job – force had to be applied! Finally, it was replaced. However, the general condition of the dummy turbines is poor. They very easily get stuck, primarily due to the heavy corrosion. A guiding system is badly needed. Heavy grease was applied to all three turbines, which did the job for the moment, but it is certainly not a solution in the long run.

Hydraulic power pack:
The release valve on the power pack proved to be malfunctioning. After talking to Torben Helligsø, Danfoss, another solenoid was tested, but that did not change anything. Neither did motioning of the adjustment screw while running. This should flush dirt in the valve if that was what was causing the problem. However, putting on a permanent magnet on the valve seemed to do the trick, however, it means that the hydraulic pressure cannot be released by the PLC. This points towards a bad electrical connection from the PLC to the solenoid, being the problem. This was not investigated further, **but needs to be taken care of soon**.
The water level in the power pack was low. The last 5 L which was available was filled in, but more is need – **order now and bring on next visit**.
It was also noted that the needle manometer next to the filter on the power pack was leaking.

Cooling system:
After the installation of the cooling system at last visit, it had been working fine for some days. However, Friday it was obvious that it was not cooling anymore. The reason was found to be that the hose had fallen of the pump, due to insufficient securing of the pump – the pump had been moved around by wave action. Therefore a more stable setup with a wooden pole was made, which seems to have solved the problem.

Underwater takes in turbine draft tubes:

A stick for mounting the underwater camera on had been prepared and brought out there, to enable inspection of the fouling inside the turbine draft tubes. However, it seems the camera was fixed to tightly to stick, resulting in crushing of the glace – and this was not seen until the camera stopped working as it was submerged!!! **New camera needed.**

SG's:
MGC+ and CatMan was setup to acquire data from SG's in addition to all other data. Now SG and all other available data is store continuously in half hour data sets.

040910, Visit report

040908: Per & Martin (AAU)
040909: Per & Martin (AAU), LC & EFM (LOW/SPOK)
040910: Leen & JPK (AAU), LC & EFM (LOW/SPOK)

040908:
Checked waterlevel in ballast tanks in both platform and reflectors, results are given in Excel sheet (on i5wdpc). Power (24V) made available for new pressure transducer on pile.

040909:
Submerged weight of moussles estimated - 15 kg pr. m^2, 10 - 15 cm thickness, underneath damping plate.

040910:
FORCE_C connected - however junction box on reflector contained water, again. Clips corroded.
Readings looks veird - 1800 - 5000 kN! Monday 040913 the reading was constant 17000 kN.
New pressure transducer from H. F. Jensen, type PSL 4.1.1 output 1-5V, was temporarely installed. It is connected to channel 5-2 on the MGC+. Readings does not look right using the given (from H. F. Jensen) calibration constants, but there was no time to investigate. Will be check on next visit.
Internet connection faulty - proved to be a Sonofon problem, nation wide.
Problem with solenoid for TURB9. Lowest solenoid removed - a hole in the valve anchor was seen - hydraulic leak. New anchor ordered, as well as 'Safe Chill' - hydraulic fluid.

040923, Visit report

By JPK & NH (AAU)

Fractured 'anchor' in hydraulic valve block for Dummy turbine 9 changed. Hydraulics activated.

040925, Visit report

JPK (AAU), TT Nautech

Activated Signalix SMS messenging in case of grid fault, fire alarm and fire alarm fault.

WebCam1+2 and WLAN access point added to Q5, so they can be rebooted (together with i5wd2pc).

Ext. light can now be activated using Q8.

WCU can now be reset via Q7.

Attempt to activate wind measuring station - didn't work.

Setting up i5wd2pc after harddisk brakedown - map software still need to be installed for GPS to work.

Accelerometers on shoulders taken down and brought back home for repair.

WebCam1+2 wiped off.

Stainless steel plate fixed on siphon turbine, sheilding the coupling area.

040930, Visit to WD

Visit by Erik Grove Nielsen, Thomas Thøgersen (nautec), JPK (AAU)

Introduction of EGN to the WD and problems onboard. He thought he might be able to help talking care of solving the gnenrator control problem.

It was observed that bolts in connection between hydraulic cylinders and cylinder gates in dummy turbines where lost (in TURB8) and loose (TURB9) due to the more intensive use of the dummies during continous operation the last week. However, time had gone by before we got to fixing it. Locknuts (or contra nuts) where not used - have to be used in the future. Will be brought at next visit.

Due to the excellent weather conditions the priority of todays visit was put on getting the jobs at the pile done. Thus, time was not either found to fix a temporary level switch in the siphon turbine, check for growth in CGT's or to fix a thermometer in CGT no. 5. We have to take care of that at next visit - the restauration of additionally 2 CGT's next week.

All day was spend on mounting a new wind measuring station and a new pressure gauge for wave measurements at the pile. Wind speed (WINDSP) and direction (WINDDIR) sensors were mounted on a pipe on the top of the pile. The sensors where placed 3.05 m above the the top flange of the pile, ie. 13.05 m above the seabed.

The pressure sensor was installed on a rack, that can be retreived without diver assistance, positioning it at 4.03 m above the seabed, 1.0 m away from the pile - corresponding to point 3 in the report on 'Placement of pressure transducer for wave measurements at Wave Dragon.

24V DC supply to wind and wave sensors was taken in the PLC cabinet (top row clips to the right) and put on red (+) and blue (-) outer wires around the core in the newly installed signal cable to the pile.

WINDSP signal was put in clip 1 (+) and 2 (-) in JB on pile.
WINDDIR signal was put in clip 3 (+) and 4 (-) in JB on pile.

PRES_P2 signal was put in clip 13 (+) and 44 (-) in JB on pile.

For reference, underside of rack around stair on pile was measured to be 6.7 m above seabed.

10. Appendix B: Overtopping analysis including heel in crest freeboard calculation

An analysis has been performed where the crest freeboard has been calculated taking the motion in heel into consideration. This appendix are considering data from the period 05.12.2003 to 15.12.2003 and has primarily been prepared by a foreign student, Tim Florizoone, visiting Dept. of Civil Engineering, Aalborg University during August and September, 2004.

This appendix is not included here.

BILAG 8

Wave Dragon ApS, Rapport fase B af ENS projekt 51191/01-0033 for perioden fra 1. april 2003 til 31. december 2004

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Wave Dragon ApS
CVR 2621 9841

Wave Dragon 1:4½ -

Kalibrering, måling og opskalering samt informationsaktiviteter.

Rapport fase B af ENS projekt 51191/01-0033

for perioden fra 1. april 2003 til 31. december 2004

af

Hans Chr. Sørensen, Lars Christensen, Erik Friis-Madsen

September 2005

Rapport udarbejdet af

SPOK ApS ved
Hans Chr. Sørensen og Lars Christensen
og
Löwenmark FRI ved
Erik Friis-Madsen

for

Wave Dragon ApS
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1 Resumé

Rapporten omhandler sidste del - fase B - af projekt ENS J.Nr. 51191/01/0033 *”Konstruktion af en skala 1:4½ model af Wave Dragon til test af kræfter, bevægelser og opskyl ud for Kravlegården”* og omfatter aktiviteterne fra etableringen af Wave Dragon ved Prøvestationen i Nissum Bredning i marts 2003 til indkøringen er afsluttet i december 2004.

Design, produktion og etablering ved Prøvestationen er rapporteret som projektets fase A jævnfør reference /4/.

Forsøgene i Nissum Bredning har succesfuld verificeret de forudsagte overskylsmængder og tillige vist, at store effektivitets forbedringer kan opnås ved aktiv og forbedret styring af anlæggets flydehøjde og stabilitet. Forsøgene har endvidere vist, at de åbne luftpuder under platformen drastisk dæmper anlæggets bevægelser. Målingerne af kræfter i forankringen har også vist sig i overensstemmelse med de tidligere forsøg.

I afsnit 3 omtales det samlede kompleks af projekter opbygget omkring Wave Dragon prototypen i skala 1:4½. Det drejer sig om projekter støttet af Energistyrelsen, EU samt Elkraft System (PSO).

Afsnit 4 omhandler kalibrering og indkøring herunder etablering af fjernovervågning.

Afsnit 5 omhandler vurdering af anlægget hydrauliske respons, dvs. anlæggets bevægelser i forskellige bølgetilstande.

Afsnit 6 omhandler vurdering af kræfter i forankringssystemet samt vurdering af forankringssystemets udformning.

Afsnit 7 behandler vurdering af overskyl dvs. hvor meget vand, der samles i reservoiret altså anlæggets potentiale som el-producerende kraftværk.

Afsnit 8 omhandler turbinerne installeret samt deres effektivitet

Afsnit 9 behandler muligheden for opskalering samt resumerer de foreløbige data for produktion og fremstillingsomkostninger. Endvidere behandles udformning af samling mellem reflektorer og krop. Et datablad udarbejdet af det gamle bølgeenergiudvalg er blevet opdateret.

Afsnit 10 beskriver erfaringer med opsyn og vedligeholdelse af anlægget.

Afsnit 11 omhandler problemer med at opretholde forsikringsdækningen, og hvorledes det var nødvendigt med en meget utraditionel løsning på dette problem.

Afsnit 12 beskriver tidsplanen for projektet og årsagen til projektets forsinkelse.

Afsnit 13 omtaler formidling af projektets resultater gennemført gennem foredrag, konferenceindlæg og omtale i pressen.

Afsnit 14 beskriver, hvorledes det har været muligt med fordel at samkøre nærværende projekt og EU/PSO projektet.

I afsnit 15 angives budgettet fase B og det samlede budget for projektet Wave Dragon fra 1998-2004 .

Afsnit 16 giver en oversigt over anvendte referencer og rapporter knyttet til fase B.

I bilag 1 gives en uddybning af den forretningsmæssige udvikling.

2 Indhold

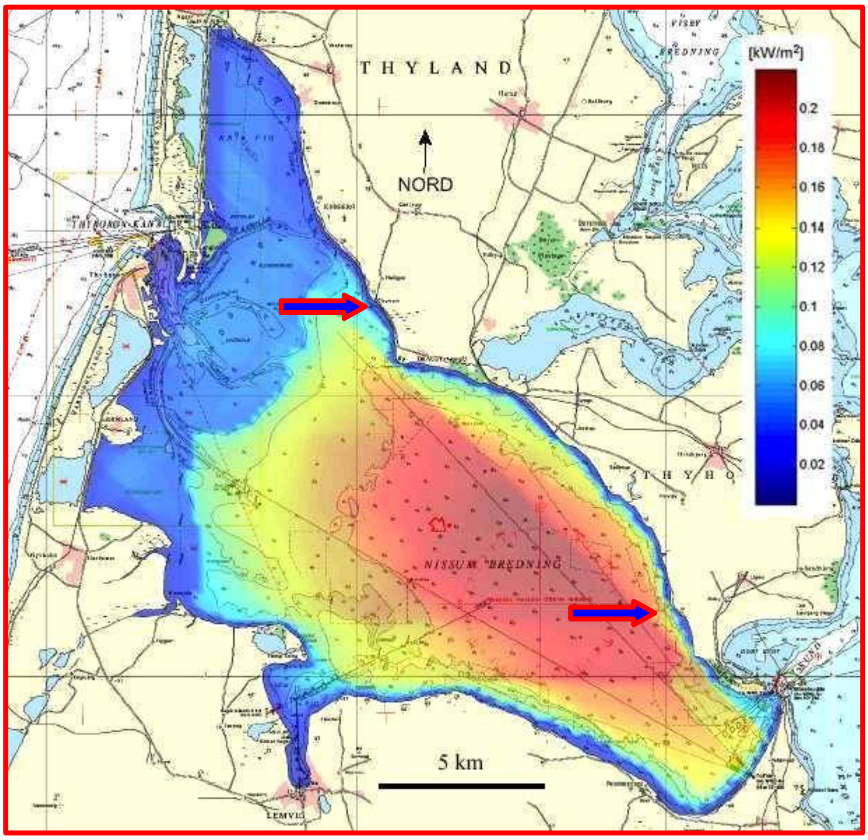
3 Indledning

Nærværende rapport omhandler rapportering af sidste del – Fase B - af projekt ENS J.Nr. 51191/01/0033: *”Konstruktion af en skala 1:4½ model af Wave Dragon til test af kræfter, bevægelser og opskyl ud for Kravlegården”* og omfatter kalibrering, måling af hydraulisk respons, kræfter og deformationer, opskyl, dvs. produktions formåen som kraftværk samt muligheden for opskalering.

Rapporten er en fortsættelse af fase A rapporten: *”Konstruktion af en skala 1:4½ model af Wave Dragon til test af kræfter, bevægelser og opskyl ud for Kravlegården”* /4/, der omfattede aktiviteterne frem til at Wave Dragon var færdigbygget og etableret ved Prøvestationen i Nissum Bredning

3.1 Formål

Det har været projektets formål /1/, /2/, /3/ at konstruere en skala 1:4½ prototype af Wave Dragon og gennemføre afprøvning af prototypen på 5 meter vanddybde ud for ”Kravlegården” i Nissum Bredning. Prototypen er forsynet med én eksisterende skala 1:3½ turbine samt 3 udløbsrør (dummy turbiner), der simulerer vandgennemstrømningen i de ekstra 6 turbiner, som skulle være installeret ved optimal bestykning. Prototypen er konstrueret således, at den kan flyde uden opdriftsbidrag fra trykluftkamrene.



Figur 3.1Placeringen ved Prøvestationen (oprindelig kun DEA projekt, nordligste placering) og ved Odby (EU/PSO projekt). Farver angiver bølgeintensiteten.

Projektet skal tilvejebringe dokumentation for virkningen af Wave Dragon's trykluft-ballasteringssystem. Denne viden kan ikke tilvejebringes gennem modelforsøg i lille skala, da luftens stivhed ikke kan skaleres korrekt uden anvendelse af en anden luftart i kamrene.

På grund af de forholdsvis små frie stræk i Nissum Bredning vil afprøvningen i skala 1:4½ ved Kravlegården ikke omfatte egentlige overlevelsesforsøg. Der vil imidlertid i hele forsøgsperioden blive målt kræfter i forankringssystemet, og blive registreret bevægelser af platformen og armene. Ved det EU finansierede projekt gives der mulighed for efterfølgende at etablere en sydligere og mere udsat position for Wave Dragon. Herigennem opnås forsøgsresultater i alle relevante søtilstande, herunder overlevelsesforsøg, der skaber et tilfredsstillende designgrundlag for at vurdere anlægsudgifterne for en fuldskalaprototype beregnet for Nordsøen. Bølgeklimaet i Nissum Bredning er ligeledes velegnet til langtidsafprøvning af bl.a. turbinerne, som i den ét år lange forsøgsperiode vil få en meget stor benyttelsestid i forhold til turbinerne på en Wave Dragon med optimal turbinebestykning.

Rapporteringen for Fase A omfattede design, bygning og installation af en Wave Dragon prototype i skalaforholdet 1:4½ /4/. Rapporteringen for nærværende fase B indeholder anlæggets indkøring. Da der på et tidligt tidspunkt af projektforløbet skete en samkøring af den efterfølgende projektfase støttet af EU og PSO, indeholder rapportens fase B i mindre grad også delelementer af disse aktiviteter. Dette skyldes ikke mindst, at opholdet ved Prøvestationen blev længere end oprindeligt antaget.

Oprindelig blev bevillingen givet som én bevilling, men for at lette likviditeten[1] som følge af de meget store omkostninger til fremstilling af prototypen, blev projektet efterfølgende opdelt i en fase A og B.

3.2 Tre projekter

Udviklingen af Wave Dragon frem mod en prototype i skala 1:1 foregår i tre hovedprojekter, hvor det her rapporterede projekt betegnes DEA projektet. De to andre projekter betegnes henholdsvis EU og PSO projektet og bygger på en videreførelse af DEA projektet omfattende en placering i den sydøstlige del af Nissum Bredning, hvor der gennemføres målinger af spændinger og regulering af turbiner. I forbindelse med EU/PSO projekterne installeres omfattende måleudstyr og yderligere 6 turbiner.

Finansieringen af de tre projekter fremgår af deres betegnelse, idet DEA refererer til støtte fra Energistyrelsen (Danish Energy Authority) og EU til støtte fra EU’s 5. rammeprogram og PSO til støttemidlerne under Elkraft System (Public Service Obligation).

Ålborg Universitet har endvidere modtaget støtte til en mindre del af projektet gennem Den Obelske Familiefond.

I tabel 3.1 er givet en summarisk redegørelse for de tre projekter, og tabel 3.2 opsummerer de deltagende virksomheder og institutioner.

[1] Ved bevillinger fra Energistyrelsen tilbageholdes 15% af det bevilgede beløb som sikkerhedsstillelse for projektets korrekte afvikling. Når en meget stor del af omkostningerne går til fremstilling af selve prototypen, resulterer dette i et tilbagehold over uforholdsmæssig lang tid. Det blev derfor efterfølgende accepteret, at der kunne ske aflevering i to faser.

Table 3.1 De tre projekter omfattende Wave Dragon prototype 1:4½

Project	**Number**	**Total** 1000 €	**Funding** 1000 €	**Other** 1000 €
DEA	51191/01-0033	1,710	1,305	405
EU	ENK5-CT-2002-00603	2,630	1,533	847 + 27 from “Obel”
PSO	Ordre-102011, FU2302		250 +95	

<u>The DEA project.</u>

Time table: October 12, 2001 to April 1, 2004, postponed to December 31, 2004
Content: Design, construction and testing of a Wave Dragon test rig, prototype 1:4½ deployed in the NE part of Nissum Bredning in sheltered water. A model turbine from a previous EU /DEA project is installed.
Contract: Wave Dragon ApS, invoices to WD
Coordinator: SPOK ApS.

<u>The EU project.</u>

Time table: October 1, 2002 to June 30, 2005, postponed to April 1, 2006[2]
Content: Design, construction and installation of 6 additional turbines and 6 generators. Instrumentation, deployment and grid connection at the SE part of Nissum Bredning. Mooring, feasibility and market analysis.
Contract: Each partner with EU, cost statement to SPOK ApS
Coordinator: SPOK ApS.

<u>The PSO project.</u>

Time table: As the EU project
Content: As the EU project (Co financing of the EU-project)
Contract: Wave Dragon ApS, invoices to WD based on the EU cost statements.
Coordinator: SPOK ApS.

[2] Forsinkelse forårsaget af uheld 8. januar 2005 med brud i målecelle placeret mellem forankringstov og forankringspæl.

Tabel 3.2 Deltagende virksomheder samt kontaktpersoner.

Forkortelse	Virksomhed	Rolle	Kontaktperson
AAU	Aalborg Universitet	Modellering, måling og instrumentering	Peter Frigaard Jens Peter Kofoed
ATA [1]	Armstrong Technology Associates Ltd.	Design og stabilitet	Duncan Dunce
Löw	Löwenmark FRI	Opfinder, design hydrauliske og pneumatiske systemer, kvalitetssikring	Erik Friis-Madsen
MTH [2]	MT Højgaard A/S	Konstruktion af Wave Dragon	Jens Præst
KOS	Kössler GmbH	Turbine producent	Werner Panhauser Eric Kössler
VTK [3]	VeteranKraft AB	Turbine design	Evald Holmén
TUM	Technical University Munich	Turbine design og regulering	Wilfried Knapp
BAL	Balslev A/S	Elektrisk design, styring og regulering	Henrik Rosenberg
NIRAS [4]	NIRAS AS	Forudsigelse af bølgekraftforhold, forankring	Andreas Raulund
ESBI	ESBI Engineering Ltd	El-teknik i forbindelse med net-tilslutning	Tommy Bree
Nör	Nöhrlind Ltd.	Videreførelse skala 1:1	Taus Nöhrlind
SPOK	SPOK ApS	Koordination og ledelse, vurdering af miljøforhold og konstruktion	Hans Chr. Sørensen Lars Christensen

[1] Trådt ud af EU/PSO projektet den 1. januar 2005 pga. omlægning af opgaver i virksomheden. Opgaver overtaget af NIRAS og SPOK.
[2] I dag datterselskabet Promecon A/S
[3] Trådt ud af EU/PSO projektet den 1. oktober 2004 pga. ophør (pensionering). Opgaver overtaget af TUM, Technical University Munich
[4] Erstatter DHI i EU/PSO projektet, da DHI ikke ønskede at deltage i projektet uden 100% finansiering af timeomkostningerne, EU finansierer kun 50%.

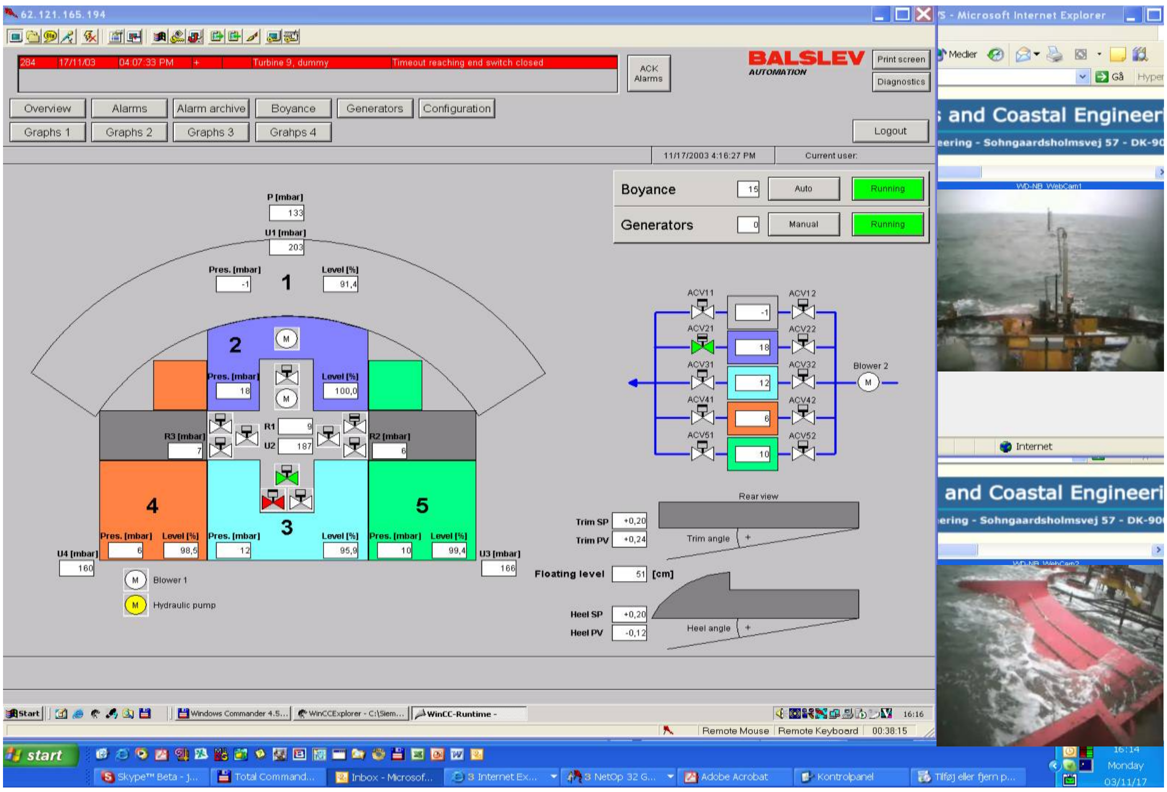
4 Kalibrering og indkøring

Oprindeligt var kalibrering af turbinen, målesystemer og hydrauliske egenskaber fastlagt til at skulle ske i havneområdet i Ålborg. Da isen i havnen i vinteren 2003 imidlertid umuliggjorde dette blev kalibreringen henlagt til Prøvestationen.

Kalibreringer i åben sø må frarådes ved kommende projekter, da forholdene ved prøvestationen er for uforudsigelige rent vejrmæssigt set.

Instrumenteringen og kalibreringen er beskrevet i fire rapporter fra Ålborg Universitet /5/, /6/, /23/ og /26/.

Overvågningen sker ved anvendelse af et traditionelt SCADA system, se figur 4.1 og eksempel på data fra vejrstation i figur 4.2 og fra turbine og el-produktion i figur 4.3. SCADA systemet har fungeret efter hensigten og det har været muligt fra et hvilket som helst sted i verden, hvor det er muligt at få Internet forbindelse at kontrollere anlægget. Nedenstående er vist nogle eksempler på output.

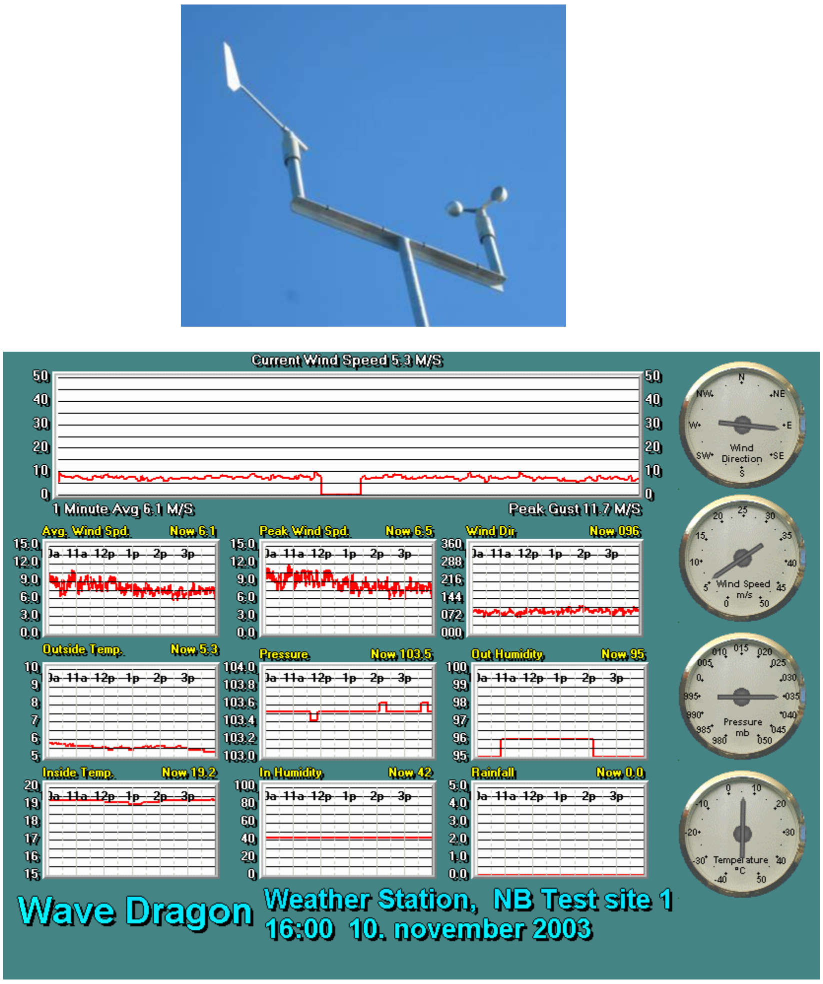


Figur 4.1 Kontrolsystemets skærmbillede fra SCADA systemet. Til højre er vist billeder fra to web kameraer anbragt på reflektor og målecontainer.

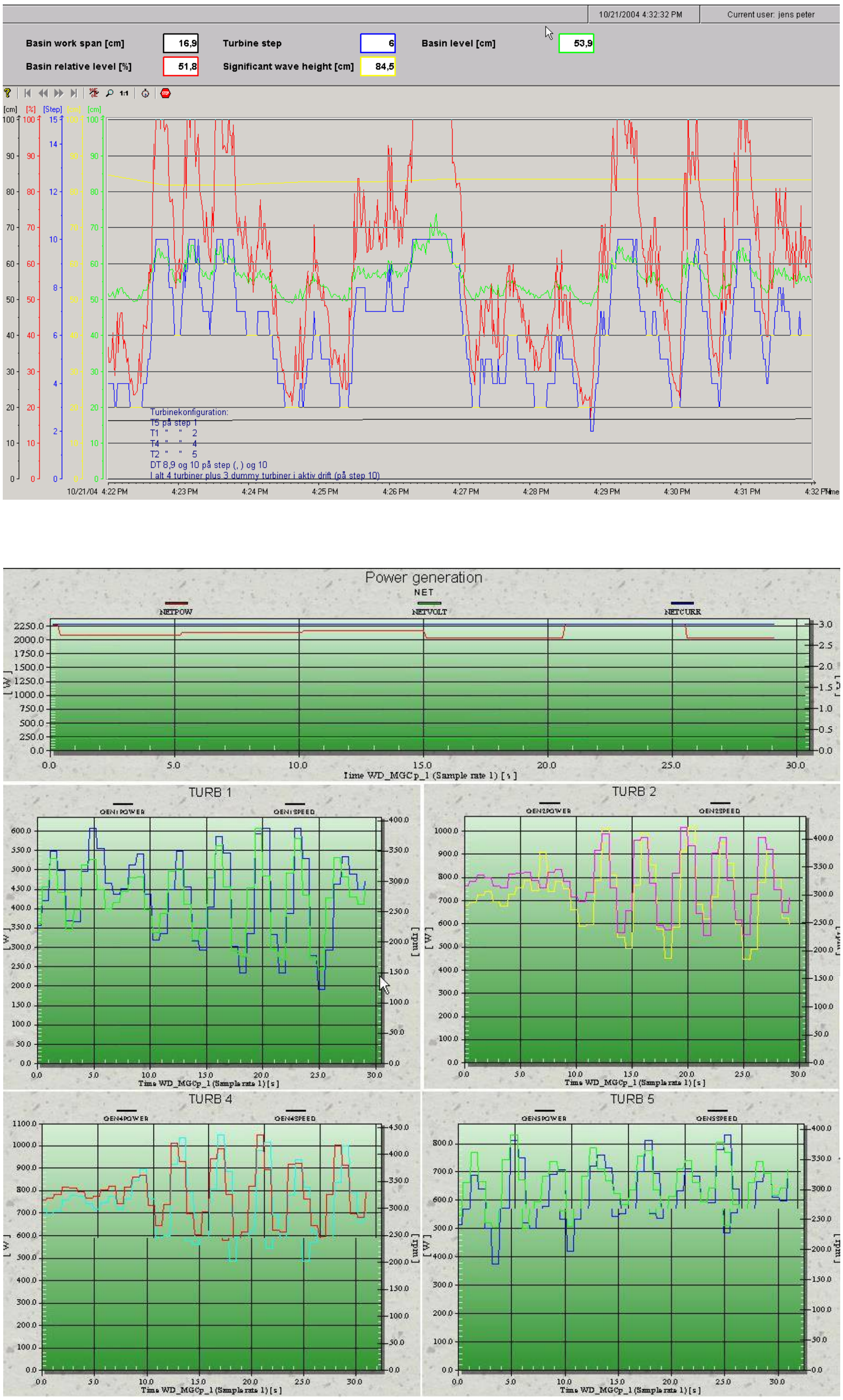
Nogle praktiske erfaringer fra indkøringen:

- Det har været vanskeligt at etablere bredbåndsforbindelse til lokaliteten ved Prøvestationen, da området ikke er prioriteret af teleselskaberne. Kun velvillig bistand fra Sonofon har muliggjort, at signaler efter overførsel gennem lyslederkabel indlagt i elkablet overføres via radiolink til modtage station i Lemvig.

- Sammenkobling af signaler fra dataopsamlingsenhed (MGC+) og SCADA system fra Siemens har vist sig uhyre kompliceret, da de to systemer arbejder med forskelligt teknologi. Men efter lang tid lykkedes det.
- Installationer, der skal bevæge sig, skal være forberedt til saltvand og stilstand i længere perioder. Vi sparede materialer ved at konstruere dummy turbinerne i almindeligt stål, da levetiden var begrænset. Men stilstand i perioder har medført, at der opstår rust, der blokerer for automatisk opstart, idet rusten først skal bankes af.
- Styring over Internettet fungerer normalt fint, men man skal være forberedt på, at forbindelsen kan afbrydes uden man opdager det, hvis afbrydelsen sker i forbindelse med ud-logning. Det kan derfor altid anbefales at være to personer på fjernovervågning, således at der er mulighed for at konstatere uregelmæssigheder.



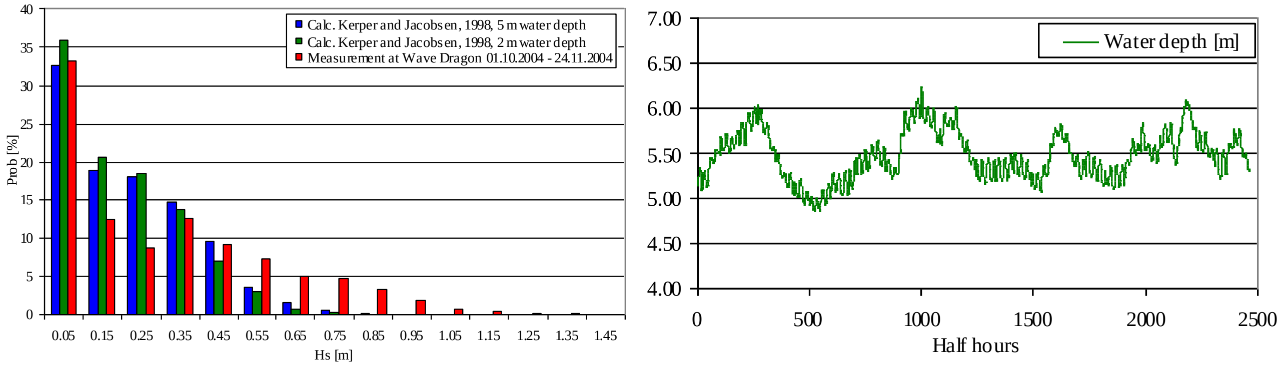
Figur 4.2 Eksempel data fra anlæggets vejrstation, hvor der måles temperaturer, lufttryk, fugtighed og nedbør.



Figur 4.3 Øverst: Eksempel på data fra SCADA system. Her af ses også hvordan turbinedriften, og hermed el-produktionen, følger vandstanden i reservoiret, og hermed variationen i overskyl. I given eksempel er tre cylinder gate turbine samt sifonturbinen i næsten konstant drift, men hovedparten af variationerne optages af dummyturbinerne. Nederst: El-produktion fra de fire aktive turbiner, samt samlet el-produktion, der kommer på nettet, i et ca. 30 sek. udsnit af øverste graf.

Bølgeforholdene ved prøvestationen viste sig i praksis at være anderledes end forudsagt gennem simuleringer. Som det fremgår af figur 4.4, er der højre hyppighed af de større bølger end forventet.

North Sea							
Hs [m]	<0.5	1	2	3	4	5	>5.5
Tp [s]		5.6	7.0	8.4	9.8	11.0	
Prob. [%]	15.6	47.6	21.4	9.6	4.1	1.3	0.4
Scaled to WD-NB (1:4.5 lengthscale)							
Hs [m]		0.22	0.44	0.67	0.89	1.11	
Tp [s]		2.64	3.30	3.96	4.62	5.19	
Measured data, WD-NB, test site 1, Oct. - Nov. 2004							
Tp [s]		2.55	2.81	3.05	3.45	3.60	
Prob. [%]	34.9	23.7	21.5	12.2	6.3	1.1	0.3



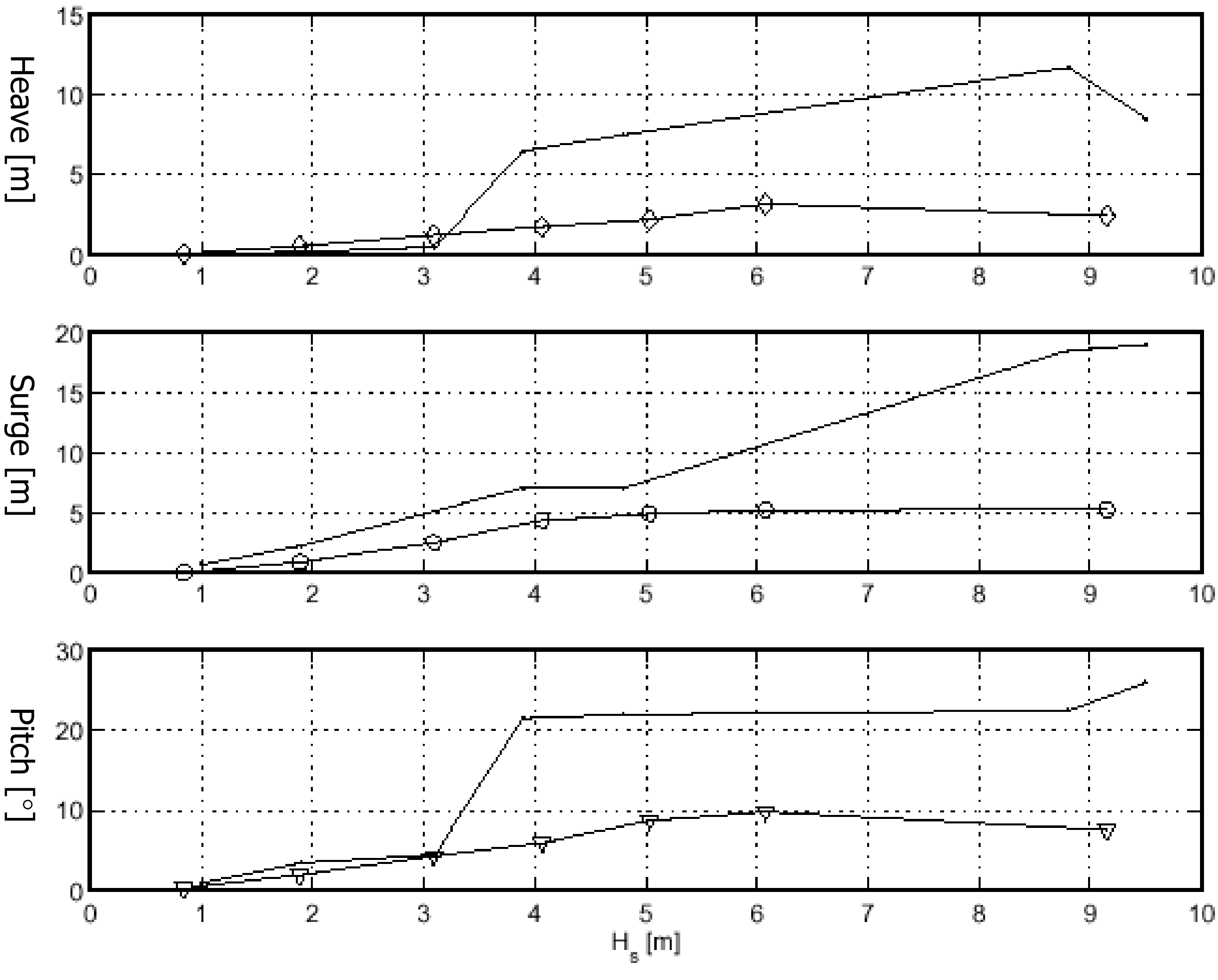
Figur 4.4 Bølgemålinger fra Prøvestationen.

