FOI-S--1264--SE

International Energy Agency R&D Wind

INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
ANNEX XI

43rd IEA Topical Expert Meeting

Critical Issues Regarding Offshore Technology and Deployment

Skærbæk, Denmark, March 2004
Organised by: Elsam

Horns Rev Photo: Elsam

FOI SWEDISH DEFENCE RESEARCH AGENCY

Scientific Co-ordination:
Sven-Erik Thor
FOI, Aeronautics - FFA, 172 90 Stockholm, Sweden

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Copies of this document can be obtained from:

Sven-Erik Thor
FOI
Aeronautics – FFA
172 90 Stockholm
Sweden
sven-erik.thor@foi.se

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IEA R&D Wind

IEA Topical Expert Meeting #43

Critical Issues Regarding Offshore Technology and Development

International Energy Agency R&D Wind

ANNEX XI
BASE TECHNOLOGY INFORMATION EXCHANGE

OPERATING AGENT:
Sven-Erik Thor
FOI, Aeronautics – FFA
SE 172 90 Stockholm
Sweden
Telephone: +46 8 5550 4370
E-mail: trs@foi.se

The objective of this Task is to promote wind turbine technology through cooperative activities and information exchange on R&D topics of common interest. These cooperative activities have been part of the Agreement since 1978.

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry".

The objective of the second subtask is to conduct joint actions in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates Joint Actions in research areas of current interest, which requires an exchange of information. So far, Joint Actions have been initiated in *Aerodynamics of Wind Turbines, Wind Turbine Fatigue, Wind Characteristics, Offshore Wind Systems and Wind Forecasting Techniques.* Symposia and conferences have been held on designated topics in each of these areas.

In addition to Joint Action symposia, Topical Expert Meetings are arranged once or twice a year on topics decided by the IEA R&D Wind Executive Committee. One such Expert Meeting gave background information for preparing the following strategy paper "Long-Term Research and Development Needs for Wind Energy for the Time Frame 2000 to 2020". This document can be downloaded from source 1 below.

Since these activities were initiated in 1978, more than 60 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

All documents produced under Task XI and published by the Operating Agent are available to citizens of member countries from the Operating Agent, and from representatives of countries participating in Task XI.

More information can be obtained from:

1. www.ieawind.org
2. www.windenergy.foi.se/IEA_Annex_XI/ieaannex.html

IEA R&D Wind - List of Topical Expert Meetings

For more informatiuon visit http://www.windenergy.foi.se/ and click on IEA
Documents can be obtained from Sven-Erik Thor at trs@foi.se

Nr	Title	Date	Year	Location	Country
43	Critical Issues Regarding offshore Technology and Deployment	March	2004	Stockholm	Sweden
42	Acceptability in Implementation of Wind Turbines in Social Lanc	March	2004	Kolding	Denmark
41	Integration of Wind and Hydropower Systems	November	2003	Portland	USA
40	Environmental issues of offshore wind farms	September	2002	Husum	Germany
39	Power Performance of Small Wind Turbines not connected to the Grid	April	2002	Soria, CIEMAT	Spain
38	Material Recycling and Life Cycle Analysis (LCA)	March	2002	Risø	Denamrk
37	Structural Reliability of Wind Turbines	November	2001	Risø	Denmnark
36	Large Scale Integration	November	2001	Newcastle	UK
35	Long term R&D needs for wind energy. For the time frame 2000 – 2020	March	2001	Petten	the Netherlands
34	Noise Immission	November	2000	Stockholm	Sweden
33	Wind Forecasting Techniques	April	2000	Boulder	Usa
32	Wind energy under cold climtes	March	1999	Helsinki	Finland
31	State of the art on Wind Resource Estimation	October	1998	Lyngby	Denmark
30	Power Performance Assessments	December	1997	Athens	Greece
29	Aero-acoustic Noise of Wind Turbines	March	1997	Milano	Italy
28	State of the art of aeroelastic codes for wind turbines	April	1996	Lyngby	Denmark
27	Current R&D needs in wind energy technology	September	1995	Utrecht.	Netherlands
26	Lightning protection of wind turbine generator systems and EMC problems in the associated control systems	March	1994	Milan	Italy
25	Increased loads in wind power stations (wind farms)	May	1993	Gotherburg	Sweden
24	Wind conditions for wind turbine design	April	1993	Risø	Denmark
23	Fatigue of wind turbines, full-scale blade testing and non-destructive testing	October	1992	Golden, Colorado	USA
22	Effects of environment on wind turbine safety and performance	June	1992	Wilhelmshaven	Germany
21	Electrical systems for wind turbines with constant or variable speed	October	1991	Gothenburg	Sweden
20	Wind characteristics of relevance for wind turbine design	March	1991	Stockholm	Sweden
19	Wind turbine control systems-strategy and problems	May	1990	London	England
18	Noise generating mechanisms for wind turbines	November	1989	Petten	Netherlands
17	Integrating wind turbines into utility power systems	April	1989	Herndon	USA
16	Requirements for safety systems for LS WECS	October	1988	Rome	Italy
15	General planning and environmental issues of LS WECS installations	December	1987	Hamburg	Germany
14	Modelleing of atmospheric turbulence for use in WECS rotor loading calculations	December	1985	Stockholm	Sweden
13	Economic aspects of wind turbines	May	1985	Petten	Netherlands
12	Aerodynamic calculation methods for WECS	October	1984	Copenhagen	Denmark
11	General environmental aspects	May	1984	Munich	Germany
10	Utility and operational experience from major wind installations	October	1983	Palo Alto	California
9	Structural design criteria for LS WECS	March	1983	Greenford	UK
8	Safety assurance and quality control of LS WECS during assembly, erection and acceptance testing	May	1982	Stockholm	Sweden
7	Costing of wind turbines	November	1981	Copenhagen	Denmark
6	Realibility and maintenance problems of LS WECS	April	1981	Aalborg	Denmark
5	Environmental and safety aspects of the present LS WECS	September	1980	Munich	Germany
4	Rotor blade technology with special respct to fatigue design	April	1980	Stockholm	Sweden
3	Data acquisition and analysis för LS WECS	September	1979	Blowing Rock	USA
2	Control of LS WECS and adaption of wind electricity to the network	April	1979	Copenhagen	Denmark
1	Seminar on structural dynamics	October	1978	Munich	Germay

INTRODUCTORY NOTE
IEA Topical Expert Meeting #43
on
Critical Issues Regarding Offshore Technology and Deployment

Peter Hauge Madsen, Walter Musial and Sven-Erik Thor

Background

The market-driven up-scaling and offshore application requires better understanding of a number of issues. In 2003, the worldwide installed capacity of grid-connected wind power exceeds 30GW corresponding to an investment of approximately 30 billion Euro. The global wind energy installed capacity has increased exponentially over a 25 year period and in the process the cost of energy from wind power plants has been reduced by an order of magnitude. In Germany, approximately 5% of electric energy is now produced by wind turbines and in Denmark, the fraction of energy coming from the wind is close to 20%. In most other countries the contribution is less than 1%.

There are several compelling reasons to move the technology offshore, including:

- Higher-quality wind resources (Reduced turbulence and increased wind speed)
- Proximity to loads (Many demand centers are near the coast)
- Increased transmission options
- Potential for reducing land use and aesthetic concerns
- Reduced scaling concerns for transportation and erection

Two larger demonstration wind power plants have already been constructed in Denmark, each with a capacity of 160MW. In all, on a *regional basis* wind power has developed from being a marginal "alternative" energy source to a quickly maturing mainstream technology. On a *global scale*, the wind power technology is still in its adolescence and has much growing and maturing in front of it, and it is believed that a sizable fraction of the growth will happen offshore.

Quotations

As inspiration the following quotes are offered:

H.J.T. Kooijman et.el. **Large scale offshore wind energy in the North Sea – A technology and policy perspective**

The main technical challenges are the increase of turbine availability by improvement of turbine O&M and a further reduction of wind farm array losses by introducing new ways of turbine operation and farm layout. Focusing on The Netherlands, a significant upgrade of the grid is required to successfully feed in the Dutch goal of 6000 megawatt in 2020. kooijman@ecn.nl

L.W.M. Beurskens, M de Noord, **Offshore wind power developments: An overview of realisations and planned projects ECN-C--03-058**

Installing wind turbines offshore has a number of advantages compared to onshore locations. At a sufficient distance from the coast, visual intrusion and noise are minor issues. These advantages make it possible for offshore wind turbines to be larger (and thus have more Megawatt (MW) capacity installed) and less attention needs to be devoted to reduce noise emissions, which entails additional costs for onshore wind turbines. Another advantage is the wind pattern, which is more uniform at sea than on land. A less fluctuating load means a decrease in wear. Wind speed is also much higher offshore than onshore, which means that more electricity can be generated per square metre of swept rotor area.

On the other hand, investment costs are higher and accessibility to the turbines is poorer, resulting in higher maintenance costs. Also, environmental conditions at sea are more severe: more corrosion due to salt water and additional load from waves and ice. And obviously, offshore construction is more complicated.

In Europe, the amount of space available for offshore wind turbines is many times larger than onshore. The potential for wind energy is therefore also considerably greater. As an example for the Netherlands, based on the area available outside the 12-mile zone (about 22 km) with a water depth of less than 20 metres, there is room for roughly 3 GW of wind power.

The North Sea, boarding the Netherlands, has the advantage of a relatively shallow sea: nearly the entire Netherlands Exclusive Economic Zone (delimitation of the Netherlands Continental Shelf) is less than 50 metres deep. The Netherlands shares this advantage with countries such as Belgium, Denmark, the UK and Germany. Other European countries with an extensive coastline, such as Ireland and Spain, have a relatively small sea area with water depths less than 50 metres. When competition in large-scale renewable energy supply starts between the different European countries, the Netherlands will possibly have a comparative advantage because it has such a large sea area at its disposal. Figure 1 shows the cumulative installed offshore capacity to date.

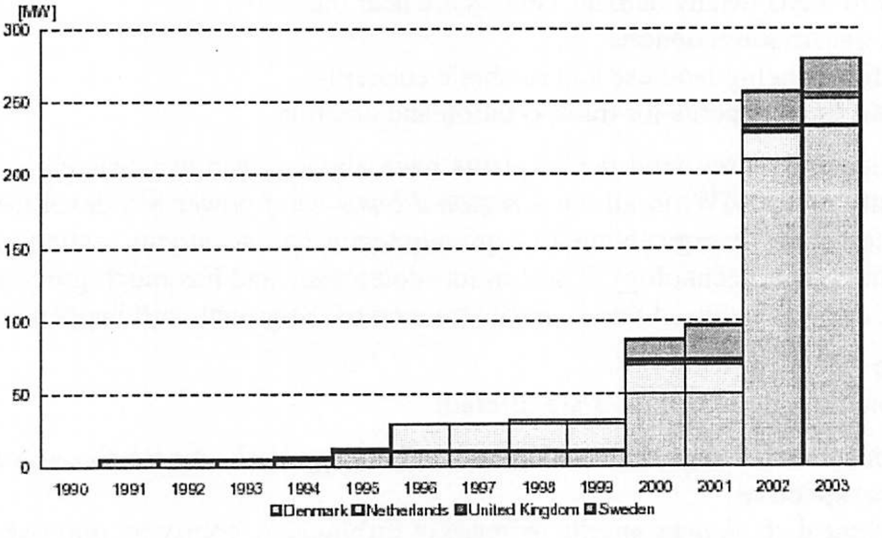


Figure 1 - Realised offshore wind power until February 2003

Peter Goldman **"DOE Outlook for Deepwater Wind" Workshop on Deep Water Offshore Wind Energy Systems",** Washington, DC, October 15-16, 2003

Those nations with long coastlines but without shallow seas within their continental shelf will be interested in exploring technological developments relating to deeper water offshore installations. Some of these nations show a significant potential for the use of offshore energy. China and the U.S. have the highest potential, followed by Brazil and Japan as shown in Figure 2.

In October 2003, a workshop was held in Washington, D.C. to discuss deep water technologies with US and European experts, see:http://www.nrel.gov/wind_meetings/offshore_wind/. From this it was evident that there is a keen interest in this area, which compliments the recent commercial progress of shallow water installations.