5 Test af hydraulisk respons

Anlæggets evne til at ligge relativt stille i typiske bølgesituationer med høj produktion er helt afgørende for energiproduktionen.

Anlægget er optimeret gennem omfattende forsøg i bølgetank og numerisk beregning med en model i skala 1:50 /8/ og /9/.

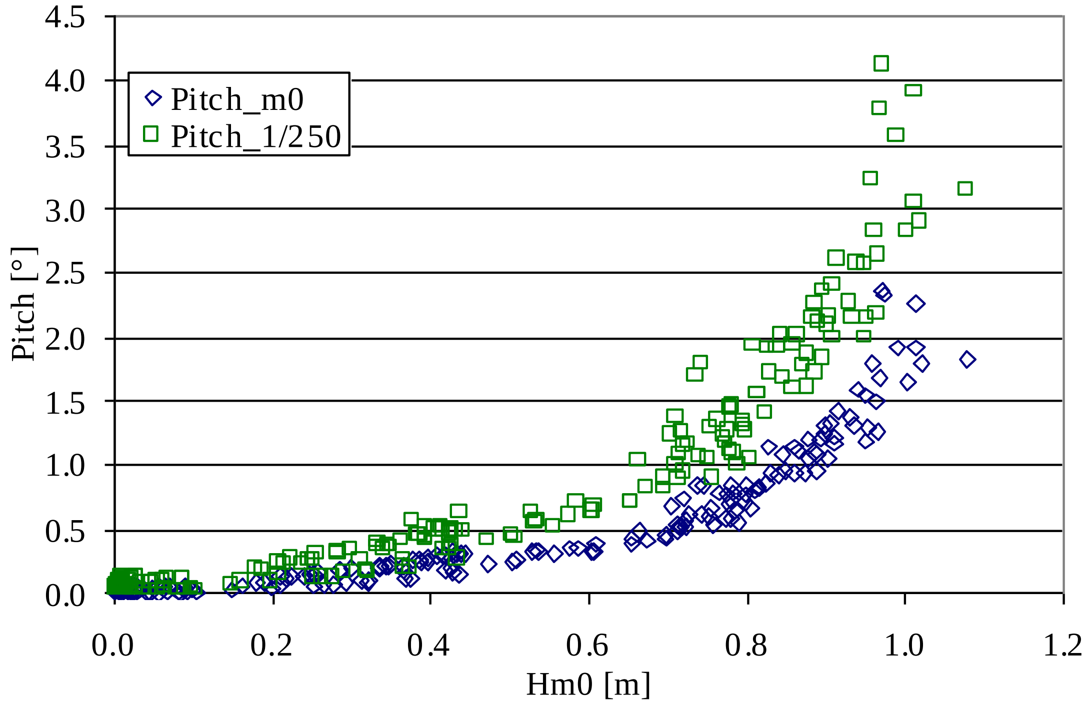
Egensvingningstiden for den første generation af anlægget viste sig at lige for tæt på bølgeperioden ved 3 - 5 meter bølger i fuld skala, se øverste grafer i figur 5.1



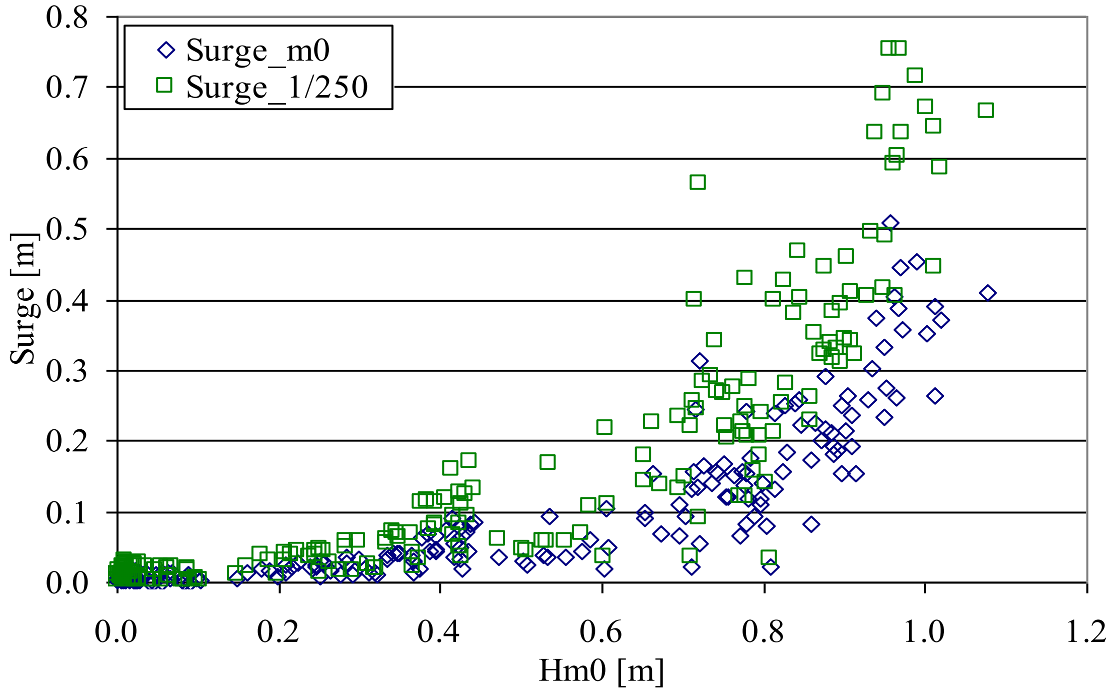
Figur 5.1 Heave, surge og pitch som funktion af bølgetilstanden modelforsøg skala 1;50 (H_S i meter svarende til fuld skala), kilde /8/

1:50 modellen blev herefter modificeret og tilfredsstillende resultater opnået (nederste del af graferne figur 5.1).

Prototypen i skala 1:4½ er baseret på samme geometri, og i henhold til modellovene skal man derfor kunne forvente samme resultater. Den eneste parameter, det ikke har været muligt at modellere korrekt, har været luftpuderne i de åbne trykkamre. Luftens sammentrykkelighed har således ikke fulgt modellovene, hvorfor en afvigelse forårsaget heraf kan ventes. Det vurderes, at indflydelsen fra luftpuderne vil betyde en forbedret opførsel, dvs. mindre Pitch. Forsøgsresultaterne bekræfter dette, idet der kun er konstateret halvt så store bevægelser, se figur 5.2

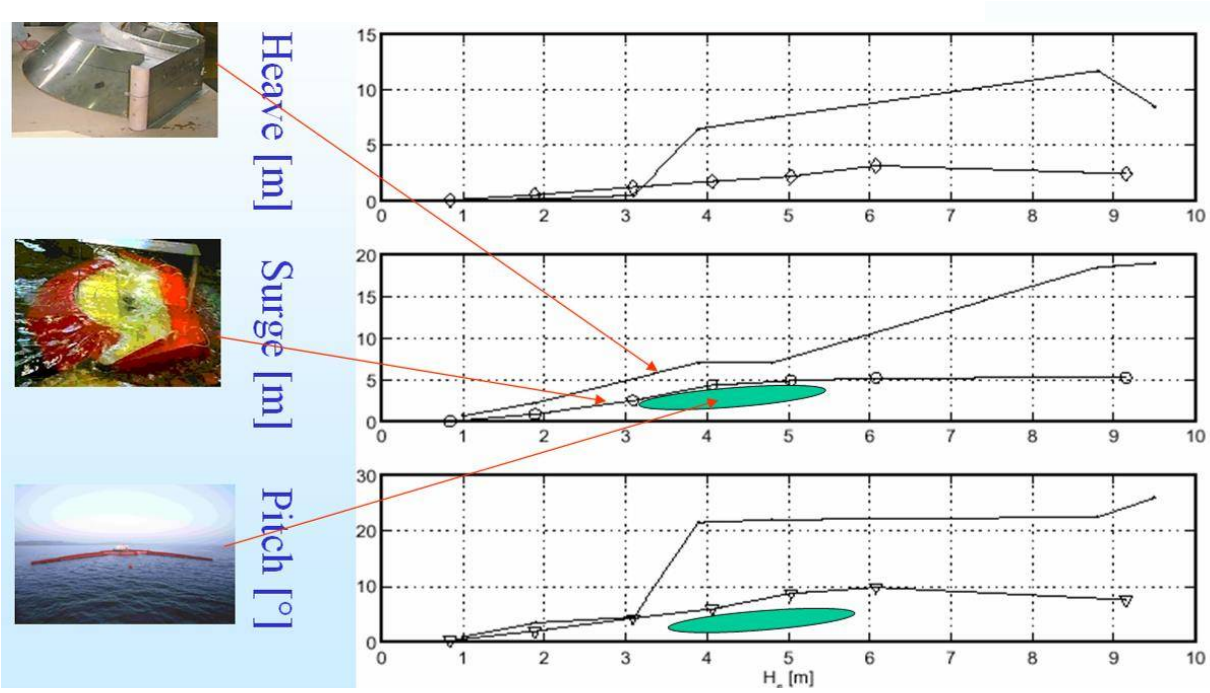


Figur 5.2 Pitch som funktion af bølgetilstanden (H_s i meter svarende til aktuelle lokalitet i Nissum Bredning. I fuld skala skal bølgehøjden multipliceres med 4,5). Kilde /11/



Figur 5.3 Surge som funktion af bølgetilstanden (H_s i meter svarende til aktuelle lokalitet i Nissum Bredning. I fuld skala skal bølgehøjden multipliceres med 4,5). Kilde /11/

Sammenlignes de to sæt målinger fra henholdsvis skala 1:50 forsøgene med skala 1:4½ forsøgene fremgår det, at prototypeforsøgene i Nissum Bredning kun viser halvt så store værdier. Vigtigt er endvidere, at der ikke kan forventes en stigning for bøgetilstande ud over de målte værdier, hvilket dog savner dokumentation, da bølgerne ikke har været så høje ved prøvestationen, som skala 1:50 forsøgenes bølgetilstande. På figur 5.4 er de to sæt grafer for Pitch sammenhold i samme målestok.



Figur 5.4 Pitch som funktion af bølgetilstanden (H_S i meter svarende fuld skala) sammenlignet for prototype i skala 1:4½ og model i skala 1:50.

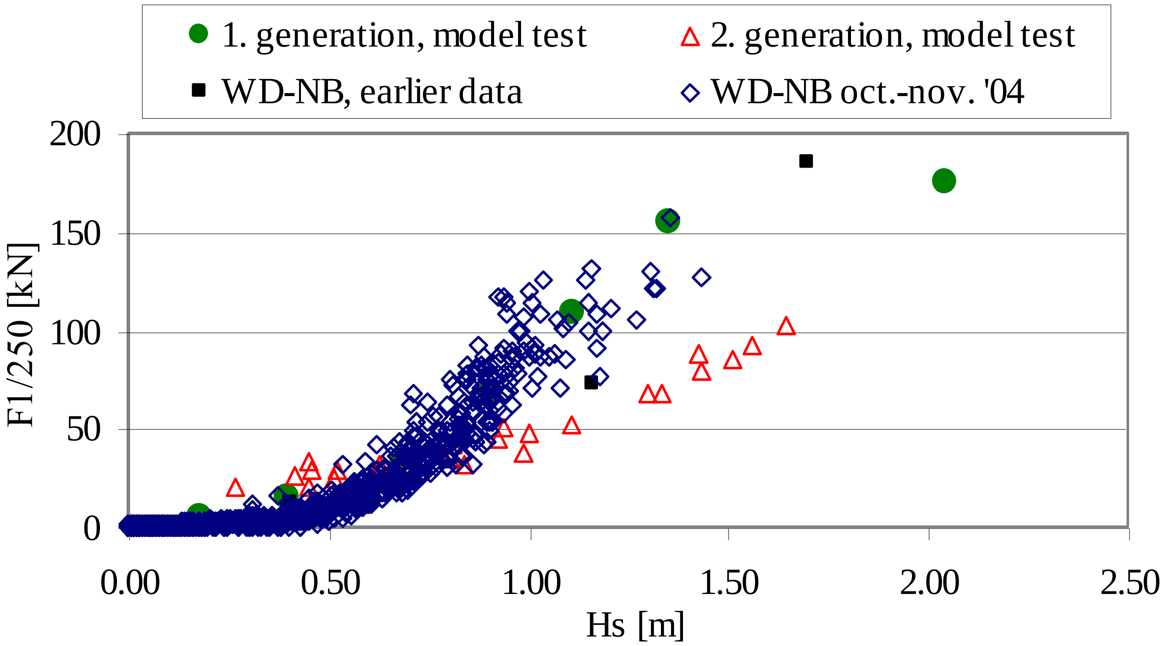
6 Målinger af kræfter og deformationer

Målingerne af forankringskræfter på prototypen sammenholdt med tilsvarende målinger på 1:50 modellen viser god overensstemmelse, som det fremgår af figur 6.1.

Det ser dog ud til, at værdierne er lidt højere end tilstræbt, idet kræfterne i prototypen svarer til kræfterne i den første generation af 1:50 modellen, hvor forankringssystemet var lidt for stift. Forklaringen kan være tilstedeværelsen af begroning på tovværket, hvilket vil ændre stivheden, se figur 6.2. En anden forklaring kan være at elasticiteten i tovene med tiden blev væsentlig mindre.

For at afklare dette, kræves gennemførelse af en række specifikke målinger i den kommende forsøgsfase.

Det på 1:4½ skala prototypen anvendte forankringsarrangement er ikke det, der vil blive anvendt i fuld skala. Den ringe vanddybde og det forhold, at fuldskala forankringssystemet ikke kan nedskaleres, har gjort det nødvendigt at simulere forankringssystemets karakteristika ved hjælp af elasticitet i tovværket. Det er i al væsentlighed disse løsninger, der formodentligt har givet anledning til de høje forankringskræfter og en række praktiske problemer i forsøgsperioden.

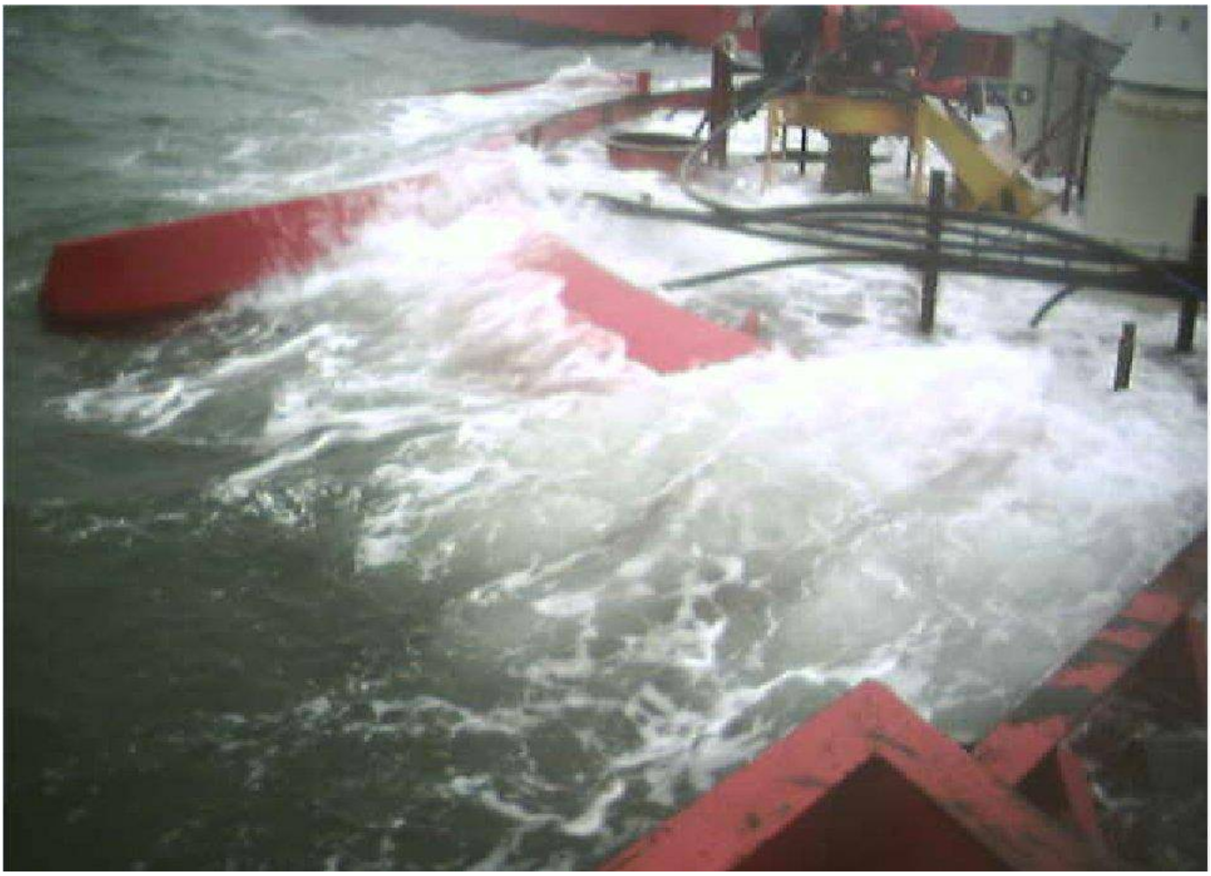


Figur 6.1 Forankringskræften F1/250 (gennemsnit af den 1/250 største ekstremværdi) som funktion af bølgetilstanden (H_s i meter svarende aktuelle bølgeklima i Nissum Bredning) sammenlignet for prototype i skala 1:4½ og model i skala 1:50.

Figur 6.2 Begroning på tovværk efter 1½ års ophold i vandet.

7 Målinger af overskyl

Den vigtigst del af forsøgsserien har været at finde dokumentation for, hvor meget vand der kommer op i reservoiret, idet el-produktionen er proportional med den hydrauliske ydeevne.



Figur 7.1 Opskyl af vand i reservoiret er en af de vigtigste parametre at kunne kontrollere ofr etablering af el-produktion på Wave Dragon.

I det tidligere gennemførte projekt støttet af Energistyrelsen og EU CRAFT programmet /7/ og /8/ blev der baseret på modelforsøg i skala 1:50 udviklet en matematisk model for overskyl som funktion af den relative højde af reservoiret over vandoverfladen (fribord), ligning (1), se figur 7.1 og 7.2.

Årsagen til spredningen og afvigelsen omkring den forventede kurve på figur 7.3 skyldes /11/:

- Idealt set skal kontrolsystemet sikre at reservoiret niveau er fastlåst under forsøg i samme bølgetilstand. Dette har ikke altid været tilfældet, da der parallelt har været gennemført forsøg med justeringer af ballasttanke for at sikre optimal stabilitet. Disse data er ikke frasorteret.
- Når fribordet har været under den optimale værdi for den aktuelle bølgetilstand, har turbiner og dummy turbiner ikke altid været i stand til at absorbere al vandet, hvorfor der er sket overskyl af vand over kanterne af reservoiret. Disse data er ikke frasorteret.
- Som følge af begrænsninger i Wave Dragons fri bevægelse op mod bølgerne (begrænset til $\pm$ 60^{o}) har der ikke altid været optimal udnyttelse af bølgeenergien i nogle vejrsituationer. Disse data er ikke frasorteret.

- Måleusikkerheden for Wave Dragons flyde niveau og dermed fribordets relative højde, har stor betydning. Usikkerheden har i perioder været stor som følge af drift af nulpunktet for nogle af trykmålerne foranlediget af begroning på målecellerne.

(Eq. 1) $$Q^* = 0.025 \exp(-40 R^*)$$

where

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

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

q = discharge rate due overtopping [m^3/s]

H_s = significant wave height [m]

L = ramp width [m]

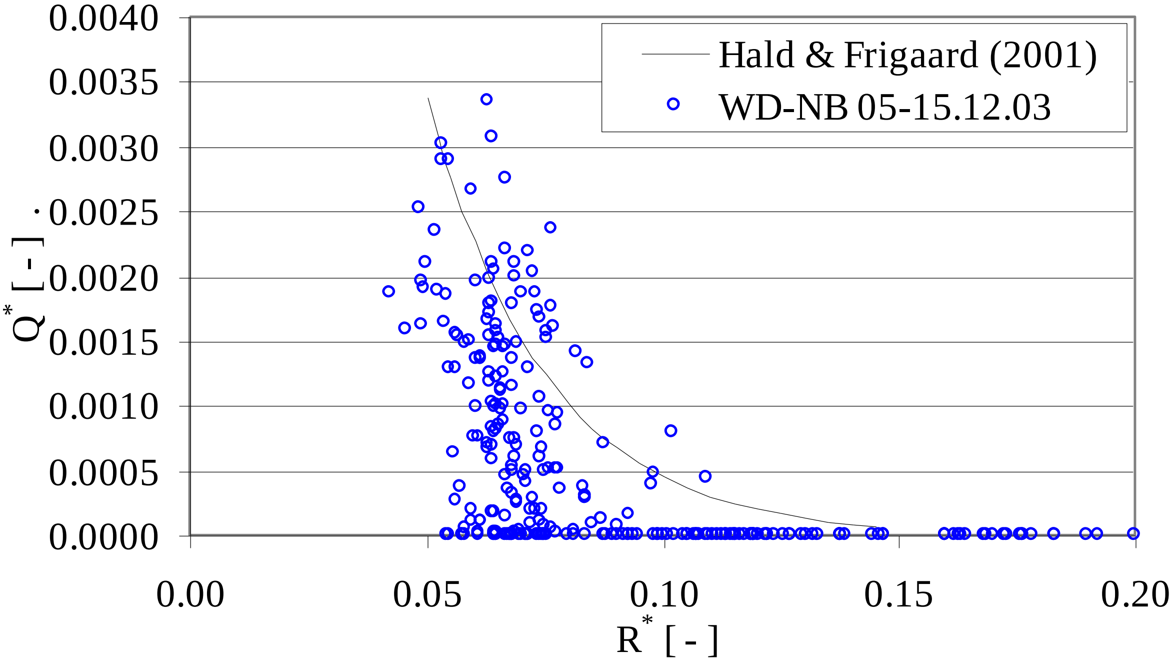
s_{op} = wave steepness, $s_{op} = H_s / L_{op}$ [-]

L_{op} = deep water wave length, $L_{op} = \frac{g}{2\pi} T_p^2$ [m]

T_p = Peak period [s]

R_c = Crest freeboard relative to MWL [m]

Figur 7.2 Formel (1) til fastlæggelse af overskyl (overtopping) som funktion af relativ højde over vandoverfladen(crest height), kilde /7/.



Figur 7.3 Overskyl (overtopping) som funktion af relativ højde (fribord) over vandoverfladen (crest height), kilde /11/.

Imidlertid kan det også konstateres, at der er målepunkter, der falder over det forventede niveau, hvilket indikerer, at der er mulighed for at opnå større overskyl end formel (1) udtrykker.

Følgende konklusionen kan drages ud fra forsøgene:

- at opskyllet under dagens normale driftsforhold mod god nøjagtighed kan beregnes ud fra en generisk overskylsformel (1), figur 7.2,
- at resultaterne for overskyl viser en stor spredning, hvor datagrundlaget (figur 7.3) er samtlige observationer, inklusiv bevidst ikke-optimale styringstilstande,
- at en stor del af observationerne repræsenterer situationer, hvor der er opnået væsentlige højere energiabsorptioner end de forudsagte.

Det vurderes derfor, at der vil være muligheder for ved optimering af styringen at opnå et gennemsnitligt højere output end de i formel (1) forudsagte.

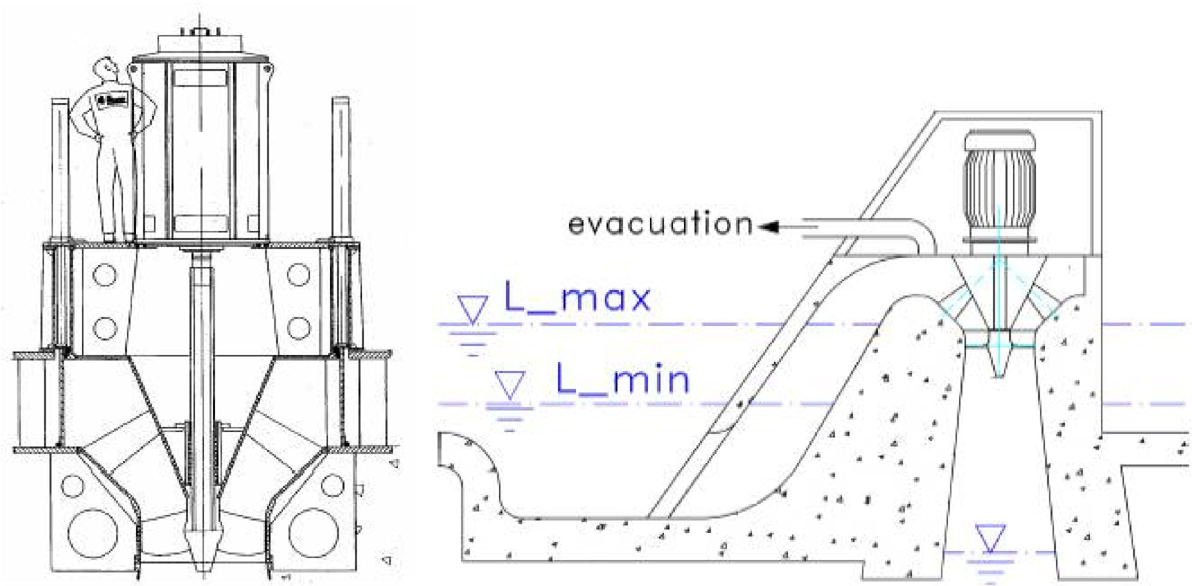
Mulighed for, at forbedre opskyl er en væsentlig del af det kommende forsøgsprogram.

8 Vurdering af turbine effektivitet

Turbinerne til Wave Dragon er specielt udviklet til projektet, idet

- Turbinerne skal kunne fungere med en højdeforskel (head) fra 0,4 m til 4 m, hvilket ligger ved den nedre grænse af de praktiske erfaringer fra vandkraftværker, men samtidigt er en ekstrem stor variation i forhold til, hvad man normal anvender inden for vandkraftværker.
- Turbinerne skal kunne fungere med meget hyppige skift af vandmængde og den begrænsede kapacitet af reservoiret, hvilket betyder at turbinerne meget ofte skal gå fra nul til fuld last.
- Turbinerne skal fungerer i et meget bask miljø (havmiljø) med begrænsede muligheder for vedligeholdelse på en ubemandet platform.

Turbinerne er derfor udformet så simpelt og med så få bevægelige dele som muligt /12/. Der er anvendt turbiner med faste ledeskovle og fast vinkel for propellen. Ved anvendelse af 12-16 turbiner af relativ lille størrelse kan disse sluttes til og fra hurtigt og effektivt i modsætning til, hvis en enkelt stor turbine var valgt. For at sikre højst mulig effektivitet over en bred vifte af trykforskelle (head) anvendes variabel omløbshastighed med direkte koblede permanent magnet generatorer styret af en frekvensomformer. Anvendelsen af 12-16 turbiner har den fordel, at der kun tabes en begrænset produktion ved nedbrud af en enkelt turbine.



Figur 8.1 Fuld skala Wave Dragon cylinder gate turbine (venstre) og sifon turbine (højre)

Turbinerne er udviklet baseret på erfaring og anvendelse af CFD simulering. Ved test i prøvestanden i München er fundet en virkningsgrad på 90,1%.

For at begrænse omkostningerne er der ved bestykningen af prototypen i Nissum Bredning valgt at anvende:

- Model sifon turbinen afprøvet i skala 1:3½ i München med en effekt på 2,6 kW
- 6 specielt udviklede cylinder gate turbiner, hver med en effekt på 2,6 kW
- 3 dummy turbiner, der anvendes som spidslast enheder, hver med en effekt svarende til to af de ovenstående turbiner.

Sifon turbinen og dummy turbinerne blev installeret allerede fra starten, og sifon turbinen var i stand til at producere el allerede fra opstarten i slutningen af april 2003. Regelmæssig produktions skete fra juni måned 2003. Wave Dragon blev hermed verdens første offshore bølgekraftanlæg, der leverede el til nettet.

Figur 8.2 De seks aksial propel turbiner under montage hos Kössler GmbH (venstre) og 3 af turbinerne med cylinder-lukke om bord på Wave Dragon (højre)

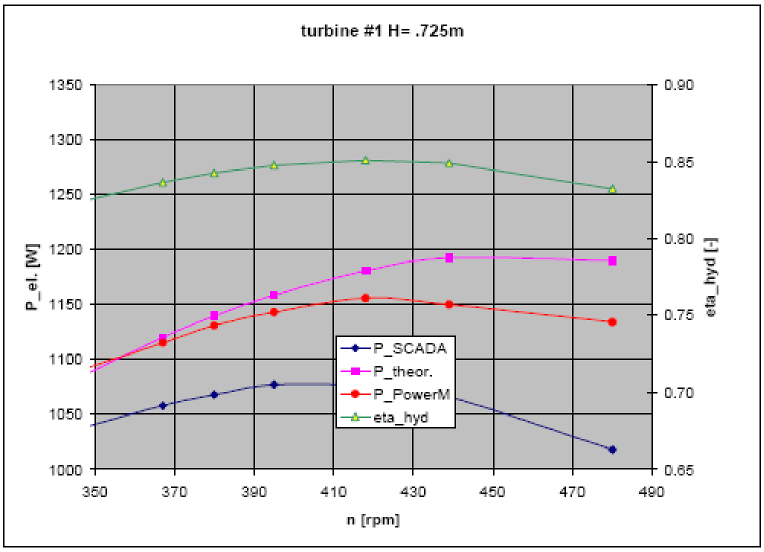
De resterende 6 turbiner blev installeret i åben sø i september 2003, hvorved vi fik mulighed for at afprøve den strategi, som er planlagt for drift og vedligeholdelse på langt sigt: løbende udskiftning af turbiner baseret på driftstimetallet, udført på havet under de regelmæssige eftersyn.

Figur 8.3 Montage af turbine på havet, september 2003.

siphon turbine: measurement 18.6.05

turbine #1			
H [m]=	0.725		
	SCADA values		Power Meter
sf [-]	n [1/min]	P [W]	P [W]
50	480	1018	1134
70	439	1066	1150
85	418	1076	1156
100	395	1077	1143
115	380	1068	1131
130	367	1058	1115
150	347	1038	1091

comment:
The turbine characteristics were taken from the cylinder gate turbine model test,
with a 3% efficiency downgrade to allow for the siphon losses.
The generator efficiencies were taken from the Munich tests with the Czech generators and were adapted with a (admittedly arbitrary) 4% efficiency downgrade

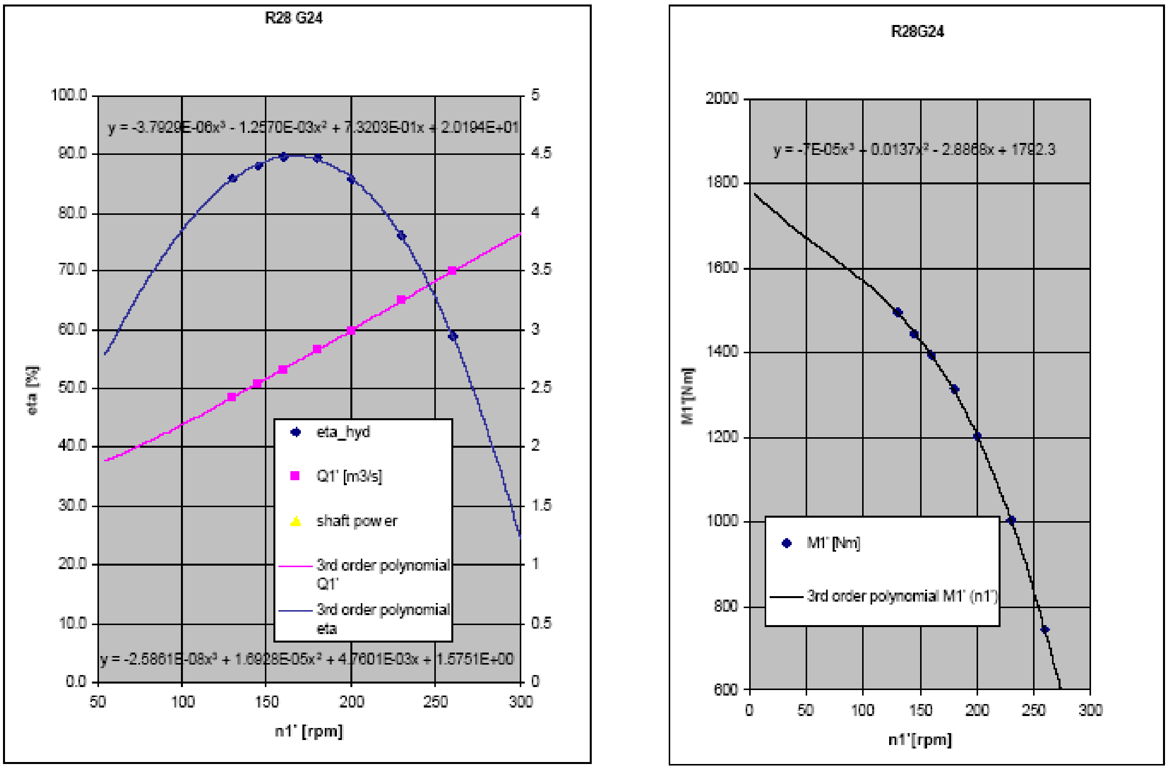


delta_eta_sipt 0.03 delta_eta_ger 0.04

n1' [rpm]	Q1' [m^3/s]	Q [m^3/s]	eta_mod [-]	Re_P	delta_eta [%]	eta_hyd [-]	i_o_loss [m]	P_runn [W]	P_frict [W]	P_shaft [W]	eta_Gen [-]	P_el [W]
191.7	2.93	0.29	0.85	2.2E+06	-1.4%	0.83	0.042	1 591	107	1 484	0.80	1 190
175.3	2.79	0.27	0.86	2.0E+06	-1.6%	0.85	0.038	1 556	94	1 462	0.82	1 192
166.9	2.72	0.27	0.87	1.9E+06	-1.6%	0.85	0.036	1 525	87	1 437	0.82	1 181
157.7	2.65	0.26	0.87	1.8E+06	-1.7%	0.85	0.034	1 481	80	1 401	0.83	1 159
151.7	2.60	0.26	0.86	1.8E+06	-1.8%	0.84	0.033	1 448	75	1 373	0.83	1 139
146.5	2.55	0.25	0.86	1.7E+06	-1.9%	0.84	0.032	1 416	71	1 345	0.83	1 120
138.6	2.49	0.25	0.84	1.6E+06	-2.0%	0.82	0.030	1 363	65	1 298	0.84	1 085

Figur 8.4 Eksempel på kalibreringsrapport fra sifonturbinen. Kilde /20/.

En række rapporter er udarbejdet om turbinernes tekniske egenskaber, hvor den seneste rapport omhandler kalibrering /20/, hvorfra et typisk diagram er vist i figur 8.4 og 8.5.



hydraulic turbine efficiency η_{hyd} and unit discharge Q1' vs. unit speed n1'

unit torque M1' vs. unit speed n1'

Figur 8.5 Virkningsgrad for turbine. Kilde /21/.

9 Evaluering for senere opskalering

Det vurderes at grundprincippet for Wave Dragon virker tilfredsstillende. Der mangler fortsat resultaterne fra EU/PSO delen af projektet for at kunne vurdere den optimale el-produktion. Disse resultater ventes rapporteret senest i foråret 2006.

Figur 9.1 Wave Dragon strandet på standen ved Prøvestationen efter stormen den 8. januar 2005 (venstre) efter brud i træk målecelle (højre), der forband forankringsliner og forankringspæl.