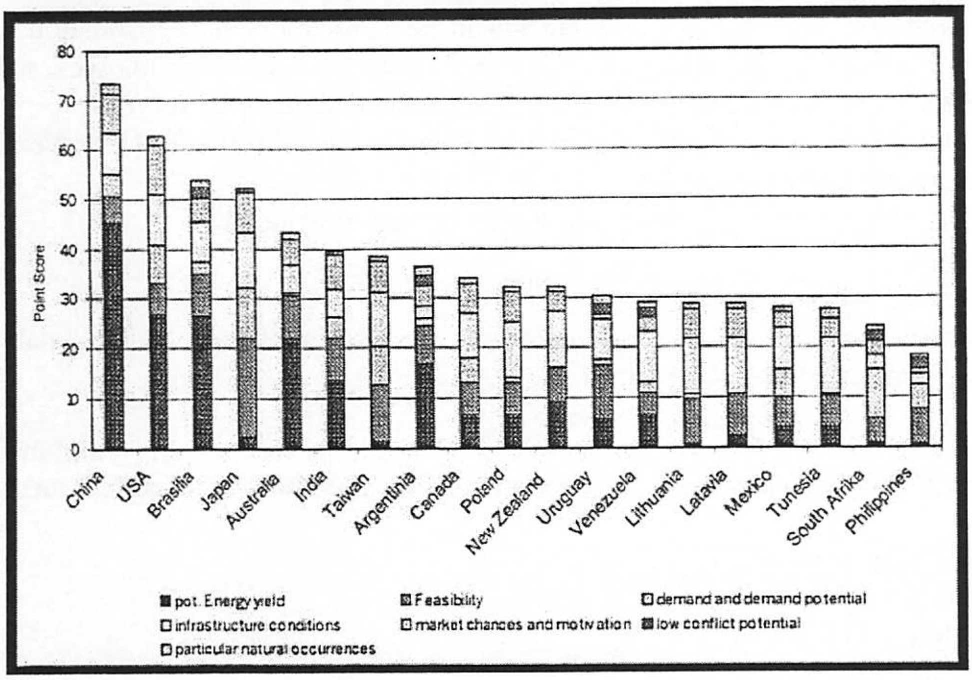


Figure 2 – Offshore Potential for Non-EU Countries

Reference: S. Siegfriedsen, M. Lehnhoff, & A. Prehn, aerodyn Engineering, GmbH
Conference: Offshore Wind Energy in the Mediterranean and other European Seas
April 10-12, 2003, Naples, Italy

Electricity produced from offshore locations is expected to be of higher value in many cases, since proximity of several major load centers to the coasts could reduce transmission constraints and costs facing large-scale onshore power generation. (e.g., New England region in the U.S.).

Preliminary estimates of wind resources offshore for recently mapped regions of the United States indicate immense areas of Class 5, 6, and some Class 7 winds at distances from 5 nautical miles (nm) offshore to 50 nm offshore. These preliminary estimates indicate that there is 668 GW of offshore wind resource in deeper waters (30 m to 100 m and greater) requiring new technologies, opening vast areas out of site of land for electric power generation. If developed, this wind resource, which is close to many coastal cities, could reduce the burden of supplying electricity to coastal cities with the inland transmission system. Deep water developments may be the preferred option for some coastal regions because they are closer to load centers, the resource is better, the potential viewshed issue is mitigated, and therefore public acceptance may be greater.

Objectives

A primary goal of the meeting is to give the participants a good overview of the challenges encountered in offshore applications. A summary and assessment of issues will be a part of the finalizing discussion.

As a source of further inspiration, a list of potential specific topics is added below.

- Layout and array effects (impact on loads, cost and energy production, mutual shadow effect of large, closely spaced wind farms)
- External conditions (e.g. Instrumentation for site assessment, etc)
- New design drivers offshore (e.g. personnel safety requirements, personnel access,)
- Reliability and statistical design procedures
- Specific loads and load combinations (e.g. extreme wind / wave load combinations)

- R&D needed to support new Requirements on standardization and certification
- Potential effects to the marine ecology (e.g., comparative methodologies and data from existing studies, preliminary conclusions from avian and mammal surveys
- Streamlining consent agreements (permitting) and public (stakeholder) involvement
- Operation and maintenance
- Innovative approaches to offshore construction and infrastructure
- Economics
- Quantifying risk assessment
- Deepwater offshore issues (e.g. moorings, floating platforms design, stability, power cabling, platform dynamic stability)

Presentations should preferably be focused on the general aspects and combinations of the challenges of offshore wind power, rather than detailed discussion of specific issues.

Tentative Programme

1. Introduction
2. Technical issues
3. Construction issues
4. Infrastructure and O&M issues
5. Environmental issues
6. Consent agreements (permitting)
7. Deepwater issues
8. Identification of critical issues and R&D needs
   - Summary of sessions
   - Discussion and conclusions
9. Discussion of an IEA annex
   - National contributions?

Intended audience

Participants will typically represent the following type of entities:

- Universities and research organizations
- Manufacturers of wind turbines
- Power companies, developers and wind turbine owners
- Certification institutes and consultants
- Government representatives

Outcome of meeting

The outcome of the meeting is a clearer understanding of the critical technical issues and R&D needs regarding future offshore development, the proceedings and a plan for future information exchange / work within this area. Is there a need for continued information exchange in this area (e.g. is there interest in an IEA annex on this topic)?

Miscellaneous

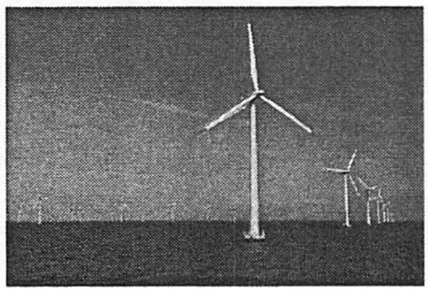
A similar meeting was held on the following topic "Environmental issues of offshore wind farms" in 2002. Copies of proceedings can be obtained from sven-erik.thor@foi.se. A summary can be downloaded from: http://www.windenergy.foi.se/IEA_Annex_XI/Summary_40_Offshore.pdf.

RISØ

IEA topical expert meeting #43

Critical issues regarding Offshore Technology and Deployment

Hosted by
Peggy Friis
ELSAM
Denmark



RISØ

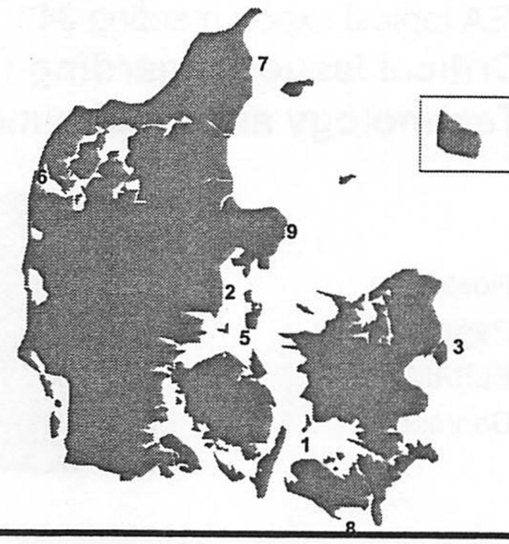
Reasons for offshore wind energy

- Better wind ressources (less turbulence and increased wind speeds)
- Proximity to loads (demand centers near the coast)
- Increased transmission options
- Potential for reducing land use and aestetic concerns
- Reduced scaling concerns for transport and erection

Offshore development in Denmark

RISØ

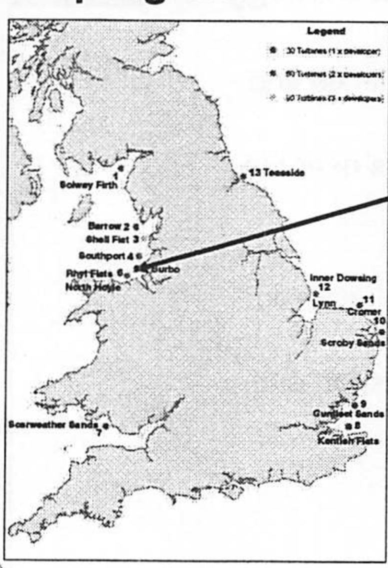
1. Vindeby 5 MW
2. Tunø Knob 5 MW
3. Middelgrunden 40 MW
4. Horns Rev 160 MW
5. Samsoe 23 MW
6. Roenland 17 MW
7. Frederikshavn 10.6 MW
8. Nysted-Roedsand 158 MW
9. Grenå 6 MW

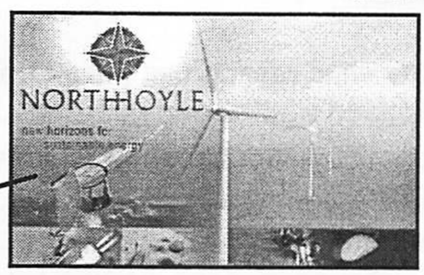


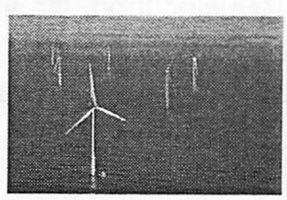
Existing and approved off-shore capacity (MW)

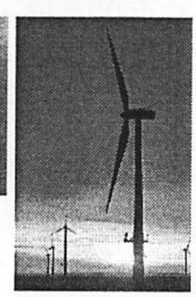
UK program

RISØ



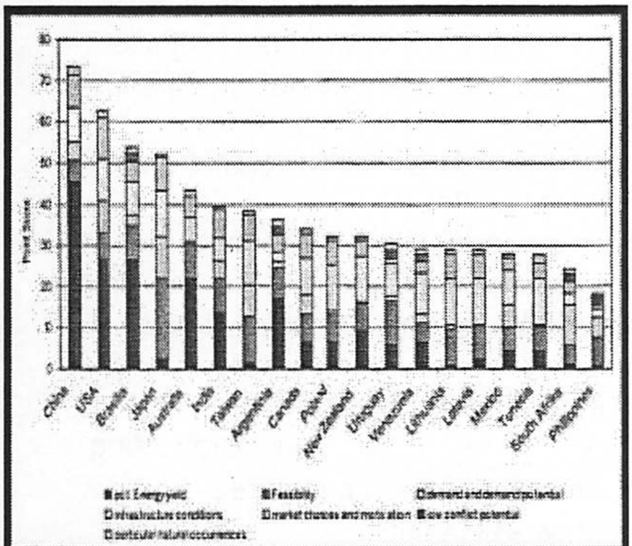






Potential Non-EU countries

RISØ



EWEA –The European Wind Industry Strategic Plan for Research and Development

RISØ

Launched 26 Jan 2004

EWEA installed capacity targets in the EU-15

	Onshore	Offshore
2010	65.000 MW	10.000 MW
2020	110.000 MW	70.000 MW

Priority R&D area Offshore wind technology - Objectives

RISØ

- Environmental impact of near- and far-shore projects
- Potential conflicts of interest (fishing, defence, oil and gas exploration etc)
- Legal research in offshore ownership in coastal waters, exclusive economic zones etc
- New design, higher tip speeds, less noise concern
- Minimization of O&M downtime
- Systems and components for erection, access and maintenance
- Design of >5 MW systems (incl. Multirotor systems)
- Offshore meteorology, short- and longterm forecasting
- Alternative and deep water support structures
- Combined wind and wave loading

Danish Strategy for wind energy research – short to medium term

RISØ

- Loads and safety
- Monitoring and maintenance
- Support structures, also for more than 15 m water depth
- Total system dynamics modelling, from soil-structure to blade tips
- Environmental impact

- Forecasting
- Regulation and transmission of production
- Integration in energy system