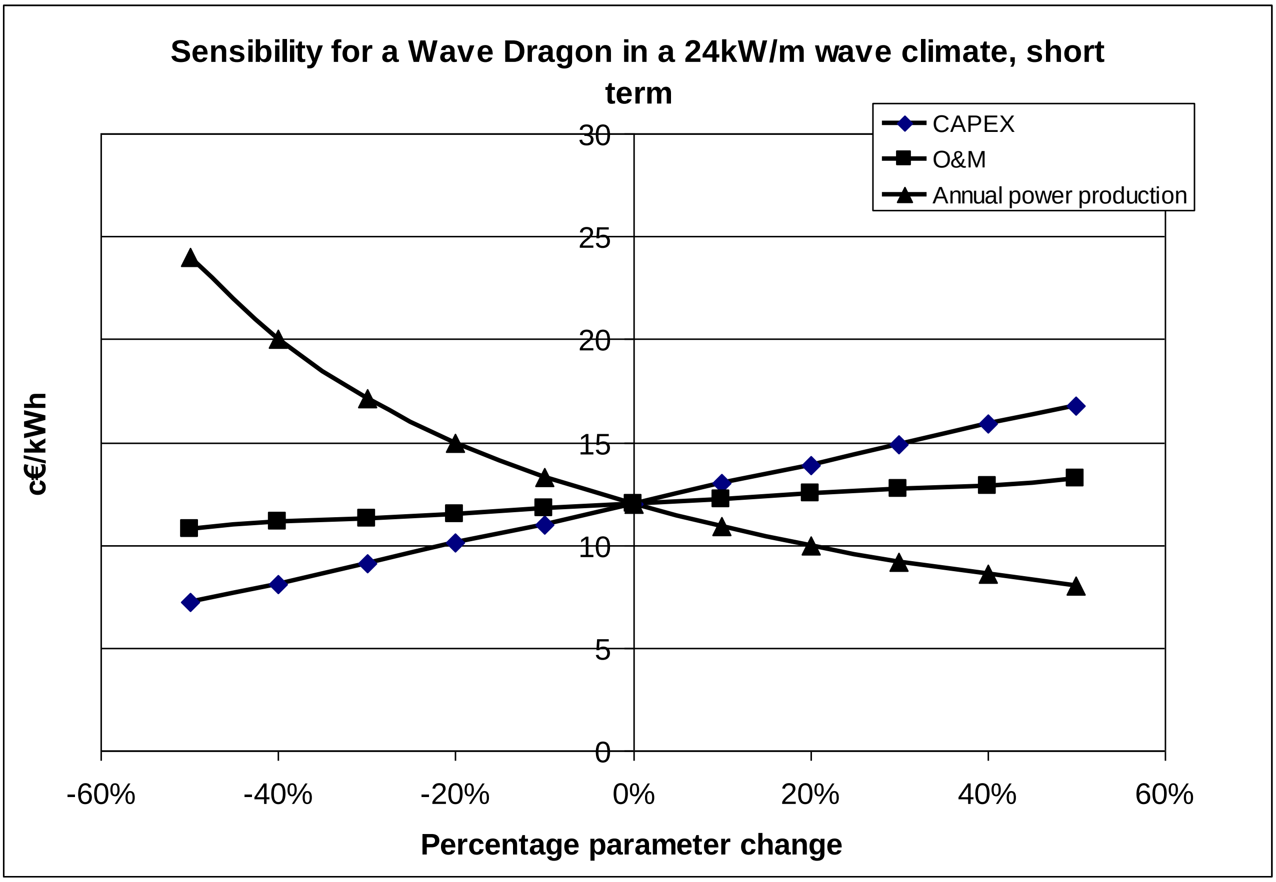
Stormen den 8. januar 2005 resulterede i et brud i en målecelle, der forbandt forankringskablerne med forankringspælen /14/. Denne hændelse anses ikke for fatal, da der inden dette tidspunkt er registreret større kræfter i forankringen i stormsituationer. Selve forankringssystemet anses derfor for at fungere tilfredsstillende.

Der er foranlediget af observationer gennem de 2 år opstået et ønske om at forbedre det bevægelige led mellem krop og reflektorer, idet ledet anses som et svagt punkt, der er udsat for stort slid med reduceret levetid til følge. Der er derfor udviklet et koncept for et mere robust led, der med støtte af PSO er afprøvet i foråret 2005 /17/, /18/.

9.1 Ekstern evaluering

I projektperioden er der gennemført en vurdering af Wave Dragon konceptet dels af EPRI /15/ og dels af Carbon Trust i forbindelse med Marine Energy Callenge programmet /16/. I UK er Wave Dragon således blevet udvalgt blandt 8 koncepter efter en international licitation til for Carbon Trust's regning at blive gået efter i sømmene (cost engineering). Evalueringen er gennemført først af ingeniørfirmaet Halcrow og senere af ingeniørfirmaerne Black & Veatch suppleret med Frazer Nash, DNV og Entec. På de grundlæggende områder er der opnået enighed om omkostningsniveauet, bortset fra en uenighed om anlæggets samlede volumen.

I figur 9.2 er vist en enkelt eksempel på en følsomhedsanalyse fra arbejdet med Carbon Trust.



Figur 9.2 Wave Dragon følsomhedsanalyse. Kilde /16/.

9.2 Markedsudvikling

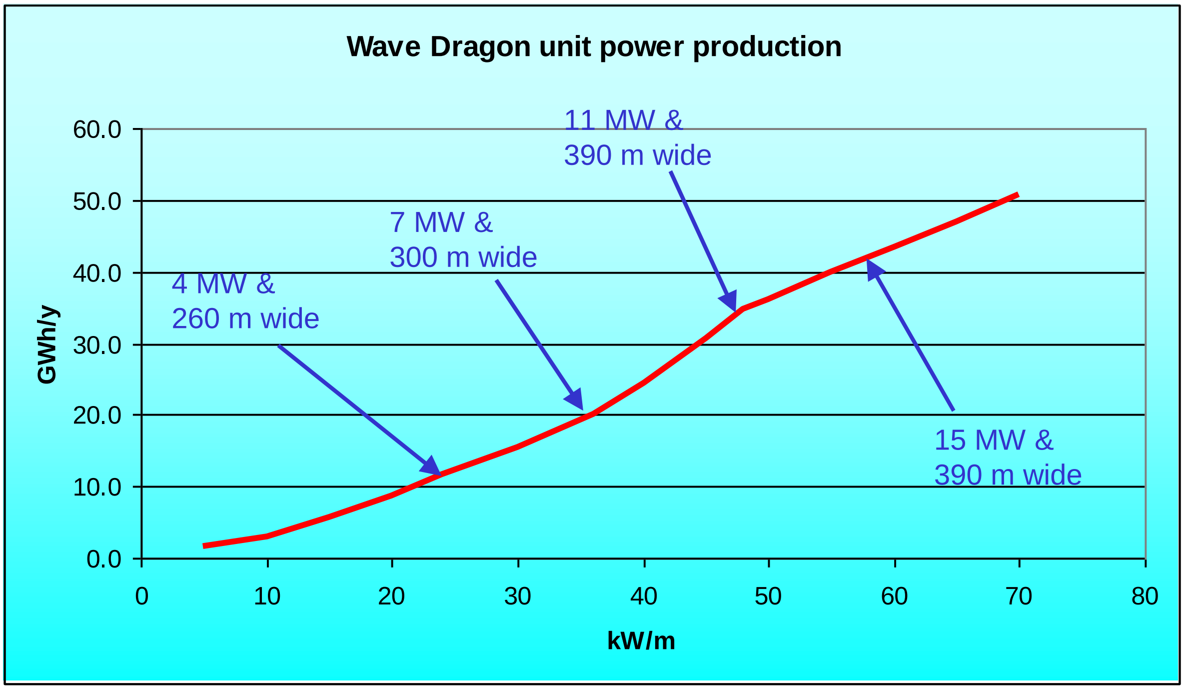
For at fastholde en løbende udvikling frem mod en kommerciel udnyttelse af bølgeenergi baseret på Wave Dragon princippet er der taget følgende initiativer, idet '*time to market'* anses for meget afgørende for succes (se også figur 9.4):

- Afprøvning og design af nyt led mellem reflektorer og krop omfattende skala 1:50 forsøg efterfulgt af ombygning af 1:4½ prototypen i Nissum Bredning år 2005-2006 (PSO midler).
- Udvikling af forbedret kraftudtag ved nyttiggørelse af bevægelser i led m.v. i samarbejde med Danfoss omfattende skala 1:50 forsøg efterfulgt af ombygning af 1:4½ prototypen i Nissum Bredning år 2005-2006 (PSO midler) /17/ og /18/.
- Afprøvning af simpel version af Wave Dragon (1. generation med nyt led jfr. ovenstående) ud for den walisiske vestkyst år 2007. Projektet er indstillet til at modtage 5 mil. £ fra den walisiske udviklingsfond for regional udvikling, og restfinansiering forhandles med to venture kapital virksomheder i udlandet.
- Undersøgelse af mulighederne for afprøvning af en 2. generation Wave Dragon med forbedret kraftudtag i skala 1:2 evt. 1:1 ved Horns Rev år 2008 (PSO midler? + Venture kapital). En alternativ placering kan tænkes ved Cornwall i UK eller i Portugal. Tilsagn om EU støtte er modtaget under 6. rammeprogram til forskningsdelen (18 mil. kr.).

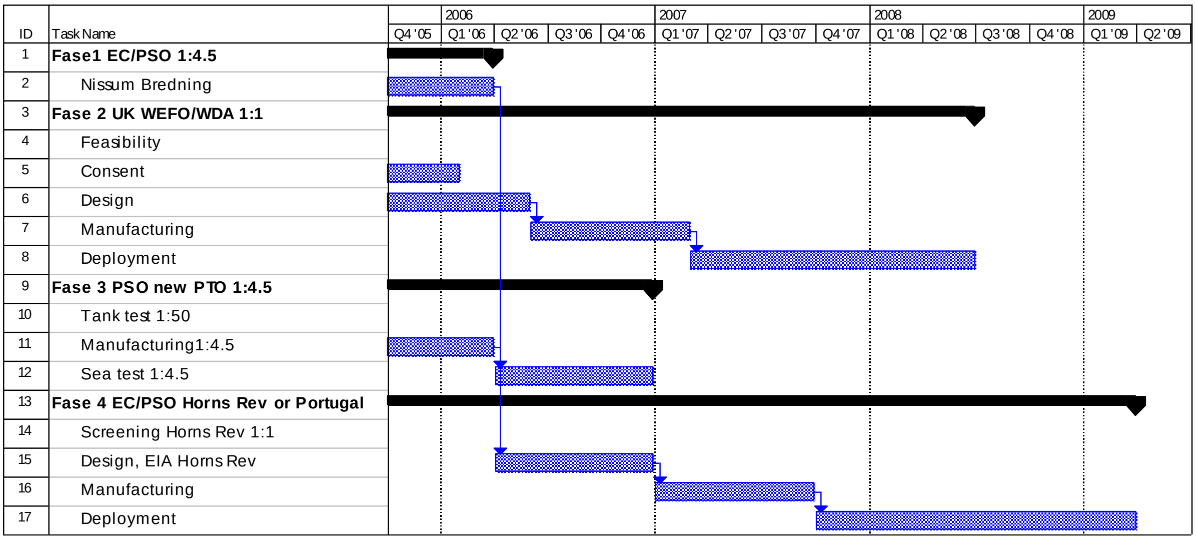
Overvejelserne er mere uddybet i bilag 1, hvorfra den forventede kWh pris er gengivet i tabel 9.1 og den forventede årlige el-produktion ved forskellig bølgeklima er vist i figur 9.3.

Tabel 9.1 Forventet kWh pris for Wave Dragon

Bølgeklima	Første anlæg	Længere sigt
24 kW/m	11,0 c€/kWh	5,4 c€/kWh
36 kW/m	8,3 c€/kWh	4,0 c€/kWh
48 kW/m	6,1 c€/kWh	3,0 c€/kWh



Figur 9.3 Wave Dragon størrelse og ydeevne som funktion af bølgeklima.



Figur 9.4 Wave Dragon udviklingsplan.

9.3 Faktablad

I forbindelse med afslutningen af Det danske Bølgekraft Program /19/ blev der udarbejde en skabelon for et datablad for de enkelte bølgekraftanlæg. I figur 9.4 er den opdaterede version angivet baseret på data fra forsøgene i Nissum Bredning.

Wave Dragon

Ansøger: Wave Dragon ApS		**Projekt navn:** WAVE DRAGON	
Journal no.	Tilsagns dato:	Tilskud	Afprøvnings sted
J.No. 51191/97-0007	22-04-98	500.000 kr.	AAU
J.No. 51191/98-0047	27-04-99	320.000 kr.	AAU
J.No. 51191/99-0046	13-09-99	300.000 kr.	AAU
J.No. 51191/00-0013	10-03-00	752.500 kr.	Power Take Off
J.No. 51191/00-0067	15-11-00	476.000 kr.	AAU
J.No. 51191/01-0017	22-06-01	150.000 kr.	Udviklingsplan
J.No. 51191/01-0033	12-10-01	9.589.000 kr.	Nissum Bredning

Rapporter:
Evaluation of the hydraulic response of the Wave Dragon, Aalborg University, February, 1999
The Wave Dragon: 3D overtopping tests on floating model, Aalborg University, May, 1999
Forsøg til belysning af hydraulisk respons, Rapport fase A, H.C. Sørensen EMU, E. Friis Madsen, Löwenmark, F.R.I, Februar 1999.
The Wave Dragon tests on a modified model, AAU, September 1999.
Hydraulic Model tests on Modified Wave Dragon, AAU, November 2001.
Wave Dragon 1:4.5 – Design, produktion og etablering i Nissum Bredning'. Rapport fase A af ENS projekt 51191/01-0033, Maj 2003
Wave Dragon 1:4½ - Kalibrering, måling og opskalering samt informationsaktiviteter, September 2005

Princip: Bølger fanges og koncentreres mellem lange fangarme og skylles op i et flydende reservoir. Vandet fra dette reservoir ledes tilbage i havet gennem en eller flere vandturbiner.

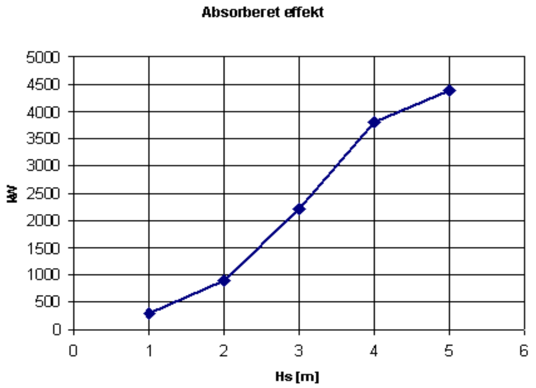
Status: Model skala 1:50, forsøg til belysning af overlevelsesforhold og energiproduktion udført på AAU. Forsøg til belysning af energiproduktion udført på AAU. Studie af vandturbiner til pulserende og varierende effektniveau gennemført under Joule Kraft. Bygning af en model i skala 1:4.5 til afprøvning ved Folkecenterets prøvestation i Nissum Bredning .

Hoveddata:

Længde:	147 m
Bredde:	259 m
Højde:	15,5 m
Egenvægt:	21.750 tons

Materialevalg:

Stål:	350 tons
Beton:	21.400 tons



Power take-off : *PTO virkningsgrad* (51 %)

Installeret effekt:	4.400 kW
Middel energiabsorption:	8.175.000 kWh
El-produktion:	4.170.000 kWh

Forankringssystem: *Slæk forankring*

Områder som kræver fortsat udvikling:
Optimering af design herunder
- Forankringssystemet og bevægelser
- Niveauregulering af reservoir
- Material optimering

Wave Dragon

Figur 9.4 Wave Dragon Datablad.

10 Tilsyn af model

Der har været ført logbog omfattende besigtigelser og besøg på Wave Dragon i Nissum Bredning, som det fremgår af /11/.

Miljøforhold.

Der er jævnligt observeret måger, terner og skarv i området. Alle de observerede fugle anvender Wave Dragon som rasteplads og som fourageringsplads. Som kuriosum kan det nævnes at en måge har bygget rede og lagt æg oven på containeren, se figur 10.1. Ternerne afsøger området umiddelbart omkring strukturen for føde. Mågerne benytter strukturen som rasteplads under fouragering i området og efterlader mængder af afbidte silde og eller brislingehoveder.

Figur 10.1 Mågerede anbragt i el-kabler.

Området benyttes også som rasteområde af mågefuglene. I testperioden har det ikke været muligt at observere, at tilstedeværelsen af Wave Dragon skulle have ændret deres adfærd. Flokke af mågefugle slår sig således lige så hyppigt ned i vandet mellem Wave Dragon og kysten som andre steder i nærområdet (nord for Helligsø teglværk og mod syd ned mod Røjensø Odde.

Figur 10.2 Andefugle (Common Merganser og Common Goldeneye) som er beskyttet i området /24/.

Ved besøg på stedet er aldrig observeret andefugle, som kunne være følsomme for støj og menneskelig aktivitet. Lokale fiskere fortæller, at de pågældende andefugle ikke heller er observeret på lokaliteter forud for placeringen af Wave Dragon.

I umiddelbar nærhed af Wave Dragon har vi flere gange observeret en sæl.

Figur 10.3 Reflektorarm med begroning af blåmuslinger placeret på havnen i Thyborøn december 2004.

Stålkonstruktionen er tæt besat med et 10-20 cm tykt lag af blåmuslinger, se figur 10.3.

3 af udløbs tragtene fra turbinerne er behandlet med en speciel ”non toxic anti fouling” maling udviklet af Hempel. Disse 3 udløbstragte havde praktisk taget ingen begroning, og den begroning, der var, kunne fjernes med et stykke stift plast.

Figur 10.4 Udløbstragte med og uden begroning.

En enkelt udløbs tragt var udført i rustfrit stål. På dennes overflade var der ingen begroning, men et tyndt lag kalk. Årsagen hertil er formodentligt, at det rustfri stål sammen med den øvrige stålkonstruktion har danne et korrosionselement, hvorved der er udskilt kalk.

Dag for dag tilsyn.

Der var ikke i planlægningen og budgettet forudsat en daglig overvågning ud over, hvad der kunne foregå ved anvendelse af de monterede web kameraer. Der var truffet aftale med *Nordisk Folkecentret for Vedvarende Energi* om at Bendy Poulsen kunne indgå i en tilkaldevagt. Bendy Poulsen skulle samtidigt fungere som kontaktperson til håndværkere i forbindelse med mindre udbedringer.

Erfaringen har vist os, at et sådant tilsyn er nødvendigt, selv om overvågningen foregår via web kamera og PC-er. Men systemet med tilkaldevagt kan ikke anbefales. Dels har der været større behov for fysisk tilstedeværelse en forudset, hvorved en tilkaldeordning, er blevet meget kostbar i forhold til en mere fast aflønning. Dels fungerer en tilkaldeordning ikke optimalt, da vi flere gange har oplevet, at måtte udskyde reparationer fra tidspunkter, hvor der var et vejrvindue, der tillod arbejde på Wave Dragon, men hvor tilkaldevagten var optaget af andre gøremål. Med de få dage, der ofte er til rådighed med godt vejr, er det vigtigt at kunne disponere over arbejdskraften med kort varsel, således at det bliver vejrvinduet, der bestemmer tidspunktet for reparation og ikke personens anden arbejdsfunktion.

Figur 10.5 Landgang fra stranden ud for Prøvestationen.

Ved Prøvestationen er det nødvendigt ved pålandsvind at starte fra strandbredden i en gummibåd, hvorfor det har været ekstra vanskeligt at komme ud til Wave Dragon, selv om forholdene på Wave Dragon har tilladt besigtigelse. Adgangsforholdene til Wave Dragon foregår således uden problemer, da bagsiden ligger i læ af bølgerne. Landgang fra Prøvestationens pier er vanskeligere i pålandsvind end direkte fra stranden på grund af bølgegang. Det har således været landgang fra stranden, der har været den kritiske faktor.

11 Forsikring

Markedet for forsikring har været meget usikkert siden 11. september 2001. En række uheld med kabler på de første offshore vindmølleparker har yderligere givet problemer med at opnå reassurance.

Det var derfor meget tidskrævende og i lange tider usikkert, om der overhovedet kunne opnås forsikringsdækning af Wave Dragon efter udlægningen i Nissum Bredning.

Trods dette lykkedes det i første omgang at opnå en favorabel forsikringsaftale gennem mæglerfirmaet *AON Denmark* med *IF Forsikring*. Der blev indgået en kaskoforsikring med en dækning på 8 mil. kr. med en årlig præmie på 50.000 kr. og en ansvarsforsikring i henhold til sølovens regler, dog maks. 7,5 mio. kr., med en årlig præmie på 7.000 kr.

Forsikringen kom i brug umiddelbart efter etableringen i Nissum Bredning, idet der uden forvarsel i weekenden efter samlingen den 28. marts 2003 opstod en lokal storm med vindhastigheder på 20-25 m/sek /4/. Skaderne beløb sig inklusiv udbedring til 364.779 kr. Forsikringen dækkede alle eksterne omkostninger (242.757 kr. minus selvrisiko på 50.000 kr.), mens egne omkostninger afhold af SPOK, Löwenmark, Promecon og Aalborg Universitet imidlertid ikke blev dækket (242.757kr.). Efterfølgende måtte vi konstatere, at vi havde været bedre stillet, hvis vi havde anmodet fremmet arbejdskraft om assistance,

Efter 1 år blev forsikringen opsagt, da *IF Forsikring* ikke længere ønskede at være aktive inden for dette forsikringsområde.

Ud over AON Denmark søgte vi at få etableret en forsikring gennem et par engelske forsikringsmæglere. Tilbuddene var imidlertid af en størrelsesorden, hvor vi ikke havde mulighed for at betale, ligesom vi også fandt dem prohibitive i forhold til værdien af Wave Dragon.

Det aftaltes derfor, at ejerskabet af Wave Dragon overgik til Aalborg Universitet allerede pr. 1. april 2004, hvorved forsikringen blev overtaget af universitetet. Overtagelsen af Wave Dragon før oprindeligt planlagt (udgangen af projektperioden) havde endvidere den fordel, at det var muligt for Laboratoriet at opnå ekstra bevillinger til internt brug i projektet.

Det vurderes, at forsikringsforhold er et område, der bør påkalde sig bevågenhed, da mangel på ”fornuftig forsikring” kan forhindre den videre udvikling af anlæg i retning til fuld skala.

12 Tidsplan

Den realiserede tidsplan blev forsinket i alt 9 måneder. Der er som der fremgår af nedenstående flere årsager hertil, men det gennemgående tema er, at det koster tid (og ingeniør timer), hvis man ikke har penge nok og bliver nødt til at gennemføre besparelser.

Nærværende projekt skulle have være afsluttet pr. 31. marts 2004, men er først afsluttet med udgangen af 2004. I forbindelse med analyser af det indsamlede datamateriale måtte vi konstatere, at der med udgangen af marts 2004 ikke var tilstrækkeligt grundlag for at præsentere andet end foreløbige resultater, hvorfor projektafslutning i samråd med Energistyrelsen blev besluttet udskudt til 1. oktober 2004, således at endelig rapport skulle afleveres senest 30. november 2004.

Projektets forlængede placering ved Prøvestationen nødvendiggjorde en forlængelse af tilladelsen /25/ til placeringen på dette sted /13/. Forsinkelsen foranlediget af stormen den 8. januar 2005 har krævet en fornyet høring, hvorefter der er er opnået en tilladelse frem til udgangen af 2006 /27/.

En række følgeskader efter uheldet ved etableringen i Nissum Bredning /4/ betød, at projektet blev finansielt nødlidende, hvorfor der i foråret 2004 blev fremsendt en ansøgning om ekstrafinansiering til Energistyrelsen, primært vedr. følgende punkter:

- Etablering af et automatisk brandslukningsanlæg i kontrolrummet (forsikringskrav).
- Etablering af større flydestabilitet for såvel platform og arme. Dette kan opnås ved at erstatte vandballast med letbeton udstøbt i bunden af de vandtætte rum i armene og på platformens dæk.
- Udbedring af skader på kabler, reflektorer og platform.
- Renovering af den laboratorietestede sifon turbine, der også skal anvendes i de planlagte forsøg på test site 2, idet turbinen har taget væsentlig skade på grund af korrosion.

Manglende tilsagn om ekstra finansiering betød, at renoveringen ikke kunne iværksættes før i efteråret 2004 med støtte fra PSO. Afslutningen af projektet kunne derfor først gennemføres med udgangen af år 2004.

Uheldet i forbindelse med stormen den 8. januar 2005 betød et voldsomt afbræk i arbejdet med færdiggørelse af rapporten, der derfor først foreligger nu, oktober 2005.

13 Formidling

Wave Dragon er det første offshore baserede bølgekraftanlæg, der er sluttet til el-nettet. Samtidigt er det et af de få offshore bølgekraftanlæg af en væsentlig fysisk størrelse, der har været udsat for afprøvning i havet. Der har derfor været meget stor medie interesse om anlægget dels fra fagpresse og dels fra offentligheden i almindelighed. Dette afsnit resumerer den omtale, der har været om Wave Dragon.

Der er afholdt følgende foredrag frem til udgangen af 2004:
- Renewable Power Associations konference om bølge- og tidevandsenergianlæg i Newcastle, juli 2003, præsentation v. Hans Chr. Sørensen, SPOK
- 5. internationale bølgeenergikonference i Cork, Irland, september 2003, to indlæg v. Lars Kjeld Hansen og Hans Chr. Sørensen, SPOK
- WATTS 2004, London (England), *Wave Dragon, Operating experience and progress towards commercialization,* marts 2004, præsentation v. Lars Christensen, SPOK,
- European Commission Renewables Research Programme Press Event, Almeria (Spanien) The EC Wave Dragon Project, marts 2004 v. Hans Chr. Sørensen, SPOK
- All-Energy Opportunities conference, Aberdeen (Skotland), maj 2004, *Wave Dragon experience from offshore deployment,* præsentation v. Hans Chr. Sørensen, SPOK
- ISOPE konference, Toulon (Frankrig), maj 2004, *Overtopping Measurements on the Wave Dragon Nissum Bredning Prototype,* præsentation v. P. Frigaard, Aalborg Universitet
- Hidroenergia 2004 konference, Falkenberg (Sverige), juni 2004 *Wave Dragon. Wave power plant using low-head turbines* v. P. Frigaard, Aalborg Universitet
- Selskabet for grøn teknologi/IDA, juni 2004, *Wave Dragon*, v. Hans Chr. Sørensen, SPOK

Der er udarbejdet følgende publikationer/artikler:
- Aktuel Naturvidenskab, nr. 2 2004: '*Wave Dragon – bølger i stikkontakten*' af Jens-Peter Kofoed et al.
- International Water Power and Dam Construction, May 2004: '*Danish Dragon',* af Lars Christensen et al.
- 19. World Energy Conference, artikel og plakat
- PSO/EFP informationsmøde august 2004 plakat

Se i øvrigt listen over referencer.

Wave Dragon er af andre blevet præsenteret i følgende større artikler/programmer:
- Kraft Journalen, nr. 3 2004: *'Bølgekraftværker er en realitet'*
- Umweltjournal, marts 2004, *'Effektiver Einsatz alternativer Energien'*
- Tek-Nat Videnskabet, nr. 18 2004, Aalborg Universitet: *'Drage i stedet for olie'.*
- Die Welt 28. maj 2004: *'Die ersten Wellenkraftwerke liefern jetzt Strom*'
- WDR5 Leonardo – Wissenshaft und mehr, 17. juni 2004: *'Der Wellen fressende Drache Wave Dragon produziert aus der Energie der Meereswellen*'
- Den seriøse tysk-franske kanal "Arte" den 9. september 2003. Udsendelsen blev gentaget den 6. oktober på den verdensomspændende, tysksprogede tv-kanal DW-World.de, der sender til hoteller etc., og præsenterer projektet i en særudsendelse.
- Den tyske tv-kanal PRO7 har haft et tv-hold med ved installationen af turbiner og vil sende en udsendelse herom senere på året.
- Loke film har filmet ved installationen af generatorer i november 2003.

Hertil kommer en række interview til dagspressen.

14 Samkøring med EU/PSO projektet

Som følge af forsinkelsen af produktionen af Wave Dragon rapporteret i fase A rapporten /4/ opstod en situation, hvor det blev besluttet, at samkøre aktiviteterne med EU/PSO projektet, der var planlagt at skulle følge umiddelbart efter nærværende projekt.

Det åbnede mulighed for at opnå rationaliseringsfordele ved at måleudstyr og ledninger til instrumentering kunne placeres i tilknytning til produktionen af Wave Dragon.

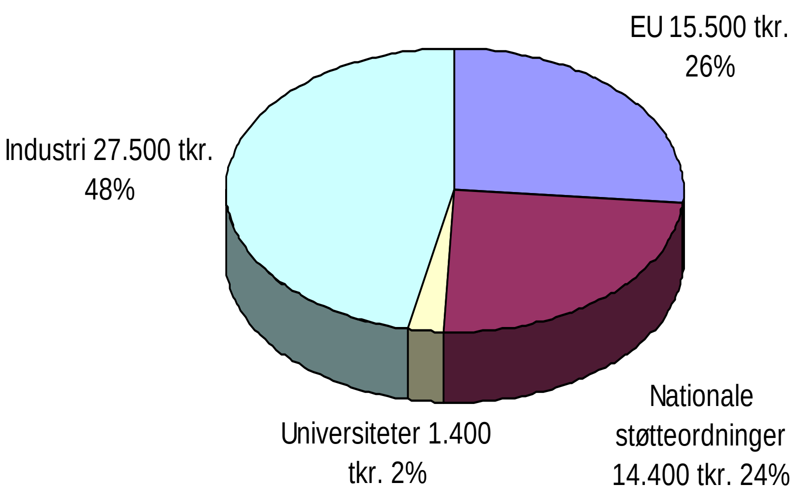
Bilagsrapporterne til denne rapport er derfor ofte integrerede rapporter, hvor der ikke er skelnet skarpt mellem de forskellige projekters specifikke formål.

15 Økonomisk oversigt

Tabel 15.1 Budget og regnskab Fase B.

	Totale omkostninger antal timer		
Løn + overhead	4.725	kr.	2.864.547
Indkøb og installation af hydrauliske spil, turbine (modificering), trykluftssystem m.v.		kr.	110.000
Måleudstyr (Accelerometre, tryktransducere, strain gauges m.v.		kr.	200.000
Rejser		kr.	176.000
Udgifter til trykning, foto, video m.v.		kr.	54.000
Forsikring		kr.	50.000
Ialt		**kr.**	**3.454.547**
Heraf tilskud (64% jvf. tilsagsbrev)		kr.	2.214.000

Hertil kommer en ekstra bevilling på 710.000 kr. bevilget via PSO som udvidet medfinansieringen af EU/PSO projektet.
De reelle omkostninger har langt overskredet disse beløb. Der henvises til den økonomiske afrapportering.



Plus betydelige bidrag fra leverandører, samt leverancer til kostpris, f.eks.
- ✓ **Danfoss**
- ✓ **Hempel**
- ✓ **Siemens**
- ✓ **Flygt**
- ✓ **HydroCables**

Industri: SPOK ApS (DK) - Löwenmark F.R.I (DK) - Promecon A/S (MT Hojgaard AS) (DK) - Balslev A/S (DK) - NIRAS AS (DK) - Armstrong Technology Associates Ltd. (UK) - VeteranKraft AB (S) - Nöhrlind Ltd (UK) - Kössler Ges.m.b.H. (A) - ESBI Engineering Ltd. (IE) - Wave Energy Centre (PT)

Figur 15.1 Finansiering af forskning og udvikling samt prototype test af Wave Dragon bølgeenergi teknologien fra 1998 til 2004.

16 Referencer

/1/ Ansøgning til Energistyrelsen, maj 2001

/2/ Tillæg til Ansøgning til Energistyrelsen, 11. september 2001

/3/ Tillæg til Ansøgning til Energistyrelsen om faseopdeling 16. december 2002

/4/ Sørensen, H.C., Christensen, L. & Friis-Madsen, E., 2003. *'Wave Dragon 1:4.5 – Design, produktion og etablering i Nissum Bredning'*. Rapport fase A af ENS projekt 51191/01-0033, København.

/5/ Kofoed, J.P. 2003, *Statusrapport – Instrumentering af Wave Dragon, Nissum Bredning'*, Aalborg Universitet, Aalborg.

/6/ Kofoed, J.P., Riemann, S. & Knapp, W. 2004, '*Calibration and Validation of Measurement Syste Wave Dragon, Nissum Bredning'*. Aalborg Universitet, Aalborg.

/7/ Hald, T. and Frigaard, P. 2001. '*Forces and Overtopping on 2. Generation WD for Nissum Bredning*'. Phase 3 project, Danish Energy Agency. Project No. ENS-51191/00-0067. Dep. of Civil Eng., Aalborg University, Denmark.

/8/ EMU et al. 2001. *'Low-pressure hydro turbines and control equipment for wave energy converters (Wave Dragon)'*, publishable final report Joule-Craft JOR3-CT98-7027, Copenhagen, Denmark.

/9/ Soerensen, H.C. et al. 2003. '*Development of Wave Dragon from Scale 1:50 to prototype*'. The Fifth European Wave Energy Conference, Cork, Ireland.

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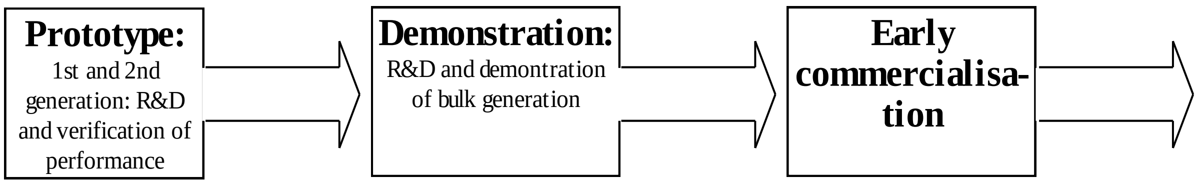
Bilag 1 Forretningsmæssigt udviklingsforløb

Perspektiver for videreudvikling af Wave Dragon

FORTROLIG

1. FORRETNINGSMÆSSIGT UDVIKLINGSFORLØB

En forretningsmæssig udvikling af Wave Dragon teknologien vil efter en succesfuld test og udvikling af 1. og 2. prototypen i Nissum Bredning omfatte en, formodentlig to, demonstrations enheder i fuld produktionsstørrelse førend en egentlig kommerciel udnyttelse af teknologien kan finde sted. Prototype forsøgene skal fungere som verifikation af energiproduktionspotentialet, som platform for en løbende udvikling af systemerne og endelig som demonstration af teknologiens overlevelsesmuligheder. I demonstrationsfasen forsættes produktudviklingen samtidig med at der sker en kontinuerlig produktion af el.



Wave Dragon er i dag den offshore bølgeenergiteknologi der har den uovertrufne længste track record, 15.600 timer i søen. 1.generations prototype test er gennemført og planerne for 2. generations prototype test er udarbejdet og parat til at blive iværksat. Samtidig er planlægningen af multi MW demonstrationsanlæg i fuld gang (da den er meget tidskrævende). I øjeblikket udføres der site feasibility og site planlægning for hhv. projekt i syd vest Wales og i den danske del af Nordsøen.

2. UDVIKLINGSMÆSSIGE INDSATSOMRÅDER

En succesfuld udvikling af en bølgeenergiteknologi kræver udover miljømæssig bæredygtighed, at det kan vises eller sandsynliggøres, at teknologien er teknisk levedygtig og kan overleve de ekstreme forhold den skal fungere under. Teknologien skal samtidig demonstrere, at der kan produceres el til en fornuftig pris ved introduktionen af teknologien og at prisen på sigt kan forvente, at nå et leje, hvor den er sammenlignelig med andre vedvarende energi kilder. Der udover overses det ofte, at det er vigtigt i sig selv, at være først på markedet med en teknologi (hvis den virker) og at teknologien skal rumme signifikante muligheder for en fortsat effektivisering (sml. udvikling i vindmølle sektoren).

Time-to-market
Der foregår i øjeblikket en accelereret udvikling af flere forskellige bølgeenergiteknologier, og da de første teknologier, der når en succesfuld introduktion på markedet, sandsynligvis vil sætte standarden for markedet (som den 3 vingede danske mølle gjorde det på vindmøllemarkedet), er det af overordentlig stor betydning at gennemløbe prototype og demonstrationsfaserne hurtigst muligt, hvilket i praksis betyder at det er vigtigt, at igangsætte planlægnings- og designfaser for demonstrations anlæg førend forrige fase er tilendebragt.

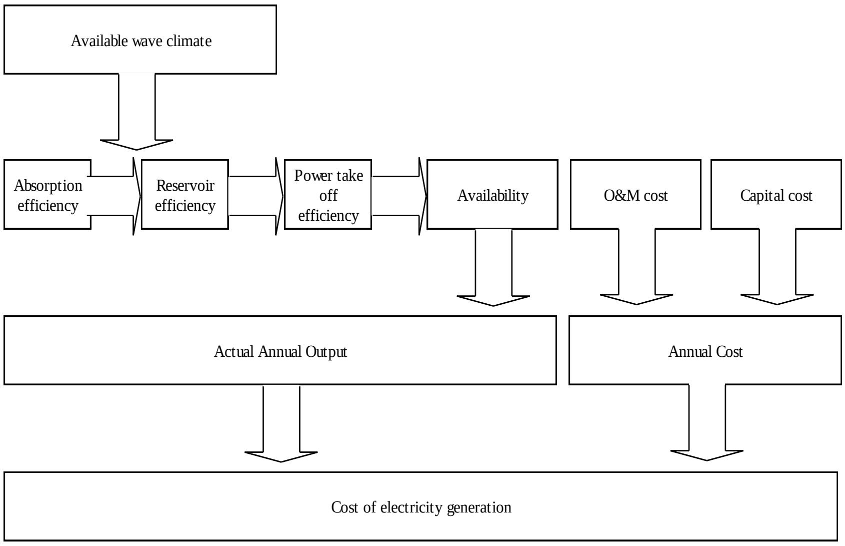
Teknisk levedygtighed
Den tekniske levedygtighed kan i vid udstrækning evalueres ved formaliserede ”risk accessment analyser” samt ved standardisering af udviklingsprocessen og produktet efter

anerkendte normer mv., Men en endelig verifikation kræver naturligvis at teknologien demonstreres over en længere periode i dets naturlige miljø. I forhold til konkurrerende teknologier har anlæg af overskylstypen (som Wave Dragon) en række fordele, idet de i kraft af deres størrelse kan bære en relativt højere investering i forankringssystemer, og da de ikke er afhængig af at energien skal absorberes via store bevægelser af anlægsdele.

Wave Dragon har allerede vist, at den kan overleve og fungere i et offshore miljø gennem længere tid.

Økonomisk levedygtighed

Vurderingen af Wave Dragons økonomiske levedygtighed sker på grundlag af den forventede omkostning ved at producere el, dvs. kr./kWh, baseret på nedenstående (traditionelle) metodologi:



Forud for prototype forsøgene viste feasibility studierne at en 4MW Wave Dragon enhed i et 24kW/m bølgeklima ville koste 85 mio. kr. ved introduktion på markedet, når enheden blev produceret én ad gangen. Med forventede O&M omkostninger på mellem 900.000 og 1.800.00 kr pr. år pr. anlæg ville kost prisen for en kWh være 11c€/kWh eller 75 øre pr kW/h. Feasibility studierne viste endvidere, at en kWh pris på 4 c€ ville kunne opnås på længere sigt i et 36kW/m bølgeklima.

Forventet el produktion

Prototype forsøgene i Nissum Bredning skal verificere den forventede årsproduktion fra en Wave Dragon. Aalborg Universitets studier af Wave Dragons overskyl – dvs. evne til at absorbere bølgeenergi – vedrører første led i denne energi omsætnings kæde. Studierne har vist, at prototypen har en overskylskarakteristika som forudsat i feasibility studierne, og at væsentlige forbedringer kan opnås ved at forbedre kontrolsystemerne.

De senere forsøg med prototypen skal verificere de to efterfølgende led i kæden, ”reservoir efficiency” og Power-Take-Off efficiency”.

Anlæggets availability testes ikke som sådan i de igangværende prototype forsøg, forstået på den måde, at det ikke er et mål i sig selv, at teste el-produktion i længere perioder. Derimod er der gennemført et teoretisk studie af teknologiens availability under det engelske ”Marine Energy Challenge Programme”, hvor en teoretisk model er blevet opbygget, og forskellige simuleringer af teknologien baseret på erfaringerne i offshore olie- og gasindustrien, er gennemført. Disse modeller viser en availability på 97,5%. I vores feasibility beregninger benyttes 95%.

På nuværende tidspunkt understøtter test resultater og teoretiske studier de el-produktionspotentialer, der indgår i feasibility studierne for Wave Dragon.

Bølgeklima

Feasibility studierne af Wave Dragon var oprindeligt baseret på et 24 kW/m reference bølgeklima svarende til den maksimale værdi i Nordsøen. Det er vigtigt at forstå, at Wave Dragon skal bygges som en meget stor enhed for at forblive så ubevægelig i vandet som muligt. Den størrelse og geometri Wave Dragon er testet i forhold til, skal opfattes som en minimums størrelse i forhold det givne bølgeklima (i det aktuelle tilfælde 24kW/m), og i praksis er det alene omkostningerne, der sætter grænse for, hvor stor Wave Dragon kan bygges.

Forventede omkostninger

Omkostningerne ved at bygge og drive et Wave Dragon anlæg er i sagens natur ikke blevet "testet" endnu og baserer sig derfor på beregninger, enten indhentede tilbud (anlægsomkostninger samt drift og vedligehold) eller simuleringer (drift og vedligehold).

Anlægsomkostninger

Omkostningerne ved at konstruere Wave Dragon anlæg er blevet estimeret i to omgange. Første gang i forbindelse med det oprindelige Wave Dragon feasibility studie. Dengang nåede man i samarbejde med de industrielle partnere frem til en pris for en Wave Dragon til et 24kW/m bølgeklima på 85 mio. kr. (2001) når de produceres enkeltvis.

Efterfølgende har Halcrow Ltd. i 2004 gennemført et omfattende studie af prisen for en Wave Dragon enhed. De nåede frem til en pris på 87 mio. kr. pr enhed (ex. installation).

Begge anlægspriser er ekskl. omkostninger til detaljeret design. Ved etablering af enkelt anlæg skal denne omkostning (10-15% af et enkelt anlægs pris) tillægges det enkelte anlæg, og tilsvarende spredes ud på alle anlæg ved anlæggelse af en multi-enheds park.

Disse feasibility studier har endvidere vist endog meget store muligheder for omkostningsbesparelser. Allerede ved konstruktion af enkeltstående anlæg kan omkostningerne nedbringes med op til 25% ved at bygge selve strukturen (der udgør 50% af omkostningerne) ved brug af betonelementer og modulær konstruktion. Herudover vil almindelige storskalafordele kunne nedbringe bygge omkostningerne betragteligt i tilfælde af anlæg af større parker.

Enheds anlægsomkostningerne er beregnet til at være ca. 21.000 kr. pr. installeret kW ved introduktion på markedet af et anlæg til 24 kW/m bølgeklima.

Drifts- og vedligeholdelsesomkostninger

Driftsomkostningerne til drift, vedligehold og f.eks. femårige hovedistandsættelse er af Halcrow Ltd blevet beregnet til 1.650.000 kr. pr. år. Beregningen er baseret på en detaljeret system model hvor erfaringerne fra den britiske del af offshore olie og gas industrien. Disse driftsomkostninger omfatter bemandet overvågning, årlige tilsyn og reparationer, uventede tilsyn og reparationer, årlige udskiftninger, femårige hoved eftersyn og omfattende reparationer og udskiftninger.

kWh pris

Gennemføres der beregninger af den forventede kWh omkostning for højere bølgeklimaer (og dermed større og mere omkostningstunge Wave Dragon enheder) viser de væsentlige lavere elpriser, at Wave Dragon har et væsentlig eksportpotentiale til lande som f.eks. UK, Irland, Frankrig, Portugal, Spanien, Australien og mange flere.

Bølgeklima	Første anlæg	Længere sigt
24 kW/m	11,0 c€/kWh	5,4 c€/kWh
36 kW/m	8,3 c€/kWh	4,0 c€/kWh
48 kW/m	6,1 c€/kWh	3,0 c€/kWh

BILAG 9

AAU, Report on damage in storm 05.01.08: Failure of moorings, drift a shore WD

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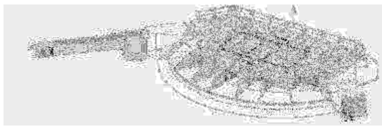

Report on damage in storm 05.01.08: Failure of moorings, drift a shore
-
Wave Dragon, Nissum Bredning

CONFIDENTIAL

Project:

Sea Testing and Optimization of Power Production on a Scale 1:4.5 Test Rig of the Offshore Wave Energy Converter Wave Dragon

according to EU ENERGIE contract no. ENK5-CT-2002-00603

Jens Peter Kofoed, Aalborg University
Erik Friis-Madsen, Lars Christensen and James Tedd, Wave Dragon Aps.

January, 2005

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Wave Dragon ApS

BILAG 10

TUM, Report on the refurbishment of the siphon turbine carried out 10.5. to 15.5.2004

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Wave Dragon:
Report on the refurbishment of the siphon turbine carried out 10.5. to 15.5.2004

Introduction:
The siphon turbine used for turbine development in the laboratory tests has been implemented on the Wave Dragon. The lower half of the turbine had been converted for saltwater use in the laboratory in Munich before it was shipped too Promecon in Aalborg. The top half including the shaft, bearing, and generator support had been redesigned by Matti Sorto and the modifications have been carried out by Promecon.
During a visit in January 2004 it had been found that the turbine did not work any longer. A brief analysis revealed corrosion on the whole generator support and heavy corrosion on the bearing and shaft coupling. A very high frictional torque was found when turning the shaft.

	
generator support 1/2004	bearing and shaft coupling 1/2004

It was also found that the stainless tube used to separate the water from in the evacuation tract had a split at the top, thus preventing proper evacuation of the turbine inlet.
TUM decided to overhaul the whole turbine in order to bring it back into operation.
Based upon the above findings, a number of new components have been designed and manufactured, and a 3 man team (Thomas Siewert, Sven Riemann, Wilfried Knapp) travelled from Munich to Nissum Bredning to carry out the overhaul, assisted by local man Bendy Poulsen. The

operation was finished within 5 days, after which the turbine was re-commissioned and found to work very well.

1. Inspection of turbine, review of the situation

After arrival on the platform (15.5.04) the turbine was thoroughly investigated and dismantled. The turbine shaft was by then almost impossible to turn. In the following, the condition of the different turbine parts is described, the reason for failure or deterioration of the respective component is given.

1.1. generator:
corrosion damage on stator case, saltwater in connection box, windings damp, bearings destroyed by corrosion.
Reasons: lack of protection against sea water spray, very unsuitable orientation (connection box facing the sea!), cable junctions poorly sealed.

1.2. generator support: heavy corrosion on top plate. All fastening bolts heavily corroded.
Reasons: complete lack of painting, use of zinc plated and black steel bolts.

1.3. generator intermediate flange: heavy corrosion. All fastening bolts heavily corroded.
Reasons: complete lack of painting, use of zinc plated and black steel bolts.

1.4. shaft coupling:
heavy corrosion. Coupling wrongly installed, i.e. no axial play at all, thus putting strain on generator and turbine bearing.
Reasons: unsuitable material, wrong installation.

1.5. turbine thrust bearing:
heavy corrosion damage on shaft sleeve and clamping ring, lip seal destroyed, bearing filled with salt water, roller bearings damaged by corrosion.
Reasons: unsuitable materials, poor design of top seal, lack of protection

1.6. bearing spacer: heavily corroded.
Reason: no paint at all.

1.7. turbine shaft:
good condition in view of corrosion, but top end wrongly machined, so that the clamp fit could not be installed properly.
Reason: The analysis has shown that Matti Sorto's drawing for the modification was wrong, and Promecon have executed the machining as per the drawing, not

noticing that about 90% of the clamping area have been machined away. The shaft was obviously fitted without taking notice of this. Probably the loss of the turbine shaft and runner were only prevented by a grub screw in the shaft coupling!

1.8. rubber bearing:
good condition, but water grooves approx. 30% filled with rust particles and dirt.
Reason: too much rust and dirt in lubricating water, too close gap of the labyrinth seal underneath the bearing.

1.9. lubricating water level sensor:
sensor and connector destroyed by corrosion, mounting plate heavily corroded.
Reason: unsuitable material of mounting plate, possibly poorly installed sealing on connector, lack of protection.

1.10. lubricating water pump:
not working, float switch defect.

1.11. inner turbine cone:
fair condition, no serious corrosion

1.12. guide vanes:
good condition

1.13. turbine inlet case: fair condition, no serious corrosion

1.14. turbine runner:
fair condition, slight corrosion on runner blades. Hub cone missing, thus corrosion inside hub.
A closer analysis revealed that Promecon obviously have not bothered to fit the turbine cone at all. They also fitted a normal steel washer to hold the hub instead of a stainless one, which gave corrosion problems.

1.15. draft tube:
good condition, some marine growth (mussles) that were very easy to remove from the stainless steel surface.

1.16. evacuation system:
- butterfly valve o.k.
- operating cylinder: seems defunct (sticking in end positions)
- water separation vessel: crack at top of pipe, loose piping
- evacuation dome (100mm pipe on turbine top): heavily corroded
- level sensor: cable poorly fitted but sensor still o.k.

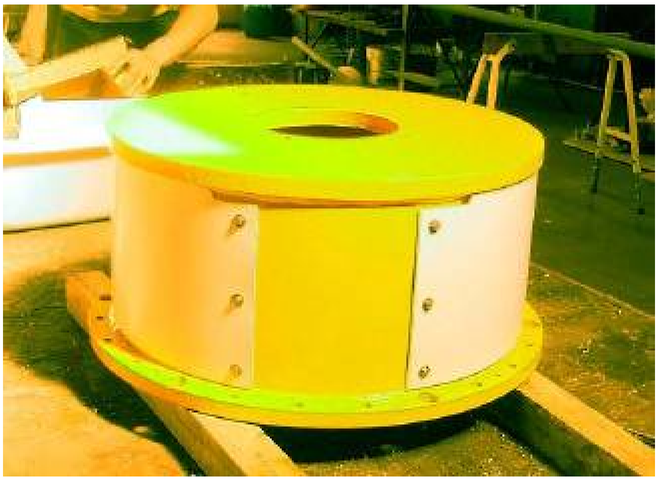
2. Action taken

The turbine was completely dismantled. The damaged parts were repaired or replaced. In the following a description is given how the above mentioned components were treated.

2.1. generator:

the generator was overhauled by the makers at Thyboroen. It was dismantled, the windings oven-dried, reassembled with new seals and bearings and freshly painted. The winding insulation was high-voltage tested and was found to be o.k..

After re-fitting, a removable plastic protection hood was mounted over the generator



2.2. generator support:

sandblasted and painted. The unnecessary apertures were covered with removable plastic shields.

2.3. generator intermediate flange: sandblasted and painted.

2.4. shaft coupling:

A new coupling of stainless steel was machined and fitted.

2.5. turbine thrust bearing:
The thrust bearing has been redesigned with a better arrangement of the lip seal, which is now protected and facing downward. A new bearing top cover, shaft sleeve and lip seal carrier have been machined from seawater-resistant Aluminium bronze.


2.6. The gravity seal in the bottom of the casing was bored out and a new one made from stainless steel was welded in. All the bearings and seals were renewed and the bearing was carefully reassembled using stainless nuts and bolts.

2.7. bearing spacer:
sandblasted and painted.

2.8. turbine shaft:
The turbine shaft was cleaned and the top end re-machined to give a proper shrink fit in the specially made bearing sleeve. A new stainless steel clamp ring was fitted.

2.9. rubber bearing:
the rubber segments were cleaned and refitted. The labyrinth seal was modified to provide an outlet for foreign matter that is brought along with the lubricating water.

2.10. lubricating water level sensor:
A new sensor was fitted on a stainless steel plate. Utmost care was taken in fitting the connector trying to ensure waterproofing. When testing the new sensor it was found to be without power. The corresponding 1A fuse in the switchboard was located and changed.

2.11. lubricating water pump:
The defect (and unnecessary) float switch was removed and the cable end short-circuited.

2.12. inner turbine cone:
reassembled using stainless steel bolts

2.13. guide vanes:
reassembled

2.14. turbine inlet case:
reassembled

2.15. turbine runner:
cleaned and reassembled.
A stainless steel thrust washer was machined and fitted to replace the corroded black steel one. A new hub cone was machined from PVC and was fitted with a stainless draw bolt.

2.16. draft tube:
marine growth (mussels) removed

2.17. evacuation system:

- the defect hydraulic cylinder was removed and the pipes closed.
- a new water separation vessel has been made from stainless steel and was fitted. A substantial bracket to support the end of the 50mm PE pipe was fabricated and fitted.
- the non-return valve was cleaned and refitted between stainless flanges to ensure reliable operation
- the connector of the level sensor was re-fitted and sealed.

3. Start-up of the refurbished turbine

After assembly, the turbine was tested. The hydraulic cylinder for operating the aeration valve was not yet replaced, thus the valve had to be operated manually.
After evacuating the inlet, the turbine turned only very slowly. This was tracked down to a logical problem in the SCADA system: As the aeration valve was closed manually, it remained logically open in the SCADA system, which seems to keep the generator short-circuited. After changing the logical value, the turbine operated normally.
A number of braking curves at different head values were measured, which still need to be evaluated. The turbine delivered 1060W at a pressure head of approx. 68cm, which was considered a very satisfactory efficiency.

4. Remaining to-do's

This section applies only to the siphon turbine and to general issues, the cylinder gate turbines will be dealt with in a separate report.

- the hydraulic cylinder for the aeration valve needs to be refitted, connected and properly adjusted.
- A number of aeration holes need to be drilled in the generator hood. We suggest to drill two 30mm holes on the side facing the Container and two more near the top of the bucket. A tool for boring these holes has been bought and is in the container (yellow plastic case), unfortunately we could not drill the holes on the last day due to the heavy sea conditions. THE TURBINE MAY NOT BE OPERATED FOR ANY LONGER PERIOD (more than 10 mins) BEFORE THIS MODIFICATION HAS BEEN CARRIED OUT.
- The logical implementation of the lubrication water level sensor needs no be modified: It The pump and turbine must be governed in the following way:
  The pump is started together with the evacuation blower when the turbine is required to start. The generator must stay short-circuited until the water level is up to the sensor. If this does not happen within a timeout period of 1 min, the turbine start must be cancelled and an alarm logged. If a low level occurs during turbine operation, the turbine must be shut down immediately (Aeration valve opened) and an alarm must be logged. THE TURBINE MAY NOT BE OPERATED REMOTELY BEFORE THIS MODIFICATION HAS BEEN CARRIED OUT.
- It would be strongly advisable to update (or make available) the documentation of the switchboard cabinets. At the moment it is criminological work to find out where a generator is connected or where a fuse for a certain component is. By the way, we used the last spare 1 Amp 5x20mm fuse, so it would be as well to provide a few more of these.
- It would also be strongly advisable to re-install a new tool board, as the fire extinguisher is now taking up almost all of the space where the tools had been. These are now all thrown into a big bucket…
- The end stop sensors on all of the dummy turbine cylinders seem defunct and need to be repaired.
- The dummy turbine nearest to the ladder still needs to be modified like the two other ones, i.e. changing the position of the upper cylinder yoke as it does not close completely any more.

28.05.2004

Wilfried Knapp

BILAG 11

TUM, Report on the condition of the cylinder gate turbines after the stranding of the Wave Dragon

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Report on the condition of the cylinder gate turbines after the stranding of the WD

0. Summary

On January 8, 2005, the WD was stranded on the beach due to a main mooring connection being broken in a severe storm. The turbine draft tubes are protruding below the bottom of the platform by 510mm, and are thus the lowest point of the whole device to hit the ground. The draft tubes are directly attached to the turbine discharge ring which surrounds the runner. For this reason, a damage not only the draft tubes had to be considered, but also a deformation of the discharge rings and the runners. Also further damage was likely to occur during the recovery of the platform, when it was to be tugged off the shore.

It was thus decided to remove all 6 turbines from the platform while it was at shore and to bring the turbines to the Folkecenter workshop where they could be inspected and repaired.

The inspection showed that the damages were by far not as severe as expected. Obviously the ground at the location of the stranding was rather soft, consisting of sand and gravel, without any rocks. The draft tubes were found only slightly deformed at their lower ends. The turbines had no mechanical damages, but have suffered from being flooded. It was decided to inspect and service the bearings of the turbines No. 2, 4 and 5, which had already been modified in the autumn of 2004, and to use the opportunity to rebuild and modify the turbines no. 4, 6 and 7 while they are on shore. Furthermore it was decided to shorten the draft tubes so they do not protrude below the platform any more.

1. Inspection on board, removal of the turbines

After arrival on the platform (24.1.05) we had a look at all cylinder gate turbines. The runners of 5 turbines seemed to turn almost freely, only turbine no. 3 was stuck.

On the siphon turbine, a stainless steel cover was found dented by the force of the waves.

The hydraulic pipes and cable connections were disconnected. First of all, all the bolt connections to the deck were carefully loosened. During this operation it was (luckily) found, that there was no strain on these joints, which could have happened if the platform had been standing on the draft tube ends.


To hoist the turbines from deck, a 19m/ton crane lorry was ordered. In order to get the lorry near enough to the platform, a ramp had to be built for the lorry. All the turbines were removed from the platform by first loosening the bolt connections to the deck, then lifting the turbine about 1 metre, securing the draft tube with steel pipes through their pad eyes above the deck and then parting the draft tube from the turbine. Then turbine and draft tube could me lifted off the platform separately.


The turbines of the starboard group could be lifted as complete units as they were nearer to the lorry, but the turbines of the portside group had to be further dismantled and the cylinder gate had to be lifted off separately as the crane was not able to lift the whole unit at this distance.

The turbines were mounted on specially prepared pallets on the shore and then loaded onto the lorry, which brought them to the Folkecenter workshop.

2. Inspection of the turbines

2.1. Draft tubes

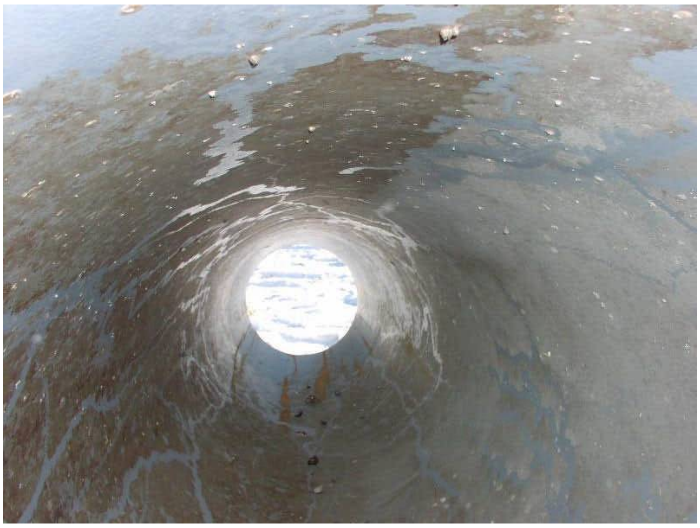
The draft tubes had, obviously due to the soft ground at the location of the stranding, only sustained minor damages, which are given in Tab. 3.1 and the following picture.

The daft tubes painted with the normal epoxy paint system were found heavily overgrown with marine growth; the layer being about 2 cm thick at the upper end and growing to 7 cm at the lower end. The tubes painted with the Hempel anti-fouling paint were found almost clean, with only a few mussels stuck to them that could easily be removed by hand. Interestingly this applies also to turbine No. 3, which had not been run at all up to now. The pictures below show an epoxy painted and a Hempel painted draft tube in comparison. The growth has already collapsed a bit as the pictures were taken after leaving the tubes out in the winter weather for one day.

Turbine No.	draft tube material	size of damages (in cm)			growth
		width	height	depth	
2	steel, Hempel	-	-	-	very little
3	steel, Hempel	-	-	-	very little
4	steel, Hempel	8	2	+1	very little
5	stainless steel	16 14	7 6	-4 -3	very little; some lime scale
6	steel, epoxy paint	-	-	-	heavy
7	steel, epoxy paint	15 8	6 5	-1 -3	heavy

table 3.1. condition/damages of draft tubes

draft tube with conventional epoxy paint



draft tube with Hempel anti-fouling paint

2.2. turbines

The turbines were investigated concerning accident damages and general condition. In the case of the already rebuilt turbines no. 2,4 and 5 this task was straightforward as all the critical components could be accessed after removing the inspection covers. With turbines no 3, 6 and 7 the cylinder gates had to be removed to gain access to the shaft and bearings.

2.2.1. turbines no. 2, 4 and 5:

These turbines had already been rebuilt during the summer 2004. The runners and discharge rings were found in good condition, without any damages. The thrust bearing assemblies looked as if they had been flooded with salt water for some time. This might have happened while the Wave Dragon was on the drift as some of the turbines were still open when the cable connection was lost, and the platform has probably got heavily flooded during the storm.

These turbines were not yet dismantled. A decision on this will have to be taken at the next visit. On turbine no. 5 it will probably suffice to change the bearing oil, but on no. 2 and 4 it might be wise to replace the ball bearing, which will necessitate taking out the generator and the turbine shaft.

thrust bearing assembly turbine no. 2

thrust bearing assembly turbine no. 5

The radial (rubber) bearings seemed to be in good condition. The space around them contained clean water, with only very little sand.

rubber bearing assembly turbine no. 4

rubber bearing assembly turbine no. 5

2.2.2. turbines no. 3, 6 and 7:

These turbines had not been used, as they had not yet been modified and rebuilt, due to reasons of cost. However, with the turbines being on shore now, it was decided to rebuild them as well, as this can be done relatively easily in a workshop, at least compared to work out on the sea.

The bearing conversion to a grease lubricated bearing on turbine 2 and 4 was mainly done because a solution allowing for a quick change out on the sea was required when these turbines were rebuilt. For turbines 3, 6, and 7 it was decided to rebuild and modify the original oil filled bearing, as this time this could be prepared with plenty of time in the TUM workshop. Thus turbines no. 3 and 7 were dismantled to take the bearings to Munich for repair, together with the bearings that had been taken out of turbine no. 2 and 4 earlier in the year.

In dismantling, no damages due to the stranding have been found, but the corrosion damages to the thrust bearings and generator and sand filling to the radial bearing were as expected.

thrust bearing assembly turbine no. 3

rubber bearing assembly turbine no. 3

The thrust bearings were almost completely destroyed by corrosion, and contained only about 100cc of oil/water mixture as lubricant. The radial bearings were completely filled with sand. The discharge ring and guide vanes were in good condition, but the runner, especially in case of turbine no. 7, was rather overgrown with small shells. We think this is mainly due to the fact that the turbine has never been operated while being in the sea for about 15 months.

discharge ring and guide vanes turbine no. 7

runner turbine no. 5

The generators were found salt encrusted and corroded. They will be opened, cleaned and sealed before re-installation. The turbines have been completely dismantled and will be stored, together with the other turbines, at the Folkecenter until re-assembly.

generator turbine no. 7

dismantled components turbines no. 3 + 7

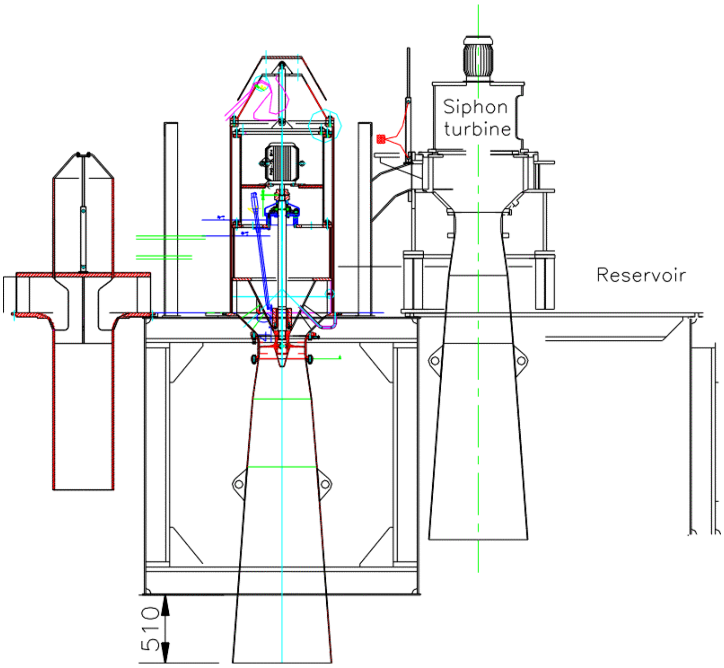
Turbine no. 6 has not been dismantled yet, but it is assumed that it will be found in the same condition.

4. Further to-do's

4.1. draft tubes

Due to time constraints, the turbines will have to be installed back onto the platform before the new shoulder joints will be implemented. In dragging he hull up the ramp at the Agger shipyard, the draft tubes protruding from the bottom of the hull will be obstructive. There is also a substantial risk of damaging the turbines if it cannot be assured that the draft tube ends will always be clear of the ground during all slipping and towing operations. It was thus investigated how far the draft tubes need to be shortened to make them stand back behind the bottom of the hull, and what the effect on the turbine performance is.

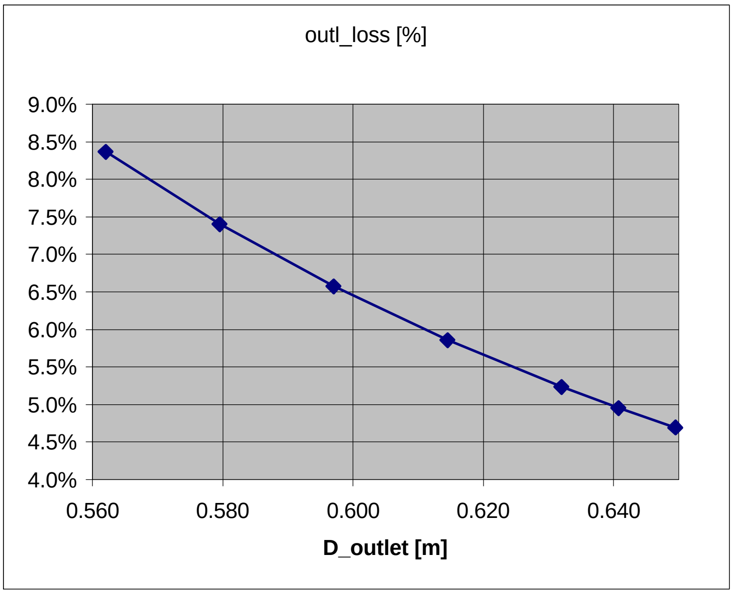
bottom view of platform without turbines



situation of cylinder gate turbine draft tubes

From the above drawing the draft tubes need to be shortened by 550mm. The decrease of turbine efficiency resulting from the shortening of the draft tubes is shown in the following tabulation. The calculation is based on the assumption of a uniform velocity distribution in the draft tube outlet and an exit loss factor of 1.0.

shortening [m]	D_outl [m]	outl_loss [%]
0.00	0.737	2.8%
0.10	0.720	3.1%
0.20	0.702	3.4%
0.30	0.685	3.8%
0.40	0.667	4.2%
0.50	0.650	4.7%
0.55	0.641	5.0%
0.60	0.632	5.2%
0.70	0.615	5.9%
0.80	0.597	6.6%
0.90	0.580	7.4%
1.00	0.562	8.4%



When the draft tube is shortened by 550mm, the exit losses will increase from 2.8% to 5%, thus a reduction in turbine efficiency of 2.2% must be expected. This seems well justified in consideration of the risks of damage that can thus be avoided.

Furthermore the draft tubes treated with the conventional epoxy paint will have to be sandblasted and treated with the Hempel paint system.
Shortening and re-painting the draft tubes is a job that needs to be started as soon as possible!

4.2. turbines

The thrust bearing assemblies of turbines no. 3, 6 and 7 are at the present time being modified and rebuilt at the TUM workshop. It is planned to reassemble the turbines by end of March 2005.

4.3. generators

The generators of turbines no. 3 and 7 need to be dismantled, dried, cleaned and re-assembled, making sure that all joints are well sealed.

The generator of turbine no. 6 is at the present time being shipped to TUM. It will be investigated on a motor test rig to identify its characteristics, mainly the efficiency, which is unfortunately completely unknown up to now.

4.4. generator control

TUM is at the present time trying to identify the reasons for the generator control problems in co-operation with Armin Solies, DEIF. Two alternative ways of solving the problem are being evaluated at the time being:

A.) Trying to make the current control system work. This only makes sense if the following prerequisites are met:

* The original data specification of the PMG's, including efficiency and idle voltage constant must be known.
* The PMG must have been tested and must have performed reasonable well and stable. Its performance characteristics must have been identified.
* A general agreement needs to be made between the WD co-ordinators and Henning Jensen, DEIF, about the involvement of DEIF in the WD project.

B.) Substituting the PMG's with asynchronous generators.
This has been investigated by TUM, and seems viable. The benefits are a stable efficiency characteristic of the generator, and a much simpler speed control algorithm. At the present time we have no statement from DEIF concerning the re-programming of the inverter for asynchronous generators.

A decision will be made after the tests of the PMG in Munich.

It is of crucial importance that practical work on the inverter system and generator control is started immediately after the reinstallation of the turbines. From the experience made up to now, we absolutely insist on not deploying the WD at test site 2 before this issue is satisfactorily solved.

Munich, 2.03.2005

Wilfried Knapp

BILAG 12

HEMPEL A/S SPECIFICATION SHEET WAVE DRAGON Turbine Tunnels HEMPASIL HEMPASIL NEXUS 27302 & HEMPASIL 77500 påføring på Turbinerør for Wave Dragon, udført af Dan-Coat

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HEMPEL A/S

SPECIFICATION SHEET

SF 10-01 HQ 1

Project: **WAVE DRAGON**
Area: **Turbine Tunnels HEMPASIL**

Surface preparation:

Oil and grease etc. to be removed by emulsion cleaning. Entire area to be (high pressure) fresh water cleaned in order to remove salts and other contaminants. When the surface is dry: Abrasive blasting to minimum Sa 2½ according to ISO 8501-1:1988 with a surface profile corresponding to Rugotest No. 3 BN 11.

Product name (including quality number)	Treated area %	Shade	Shade no.	Film thickness (micron) Wet	Dry	Theoretical spreading rate (m²/ltr)	Application methods Brush	Roller	Spray	Recommended Nozzle orifice	Nozzle pressure
HEMPADUR MULTI-STRENGTH 45751	f/c	Grey	12340	200	150	5.3	X		X	.021"-.023"	250 bar
HEMPADUR MULTI-STRENGTH 45751	f/c	Redbrown	50630	200	150	5.3	X		X	.021"-.023"	250 bar
HEMPASIL NEXUS 37500	f/c	Reddish grey	12430	100	50	10.8	(X)		X	.019"-.021"	175 bar
HEMPASIL SP-EED TIE COAT 27301	f/c	Black	19990	200	100	4.8	(X)		X	.019-.021	150 bar
HEMPASIL SP-EED 87040	f/c	Grey	15150	225	150	4.7				.019"-.021"	150 bar
t/u: touch up	f/c: full coat	Total d.f.t.			600		X: Recommended	(X): Possible			

Recoating intervals. Ample ventilation Hrs=Hour(s) Mth=Month(s) N/R=Not Recommended

Quality no	D.F.T. (micron)	Recoated with quality no	40°C Min.	40°C Max.	30°C Min.	30°C Max.	20°C Min.	20°C Max.	10°C Min.	10°C Max.	0°C Min.	0°C Max.	-10°C Min.	-10°C Max.
45751	150	45751	80 Min	9 Day	2 Hrs	15 Day	4 Hrs	30 Day	11 Hrs	75 Day	N/R	N/R	N/R	N/R
45751	150	37500	75 Min	9 Day	2 Hrs	15 Day	4 Hrs	30 Day	10 Hrs	75 Day	N/R	N/R	N/R	N/R
37500	50	27301	N/R	N/R	6 Hrs	18 Hrs	8 Hrs	24 Hrs	16 Hrs	48 Hrs	36 Hrs	5 Day	72 Hrs	9 Day
27301	100	87040	10 Hrs	None	16 Hrs	None	24 Hrs	None	54 Hrs	None	N/R	N/R	N/R	N/R
Drying time before taking into use, before un-docking			12 Hrs		18 Hrs		24 Hrs		43 Hrs		N/R	N/R	N/R	N/R

Remarks and Product information see next page.

HEMPEL A/S

SF 10-01 HQ 1

Project: **WAVE DRAGON**
Area: **Turbine Tunnels HEMPASIL**

Remarks:

When the working procedure calls for a blast primer HEMPADUR 15590 in 40 micron dry must be used.

Consult the separate APPLICATION INSTRUCTIONS.

HEMPASIL SP-EED products contain silicone materials which may contaminate other paint materials and surfaces. It is recommended that all other paint work is completed prior to application of HEMPASIL 27301 and that special care is taken during both application and cleaing.

A minimum of 24 hours should be allowed before undocking, irrespective of temperature (above 15C).
If the temperature is below 15C then a minimum of 48 hours should be allowed before undocking.

All hoses used must be extremely clean and, if possible, should be new. It is recommended that the same paint hoses are used for both HEMPASIL TIE COAT and HEMPASIL SP-EED, with thorough cleaning between the two operations. All efforts (including masking if necessary) should be made to ensure that silicone contamination in the form of spray dust is kept to a minimum. Any equipment used, e.g. brushes, rags or cans should either be disposed of or thoroughly cleaned after use.

Any masking should be done carefully, the topsides area and any other area not to be coated with HEMPASIL should be covered with plastic. This plastic should be properly secured so that it does not fall or blow into any freshly applied paint. Check the masking prior to every application to make sure that it is secure. In the event that the thickness of the HEMPASIL NEXUS is above that specified then extend the recoating interval.

Product information:	Shade no.	Volume solids %	Curing agent	Mixing ratio volume	Pot life 20°C	Dry to touch 20°C	Flash point °C	Thinner	Application restrictions Min. temp. °C	Max. RH%
HEMPADUR MULTI-STRENGTH 45751	12340	79	97652	3 : 1	1 h	7 h	27	08450	10	90
HEMPADUR MULTI-STRENGTH 45751	50630	79	97652	3 : 1	1 h	7 h	27	08450	10	90
HEMPASIL NEXUS 37500	12430	54	95570	3 : 1	2 h	3 h	25	08450	-10	
HEMPASIL SP-EED TIE COAT 27301	19990	48			1 h	4 h	18		5	
HEMPASIL SP-EED 87040	15150	70	97080	7 : 1	2 h	4 h	32		5	

HEMPEL - RAPPORT

HEMPASIL NEXUS 27302 & HEMPASIL 77500
påføring på Turbinerør
for Wave Dragon, udført af Dan-Coat.

HEMPEL - RAPPORT

KUNDE:	Löwenmark FRI	**DATO:**	12. - 15. april 2005
STED:	Agger Værft, Havnevej 6, 7770 Vestervig	**PROJEKT:**	Wave Dragon, Turbinerør
EJER:	Wave Dragon ApS	**ÅRSAG:**	Inspektion/testpåføring

KONTAKTPERSONER: Jan Møller & Leif, Dan-Coat

HEMPEL KONSULENT: Jytte Nørgaard Clausen

Omfang / status:
På foranledning af Erik Friis Madsen, Löwenmark FRI er Dorte Gram, HEMPEL blevet bedt om at sponcerer Anticorrisiv- og Silikonemaling til Wave Dragon projektet, hvilket er gjort under for udsætning af, at Bo Bluhme stiller en Coating Adviser tilrådighed til opgaven.

Projektet bestå af 3 stk. Turbinerør nr. 1 og nr. 2 udført i stål og tidligere behandlet med 2 x zinkrig epoxy og 2 x solventfri epoxy. Nr. 3 er udført i rustfri stål og er ubehandlet. Turbinerørene er koniske og påstår af 3 svøb, hvor der i den smalle ende er påsvejst en flange med boltehuller, der er endevidere påsvejst 4 beslag på hver Turbinerør.

Under svirpning af eksisterende malingssystem har det vist sig dårlig vedhæftning, derfor er alle 3 Turbinerør fuldblæst, hvilket er afvigende fra oprindelig malingsspecifikation udarbejdet af Nick Marsh, Hempel. Aftalt pr. telefon med Jytte Nørgaard.