Potential issues

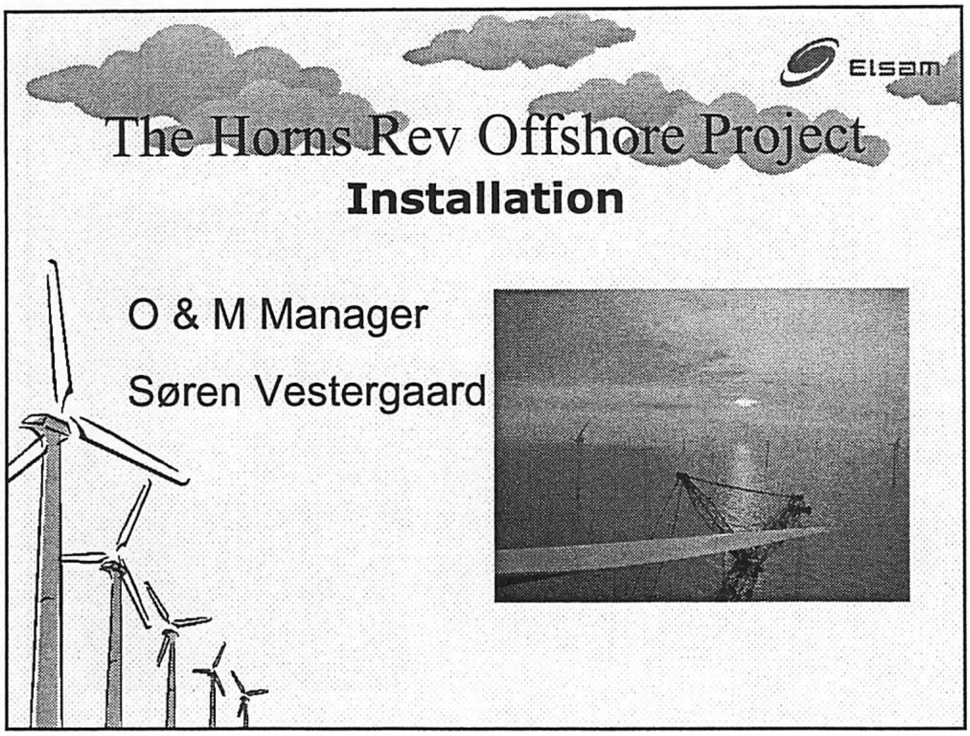
RISØ

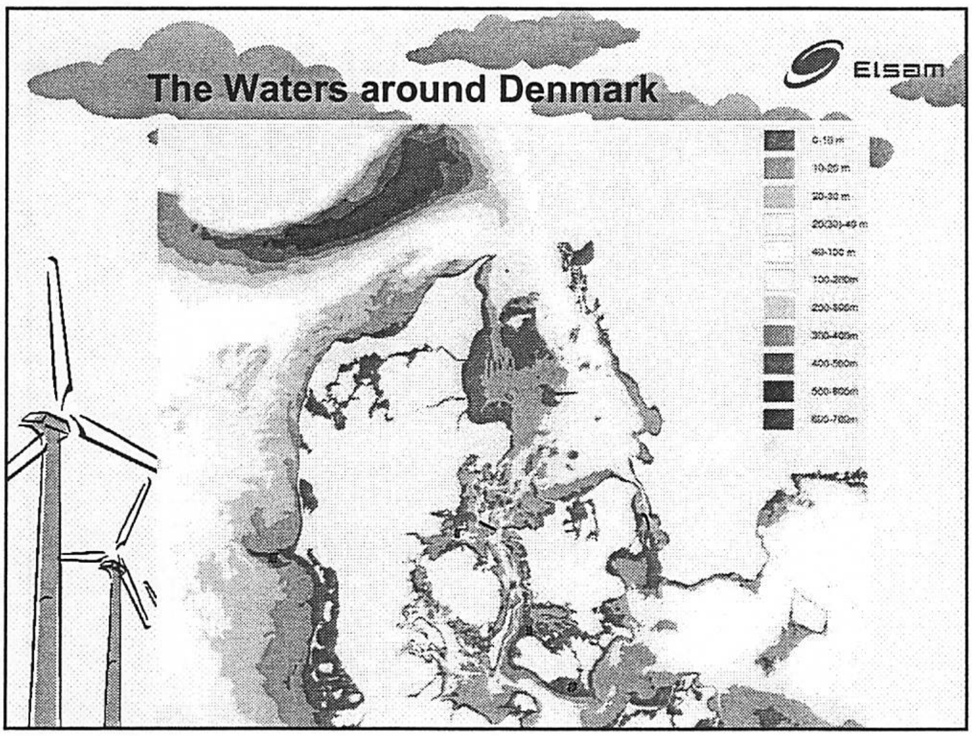
- Layout and array effects (impact on loads, cost and energy production, mutual shadow effect of large, closely spaced wind farms)
- Specific loads and load combinations (e.g. extreme wind / wave load combinations)
- External conditions (e.g. Instrumentation for site assessment, siting and energy prediction)
- New design drivers offshore (e.g. personnel safety requirements, increased personnel access)
- Reliability and statistical design procedures
- R&D needed to support new requirements on standardization and certification
- Streamlining consent agreement (permitting) and public involvement
- Operation and maintenance
- Innovative approaches to offshore construction and infrastructure
- Economics
- Quantifying Risk assessment
- Deepwater offshore issues (e.g. moorings, floating platform design, stability, power cabling, dynamic stability)