Arbejdet er udført hos Dan-Coat på Agger Værft i en mindre uisoleret stålhal, hvilket ikke have været de bedste forhold hvad angår klima forholdelt, dog på trods af dette, har det ved en positiv indstilling og samarbejde imellem Dan-Coat og Hempel lykkes at opnå et tilfredsstillende resultat.

Rapporten omfatter observationer og kontrol fra og med fuldblæsning, påføring af hver enkelt coat til og med slut kontrol.

Arbejdet er udført i henhold til nedenstående specifikation.

Forbehandling:
Olie og fedt etc. fjernes ved emulsionsrensning. Salte og anden forurening fjernes ved højtryksspuling med ferskvand. Når overfladen er tør fortsættes som følger: Sandblæsning til minimum Sa 2½ ifølge ISO 8501-1:1988 og en ruhed svarende til Medium (G) ifølge 8503-1:1988

Malesystem:

HEMPADUR 45143	grå	11480	1 x 150 mym
HEMPADUR 15570	grå	12170	1 x 150 mym
HEMPASIL NEXUS 27302	sort	19990	1 x 120 mym
HEMPASIL 77500	grå	15150	1 x 150 mym
Total lagtykkelse			**570 mym**

HEMPEL - RAPPORT

Forbrugte lot:

HEMPADUR 45148	grå	11480	225010594
HÆRDER 97430	klar	00000	013070070
HEMPADUR 15579	grå	12170	015044076
HÆRDER	klar	00000	015033688
HEMPASIL NEXUS 27309	sort	19990	014108112
NEXUS ADDITIVE 99700	klar	00000	015010940
NEXUS HÆRDER 98100	klar	00000	015033652
HEMPASIL 77509	grå	15500	015033624
HEMPASIL CROSSLINKER 97080	klar	00000	015033486
HEMPEL'S TOOL CLEANER 99610	klar	00000	-
HEMPEL'S FORTYNDER 08450	klar	00000	015033844
HEMPEL'S FORTYNDER 08080	klar	00000	-

Sandblæsning:

D. 12.04., pæn og vel udført blæsearbejde. Rensningsgrad SA3 ifølge ISO 8501-1:1988 og en ruhed svarende til Medium (G) ifølge 8503-1:1988.

Malepumpe/udstyr:

For alle påføringer er der anvendt en fremragende elektrisk GRACO pumpe, med elektronisk display.

Påføring af HEMPADUR 45143/11480:

D. 12.04.kl. 17.00, produktet er påført fortyndet 5 % med HEMPEL'S fortynder 08450, arbejdstryk 225 bar, dyse 419, vådfilm check 350 - 400 mym.

Klimaforhold målt med ELCOMETER 319:

Lufttemperatur: 9 C°, Ståltemperatur: 8,3C°, RH: 76,6%, DP: 5 C°.

DFT målinger HEMPADUR 45143/11480:

Målt med Elcometer 300, kalibreret på glat plade målt som følger:

Turbinerør nr. 1, antal målinger: 40, gennemsnit 177 mym, min. 67 mym, max. 225 myn.
Turbinerør nr. 2, antal målinger: 40, gennemsnit 172 mym, min. 91 mym, max. 315 myn.
Turbinerør nr. 3, antal målinger: 40, gennemsnit 189 mym, min. 107 mym, max. 247 myn.

Bemærkninger til HEMPADUR 45143/11480:

Generelt pæn og homogen filmdannelse der følger stålets struktur, dog er der målt lave målinger indvendig og set mindre pæn sammen flydning i samme område, skyldes adkomst forhold.

Påføring af HEMPADUR 15570/12170:

D. 13.04.kl. 10.00, produktet er ej fotyndet, arbejdstryk 220 bar, dyse 419, vådfilm check 250 - 300 mym.

HEMPEL - RAPPORT

Klimaforhold målt med ELCOMETER 319:
Lufttemperatur: 11,5 C°, Ståltemperatur: 12,1C°, RH: 62,1%, DP: 4,4 C°.

DFT målinger HEMPADUR 45143/11480 & 15570/12170:
Målt med Elcometer 300, kalibreret på glat plade målt som følger:

Turbinerør nr. 1, antal målinger: 40, gennemsnit 356 mym, min. 216 mym, max. 443 myn.
Turbinerør nr. 2, antal målinger: 40, gennemsnit 374 mym, min. 247 mym, max. 478 myn.
Turbinerør nr. 3, antal målinger: 40, gennemsnit 388 mym, min. 264 mym, max. 501 myn.
(ingen bilag)

Bemærkninger til HEMPADUR 15570/12170:
Generelt pæn og homogen filmdannelse der følger stålets struktur, dog er der målt lave målinger indvendig, og set mindre pæn sammen flydning i samme område, skyldes adkomst forhold.

Rengøring af udstyr:
D.13.04, efter påføring af HEMPADUR 15570/12170, er slanger, malepumpe og pistol omhyggeligt rengjort med TOOL CLEANER 99610 og fortynder 08080. Meshfilter og sugerør med tilhørende filter for malepumpe, omrører, samt dyse tilhørende knivfilter er skiftet til nyt.

Påføring af HEMPASIL NEXUS 27302/19990:
D. 14.04.kl. 07.00, malingen har været lagret indendøre i ca. 2 døgn ved 20 - 22 C°. Produktet er ej fotyndet, arbejdstryk 140 bar ved pumpe, maleslange er 3/8″ og ca. 10 M lange, dyse 419, vådfilm check 250 - 300 mym. Produktet er sprøjtebar ved meget lavt tryk og danner en flot malingsfilm.

Klimaforhold målt med ELCOMETER 319:
Lufttemperatur: 10,6 C°, Ståltemperatur: 11,3C°, RH: 65,4%, DP: 4,3 C°.

DFT målinger HEMPADUR 45143/11480, 15570/12170 & HEMPASIL NEXUS 27302/19990:
Målt med Elcometer 300, kalibreret på glat plade målt som følger:

Turbinerør nr. 1, antal målinger: 40, gennemsnit 556 mym, min. 373 mym, max. 670 myn.
Turbinerør nr. 2, antal målinger: 40, gennemsnit 562 mym, min. 337mym, max. 797 myn.
Turbinerør nr. 3, antal målinger: 40, gennemsnit 596 mym, min. 414 mym, max. 972 myn.

Bemærkninger til HEMPASIL NEXUS 27302/19990:
Meget pæn og homogen filmdannelse der følger stålets struktur, dog er der målt lave målinger indvendig, og set mindre pæn sammen flydning i samme område, skyldes adkomst forhold.

Påføring af HEMPASIL 77500/15150:
D. 14.04.kl. 19.00, malingen har været lagret indendøre i ca. 2- 3 døgn ved 20 - 22 C°. Produktet er ej fotyndet, arbejdstryk 220 bar ved pumpe, maleslange er 3/8″ og ca. 10 M lange, dyse 419, vådfilm check 250 - 300 mym.

HEMPEL - RAPPORT

Klimaforhold målt med ELCOMETER 319:
Lufttemperatur: 14,1 C°, Ståltemperatur: 15,3C°, RH: 61,8%, DP: 6,8 C°.

DFT målinger HEMPADUR 45143/11480, 15570/12170 & HEMPASIL NEXUS 27302/19990, HEMPASIL 77500/15150:
Målt med Elcometer 300, kalibreret på glat plade målt som følger:

Turbinerør nr. 1, antal målinger: 40, gennemsnit 704 mym, min. 470 mym, max. 951 myn.
Turbinerør nr. 2, antal målinger: 40, gennemsnit 732 mym, min. 418 mym, max. 944 myn.
Turbinerør nr. 3, antal målinger: 40, gennemsnit 740 mym, min. 533 mym, max. 997 myn.

Bemærkninger til HEMPASIL 77500/15150 slutkontrol:
Generelt er samlet DFT O.K., dog er der målt få lave målinger undvendig, og der er observeret mindre pæn sammen flydning i samme område. De nævnte områder er efterfølgende rulle påført under Hempel's tilstedeværelse, d.15/4 kl. 10.30.
Montering af Turbinerørene finder sted primo i uge 17.

Med henvisning til ovennævnte, er det muligt at anvende HEMPASIL produkter på de forhold der er på danske Værfter.

Ovennævnte er gennemgået ifølge aftale med Hr. Jan Møller & Hr. Leif, Dan-Coat og med hvem ovennævnte arbejde er udført, drøftet og aftalt.

Bilag:
DFT målinger & billededokumentation

20.04.2005
HEMPEL A/S
Jytte Nørgaard Clausen

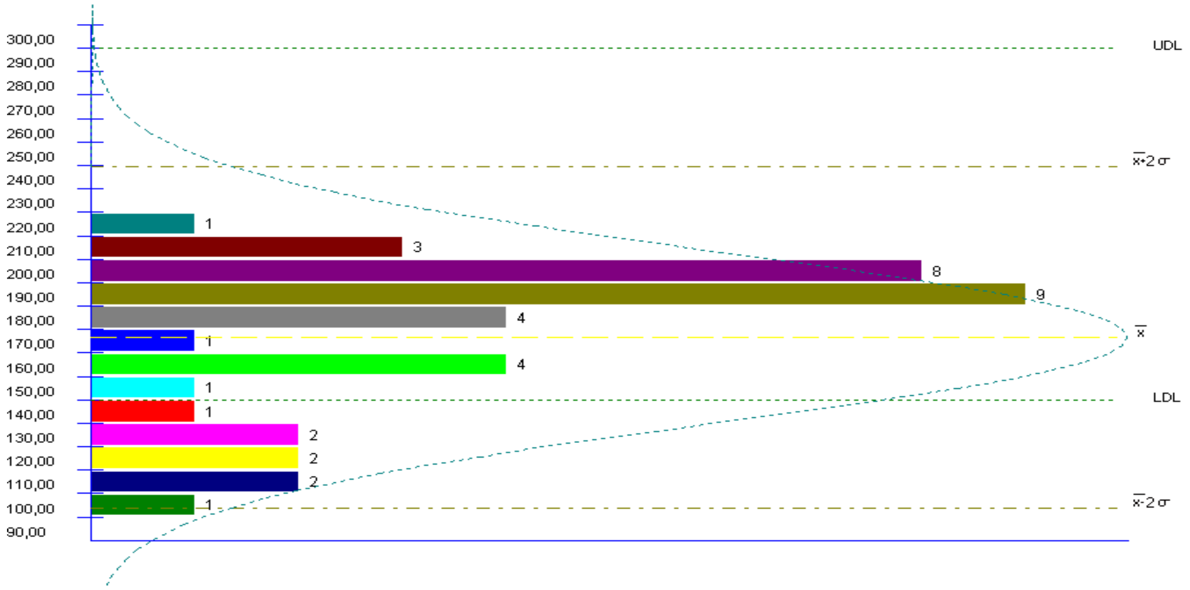
Elcometer Instruments Limited
Histogram

Batch navn: 45143 Ror 1

Substrat: Ferrous **Dato:** 13/04/2005 **Tid:** 10:53:00 **Enheder:** microns (µm)

Gennemsnit:	176,64	Max:	225,00	Antal målinger	40
Standard afvigelse	36,38	Min:	66,70		
Variationskoefficient	20,60	Høj grænse:	300,00	Målinger over: 300,00	0
		Lav grænse:	150,00	Målinger under: 150,00	9

Batch noter



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Elcometer Instruments Limited
Histogram

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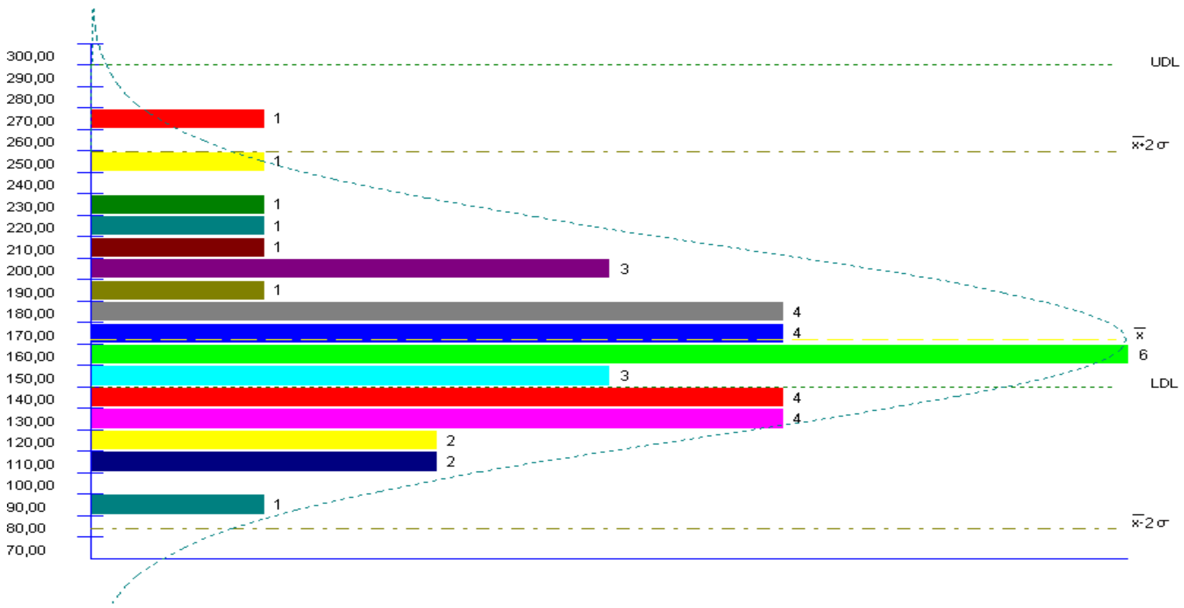

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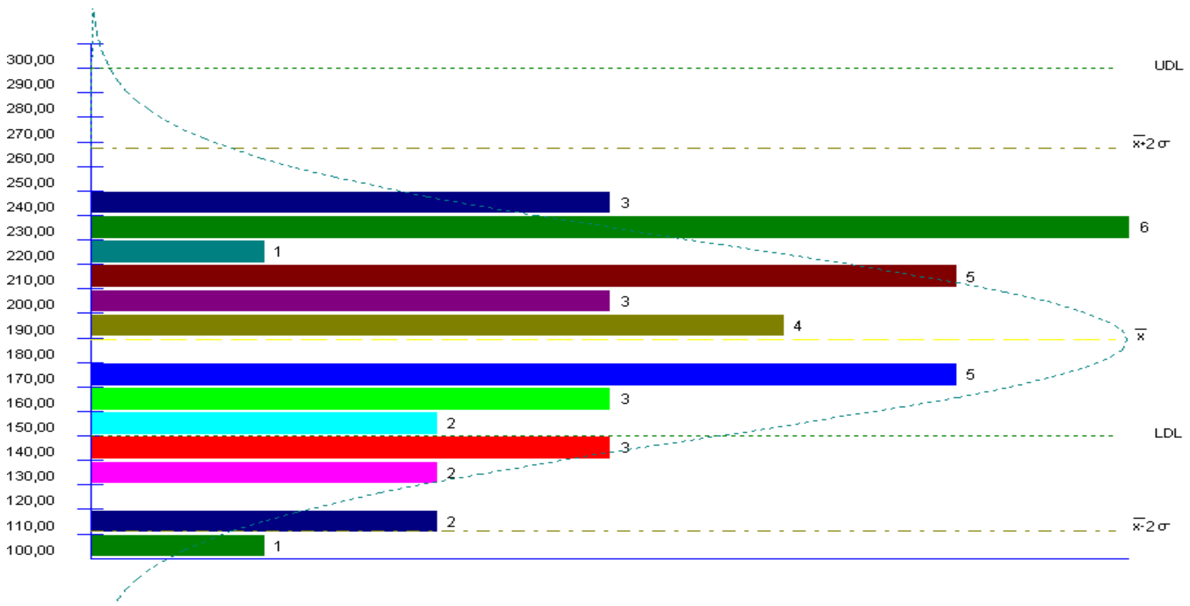

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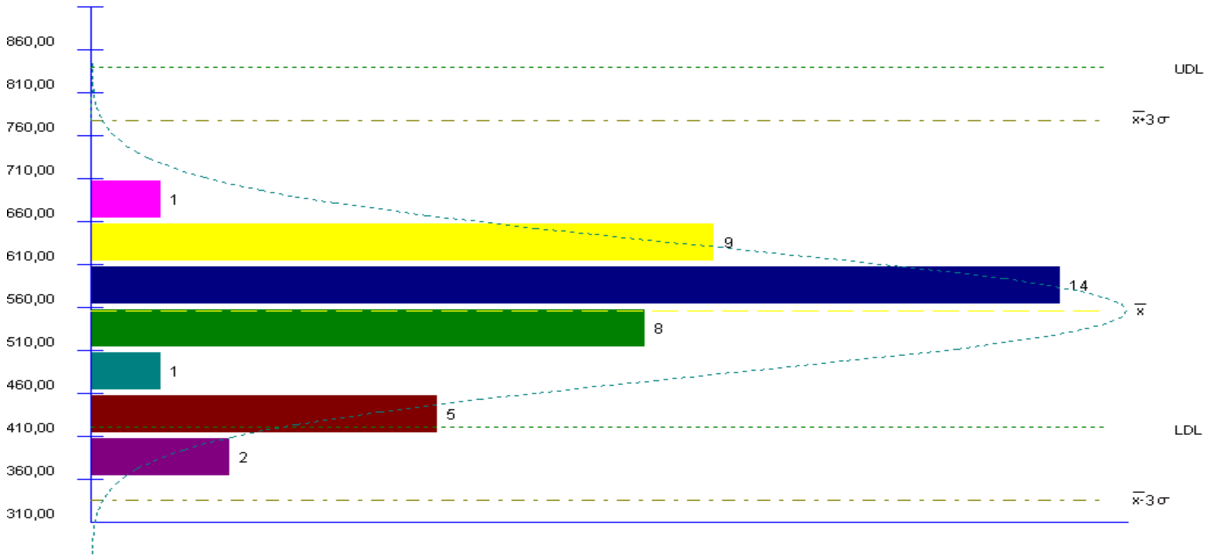

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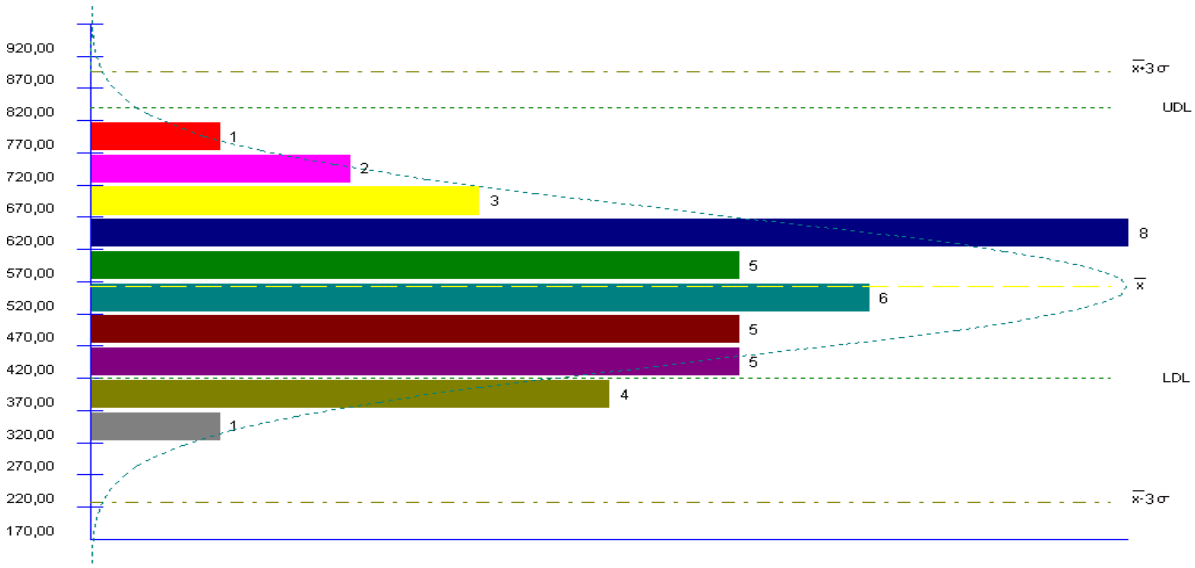

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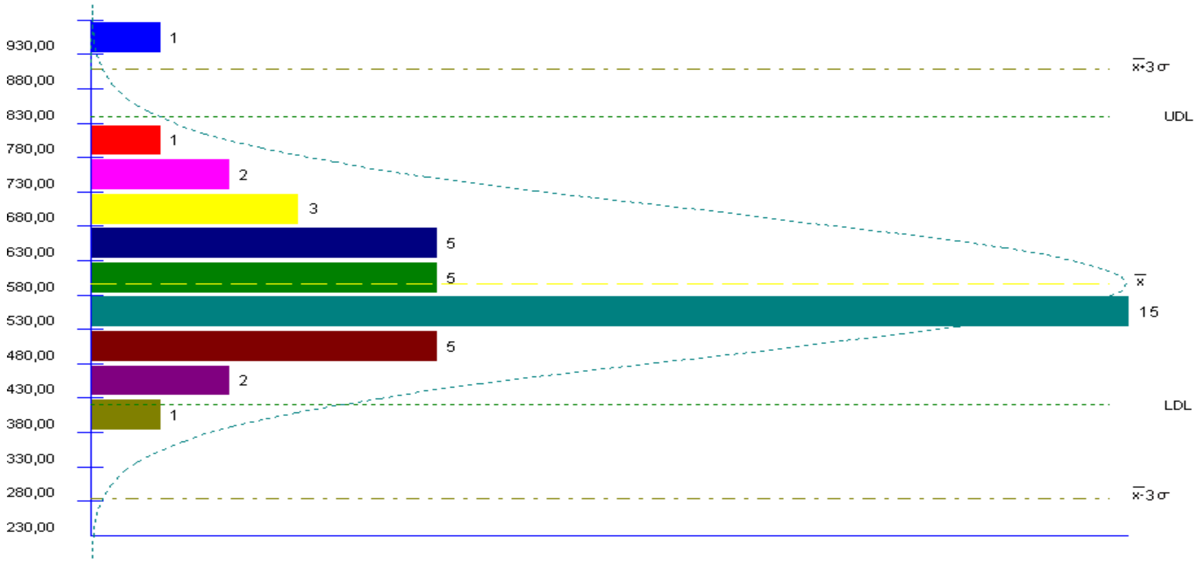

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Histogram

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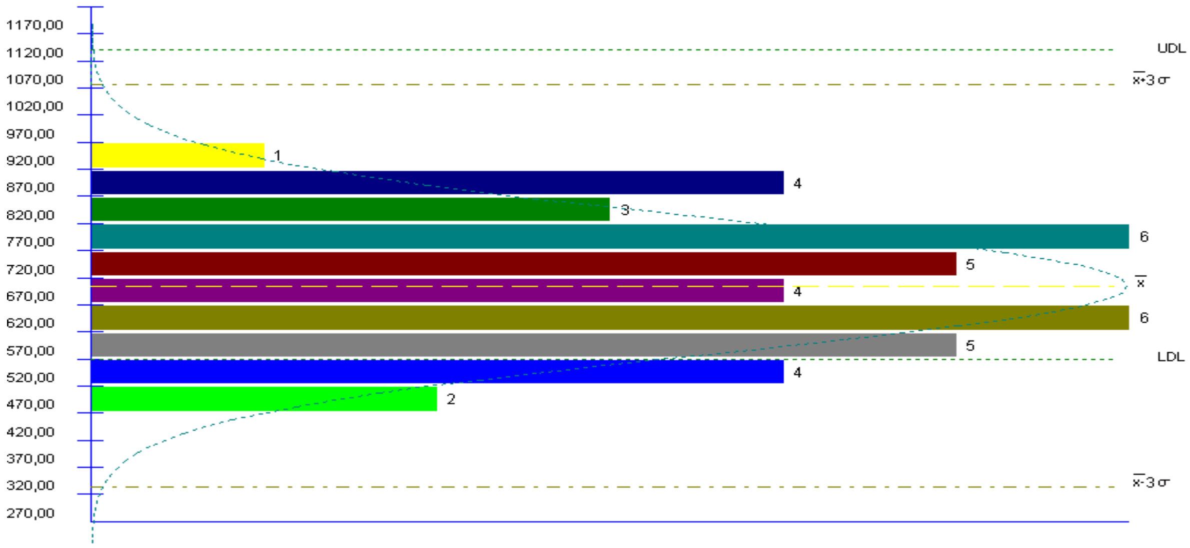

Elcometer Instruments Limited
Histogram

Batch navn: 45143,15570, 27302 og 77500 Ror 2

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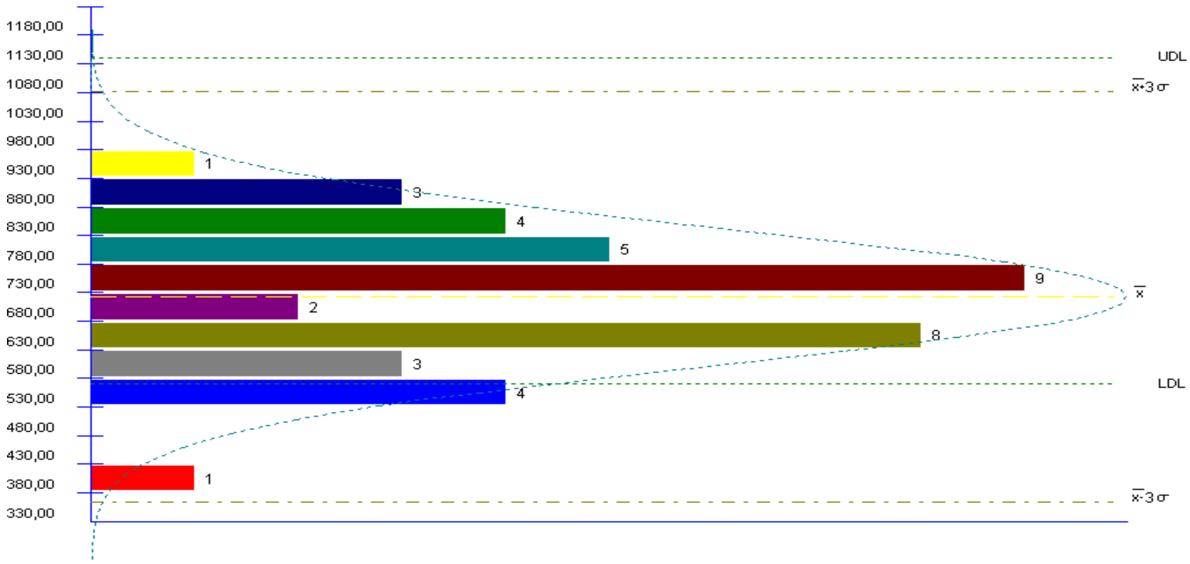

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Elcometer Instruments Limited
Histogram

Batch navn: 45143,15570, 27302 og 77500 Ror 3

Substrat: Non Ferrous **Dato:** 15/04/2005 **Tid:** 16:08:00 **Enheder:** microns (µm)

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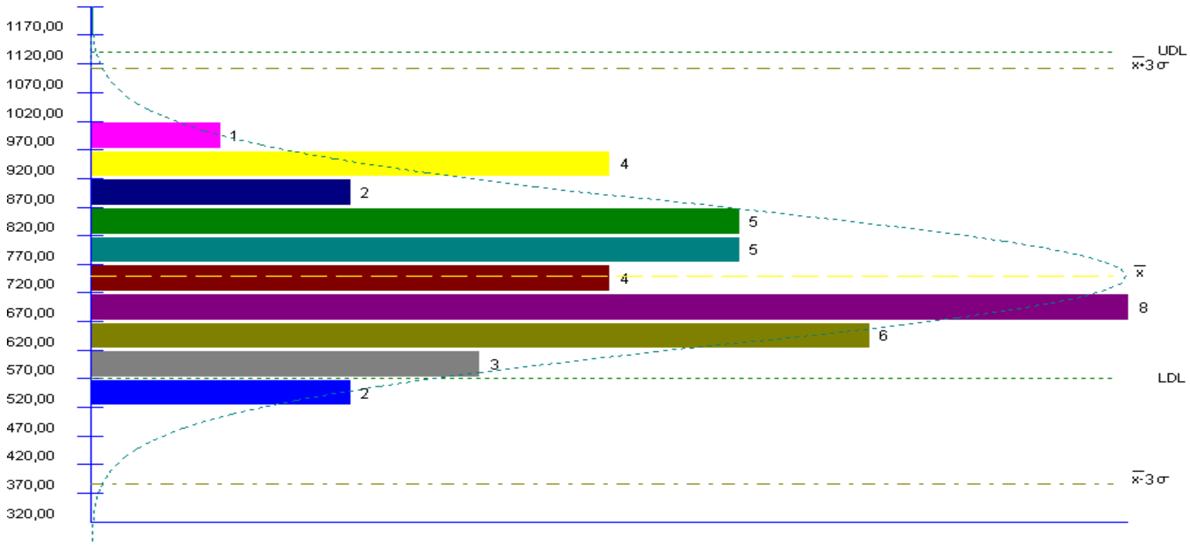


Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

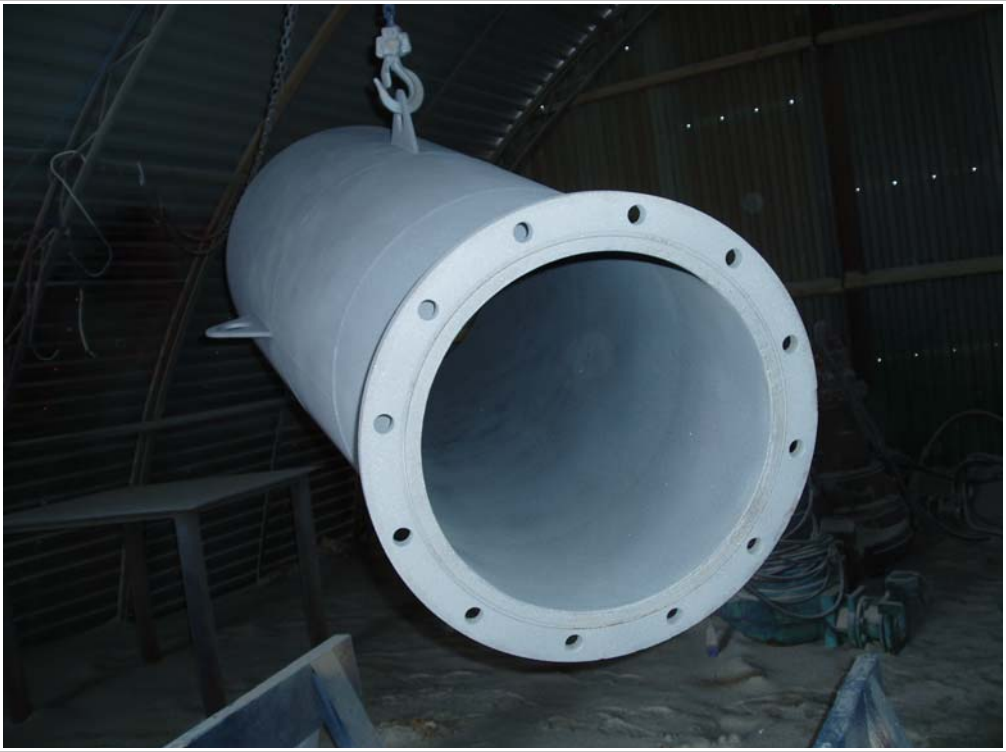
Photo no.: 1

Turbinerør efter sandblæsning.

Photo no.: 2

Turbinerør efter sandblæsning.

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 3	Turbinerør efter sandblæsning. 
Photo no.: 4	Påføring af HEMPADUR 45143/11480, bemærk udstikning. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 5	Påføring af HEMPADUR 45143/11480. 
Photo no.: 6	Vådfilms check på HEMPADUR 45143/11480, udføres af Jan Møller. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 7	Slut resultat af HEMPADUR 45143/11480. 
Photo no.: 8	DFT måling på HEMPADUR 45143/11480, udføres af Jytte Nørgaard. 

Photolegend

Object/vessel name: Wave Dragon, Tubinerør.

Photo no.: 9	Påføring af HEMPADUR 15570/12170
	
Photo no.: 10	Kontrolmåling vådfilm HEMPADUR 15570/12170.
	

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 11

Pumpetryk under påføring af HEMPADUR 15570/12170.

Photo no.: 12

Vådfilms check på HEMPADUR 15570/12170, udføres af Leif.

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 13	Slut resultat af HEMPADUR 15570/12170. 
Photo no.: 14	Slut resultat af HEMPADUR 15570/12170. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 15	Renøring af udstyr før påføring af HEMPASIL, udføres af Leif.
	
Photo no.: 16	Malepumpe klar til HEMPASIL påføring efter rengøring og skift af meshfilter og sugerør med tilhørende filter.
	

Photolegend

Object/vessel name: **Wave Dragon, Turbinerør.**	
Photo no.: 17	Klima kontrol før påføring af HEMPASIL NEXUS 27302/19990. 
Photo no.: 18	Klar til blanding af HEMPASIL NEXUS 27302/19990, bemærk ny omrører. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 19	Påføring af HEMPASIL NEXUS 27302/19990. 
Photo no.: 20	Påføring af HEMPASIL NEXUS 27302/19990. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 21

Stål temperatur før påføring af HEMPASIL 77500/15150.

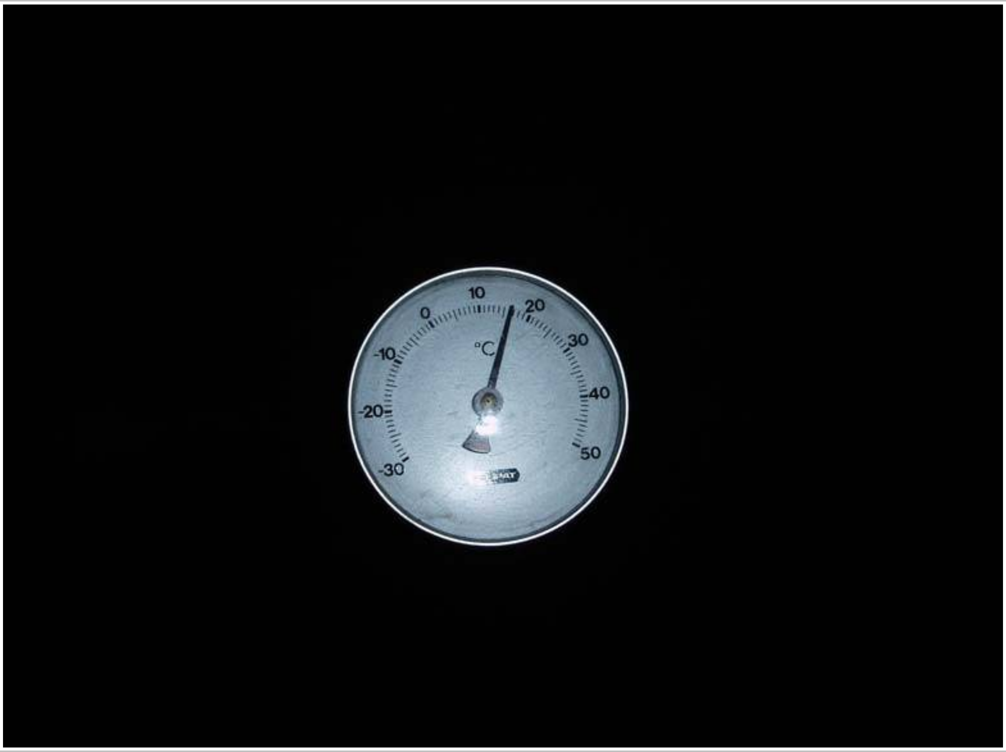


Photo no.: 22

Blanding af HEMPASIL 77500/15 50.

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 23	Påføring af HEMPASIL 77500/15150. 
Photo no.: 24	Påføring af HEMPASIL 77500/15150. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 23	Påføring af HEMPASIL 77500/15150. 
Photo no.: 24	Påføring af HEMPASIL 77500/15150. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 25	Rulle påføring af tynde områder med HEMPASIL 77500/15150. 
Photo no.: 26	Rulle påføring af tynde områder med HEMPASIL 77500/15150. 

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 27

Slut resultat.

Photo no.: 28

Slut resultat indvendig Turbinerør.

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 29	Slut resultat.
	
Photo no.: 30	Slut kontrol, DFT målinger.
	

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.

Photo no.: 31

Sandblæse- og malehal set udefra.

Photo no.: 32

De gamle Turbinerør.

Photolegend

Object/vessel name: Wave Dragon, Turbinerør.	
Photo no.: 33	De gamle Turbinerør. 
Photo no.: 34	Wave Dragon, trænger til HEMPEL maling. 

BILAG 13

TUM, EWTEC Conference paper: Water Turbines for Overtopping Wave Energy Converters

Water Turbines for Overtopping Wave Energy Converters

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ABSTRACT

In wave energy converters of the run-up type (overtopping converters, OTC's), the kinetic energy of the sea waves is used to store seawater in a reservoir above the mean sea level. The potential energy of the water in the reservoir can be exploited in a most effective way using low head water turbines. These turbines have been developed to a very high level of efficiency and reliability for use in run-of-the-river hydro power plants. If they are used in a wave energy converter however, a radically different mode of operation is required due to the stochastic time distribution of the energy input. Thus, special criteria for the choice and construction of water turbines for OTC's have to be applied.

An outline of the general turbine operating conditions will be given, and the suitability of different types of low head turbines for use in OTC's will be compared. Double, single and unregulated Kaplan turbines are covered as well as fixed and variable speed drive. It is shown that a bigger number of simple fixed blade turbines in conjunction with variable speed drive and a simple and reliable means of switching individual turbines on and off provide a very efficient solution to the problem.

NOTATION

D [m]	turbine runner dia.
H [m]	turbine head
H_s [m]	significant wave height
R_c [m]	crest freeboard height
l [m]	basin level, measured from crest
n [min^{-1}], ω [rad/s]	rotational speed
$n_q = n\frac{\sqrt{Q}}{H^{3/4}}$	specific speed
$\mathrm{Re}_D = \frac{w \cdot D^2}{2 \cdot n}$	turbine Reynolds number
Q [m^3/s]	flow rate
η_{Tu} [-]	turbine efficiency
η_{WD} [-]	overall eff. of WEC
ν [m^2/s]	kinematic viscosity of water ($\nu = 1.3 \cdot 10^{-6}$ m^2/s at 10° C)

1. INTRODUCTION

In Wave Energy Converters (WECs), the use of water turbines is primarily interesting in devices of the overtopping type. These converters consist basically of a ramp which is directed against the oncoming waves and a storage basin. When the waves hit the slope of the ramp, the kinetic energy contained in them is converted into potential energy, i.e. the water runs up the ramp and fills a reservoir which is situated above the mean sea level. The potential energy of the water in the reservoir is then exploited by releasing it back into the sea through water turbines. Low head water turbines which are suitable for this purpose have been used in run-of-the-river water power plants for many decades and have been developed to a high level of efficiency and reliability. Thus, in contrast to most of the other WEC principles, a proven and mature technology can be used for the production of electrical energy.

However, the turbine operating conditions in a WEC are quite different from the ones in a water power plant. In WECs, the turbine head range is typically between 1 and 5m, which is on the lower bounds of existing water turbine experience. While there are only slow and relatively small variations of flow and head in a run-of-the-river water power plant, the strong stochastic variations of the wave overtopping call for a radically different mode of operation in a WEC. The head, being a function of the significant wave height, is varying in a range as large as 1:3, and it will be shown that the discharge has to be regulated from 0% to 100% within time intervals as short as 10 seconds in order to achieve an optimum efficiency of the energy exploitation. From a river hydro power installation which is properly maintained, a service life of 40 - 80 years can be expected. On an unmanned offshore device, the environmental conditions are much rougher, and routine maintenance work is much more difficult to perform. Thus, special criteria for the choice and construction of water turbines for WECs have to be respected, and it seems advisable to aim for constructional simplicity rather than maximum peak efficiency. In the following paragraphs the operating conditions to be expected will be shown in detail and the suitability of different available turbine types will be discussed.

2. SHORE-BOUND AND FLOATING WEC'S

Basically, an overtopping WEC can either be conceived as a shore-bound installation or as an offshore installation which can either be floating (like Wave Dragon, see fig. 2.1) or be mounted on the sea bed.

Fig. 2.1.: Wave Dragon floating offshore converter

Fig. 2.2.: WaveSSG multi-level converter

The shore or sea-bed mounted variants cannot be adjusted to suit different wave heights. This disadvantage can be alleviated by conceiving them as multi-level devices like the WaveSSG, see fig. 2.2.

The advantages and drawbacks of the different concepts are compared in tab. 2.1.

	Shoreline single level	Shoreline multi level	Seabed multi level	Floating single level
Adaptable to tidal range	-	-	-	+
Self aligning to wave direction	-	-	-	+
Efficiency in changing sea states	-	+	+	+
Multiplication into farms possible	-	-	+	+
Ease of maintenance	++	+	-	-
Small turbine head range	-	o	o	--
Small turbine flow range	-	-	-	-

Tab. 2.1.: Comparison of different OTC concepts

3. OPERATING CONDITIONS

In respect to the turbine operating conditions, the main difference between the above concepts is the even wider turbine head range that needs to be covered in a floating, single level device which is adjusted to the wave height. With all the above concepts, the storage capacity is relatively limited. In floating devices, the volume of the reservoir is nearly in the same order of magnitude as the over-topping resulting from a single big wave. To achieve an optimum energy conversion, the turbine control will thus have to react onto single wave events or at least onto the arrival of individual wave groups, thus calling for frequent and rapid changes of the flow rate.

Maximising the overall efficiency or the annual energy output of a shoreline overtopping converter is already a complex task, as a great number of parameters need to be optimised and the effect of any parameter change has to be studied for a number of different sea states. For a floating offshore device, things are even more complicated because the floating level, and thus the overtopping characteristics, depends on the

amount of water in the reservoir, while the latter again depends on the overtopping and the turbine discharge.
A comprehensive simulation software, based on a time-domain model, has been conceived to gain insight into the operation of the Wave Dragon and to determine optimum operating parameters, see [1]. A quantitative analysis of the turbine operating parameters in terms of head and discharge has been given in [2].
In order to sample a shore bound device, a similar analysis has been made for the WaveSSG. The results can be summed up as follows:

3.1. Turbine head range

Tab. 3.1. is giving a typical North Sea wave distribution. The waves that contribute significantly to the total energy are ranging from 1 to 5 m significant height

H_s [m]	Probability [% time]	% of total Energy	max. turbine head [m]	min. turbine head [m]
0	11			
1	38	6.3	1.45	**1.40**
2	27	22.9	1.70	1.65
3	14	30.5	2.15	2.05
4	6	25.8	2.60	2.45
5	2	14.6	**3.00**	2.75

Tab. 3.1.: Turbine head in different sea states

When the crest height and the reservoir work span are adjusted for optimum energy conversion, the turbine has to cope with head values ranging from 1.4 to 3.0 m.

	Q_{max} [m^3/s]	Q_{max} [m^3/s]	H_{min} [m]	H_{max} [m]
level 1:	0.0	10.0	1.1	1.5
level 2:	0.0	5.4	2.1	3.0
level 3:	0.0	3.8	3.5	5.0

Tab. 3.2.: Turbine head in the 3 reservoirs of WaveSSG

The corresponding head values for the 3 stages of the WaveSSG are given in tab. 3.2. In each reservoir, the turbine has to tolerate a head variation of ±16%.

3.2. Turbine flow range

If the turbines are only stopped when the reservoir is completely empty, some of the water volume is used at an unnecessarily low head, thus wasting a part of the potential energy. Ideally, the turbines should be stopped as soon as the reservoir is just empty enough to accommodate the water volume that the next wave is going to bring without any spilling. Unfortunately, neither the arrival time nor the overtopping volume of the next wave can be accurately predicted.

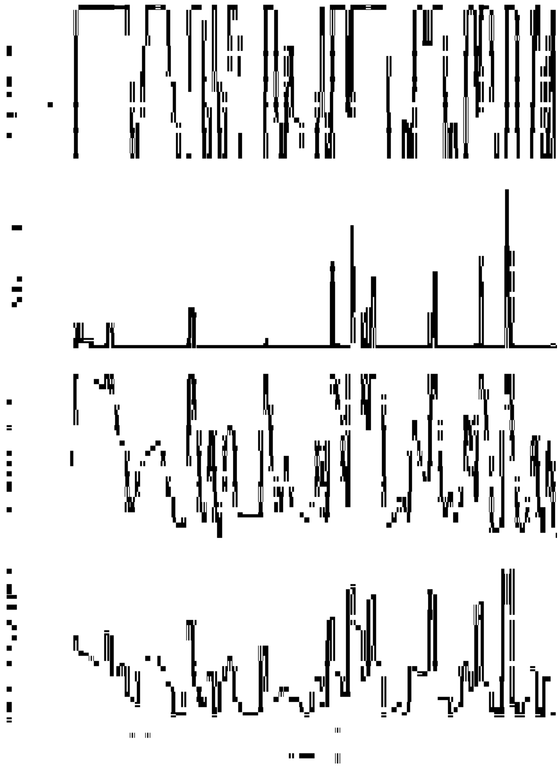

Fig 3.1.: Time history of overtopping, basin level, spillage and turbine flow rate

However, it has been found that it is a reasonable strategy to operate the turbines at maximum flow rate when the basin is full, and decrease the flow as the basin empties until all turbines are stopped at a certain minimum basin level l_{min}. In evaluating different regulation strategies the highest energy production has been obtained when the basin was emptied only very little, especially in low seas. In order to keep the basin level within this small range, the turbine flow has to be changed very frequently and rapidly, with relatively frequent periods of complete shutdown. Fig 3.3. shows a time history of the operation at a significant wave height h_s=3m.

3.3. marine environment

Turbines used in wave energy converters are subjected to a quite aggressive environment, compared to the conditions in river hydro power plants. The additional factors are:

- corrosion
- sand
- marine growth

A turbine designed for a standard hydro power application will not withstand these impacts. However, the above issues can be perfectly solved if suitable designs and materials are used. In the following, a few examples from practical experience are given:

Fig. 3.2. shows a dismantled turbine bearing which had been designed according to standard river hydropower practice. After 9 months of offshore use the seal had broken down, with subsequent intrusion of salt water and corrosion damage to the bearings.

fig. 3.2.: Corroded components of a turbine bearing.

Subsequently, the bearing has been redesigned, using seawater resistant materials and employing a combination of a gravity seal and a lip seal, see fig. 3.3. This solution has worked without problems since.

fig. 3.3.: Redesigned bearing

For the turbine parts permanently exposed to the seawater, such as guide vanes and runner blades, cathodic protection has proven to be a very efficient means of avoiding corrosion. A system with actively DC fed electrodes has been used in the turbines of the La Rance tidal power plant for almost 40 years, with very satisfactory results, see [3].

fig. 3.4.: Sand-filled water-lubricated bearing

Fig 3.4. shows a water lubricated radial shaft bearing after one year of operation. Due to an unfavourable layout of the lubrication system the bearing filled up with sand, and finally the water supply was blocked by mussels growing in the feed pipes. A modification of the water supply solved the problem.

fig. 3.5. and 3.6.: Draft tubes with and without marine growth

Figs. 3.5. and 3.6 show two turbine draft tubes that have been in the sea for one year. The tube on the left hand side was coated with a standard epoxy paint system. After one year in the sea, the layer of mussels and sea squirts was up to 10 cm thick on the outside as well as inside the tube. The tube on the right hand side was covered with a non-toxic silicone-based antifouling coating, and had very little growth after the same time of exposure.

3.4. maintenance issues

The possibilities to do maintenance work to components installed on an offshore platform are mainly restricted by the following factors:

- onboard facilities
- transport facilities
- weather conditions

It is costly and not always feasible to install cranes with long reach and big capacity on a wave energy device. Fig. 3.7. shows a temporary crane rigged up on board of the Wave Dragon in order to dismantle the turbines.

fig. 3.7.: Dismantling of a turbine on board

Large capacity transport facilities, i.e. big boats, are not always available from a nearby harbour, and they are usually rather expensive to hire. The capacity of an inflatable boat is quite limited, see fig. 3.8.
From the above it seems absolutely advisable to avoid components above a certain weight if somehow possible. This is one good reason to use a number of small water turbines rather than one big turbine.

fig. 3.8.: Transport of a turbine draft tube

Finally, the weather can put severe constraints on any repair or maintenance work. Short term weather forecasts are now quite reliable, but planning a major rebuild or modification weeks in advance is still difficult, as it might end up with a number of expensive specialist people standing on the shore and watching the waves, see fig. 3.9..

fig. 3.9.: Wave Dragon in rough weather

From the above, it is obvious that every attempt should be made to cut down the maintenance requirements of the power train components.

4. AVAILABLE TURBINE TYPES

Fig. 4.1. shows the application ranges of the known turbine types in a graph H vs. n_q. The specific speed n_q is a turbine parameter characterising the relative speed of a turbine, thus giving an indication of the turbines power density. Evidently, all turbine types except the Pelton and the cross flow type are to be found in a relatively narrow band running diagonally across the graph. Experience has shown that an optimum turbine layout is always situated within this band. Transgressing the left or lower border means that the turbine will run too slowly, thus being unnecessarily large and expensive. The right or upper border is defined by technological limits, namely material strength and the danger of cavitation erosion. However, the Pelton and the cross-flow turbine

do not quite follow these rules, as they have a runner which is running in air and is only partially loaded with a free jet of water. Thus, they have a lower specific speed and lower power density. Despite its simplicity and robustness, the cross flow turbine is not very suitable for wave power applications:

- It is difficult to ensure that its runner does not touch the tailwater surface when there are wave-induced pressure fluctuations.
- Due to the typically very narrow blade passages this turbine cannot cope very well with debris like seaweed and fishing net parts.
- Due to its low specific speed, the turbine itself is rather bulky, and it needs a gearbox to drive the generator.

This type of turbine has thus not been further evaluated.

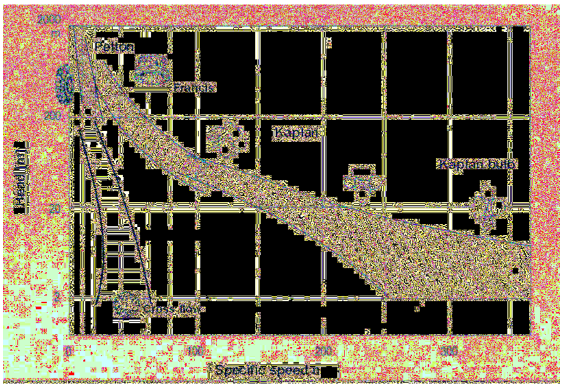

Fig 4.1.: Head range of the common turbine types, after Voith and Ossberger

Thus the Kaplan bulb type is the only turbine suitable for the head range in question. Its general construction is shown in fig. 4.2.

The shape of a turbines guide vanes and runner blades is designed to give an optimal energy conversion in its design point, which is defined by optimum values of head and flow (H_{opt} and Q_{opt}) at a given speed. For every other operating point, there will be a discrepancy between the flow angles and the blade angles, decreasing the efficiency of the turbine. Whenever a turbine is required to operate in a relatively wide head and flow range it is important that the efficiency curve is flat and widely spread. This criterion is best fulfilled by the double regulated Kaplan type, see figs. 4.3 and 4.4.

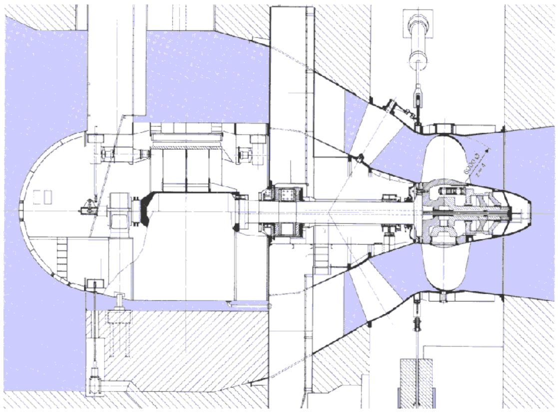

Fig 4.2.: Double regulated Kaplan bulb turbine (Voith Hydro)

In this type of turbine, both the guide vanes and the runner blades are adjustable, thus making the turbine very adaptable to varying operating conditions. This is only achieved by a relatively complex construction which implies an oil-filled runner hub with a number of critical bearings and oil seals and a great number of joints and bearings in the guide vane operating mechanism. This is not only reflected in higher manufacturing costs, but also in a higher demand for maintenance, especially when the turbine is operated in an aggressive environment i.e. saltwater with possible silt contents. For these reasons single regulated variants of the Kaplan turbine have been conceived, namely the Propeller type with fixed runner blades, the Semi-Kaplan type with fixed guide vanes and the unregulated on/off turbine with fixed runner blades and fixed guide vanes. These turbines are simpler in construction, but they have a much narrower efficiency curve, see figs. 4.3. and 4.4.

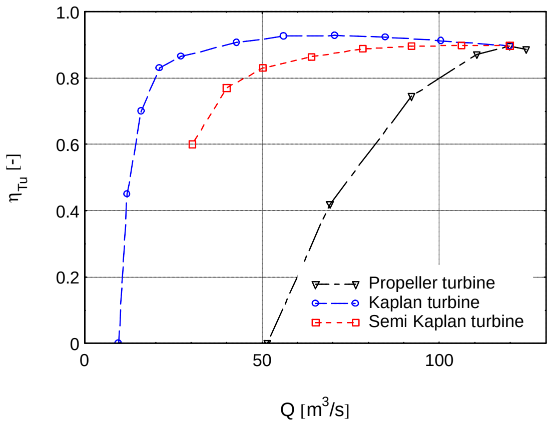

Fig 4.3.: Efficiency vs. flow at design head

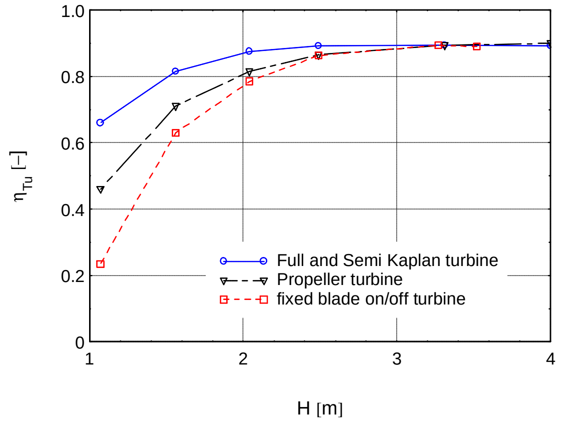

Fig 4.4.: Efficiency vs. head at optimum flow rate

	Double regulated Kaplan	Semi-Kaplan turbine	Propeller turbine	16 fixed speed on/off turbines	16 variable speed on/off turbines
η_{opt}	.93	.90	.90	.91	.91
$\bar{h}\,(H = H_{opt})$	.85	.68	.39	(.90)	(.90)
$\bar{h}\,(Q = Q_{opt})$	.87	.87	.81	.66	.90
D [m]	5.4	5.4	5.4	1.2	1.2
n [min^{-1}]	50	50	50	250	100-250
robust-ness	-	o	+	+++	+++
turbine price	1.4	1.2	1	.9	.9
price of generator	1.0	1.0	1.0	0.9	1.2
price of turbine + generator	2.4	2.2	2.0	1.8	2.1
overall rating	++	++	+	+++	++++

Tab 4.1.: Comparison between double, single and unregulated turbines

Table 4.1. is giving a comparison of the turbine types discussed so far. The example is based on a layout point of H=3m and Q=125 m^3/s. The second row is giving the average efficiency for the flow range from 10% to 100% while the average efficiency for the head range from 1.4m to 4m is shown in the third row. Rows 6 and 7 give a rough ranking of the robustness and the manufacturing price.
From this comparison it is obvious that the double regulated Kaplan turbine is the technically most efficient solution, but at the expense of being costly to manufacture and difficult to maintain. The two single regulated types are distinctly lower in average efficiency, but have advantages due to their simplicity. However, this comparison is only valid for a single turbine running at constant speed. The last columns are giving the corresponding values for a set of 16 very simple fixed blade turbines running at fixed and variable speed, see paragraphs 5 to 7. The ranking given in the last row is taking into account the data given above as well as the considerations made in paragraphs 5 to 8.

5. MULTIPLE TURBINES

If the projected plant is of a certain size, it should be considered to use a number of smaller turbines instead of a single big turbine.

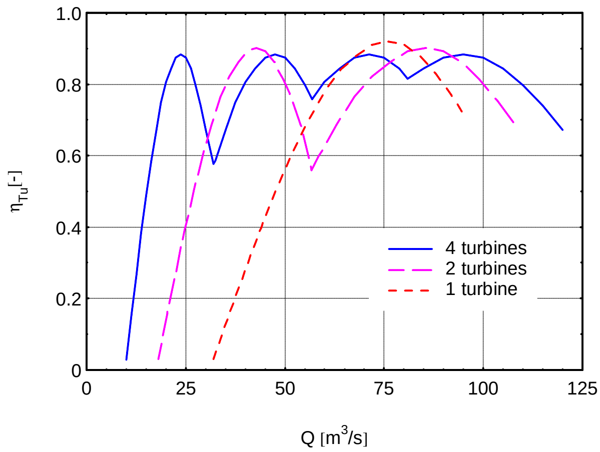

Fig. 5.1.: Turbine efficiency vs. flow rate for a single and a multiple turbine configuration.

This has the following advantages:

- By stopping a number of turbines at lower flow rates, the flow rate can be regulated over a wider range without sacrificing efficiency, see fig. 5.1.
- Single units can be taken out of service for maintenance without stopping production.
- There is no need for high capacity hoisting and transport equipment to perform repair and maintenance work, cf. paragraph 3.4. The smaller turbines have shorter draft tubes, and are thus easier to accommodate in the whole device, see fig. 5.2.
- The smaller turbines have a higher speed (see fig. 5.3.), which reduces the cost of the generator.

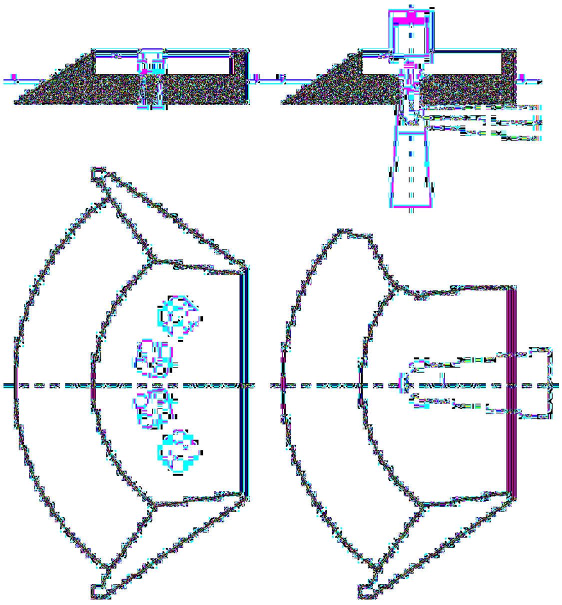

Fig. 5.2.: Installation of 16 small turbines vs. a large single turbine

Fig. 5.3. depicts the results of a parameter study in which the turbine number i_t has been varied in a wide range while adjusting the size of the turbines in a way that the total discharge was kept constant. From the similarity laws and cost statistics, the following proportions can be derived:

runner diameter	D	~	$i_t^{-0.5}$
speed	n	~	$i_t^{0.5}$
cost of all turbines	C_t	~	$i_t^{0.1}$
cost of generators	C_g	~	$i_t^{-0.05}$

The increase in the production cost of the smaller turbines is partly compensated by the fact that the generators become smaller and cheaper at higher speeds.

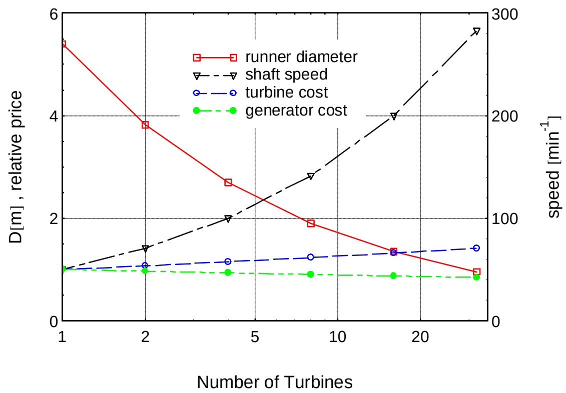

Fig. 5.3.: Runner diameter, speed and relative production cost vs. turbine size

Apart from the slightly increasing production cost there is one more reason for not using too many small turbines: with decreasing size, the turbines peak efficiency decreases along with Reynolds number Re_D, see fig. 5.4.

It can be seen that the Reynolds effect is not too pronounced as long as the turbine is not too small. As a general rule, Re_D should not be smaller than $1.5*10^7$.

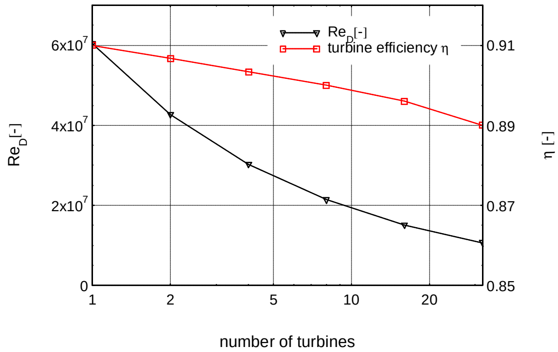

Fig. 5.4.: Reynolds number and turbine efficiency vs. turbine number

6. VARIABLE SPEED DRIVE

In normal hydro power stations, the turbines are operated at constant speed, as they are coupled directly to the synchronous generators feeding into a fixed frequency grid. However, if the generator is connected to a frequency converter, the turbine can be operated in a relatively wide speed range. This is very advantageous in situations where a large variation in turbine head occurs. By adapting the speed to the actual turbine head, the efficiency of the turbine can be kept almost constant, see fig. 6.1.

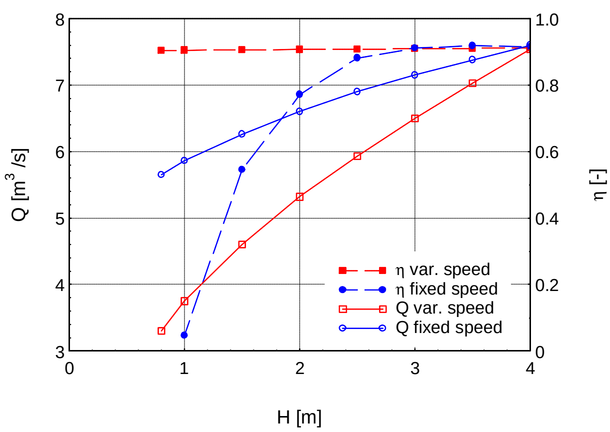

Fig. 6.1.: Turbine efficiency and flow rate vs. head for fixed and variable speed drive

In this case, the flow rate drops strongly along with the head, which has proved to be advantageous as well. In the development of the Wave Dragon, different turbine regulation strategies have been evaluated by means of a simulation software. Maximum overall plant efficiency was obtained when the turbine flow was reduced along with the emptying of the reservoir. Fig 6.2. shows an optimum flow control function Q_{Tu} vs. basin level l :

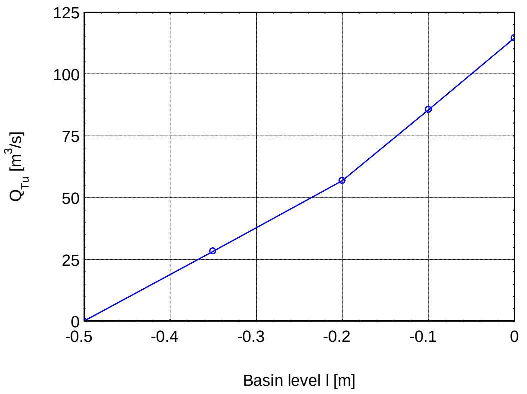

Fig. 6.2.: Control function $Q_{Tu}(l)$

In order to regulate the flow over such a wide range without getting too low turbine efficiencies, a number of turbines has to be stopped at lower basin levels, which is resulting in very frequent turbine start/stop cycles. Variable speed turbines have a distinctive advantage in this respect, as their discharge decreases strongly along with the head (see fig. 6.1), which provides a very advantageous self regulating effect. This does not only lead to an increase in yearly energy production, but also to a much smoother power delivery and a higher load factor, see fig. 6.3. Both of the graphs are based on a system of 4 unregulated on/off turbines.

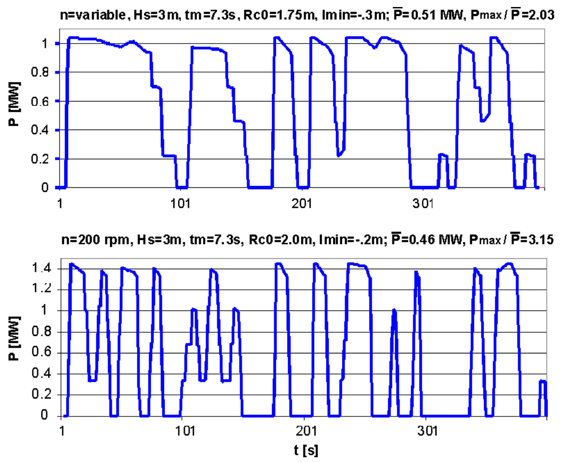

Fig. 6.3.: Power delivery vs. time with variable speed and fixed speed turbines

7. UNREGULATED (ON/OFF) TURBINES

It has been shown that variable speed drive turbines can be operated in a wide head range and have a flow vs. head characteristic which does by itself fulfil a part of the regulation strategy. If the projected plant is big enough to justify the use of a relatively big number of turbines, it is possible use very simple and rugged on/off turbines in conjunction with any means of interrupting the flow to switch the turbine on and off. In the case of the Wave Dragon, it has been shown that 4 on/off turbines are already sufficient to regulate the discharge as needed. Two alternative methods for interrupting the flow have been analysed, the first one using a big hydraulically operated cylinder gate, the second one using a siphon principle, see fig. 7.1. and 7.2. The operation of the gate is obvious from fig. 7.1. The siphon type is stopped by simply admitting air into the top of the inlet duct; the turbine is started again by partly evacuating the air until the flow starts again and takes the rest of the air along with it.

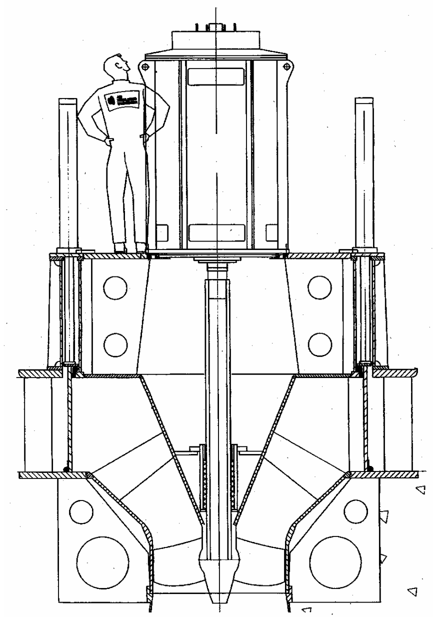

Fig. 7.1. Cylinder gate on/off turbine

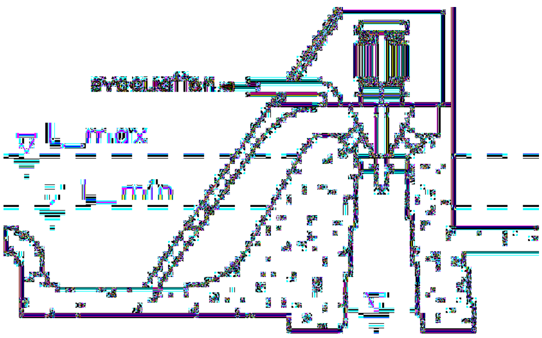

Fig. 7.2. Siphon type on/off turbine

It has been found that the cylinder gate type has the advantage of shorter start-up time and slightly better efficiency, while the siphon type has less moving parts and would thus appear to require less maintenance. Both types are being tested in the current real sea tests of the Wave Dragon.

8. COMPARISON OF DIFFERENT TURBINE CONFIGURATIONS

For a given layout of the Wave Dragon WEC, the following turbine configurations have been compared:

- 2 double regulated Kaplan turbines
- 2 Propeller turbines
- 2 Semi Kaplan turbines
- 16 fixed speed on/off turbines
- 16 variable speed on/off turbines

For each of these layouts, an optimum operating strategy and optimum values of crest height and minimum basin level for each of the sea states given in tab. 3.1 have been determined in order to calculate the annual energy production $E_{tot, yr}$.

	2 Double regulated Kaplan turbines	2 Semi-Kaplan turbines	2 Propeller turbines	16 fixed speed on/off turbines	16 variable speed on/off turbines
$E_{tot, yr}$ [GWh]	1.79	1.69	1.49	1.69	2.04
P_{max}/P_{av} [-]	12.4	13.0	13.8	12.7	10.1
$Sdev_{P,av}$ [-]	0.66	0.57	1.61	1.33	0.85

Tab 8.1.: Power production with different turbine configurations

As the propeller turbine has a very narrow range of high efficiency, see fig. 4.3, this turbine was operated in on/off mode, using its guide vanes only for optimum adaption to the current head value.

The first row in table 8.1. shows the yearly production that can be expected from each of the configurations.

In the second row, a comparison of the maximum output at the highest sea state and the yearly averaged output is given. As the maximum output determines the dimensioning of the generators and power transmission train, this ratio is has a great influence onto the specific production cost EUR/KWh. Variable speed is an advantage in this respect as well.

Finally, the standard deviation of the electrical power averaged over all sea states is given in the last row as a measure of judging the uniformity of the power production. The small values found for the regulated turbines indicate a relatively uniform power delivery, whereas the turbines operated in on/off mode show much bigger standard deviations. However, this disadvantage is largely reduced by using variable speed drive.

9. CONCLUSION

Taking into account the demand for a turbine concept with minimum maintenance requirements, high efficiency, low specific installation costs and a relatively uniform power delivery, a layout with 16 variable speed on/off turbines was considered the optimum solution for the Wave Dragon concept. A similar solution can be conceived for most other overtopping wave energy converters, and will prove to be very competitive. Further cost benefits, which can be expected from serial production of a big number of small turbines and from further development of the frequency converter technology make this concept even more attractive.

10. ACKNOWLEDGEMENTS

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(3) Abonel, Cyrille, XXXXXXX

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TUM, The Hydro Turbines of the Wave Dragon Nissum Bredning Prototype after eight years at sea

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The Hydro Turbines of the Wave Dragon Nissum Bredning Prototype after eight years at sea

Condition report after dismantling of the WD-NB prototype

München, March 2013

Dr.- Ing. Wilfried Knapp

1. Summary

Two of the six cylinder gate turbines of the Wave Dragon Nissum Bredning prototype have been dismantled after being out at sea for eight years. Although they were basically still operable, strong corrosion damage has been found on almost all the parts that were not made from corrosion resistant materials. In most cases, corrosion protection coatings had failed, with corrosion starting from inevitable spots where the protection layer had been mechanically damaged. Dynamic and static seals had failed where the sealing elements consisted of unsuitable materials or where the seals had not been assembled carefully enough.
The obvious solution is that any parts that exposed to mechanical impact need to be built from corrosion resistant materials rather than relying on corrosion protection coatings. Very great care has to be taken in designing and assembling sealing elements.
With the lessons learnt from the WD-NB prototype, it should be possible to meet the targeted structure life of 50 years and turbine life of 25 years without undue corrosion problems in a future Wave Dragon prototype.

2. Introduction

The Wave Dragon Nissum Bredning prototype was designed as a small scale (1 : 4.5) sea-going prototype of the Wave Dragon wave energy converter that was to be tested for a period of three years in a part of the Limford in northern Jutland. It was actually deployed in March 2003 and rested at sea, with intermittent periods it spent at Agger harbour and on the beach until it was dismantled in September 2011. No excessive efforts had been made with regard to corrosion protection due to the relatively short testing period originally scheduled. The hull itself, being made from 8 mm thick steel plate, was only painted on the upper side, and only upwards from slightly below the water line, see fig. 1.

fig. 1: hull of the prototype after being painted

The turbines were mainly built from ordinary S235 steel plate with a corrosion protection by epoxy paint. Some components were built from stainless steel, and a few were later replaced with redesigned components made from materials with a higher corrosion resistance. The draft tubes of the turbines No. 2 and 4 had been sandblasted and coated with a special silicone anti-fouling paint from the beginning. The draft tubes of the remaining turbines were thus treated during an overhaul in 2005. A detailed analysis of the experiences made with the different materials and coatings is given in the following chapter.

3. Condition analysis of the turbines

As with the Wave Dragon structure, the corrosion protection of the turbines was not intended to last for a very long time. The first corrosion marks became visible after a year at sea, see fig. 2.

fig. 2: turbines after installation and one year later

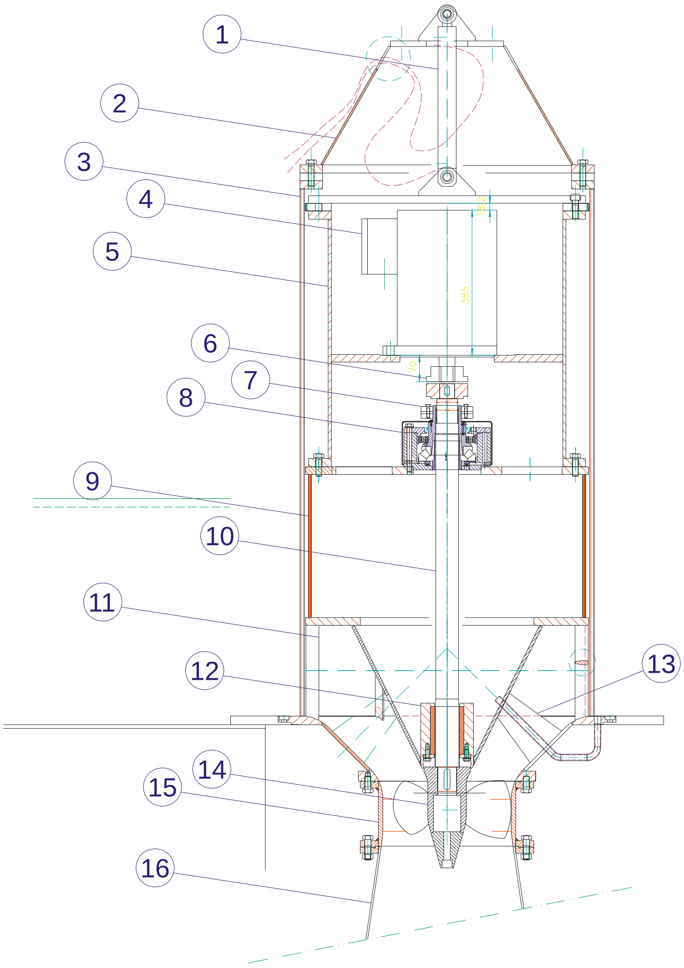
Approximately 10 months after dismantling of the Wave Dragon prototype, two of the cylinder gate turbines were transported to TUM in order to dismantle them and inspect their components. When looking at their condition, it needs to be taken into account that the turbines had not been treated very kindly during the dismantling of the WD structure, see fig. 3. Thus some components showed additional damage which could be attributed to this handling.

fig. 3: turbines on the beach during dismantling of the WD structure and one of them on arrival in Munich

In the following, the condition of the various components is described one after the other.