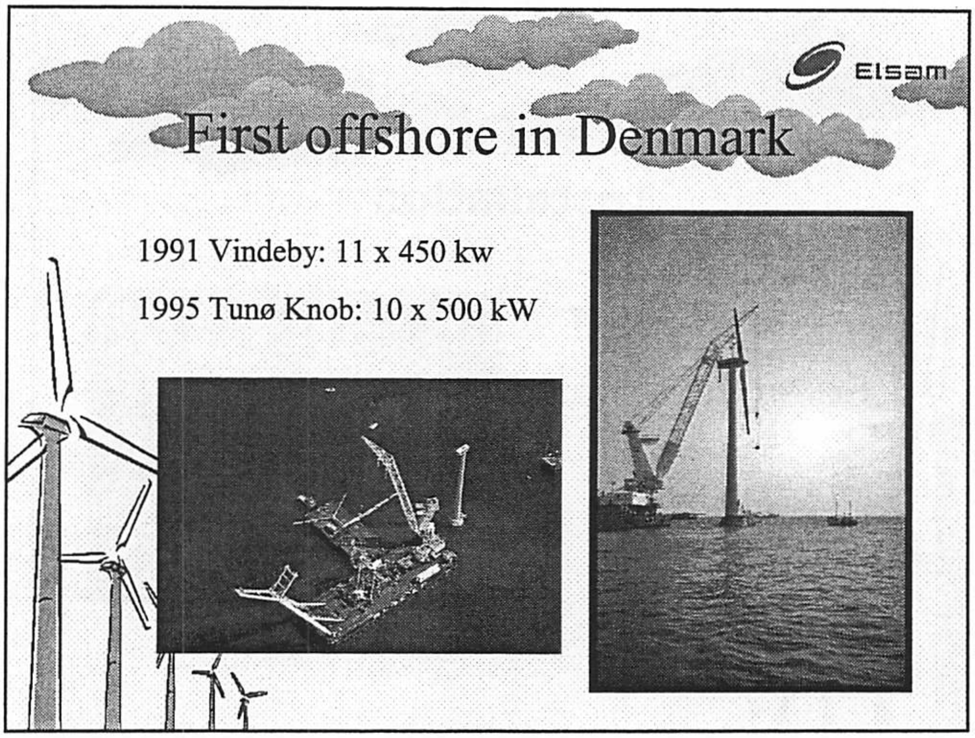
Objectives of meeting

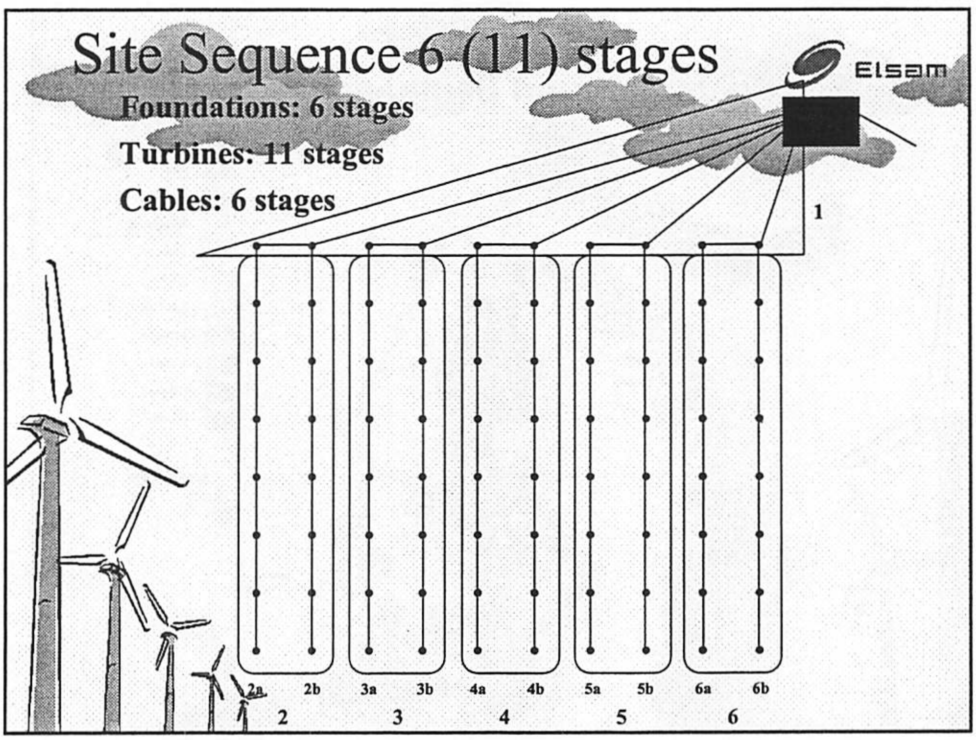
RISØ

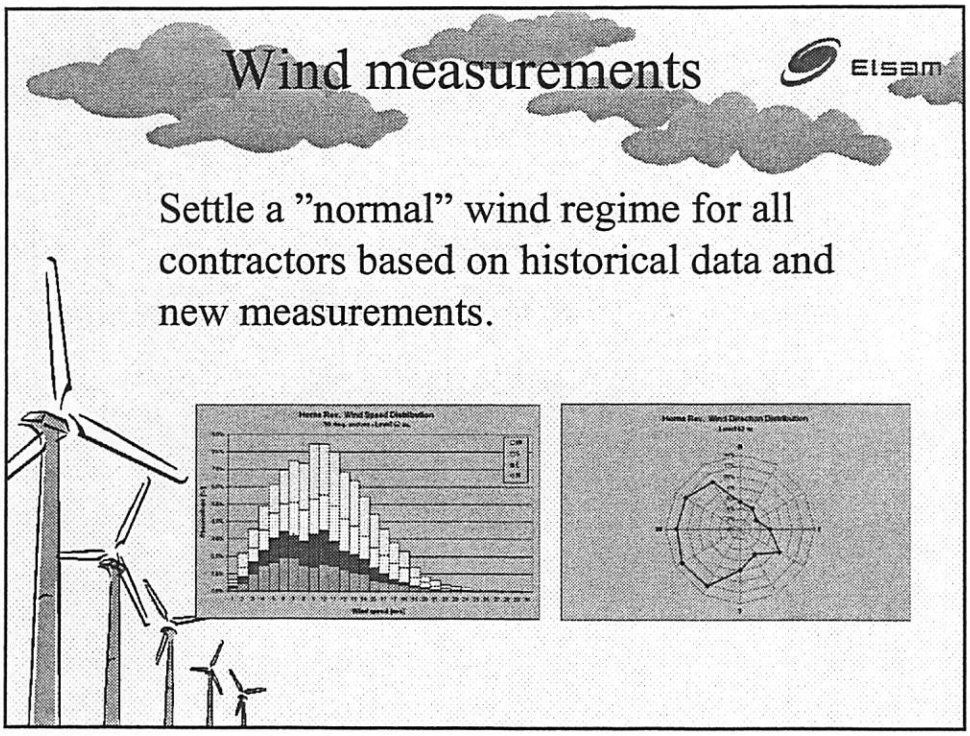
- Overview of challenges in offshore wind energy
- Summary and assessment of issues
- Identification of critical issues, suitable for an international cooperative R&D effort
- Outline of an IEA annex
- Prioritizing subtasks

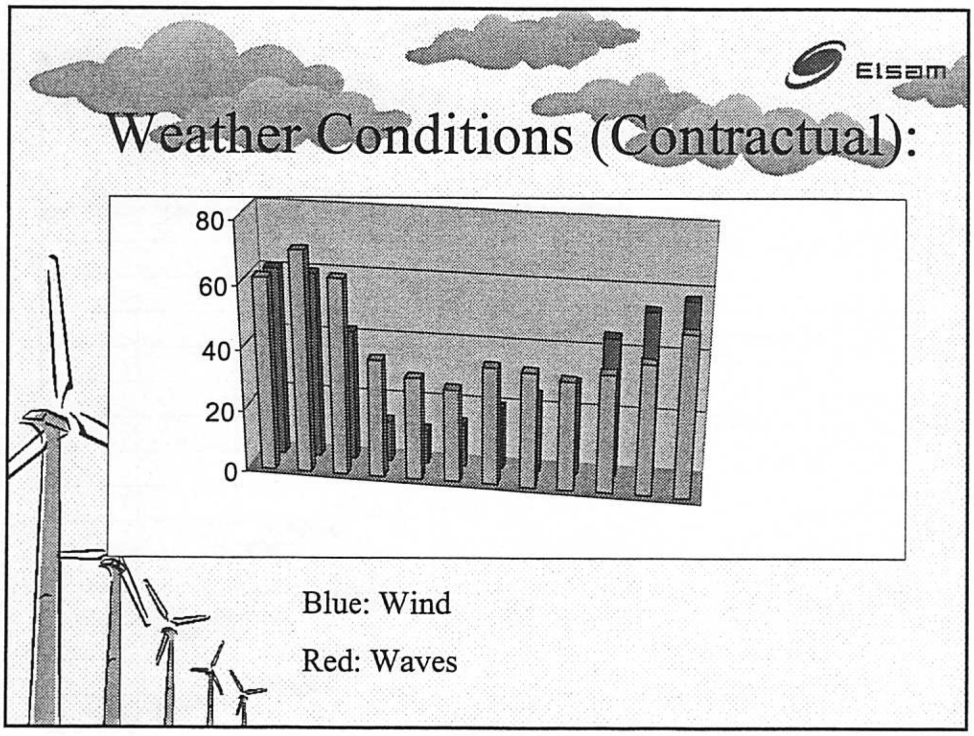

Elsam
The Horns Rev Offshore Project
Installation
O & M Manager
Søren Vestergaard