3.1. Turbine description, materials used

Fig. 4 is giving a cross section through the turbine and the denomination of the main components.



1 hydraulic cylinder
2 cylinder gate top cone
3 cylinder gate
4 generator
5 generator case
6 shaft coupling
7 shrink disk
8 turbine thrust bearing assembly
9 turbine shaft case
10 turbine shaft
11 stay vanes
12 radial turbine bearing
13 guide vanes
14 turbine runner
15 runner shroud
16 draft tube

fig. 4: cross section of the turbine and denomination of main components

The above named components were made from the following materials:

No. 1, hydraulic cylinder	Danfoss water hydraulic cylinder. Cylinder from 1.4301 stainless steel , piston rod from 1.4460 stainless steel with 20µm hard chrome coating.
No. 2 &3, cylinder gate:	S235 JGR2 steel plate, welded, sand blasted and coated with one 0.04mm layer of FRIAZINC R zinc primer followed by a 0.2mm thick layer of ICOSIT SW500 epoxy top coat. Parts 2 and 3 originally joined with zinc plated hex head bolts, later replaced with A2 stainless steel bolts.
No. 4, generator:	Cast aluminium case, steel bearing shields, painted with black paint.
No. 5, generator case:	S235 JRG2 steel plate, welded, sand blasted and coated with one 0.04mm layer of FRIAZINC R zinc primer followed by a 0.2mm thick layer of ICOSIT SW500 epoxy top coat.
No. 6, shaft coupling:	N-Eupex B110, made from EN-GJL-250 cast steel, no specific corrosion protection
No. 7, shrink disc:	unspecified Cr-Ni steel, black steel bolts later replaced by bolts in A4 stainless steel
No. 8, thrust bearing:	case and cover in S235 JRG2 steel, epoxy painted, S235 JRG2

	shaft sleeve later replaced with newly designed part made from CG-Cu Al10 Ni5 Fe4 Aluminium bronze.
No. 8a, thrust bearing:	temporary design based on a grease-lubricated flange bearing unit. Carrier plate and seal retainer machined from 1.4301 stainless steel, carrier spacer machined from 1.4021 steel.
No. 9, turbine shaft case:	welded from S235 JRG2 steel plate, corrosion protection as No. 2 & 3.
No. 10, turbine shaft:	from 1.4460 austenitc-ferritic stainless steel
No. 11, stay vanes:	machined from S235 JRG2 steel, corrosion protection as No. 2 & 3
No.12 radial turbine shaft bearing:	bearing housing made from S235 JRG2 steel bar, containing rubber bearing elements, retaining ring made from AISI 316, fixed with A4 bolts
No. 13, guide vanes:	machined from S235 JRG2 steel, corrosion protection as No. 2 & 3
No. 14, turbine runner	machined from CG-Cu Al10 Ni5 Fe4 aluminium bronze 2.0966
No. 15, runner shroud	stainless steel 1.4301
No. 16 draft tube	originally specified in 1.4301 stainless steel, executed in S235 JRG2 steel plate for reasons of cost, corrosion protection as No.2 & 3, later replaced by silicone antifouling paint system.

3.2. Hydraulic cylinder

The cylinder gate was actuated by Danfoss water hydraulic cylinders operated with a water/glycol mixture as working fluid. All the components were made of a high grade chrome nickel steel. The cylinder gate mounting pins were made from 1.4301 stainless steel.
Both cylinder and fasteners have stood the corrosion attack very well. There were no cylinder leaks observed at any time. The tarnishing of the cylinder is just extraneous rust from the black steel parts in the neighbourhood, which could easily be wiped away, as seen on the piston rod. The shackle bolts had to be cut off, however, as they were seized within the black steel rod eyes on the generator case due to corrosion of the latter.

fig. 5: hydraulic cylinder for operating gate

3.3. cylinder gate

The cylinder gate had been made of S235 JGR2 steel plate, welded, sand blasted and coated with one 0.04mm layer of FRIAZINC R zinc primer followed by a 0.2mm thick layer of ICOSIT SW500 epoxy top coat, which is the standard practice applied to sweet water hydro turbines.

fig. 6: cylinder gate

As can be seen from fig. 6, the coating only worked well in the few places where it never received any blemishes. Apart from any scuffing during handling and assembly, which might be avoidable to an extent, it is obvious that corrosion started also from all the fixing bolts and thread holes, where the coating already gets damaged when the bolts are tightened, and from any edges where the coating is normally thin and vulnerable, see fig. 7.

fig. 7: cylinder gate - corrosion on edges and connection bolts

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Also, the lower edge which forms the seal with the turbine guide vane ring naturally loses its coating very soon. This did not result in severe leaking of the seal, but corrosion worked upwards from here, see fig 8.

fig. 8: cylinder gate – corrosion on lower edge

In order to permit access to the bearings, inspection windows had been cut into the gates at a later stage. This work has been performed partly at sea and partly at the Folkecenter workshop near Nissum Bredning. Thus it was not possible to carry out the coating of the edges with primer and top coat to a very high standard. The inspection window was closed with a plate of 1.4301 stainless steel, held in place with M6 hex bolts from A2 steel. Apart from a tarnish from extraneous rust the plate coped well with the corrosion attack, see fig. 9.The threads had been treated with water resistant grease before fitting the bolts and most of them could still be unscrewed about 5 years later.

The gate cylinder was prevented from rotating by two PE guide rails and was intended to glide on Teflon strips, see fig. 10. While the former stood well up to the job, the Teflon strips were partly torn away by the increasingly rough inner surface of the cylinder gate. Probably this problem was aggravated by rust swelling up underneath the bearing strips.

fig. 9: cylinder gate cover plate

fig. 10: cylinder gate guide rails and bearing strips

3.4. permanent magnet generator

The permanent magnet generators had been made by a firm in Czechoslovakia. It was possibly due to communication problems that they were obviously not produced to withstand any salt water attack. Their aluminium case and steel top cover plate had only received some decorative painting and the name plate said they were only specified protection class IP54. It can be seen from fig. 11 that the generator casing has suffered from the corrosion attack. The rear top bearing cover had no O-ring seal. It was re-fitted with some sealant during a repair. While this could apparently not completely prevent the ingress of humidity, it seemed sufficient to protect the bearing from corrosion.

fig. 11: permanent magnet generator

Fig. 12 shows the bottom (drive) side of the generator. No corrosion resistant materials had been used here, and the bearing, being a lip-sealed type, was exposed to the eventual salt water spray occurring here. As a result, the shaft was found heavily corroded and the bearing destroyed by corrosion – the shaft could not be turned by hand any more when the turbines were dismantled. Due to the restricted space available, the generators were delivered without a connection box. This proved very cumbersome when dismantling and reassembling the turbines during a repair. They were thus converted to carry a junction box for which purpose, due to poor local availability, domestic outdoor junction boxes were used. Apart from the use of a few nuts from unsuitable material (zinc plated instead of brass) these boxes with a rubber seal cover did work quite well, see fig. 13.

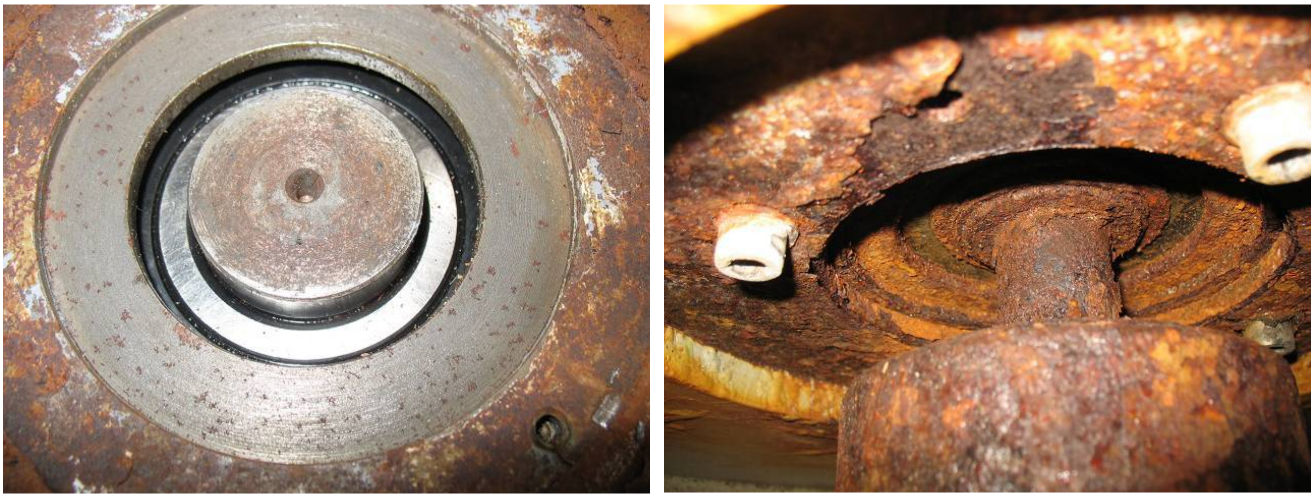

fig. 12: generator top and lower bearing

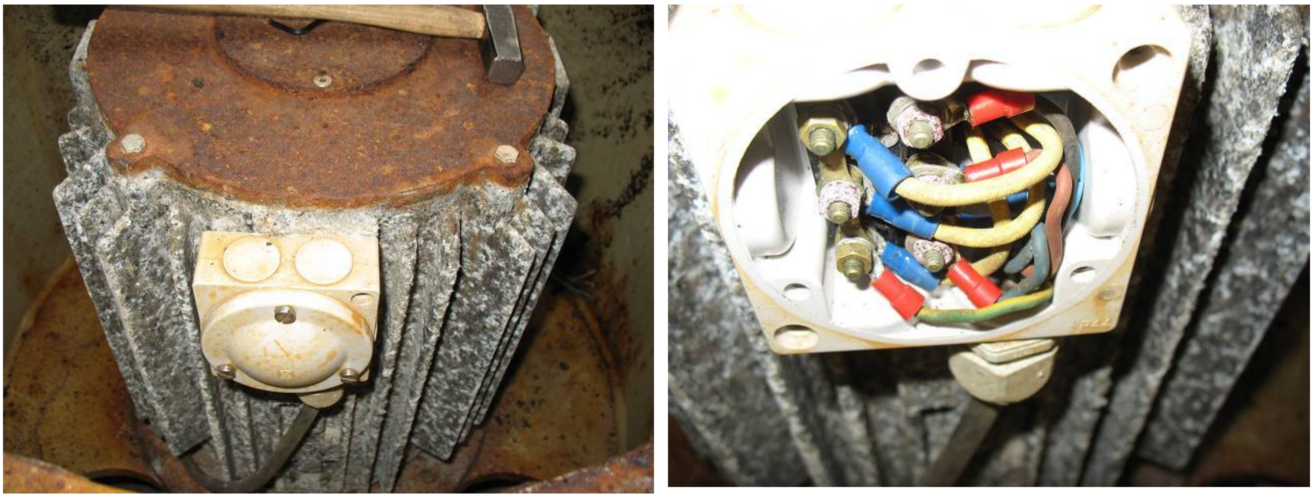

fig. 13: generator terminal box

3.5. generator case, turbine shaft case and bolt connections

The generator case and turbine shaft case were, like the cylinder gate, manufactured from S235 JGR2 steel plate, welded, sand blasted and coated with one 0.04mm layer of FRIAZINC R zinc primer followed by a 0.2mm thick layer of ICOSIT SW500 epoxy top coat. Like with the cylinder gate, the corrosion protection proved only successful in places where no mechanical impact of any kind was sustained.

fig. 14: generator case and turbine shaft case

Some of the bolt connections had originally been made with zinc plated bolts. These were exchanged for A2 stainless steel bolts at a later re-assembly. Fig. 15 shows one of the bolt connections with the typical problem: The paint layer is squashed away under the bolt head, and some of it chipped off next to the area of the bolt head. In this case, a zinc plated washer has been used instead of a stainless steel one. On the underside, where it was protected by the grease used in the assembly, the washer is still near perfect, while on the upper side, it is heavily corroded where it was exposed to the elements. The inside of the bore and the thread in the black steel part appear almost pristine, which must be credited to the extensive use of water repellent grease during the assembly. The A2 bolts are, save from some tarnishing due to extraneous rust, in perfect condition.

fig. 15: bolt connection of upper generator deck

Fig. 16 shows another such bolt connection; in this case an A2 washer was fitted under the bolt head. Bolt and washer are free from corrosion, and, remarkably, there is no increased corrosion on the black steel parts near the stainless components.

fig. 16: bolt connection of generator case and turbine shaft case

3.6. generator shaft coupling

For reasons of cost, a standard Flender N-Eupex B110 shaft coupling made from EN-GJL-250 cast steel without any specific corrosion protection has been used. Despite the fact that the internal turbine parts were basically shielded from the elements, it seems they were exposed to salt water spray rather often.

The component was still functional, albeit heavily corroded, see fig. 17

fig. 17: generator shaft coupling

3.7. turbine thrust bearing assembly

The turbine thrust bearing assemblies were derived from standard river hydropower practice. Unfortunately the designer had not borne in mind that they were to be exposed to salt water. The shaft sleeve was found heavily corroded after a few months time, and the lip seal gliding on it was destroyed, which permitted salt water entry into the bearing. Thus, the bearings were redesigned with a different sealing system and a shaft sleeve made from corrosion resistant CG-Cu Al10 Ni Fe Aluminium bronze, see fig. 18. The whole bearing assembly was also protected against dripping and spray water by a hood spun from CuZn18 gilding metal. The Aluminium bronze bearing sleeve and the redesigned seal have apparently worked quite well. The oil contained in the bearing had some humidity in it, but there was no obvious corrosion damage to the bearings, see fig. 20. The bearing hood was found almost pristine on the inside. It had some corrosion on the outside, but when the light scaling on the surface was removed by a quick etching of hydrochloric acid, the metal came out bright and without corrosion marks, see fig. 21.

fig. 18: thrust bearing rebuild in the year 2005

fig. 19: thrust bearing after rebuild in 2005

fig. 20: thrust bearing after dismantling in 2012

fig. 21: thrust bearing shield 2012

The turbine shaft was held in the bearing sleeve by means of a Benzler type 3071 shrink disc. The material specification is unfortunately unavailable. However, it seems that the disc itself consisted of a nickel-chromium steel with a moderate corrosion resistance. While the discs were still in quite good condition during the overhaul in 2005, they were now found strongly corroded, see fig. 22.

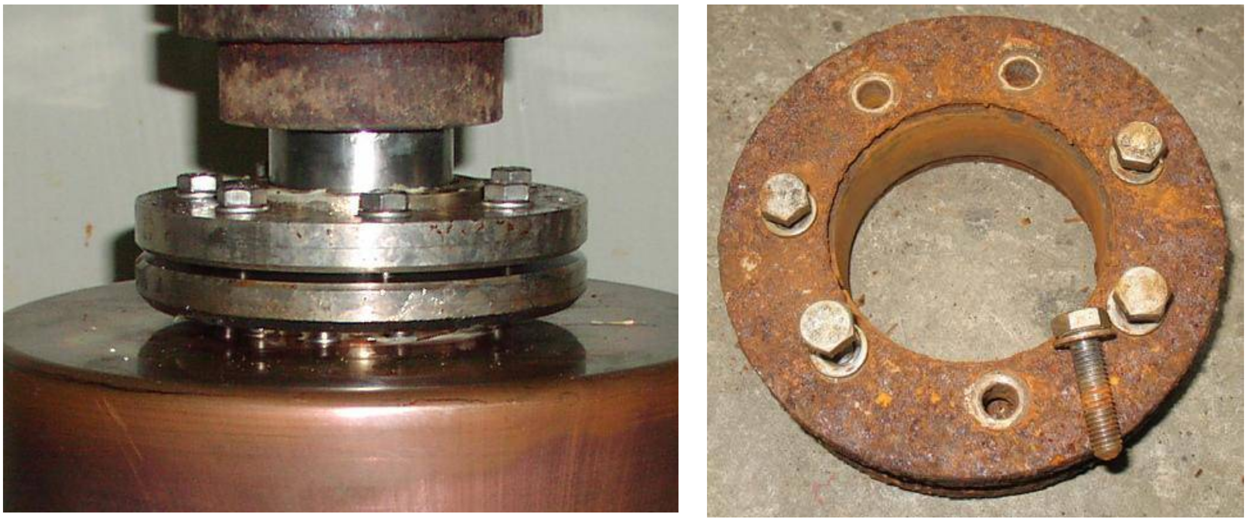

fig. 22: shrink disc assembly during overhaul in 2005 and now in 2012

During the 2005 rebuild of the Wave Dragon turbines, some of the bearing assemblies had been replaced with a relatively cheap solution based on a readily available flange bearing assembly, see fig. 23. The bearing was SKF No. FYJ 65 KF, with a case consisting of grey cast iron. The mounting platform consisted of a top plate machined from 1.4301 stainless steel and a spacer ring below it machined from 1.4021 steel. The whole bearing assembly was also protected against dripping and spray water by a hood spun from CuZn18 gilding metal.

This temporary solution did work until the end of the testing programme, but it did not cope with the corrosion attack too well, see figs. 24 and 25. The bearing protection shield itself was in good condition, but it was obviously not able to keep the salt water away from the bearing. The cast iron bearing case was rusted as well as the carrier plate and spacer below it. This is surprising especially in the case of the carrier plate, as it was reportedly made from 1.4301 stainless steel. We suspect it was either made of 1.4021 like the spacer below, or possibly the presence of the cast iron bearing case has aggravated the corrosion attack.

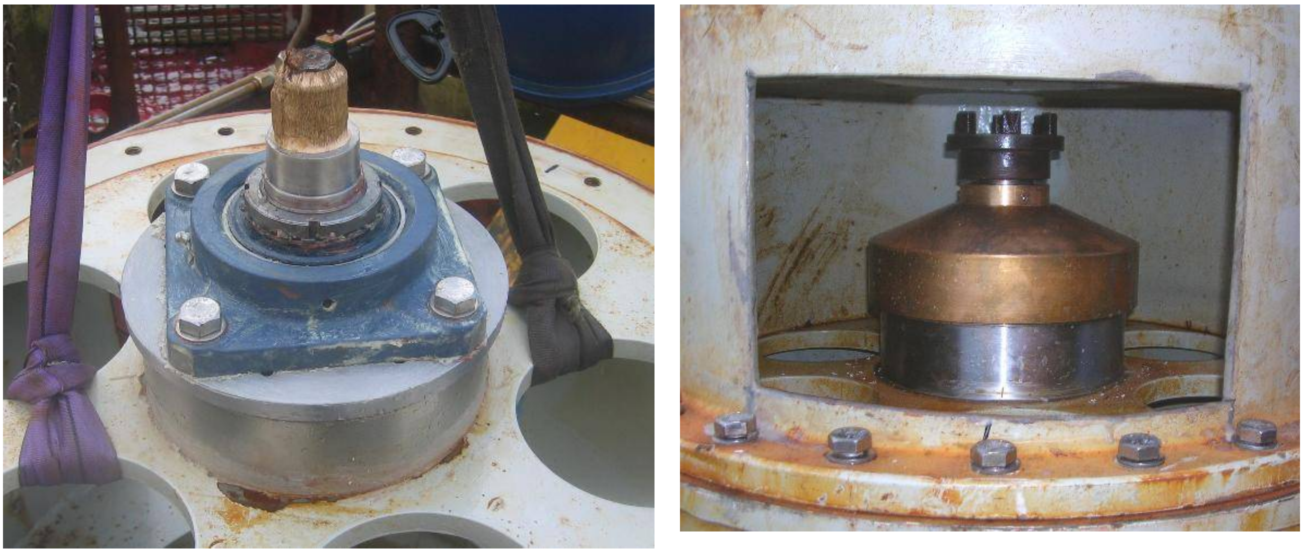

fig. 23: roller thrust bearing rebuild in the year 2005

fig. 24: roller thrust bearing assembly

fig. 25: roller thrust bearing assembly

3.9. turbine runner shaft and radial turbine shaft bearing

The runner shaft had been manufactured from 1.4460. This is an acid-resistant austenitc-ferritic steel with very good corrosion resistance particularly in chloride-bearing environments; it is normally used for propeller & pump shafts, spindles, and stirrers operating in corrosive fluids. Except for some tarnishing due to extraneous rust, the shaft had no signs of corrosion, see fig. 26. Fig 27 shows the upper shaft end after dismantling and with the extraneous rust partially cleaned off.

fig. 26: turbine runner shaft

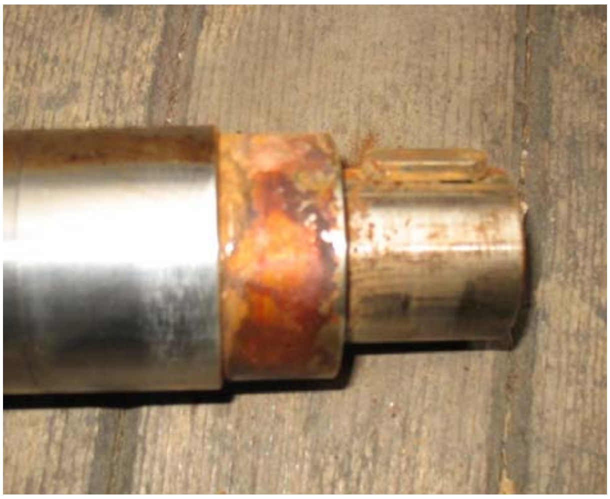

fig. 27: turbine runner shaft, upper end

Fig. 28 shows the part of the shaft that had run in the radial rubber bearing. Due to the long period of standstill after the end of the testing programme, chalk deposits had formed on the shaft in the lubrication grooves of the bearing. After cleaning these off, the shaft showed only some spots of light discoloration, see second picture in fig. 28.

fig. 28: turbine runner shaft, radial bearing section

Fig. 29 shows the radial shaft bearing, which is a water lubricated rubber type bearing as used for propeller shafts in small ships. The bearing shell had been made from S235 JRG2 steel bar, the ring retaining the rubber bearing elements was made from 1.4301 stainless steel and held in place by A4 bolts. From the pictures it is apparent that the bearing shell has suffered strong corrosion on all the exposed surfaces; the retaining plate and bolts are only covered with lime scale and extraneous rust. The inside of the bearing shell shows only very light corrosion, in some areas there was a dark discoloration only - obviously the fit of the rubber elements was tight enough to prevent the exchange of water and oxygen here, see fig. 30

The bearing was supplied with unfiltered sea water as lubricating fluid. The sand particles carried in the lubricating water could be found inside the bearing, and a closer examination of the shaft showed that the sand has worn a number of slight grooves into the surface of the shaft, see 2nd picture in fig. 31.

fig. 29: runner shaft radial bearing

fig. 30: rubber element retainer and inside of radial bearing shell

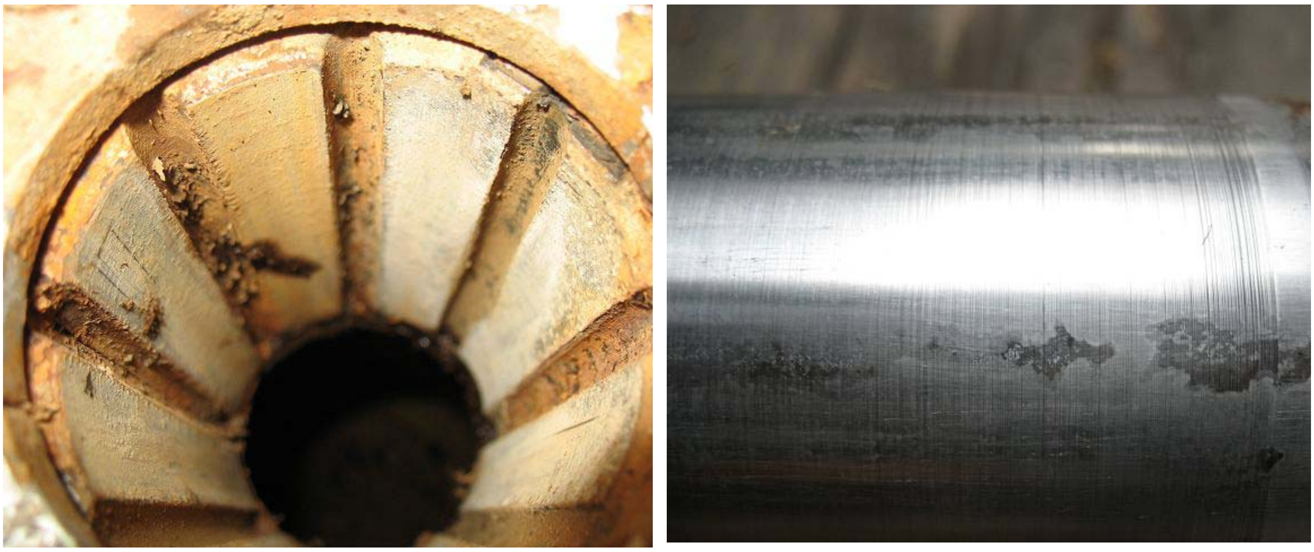

fig. 31: inside of bearing elements and radial bearing section of the turbine runner shaft

3.10. guide and stay vanes

Like the turbine case parts and the cylinder gate, the stay vanes, guide vanes and inner turbine cone had been manufactured from S235 JGR2 steel plate, welded, sand blasted and coated with one 0.04mm layer of FRIAZINC R zinc primer followed by a 0.2mm thick layer of ICOSIT SW500 epoxy top coat. As these turbine parts had frequently received various kinds of mechanical impact from foreign matter contained in the sea water, the corrosion protection failed almost completely here, see fig. 32. While there was no substantial problem during the testing period, it is apparent that better corrosion protection measures need to be taken for the turbines in a production prototype. There is also some marine growth visible on the inner turbine cone - a number of sessile barnacles had settled down here.


fig. 32: inside of bearing shell and radial bearing section of the turbine runner shaft

3.11. turbine runner

The turbine runners had been CNC machined from Cu Al10 Ni5 Fe4 aluminium bronze, Wst.-Nr. 2.0966. This is a material known for its very good corrosion resistance in seawater environments, and for its very good corrosion fatigue resistance. During the turbine overhaul in 2005, the runners showed only some tarnishing due to extraneous rust, see fig. 33, and, in the case of turbines that had stood still for longer periods, some barnacle growth on the blades. The dismantling in 2012 showed a different picture, though: some dark and hard deposit/corrosion layer had formed on the entire surface of the runners, see 2nd picture. Possibly this layer has only formed during the time when the prototype was laid up on the beach.


fig. 33: turbine runner during overhaul in 2005 and now

After etching off any lime and extraneous rust layers, the metal was found freckled with small corrosion pittings, which seem to go along with some defects in the crystalline structure of the material, see fig. 34.

fig. 34: corrosion on turbine runner

To make sure the pittings have not been caused or altered by the etching acid, some spots were cleaned by carefully rubbing the deposits off with emery paper. This revealed the same structure of corrosion pitting, see fig. 35.

fig. 35: corrosion on turbine runner

Finally, to prove or disprove the suspicion that the barnacles may cause additional corrosion by acid secretion, a barnacle was removed from the runner hub and the corresponding spot cleaned. The corrosion pattern was the same under the barnacle and adjacent to it, see fig. 36.

fig. 36: corrosion on turbine runner

3.12. turbine runner shroud

The runner shroud had been welded and machined from 1.4301 stainless steel. On the outside, it showed a deposit of limestone and some barnacles adhered to it, see fig. 37. On the inside, it was found heavily encrusted with extraneous rust. This is explained by the fact that, even with the turbines shut down, there is a constant small seepage of water from the surface from the reservoir through the turbine which carries along rust particles from the reservoir bottom.

fig. 37: runner shroud

However, after cleaning up the surface, the metal itself showed no signs of corrosion damage at all, see fig. 38. Interestingly, even the outside of the tubular part, which was neither machined nor polished, was found completely free of corrosion.

fig. 38: runner shroud after cleaning

3.13. draft tube

The draft tubes, originally planned to be built from EN 1.4301 stainless steel, were built from S235 JRG2 steel plate for reasons of cost. Corrosion protection was executed as with the turbine casing, i.e. sand blasted and coated with one 0.04mm layer of FRIAZINC R zinc primer followed by a 0.2mm thick layer of ICOSIT SW500 epoxy top coat. Already during the turbine overhaul in 2005, this coating proved to be very unsuitable. The corrosion protection capability was probably still sufficient, but this could not be judged very well, as the draft tubes were overgrown inside and outside with a 5 to 10cm thick layer of marine growth, see fig. 39.

fig. 39: growth on epoxy painted draft tubes, outside and inside

Two of the draft tubes had been painted with a non-toxic antifouling coating called Hempasil. On these draft tubes, only a minimum of growth was found, and what weeds and barnacles had settled down could be wiped off easily. Fig. 40 shows the ends of draft tubes that had been cut off in a design change in 2005 after being stored for some months on land. The epoxy coated tube section on the left still has the dried-up growth attached, while the Hempasil coated one on the. right is completely clean. For this reason, the remaining draft tubes were sand blasted and given the same silicone coating. After sandblasting to sa 2.5 cleanness, the coating was applied in 4 layers: two 0.15mm layers of Hempadur primer, one 0.12mm layer of Hempasil Nexus undercoat and a final 0.15mm layer of Hempasil silicone coating, see 2nd picture.

fig. 40: draft tube sections with epoxy and silicone paint

Apart from the excellent anti-fouling properties, this coating system has given very good mechanical resistance and corrosion protection so far. Figs. 41 and 42 show two of the draft tubes after dismantling the turbines. There is some dirt on the surface, but it is apparent that corrosion is only present in places where the draft tubes have been forcefully damaged during the scrapping of the Wave Dragon platform. Even the seating areas of the mounting bolt heads are free of corrosion damage, see 2nd picture in fig. 42.

fig. 41: draft tubes with silicone paint system

fig. 42: draft tubes with silicone paint system

4. Conclusion

From the analysis made, it becomes apparent that in a sea environment with a salinity of approx. 3.0 % to 3.4%, corrosion protection of engineering structures and electromechanical equipment is a demanding task. Traditional epoxy paint systems failed to give a protection that would last much longer than two or three years, at least on machinery components that are exposed to some mechanical impact. Clearly, for a wave energy converter with a planned life time of 50 years, a different approach is needed. As far as the turbines are concerned, the following considerations should be taken to heart:

- if at all possible, casing parts should be made from inherently corrosion resistant materials such as high grade stainless steel or plastics. This might require the loads to be exactly calculated in order to save precious materials.
- bearings and electrical components need to be enclosed in a hermetically sealed casing.
- where corrosion resistant materials are not feasible, only the best coating systems are good enough.
- cutting corners in design, manufacture, assembly and operation does never pay off, thus:
    - any possible care needs to be taken in the design process, identifying potential corrosion problems
    - great care needs to be taken in the assembly, making all joints 100% water proof and avoiding any blemishes to protection coatings.

Judging from the experiences made in Nissum Bredning and taking advantage from these, it should be possible to design a power takeoff system for Wave Dragon with 25 years life time at a economically feasible cost.

BILAG 15

FORCE Technology, Investigation of corrosion extent on samples from Wave Dragon

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Investigation of corrosion extent on samples from Wave Dragon

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Your ref.:	-
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26 February 2013

CORROSION AND METALLURGY

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Table of Contents

OVERVIEW OF APPENDICES

Appendix 1: Coating specification (in Danish)

At your request, FORCE Technology has examined a number of corroded steel plates from Wave Dragon, which has been exposed in Nissum Bredning in the period of 2003-2011.

Background information

According to the information supplied by Wave Dragon Aps, the Wave Dragon is a floating, slack-moored energy converter of the overtopping type. The first prototype connected to the grid was deployed in Nissum Bredning, Denmark.

The main components of a Wave Dragon are:

- Main body with a doubly curved ramp; a reinforced concrete and/or steel construction
- Two wave reflectors in steel and/or reinforced concrete
- Mooring system
- Propeller turbines with permanent magnet generators

The main body or platform is basically one large floating reservoir. The Nissum Bredning prototype is a traditional (ship-like) steel plate construction, primarily 8 mm steel plates.

The area in Nissum Bredning where the prototype was deployed had a water depth of approximately 6 m. Nissum Bredning should be treated as regular North Sea seawater with a salinity of approximately 3.1-3.3 %[1]. However less wave action should be presumed compared to the North Sea.

The prototype was exposed in Nissum Bredning in the period of 2003-2011. However the structure was deployed on a beach for approximately 1 year, on ground for approximately 6 months and in port for longer periods.

The submerged steel plates therefore may only have been exposed at sea for approximately 6-7.5 years, depending on the exact placement. The plates exposed above the water have only been at the sea for approximately 4.5 years; the rest of the time, they have been in port.

Figures 18-21 show received photos of Wave Dragon from the period 2003-2006.

As mentioned, the steel on the prototype of Wave Dragon consisted of 8 mm steel plates. Since the initial project period was 3 years, the steel was only coated with a one layer coating system

1 http://www.naturstyrelsen.dk/Vandet/Havet/DanskeFarvande/Limfjorden/Togt_i_Limfjorden_26_27_maj_2010.htm

(200 µm Hempadur Mastic 45888 red). The pre-treatment before coating was emulsion cleaning followed by wet sandblasting with quartz sand in order to remove mill scales. The coating specification is enclosed as Appendix 1 (in Danish).

The information above has been supplied by Wave Dragon Aps by e-mail and is available on the web at www.wavedragon.net.

Purpose of examination

The purpose of the examination was assessing the extent of corrosion on received steel plates exposed on the Wave Dragon prototype in Nissum Bredning.

Examination and results

We have received in total 6 steel plates from Wave Dragon for examination. The plates were designated:

1 Above water level.
2: Around mean water level.
3: Bottom.
?: No information regarding placement in the atmosphere/water.
Two small pieces not marked: Some of the most corroded pieces from Wave Dragon.

The two small pieces were designated 4a (smallest piece) and 4b (largest piece) by us. The received steel plates are seen in Figures 1-6. After visual examination and examination in stereo microscope, the corrosion products were removed by inhibited acid cleaning (Figure 7). The cleaned plates were examined visually and the depths of the maximum localised corrosion attacks (pitting) were measured. The observations and measurements of the maximum pit depths are summarised in Table 1 below:

Item / Location /	Comments, samples as received	Comments, after acid cleaning	Max. pit depths, mm
1 **Above water level**	The coating remains in fragmented areas on the surface on: Side with ID tag: 5 % of the area Other side: 20 % of the area The coating appears loose in the small fragmented areas. In one larger area, approx. 10x15 cm, the coating adheres rather well. The unprotected part of the surface is covered with rust with limited tendency to pitting (Figure 2).	Widespread minor pitting (figures 8, 9).	0.6 0.5
2 **Around mean water level**	Yellowish coating remains on approx. 50-60 % of the surface area. When scraping with a scalpel, the coating appears reddish below the top layer. The coating in general appears broken down and cannot be expected to provide protection. The unprotected part of the surface is covered with rust with some tendency to pitting (Figure 3).	Few micro pits (figures 10, 11).	0.2
3 **Bottom**	No coating is left on the surface. The specimen is completely covered with rust. Small flakes of corrosion products can be removed from the surface. Tendency to pitting observed. The thickness of the rust layer is assessed to < 1 mm (Figure 4).	Widespread pitting (figures 12, 13).	0.8 1.0 1.1
? **Unknown**	No coating is left on the surface. The specimen is completely covered with rust. Small flakes of corrosion products can be removed from the surface. Tendency to pitting observed. The thickness of the rust layer is assessed to < 1 mm (Figure 5).	Localised corrosion more wide in area compared to samples 1 and 3 (figures 14, 15).	0.9 1.2 1.1
4a (small) **Unknown**	Coating is left on < 5 % of the surface in small fragmented areas. The rest of the specimen is completely covered with rust. Small flakes of corrosion products can be removed from the surface. Tendency to pitting observed. The thickness of the rust layer is assessed to < 1 mm (Figure 6).	Widespread pitting (figure 16)	0.8 0.6
4b (large) **Unknown**	Coating is left on < 5 % of the surface in small fragmented areas. The rest of the specimen is completely covered with rust. Small flakes of corrosion products can be removed from the surface. Tendency to pitting observed. The thickness of the rust layer is assessed to < 1 mm (Figure 6).	Widespread micro pits. Localised corrosion in weld seam (figure 17).	Localised corrosion in weld seam: 0.8 1.1

Table 1: Observations from visual examination of the steel plates before and after acid cleaning.

Assessment

In order to compare the corrosion extent on the coated steel plates from Wave Dragon with literature data, it is essential to assess for how long a time period, the coating may have protected the steel surface from corrosion.

DS/EN ISO 12944-5 provides suggested coating systems and expected durability for both atmospheric marine environment (corrosives category C5-M) and immersed seawater (corrosives category Im2).

The actual coating system is 200 µm Hempadur Mastic with wet sandblasting as pre-treatment, presumably in a 1-coat system.

For C5-M environment, DS/EN ISO 12944-5 provides a system consisting of epoxy in a 3-coat system, in total 300 µm with an expected medium durability meaning that first maintenance must be expected after 5-15 years. For Im2, DS/EN ISO 12944-5 provides a system consisting of epoxy in a 2 coat system, in total 330 µm, again with medium durability. On this background and assuming a good pre-treatment, we assess that the present coating system on Wave Dragon in general will have protected the steel surfaces for approximately 3-5 years.

Figures 18-21 show received photos of Wave Dragon. In Figures 20 and 21, partial breakdown of the coating system is noticed (after 3 years of deployment).

The expected corrosion rates of unprotected steel in seawater can be found in Dansk Ingeniørforening´s recommendation for corrosion protection of steel structures in marine environment, DS R 464-1988. The rates are given as:

Zone	Uniform corrosion rate, mm/year	Localised corrosion rates, mm/year
Atmospheric zone (data from DS/EN ISO 12944-2)	0.08-0.2	0.2
Water line	0.1	0.2
Most corroded zone, located approximately 0.5 meters below mean tide and further down	0.2	0.4-0.6
More deep water	0.1	0.2

Table 2: Corrosion rates from DS R 464-1988.

As seen from the table, the corrosion rates are divided into uniform (general) corrosion rates and localised corrosion rates of unprotected steel in seawater. In comparison, the corrosion rate of steel protected by organic coating will be 0 mm/year until the coating has degraded and the steel becomes exposed.

The condition of the received steel plates does not allow for determination of weight loss, since the exact plate thickness is not known and since the plates do not have a well defined geometry. However, based on the visual condition of the received plates, the uniform corrosion rates have been rather low, most probably not exceeding the rates given in Table 2.

As the initial plate thickness is not known, it is impossible to give a uniform corrosion rate, but instead the depth of the localised corrosion attacks (pits) must be used in order to assess the maximum localised corrosion rates. Thus the localised corrosion rates can be compared to the expected rates. In Table 3 below, the measured pit depths have been compared to the expected corrosion rates from unprotected steel in seawater (Table 2):

Item / Location	Max. pit depth (cf. Table 1)	Maximum localised corrosion rate, mm/year based on unprotected exposure time of	
		5 years	3 years
1 Above water level	0.6	0.12	0.20
2 Around mean water level	0.2	0.04	0.07
3 Bottom	1.1	0.22	0.37
? Unknown	1.2	0.24	0.4
4a (small) Unknown	0.8	0.16	0.27
4b (large) Unknown	1.1	0.22	0.37

Table 3: Calculated localised corrosion rates based on maximum pit depths.

From Tables 2 and 3, it can be seen that the data from the literature complies quite well with the measured depths of the pitting corrosion in the steel plates. The only steel plate deviating a little is sample 2, which has been located around the mean water level. On this sample, the coating remains on approximately 50 % of the sample indicating that the coating may have been thicker or better adhering in this area. Other explanations for the rather low corrosion rate could be that the sample has been less mechanically impacted that the other samples.

Based on the available information, our best assessment is that the coating system has protected the steel surfaces for approximately 3-5 years depending on position whereupon the steel can be considered as unprotected. Then the submerged steel has been exposed unprotected in seawater for approximately 3 years on average, while the steel in the atmospheric zone perhaps has been exposed unprotected a little longer. However, the picture is a little diffuse since the submerged/atmospheric zones and exposure times are not very well defined due to the complex exposure of Wave Dragon in the period 2003-2001 (at sea, at beach, ground, in port).

However, in general, the calculated localised corrosion rates based on the maximum pits in the samples support the data from DS R 464-1988 meaning that localised corrosion rates of 0.2 mm/year can be expected for the atmospheric and water line zones for unprotected steel. For the most corroded submerged zones (0.5 m below mean water line and some meters further down) up to 0.4-0.6 mm/year can be expected. The uniform corrosion rates cannot be evaluated from these samples but, in general, the rates expected are 0.1 mm/year for the water line and 0.2 mm/year for the most corroded submerged zones.

Conclusion

Based on the received information and the conducted examinations, we have contracted the exposure of Wave Dragon in Nissum Bredning into the following simplified picture:

Protected by coating:	3-5 years (average 4 years).
Unprotected:	3 years on average.
Total exposure time:	6-8 years depending on position.

Based on 3 years of exposure, a total corrosion of 0.6 mm (uniform) and 1.2-1.8 mm (localised) of unprotected steel can be expected from the literature. The uniform corrosion rates on the received samples cannot be evaluated; however based on the visual appearance, the samples do not appear significantly corroded. The maximum localised corrosion attacks (pitting) in the samples were however measured, and attacks up to 1.2 mm were identified, matching the expected corrosion attacks from the literature.

In conclusion, the corrosiveness of Nissum Bredning is hence in line with what can be expected of exposure in natural seawater. A more detailed conclusion is not possible due to the condition of the received plates and the complex exposure of Wave Dragon.

Figure 1 The received samples with the designations 1, 2, 3, ? , 4a and 4b.

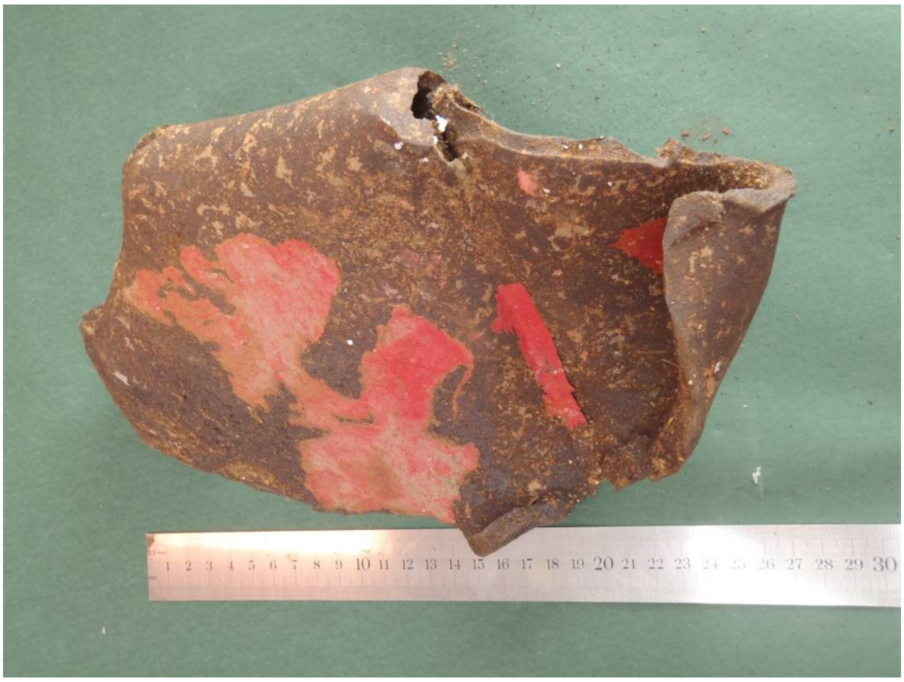

Figure 2 Sample 1 as received.

Figure 3 Sample 2 as received.

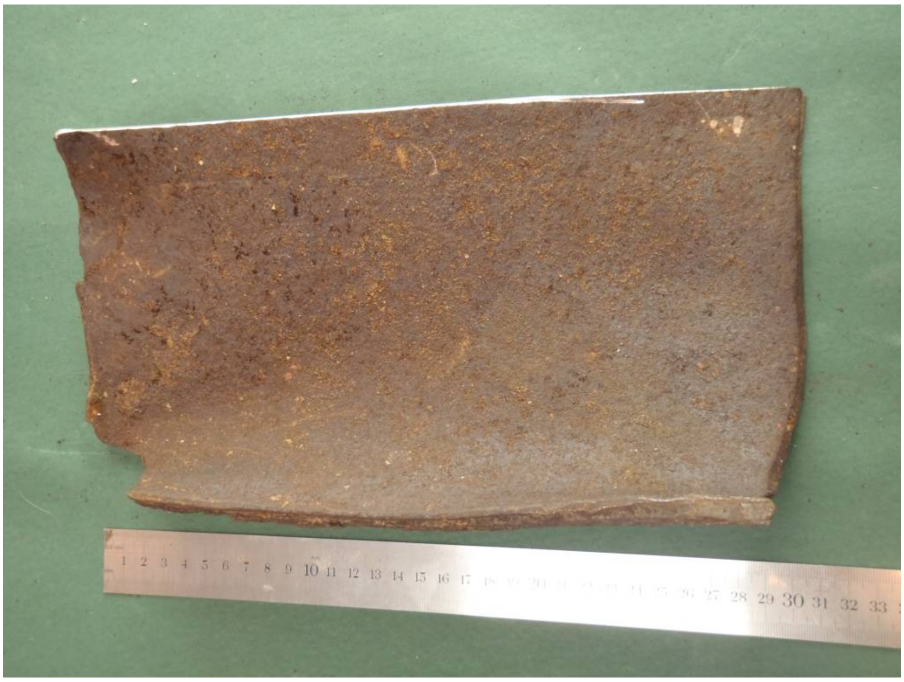

Figure 4 Sample 3 as received.

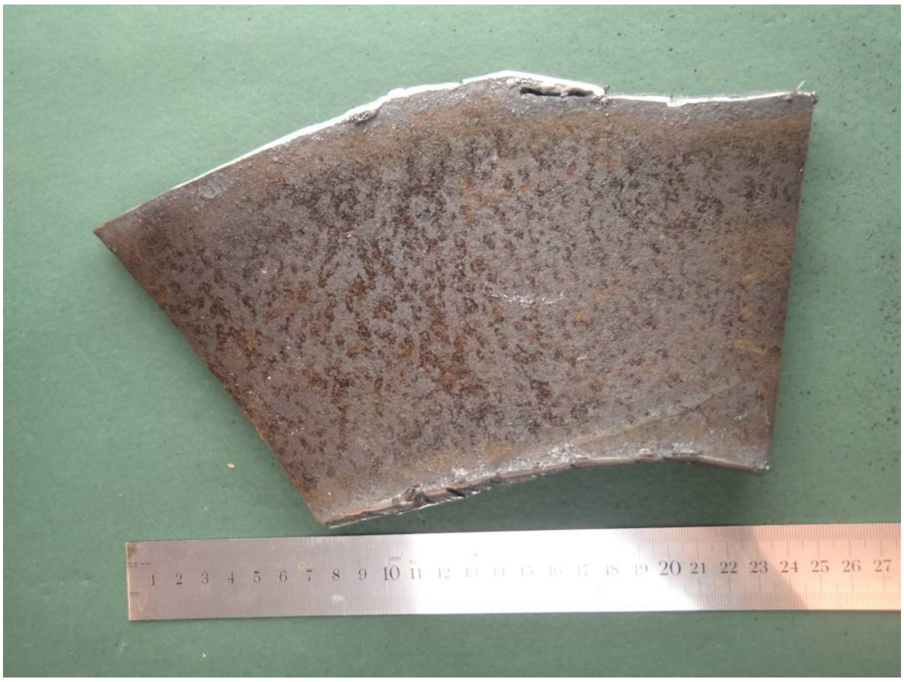

Figure 5 Sample ? as received.

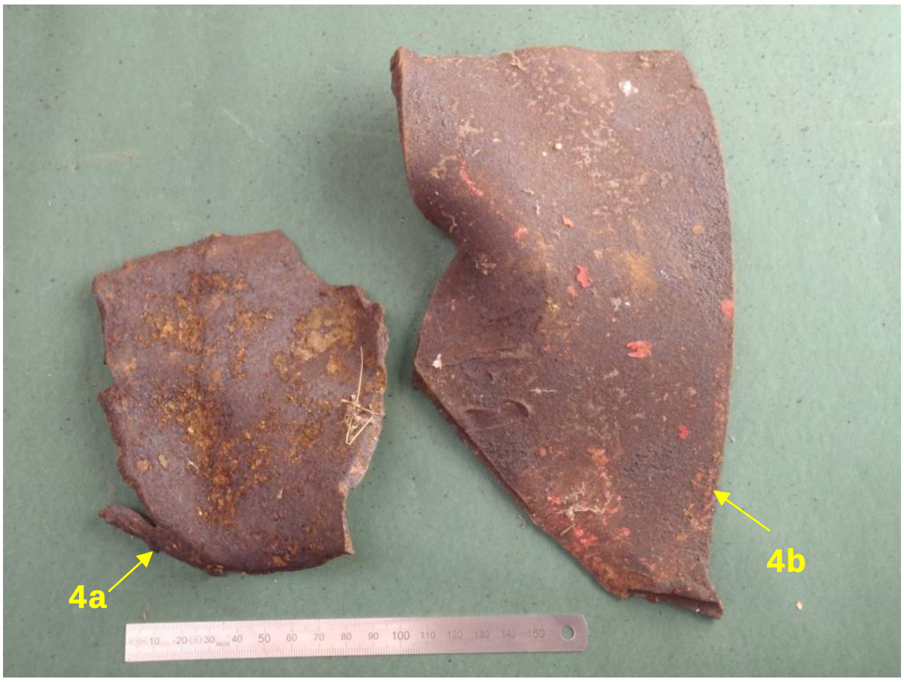

Figure 6 Samples 4a and 4b as received.

Figure 7 The samples after acid cleaning.

Figure 8 Sample 1 after acid cleaning.

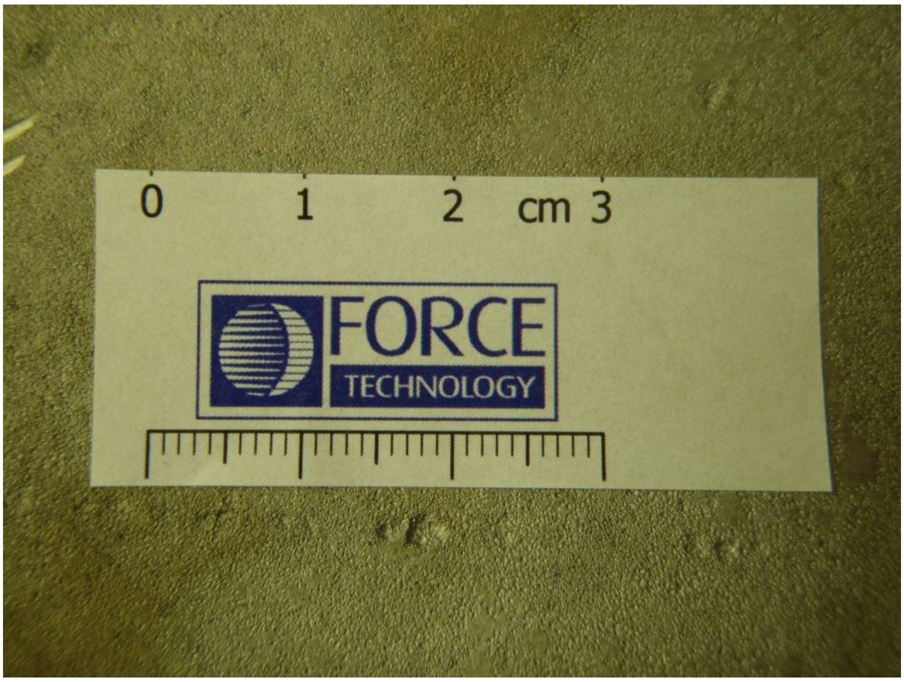

Figure 9 Pitting 0.6 mm deep in sample 1 after acid cleaning.

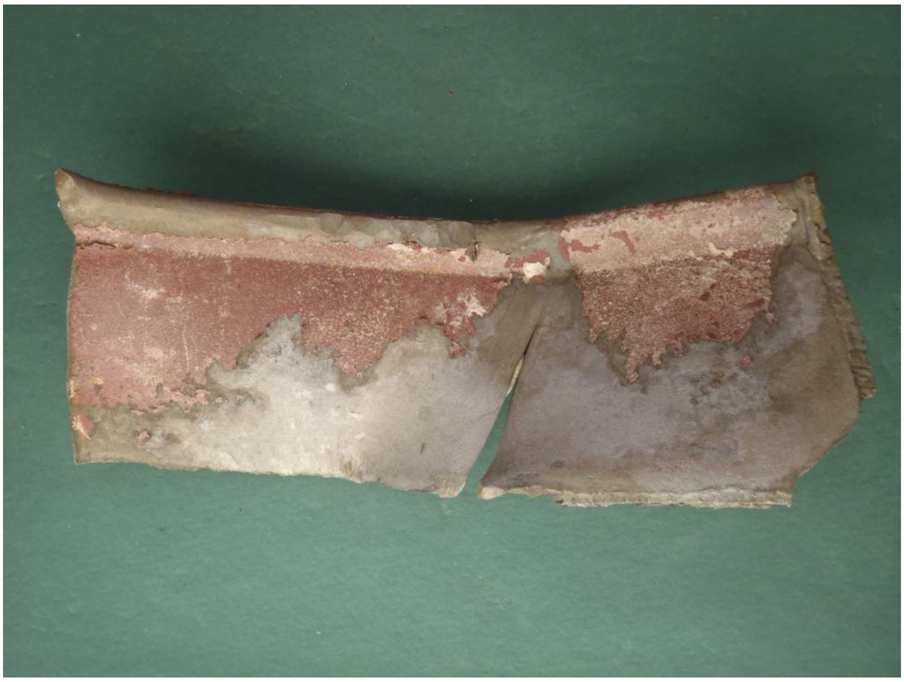

Figure 10 Sample 2 after acid cleaning.

Figure 11 Pitting 0.2 mm deep in sample 2 after acid cleaning.

Figure 12 Sample 3 after acid cleaning.

Figure 13 Pitting 1.1 mm deep in sample 3 after acid cleaning.

Figure 14 Sample ? after acid cleaning.

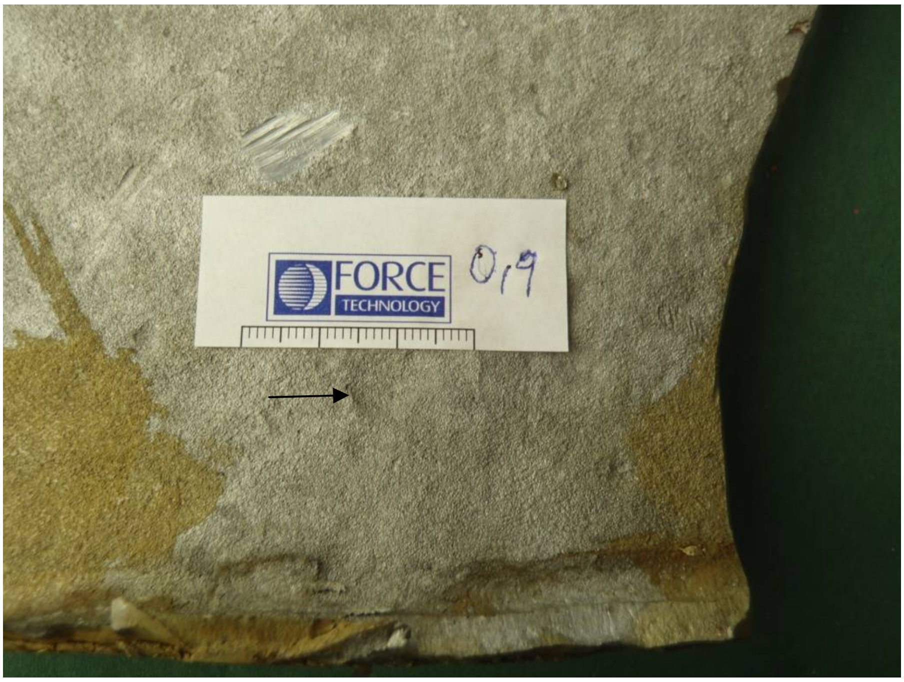

Figure 15 Pitting/localised corrosion 0.9 mm deep in sample ? after acid cleaning.

Figure 16 Sample 4a after acid cleaning.

Figure 17 Sample 4b after acid cleaning.

Figure 18 Photo of the deployment of Wave Dragon, 10-03-2003. Photo received from Wave Dragon.

Figure 19 Photo of Wave Dragon 09-09-2004. Photo received from Wave Dragon.

Figure 20 Photo of Wave Dragon 12-01-2006. Photo received from Wave Dragon.

Figure 21 Photo of Wave Dragon 12-01-2006. Photo received from Wave Dragon.

APPENDIX 1 Coating specification

(2 appendix pages including this page)

14/02 03 FRE 08:26 FAX 98 12 68 97 001

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14 FEB. 2003

Frederikshavn 12.02.2003

I henhold til aftale, har vi hermed fornøjelsen, at kunne tilbyde overfladebehandling af Wave Dragon, 800 m2 i henhold til specifikation fra Hempel. Områderne emulsionsrenses med egnet middel, efterfulgt af ferskvandsnedspuling hvor nødvendigt. Områder til opmaling, vådsandblæses for fjernelse af glødeskaller, der blæses med kvartssand korn 0,2 - 1,8 mm.

Opmaling med 200 my tørfilm Hempadur Mastic 45880 rød.

DOF Frederikshavn rengør og opryder området efter endt behandling, samt deponerer brugt blæsemiddel og tom maleremballage.

Pris **kr. 170.000,00.**

Hempel leverer maling for projekt samt vand og strøm i fornødent omfang.

Medarbejder (pedel) fra universitetet er indregnet i prisen.

Tillæg efter prisfastsættelse. evt. opmærkninger for vandlinie niveau. Timerate kr. 275,00. Tillæg opmaling af container **kr. 5.500,00.**

Alle priser er excl. moms.

Idet vi håber, at ovennævnte svarer til Deres forventninger, hører vi gerne nærmere.

Med venlig hilsen
J. Lauridsen
DOF FREDERIKSHAVN APS
Jørn Lauridsen

* SANDBLÆSNING * METALLISERING * SPRØJTEMALING * BYGNINGSMALING * 1-2 KMP. EPOXY * DAMPRENSNING * TAGMALING

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b) at få den fejlbehæftede del eller udstyr returneret til FORCE Technology for reparation, eller
c) at udskifte den fejlbehæftede del eller udstyr, således at kunden selv kan udføre den nødvendige reparation for FORCE Technologys regning.

4.5. I det tilfælde, hvor FORCE Technology har modtaget en fejlbehæftet del eller udstyr til erstatning eller reparation, skal kunden afholde transportomkostninger samt bære risikoen ved transport.

4.6. Fejlbehæftede dele eller udstyr, som er erstattet ifølge disse bestemmelser, skal stilles til FORCE Technologys disposition.

4.7. FORCE Technologys ansvar er begrænset til fejl, som opstår under forsvarlig benyttelse. FORCE Technology hæfter ikke for fejl som følge af forkert installation og vedligeholdelse samt reparation udført af andre end FORCE Technologys personale eller agent, eller ændringer udført uden FORCE Technologys skriftlige godkendelse. FORCE Technology hæfter ikke for fejl, der skyldes normalt slid.

4.8. Garantiperioden for reservedele og tilbehør er den samme som for den udskiftede del.

5. Ansvar

5.1. FORCE Technology er ikke erstatningsansvarlig for tab eller skade, medmindre det kan dokumenteres, at tabet eller skaden er opstået på grund af fejl eller forsømmelse begået af FORCE Technology i forbindelse med produktion eller udførelsen af en rekvireret opgave.

5.2. FORCE Technology hæfter ikke for driftstab, tidstab, avancetab eller lignende indirekte tab.

5.3. FORCE Technology løser rekvirerede opgaver og fremkommer med udtalelser og vejledninger på grundlag af den viden og teknik, FORCE Technology råder over. FORCE Technology påtager sig ikke erstatningsansvar, medmindre det kan bevises, at denne viden eller teknik var mangelfuld på tidspunktet for opgavens løsning.

5.4. FORCE Technology fralægger sig erstatningsansvar for skader, som måtte indtræffe i forbindelse med en anvendelse af afgivne data og prøvningsresultater, som ligger uden for den opgave og uden for det formål, i forbindelse med hvilke FORCE Technologys udtalelse er afgivet.

5.5. FORCE Technology fralægger sig erstatningsansvar for fejl i forbindelse med udtalelser, for hvilke det er anført, at disse hviler på en skønsmæssig vurdering.

5.6. Ved udøvelse af kontrol og prøvning hæfter FORCE Technology kun for skader, som måtte opstå ved, at FORCE Technology ikke rettidigt har gjort rekvirenten opmærksom på tilstedeværende mangler.

5.7. FORCE Technology har intet erstatningsansvar for indtrufne skader, såfremt en skade skyldes en egenskab ved et produkt eller en anvendelse af et produkt, som enten ikke er afprøvet eller undersøgt og beskrevet i prøvnings- eller undersøgelsesrapporten, eller som afviger fra FORCE Technologys beskrivelse i prøvnings- eller undersøgelsesrapporten af produktegenskab eller af en mulig produktanvendelse.

5.8. FORCE Technology har intet erstatningsansvar for indtrufne skader, såfremt et skadevoldende produkt ikke konkret har været afprøvet af FORCE Technology, medmindre rekvirenten godtgør, at det skadevoldende produkt er identisk med et af FORCE Technology konkret afprøvet og kontrolleret produkt.

5.9. Hvis andre end rekvirenten rejser krav om erstatning mod FORCE Technology begrundet i forhold, der ligger ud over det erstatningsansvar, som FORCE Technology i henhold til punkt 5.1. - 5.8. har påtaget sig, er rekvirenten pligtig til at overtage sagens førelse og skadesløsholde FORCE Technology for alle omkostninger, herunder sagsomkostninger og erstatningsbeløb.

6. Tvister

Såfremt der opstår tvist mellem rekvirenten og FORCE Technology i forbindelse med udførelsen af en opgave eller fortolkning af aftalen, skal tvisten, såfremt den ikke kan løses ved forhandling mellem parterne, afgøres af Det Danske Voldgiftsinstitut på grundlag af dansk ret.

FORCE Technology - General Conditions

1. Agreement

Prior to commencing work, agreement on type and scope as well as timetable and economy shall be made in writing.

2. Ownership and copyright

2.1. Reports made by FORCE Technology shall only be published in full and with source reference. Extracts shall only be quoted upon prior permission in writing.

2.2. The client shall observe FORCE Technology's obligations in accordance with the Danish employees' inventions act.

3. Non-fulfilment of agreement

FORCE Technology shall neither in whole nor in part be liable for any non-fulfilled agreements owing to events beyond the influence of FORCE Technology.

4. Warranty

4.1. Subject as hereinafter set out, FORCE Technology shall undertake to remedy any defects resulting from faulty design, materials or workmanship.

4.2. This liability is limited to defects which occur or are discovered within twelve (12) months from the time of delivery.

4.3. In respect of special components the warranty period will be the same as the warranty period which FORCE Technology is able to obtain from their suppliers.

4.4. In the event that the client wishes to submit a claim under the warranty he shall without delay notify FORCE Technology in writing of any defect that has arisen. On receipt of such notification FORCE Technology shall if the defect is one that is covered by this clause at their option:

a) repair the defective Goods or parts in situ; or
b) have the defective Goods or parts returned for repair; or
c) replace the defective Goods or parts in order to enable the client to carry out the necessary repairs at the expense of FORCE Technology.

4.5. In the event that FORCE Technology has received defective Goods for replacement or repair, the client shall bear the costs of transport and risk of damage.

4.6. Defective Goods or parts replaced in accordance with these provisions shall be made available to FORCE Technology.

4.7. The liability of FORCE Technology shall apply only to defects that occur under proper use. In particular it does not cover defects arising from faulty installation and maintenance or repairs carried out by individuals other than FORCE Technology's personnel or their agent, or alterations carried out without the consent in writing by FORCE Technology; nor does it cover normal wear and tear.

4.8. The warranty period in respect to spare parts and accessories shall operate in the same manner as the warranty period for the replaced part itself.

5. Liability

5.1. FORCE Technology shall only be liable for loss or damage if it is proved that the loss or damage is due to errors or negligence of FORCE Technology in connection with production or performance of a task.

5.2. FORCE Technology shall not be liable for any consequential loss, such as but not limited to loss of time or loss of profits.

5.3. Tasks are solved and opinions and guidance are given by FORCE Technology on the basis of the knowledge and technology available to FORCE Technology. FORCE Technology shall only be liable if it is proved that this knowledge or technology were faulty at the time of the completion of the task.

5.4. FORCE Technology shall not accept liability for loss or damage that may occur in connection with the client's use of provided data or test results which lies outside the scope of the task and purpose in connection with which FORCE Technology's opinion has been given.

5.5. FORCE Technology shall not accept liability for errors in connection with opinions given regarding which it has been stated that they are based on an estimate.

5.6. When performing verification and testing, FORCE Technology shall only be liable for damage which might occur owing to FORCE Technology's failure to notify the client, in time, of existing defects.

5.7. FORCE Technology shall not be liable for damage occurring if such damage is due to a property of a product or an application of a product which has either not been tested or examined and described in the testing or examination report, or which differs from FORCE Technology's description in the testing or examination report of the property of the product or of a possible application of the product.

5.8. FORCE Technology shall not accept liability for damage occurred if a product causing damage has not actually been tested by FORCE Technology, unless the client proves that the product is identical with a product actually tested and verified by FORCE Technology.

5.9. If a third party claims damages from FORCE Technology on grounds which lie beyond the liability to pay damages undertaken by FORCE Technology in accordance with clauses 5.1 to 5.8, the client shall be under an obligation to take over the conducting of the case and indemnify and hold harmless FORCE Technology for all costs and damages.

6. Disputes

Any dispute between the client and FORCE Technology arising out of or in connection with the performance of a task or the interpretation of the agreement shall if such dispute cannot be solved through negotiation between the parties be settled by Copenhagen Arbitration in accordance with Danish law.

2007.07

Den Danske Akkrediterings- og Metrologifond (DANAK)

DANAK akkrediterede ydelser leveres i henhold til Erhvervsfremme Styrelsens Bekendtgørelse om akkreditering af laboratorier til teknisk prøvning m.v., henholdsvis Sikkerhedsstyrelsens Bekendtgørelse om akkreditering af virksomheder til certificering af personer, produkter og systemer, samt til inspektion. De respektive standarder i DS/EN 45000 serien og EN ISO/IEC 17000 serien samt relevante ISO/IEC Guider er en del af akkrediterings-vilkårene. DANAK specifikke krav til kalibreringscertifikaters indhold medfører bl.a. en bedømmelse af laboratoriets måleevne og dets sporbarhed til nationale normaler.

The Danish Accreditation and Metrology Fund (DANAK)

All DANAK accredited services are supplied in accordance with the National Agency of Industry and Trade's statutory Accreditation of laboratories for technical testing etc. respectively The Technical Safety Council statuory of Accreditation of organisations for certification of personnel, products and systems, and for inspection. The respective standards in the DS/EN 45000 series, the EN ISO/IEC 17000 series and the relevant ISO/IEC Guides are part of the conditions for accreditation. The DANAK specific demands to the content of calibration certificates imply an assessment of the measurement capability of the laboratory and its traceability to recognised national standards.

BILAG 16

Wave Dragon ApS, Wave Dragon pilot plant - photos 2002 - 2012

Blegdamsvej 4, DK-2200 Copenhagen N, Denmark, Phone: +45 3536 0219/ +45 3537 0211 Fax: +45 3537 4537 E-mail: info@wavedragon.net

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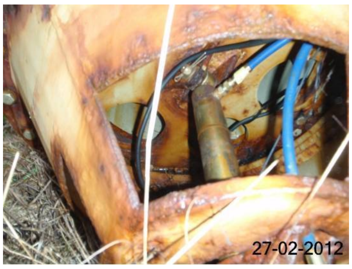

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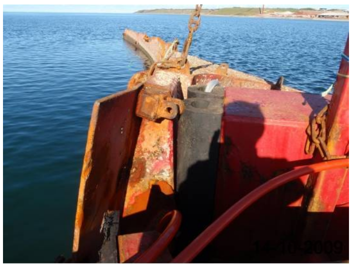
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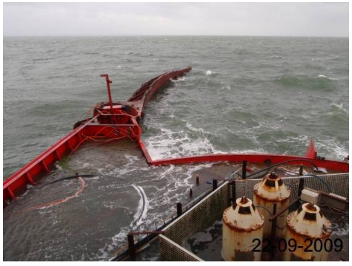

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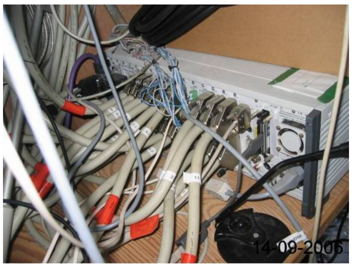

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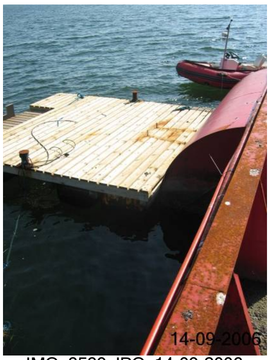

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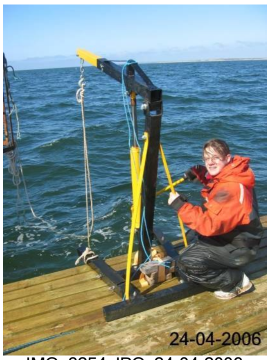

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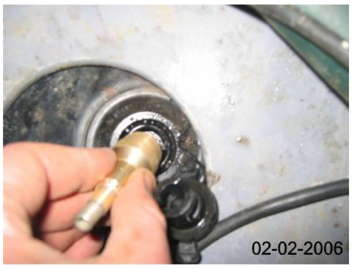

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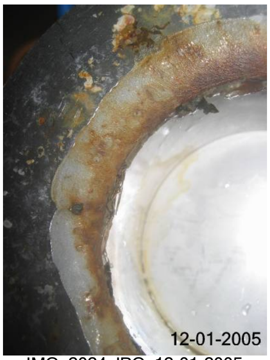

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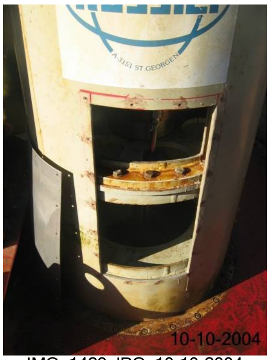

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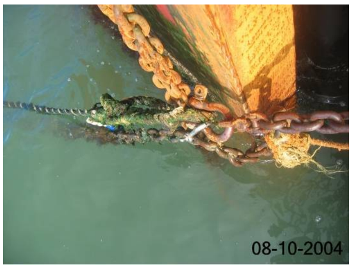

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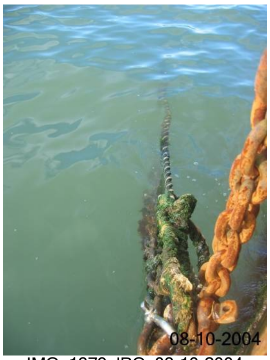

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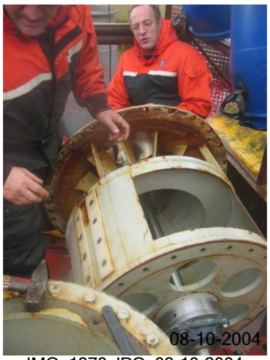

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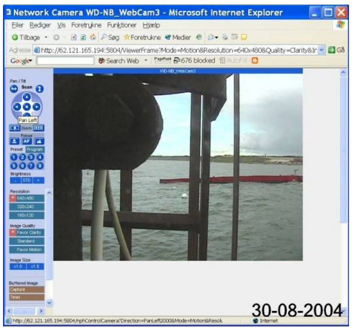

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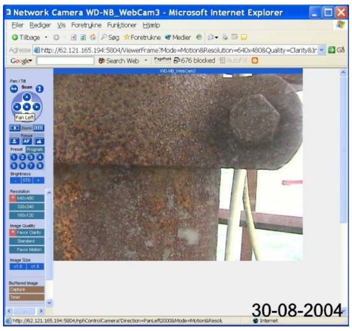

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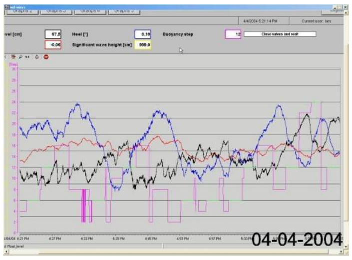

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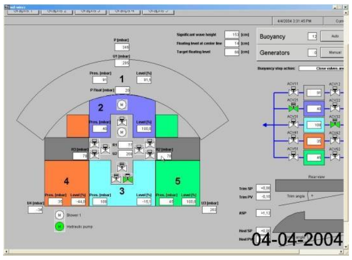

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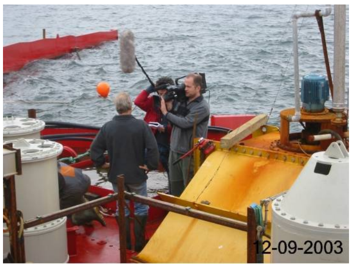

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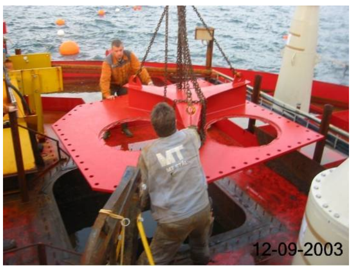

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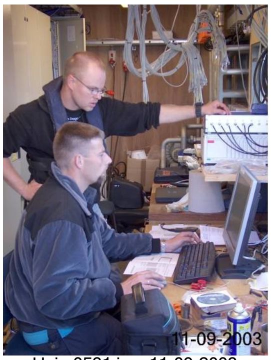

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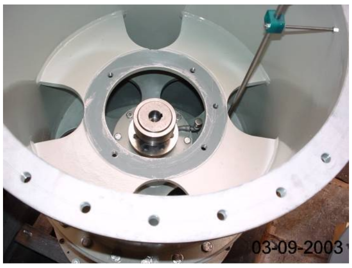

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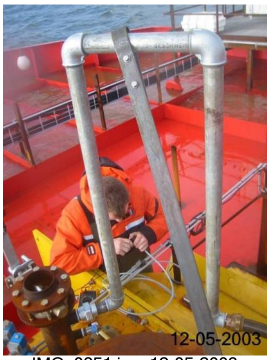

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4, WD efter soesætning, JPK 125.JPG, 20-03

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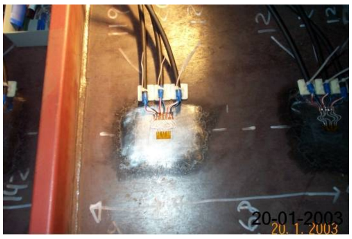

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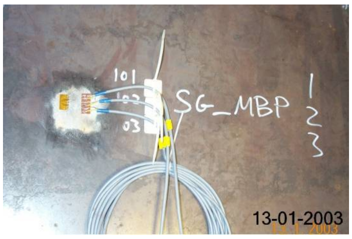

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