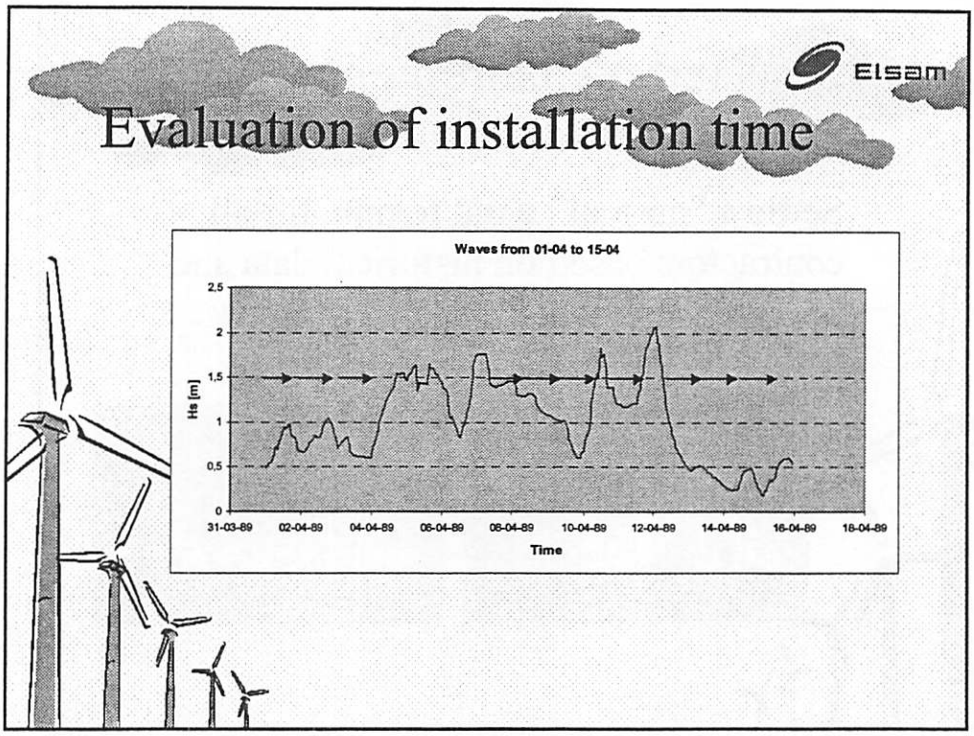

The Waters around Denmark
Elsam


Elsam
First offshore in Denmark
1991 Vindeby: 11 x 450 kw
1995 Tunø Knob: 10 x 500 kW


Site Sequence 6 (11) stages
Elsam
Foundations: 6 stages
Turbines: 11 stages
Cables: 6 stages
1
2a
2b
3a
3b
4a
4b
5a
5b
6a
6b
2
3
4
5
6


Wind measurements
Elsam
Settle a "normal" wind regime for all contractors based on historical data and new measurements.

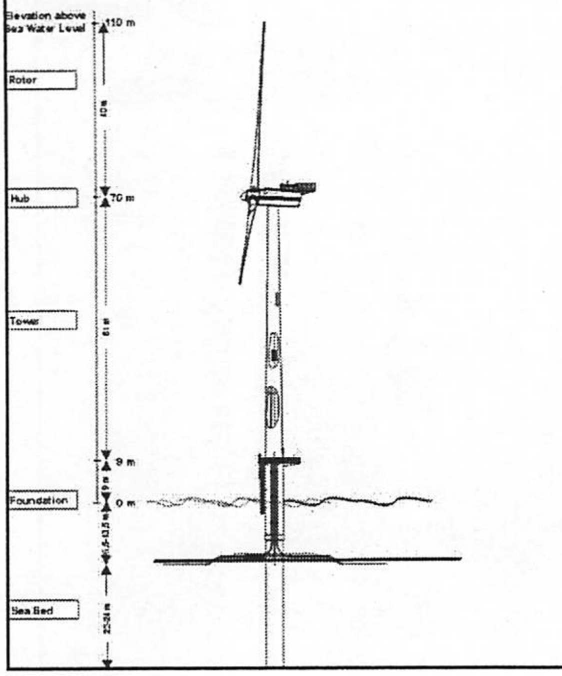

Elsam
Weather Conditions (Contractual):
80
60
40
20
0
Blue: Wind
Red: Waves



Elsam

Time Schedule for Site Works

Opgavenavn	March 2002	April 2002	May 2002	June 2002	July 2002	August 2002	September 2002
Stage 1, 10 units							
Foundations, and scour protection							
Turbines							
Cables							
Stage 2, 14 units							
Foundations, and scour protection							
Turbines							
Cables							
Stage 3, 14 units							
Foundations, and scour protection							
Turbines							
Cables							
Stage 4, 14 units							
Foundations, and scour protection							
Turbines							
Cables							
Stage 5, 14 units							
Foundations, and scour protection							
Turbines							
Cables							
Stage 6, 14 units							
Foundations, and scour protection							
Turbines							
Cables							



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Main Data:

Maximum power: 160 MW

Annual production: 600 GWh

Average wind (62 m): 9.7 m/s

Number of turbines: 80

Distance between: 560 m

Farm area: 20 km^2

Distance to shore: 14-20 km

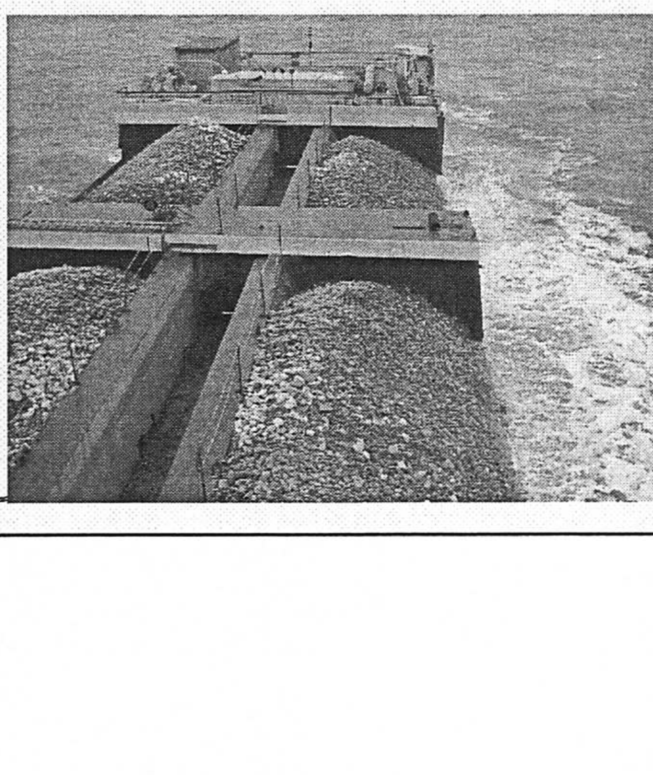
Water depth: 6.5–13.5 m

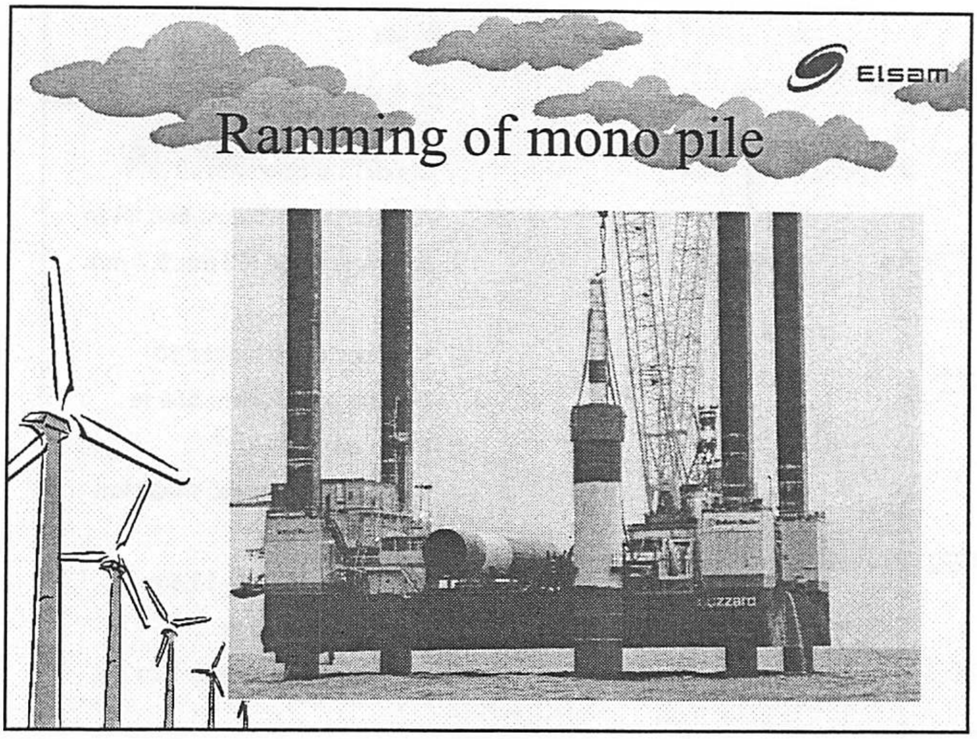
Design wave: 8 m

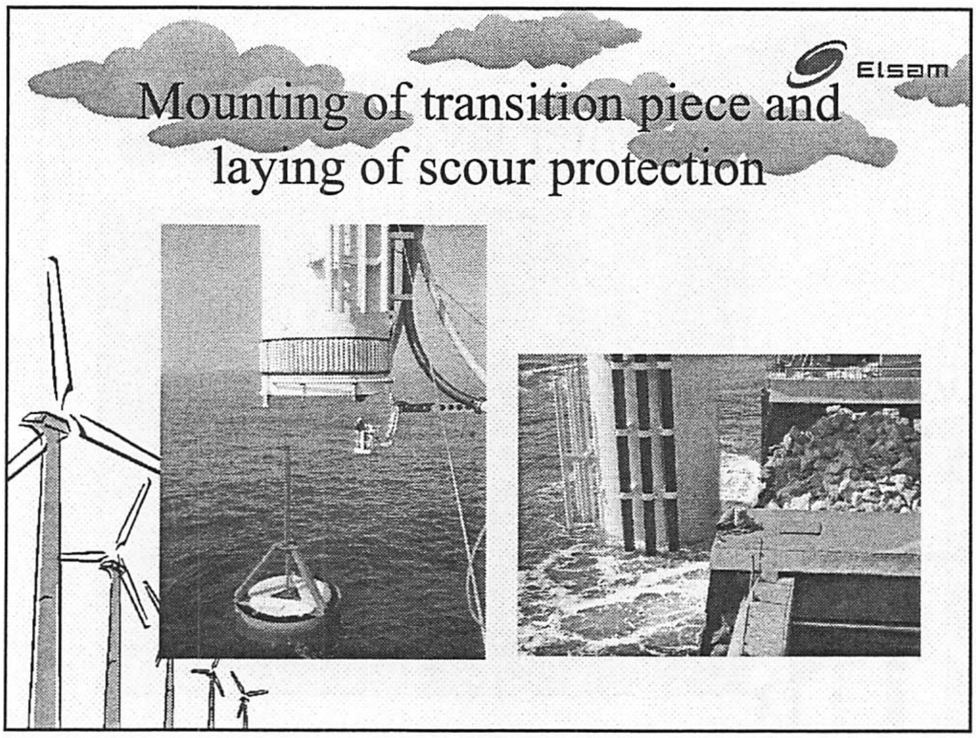
Average sign. wave: 1 m

Elsam

Filter layer




Elsam
Ramming of mono pile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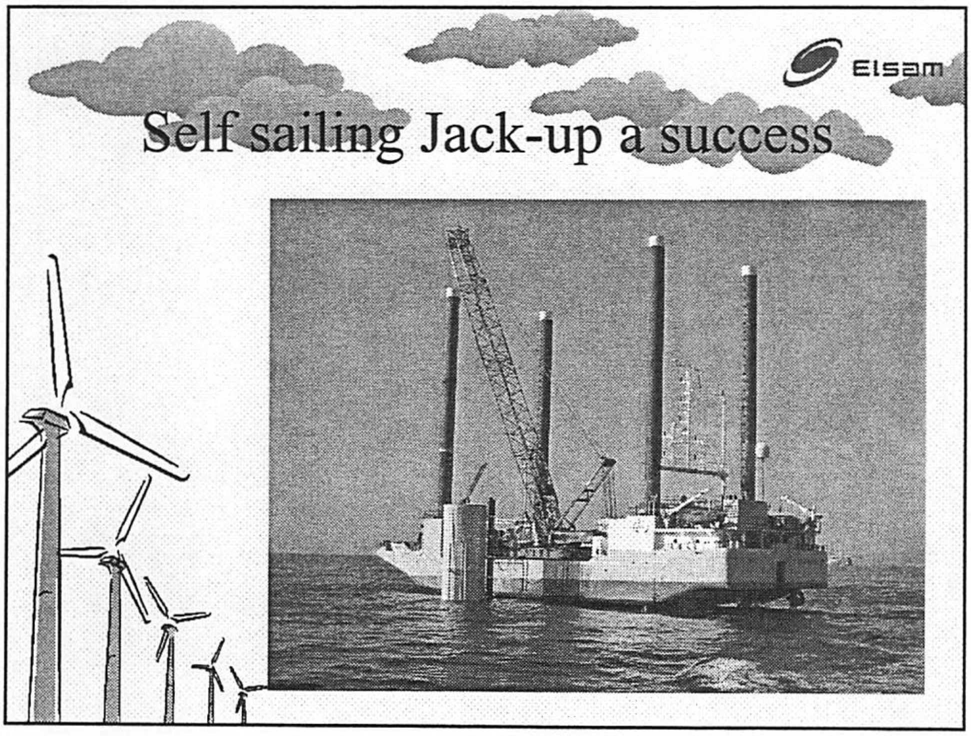
Mounting of transition piece and
laying of scour protection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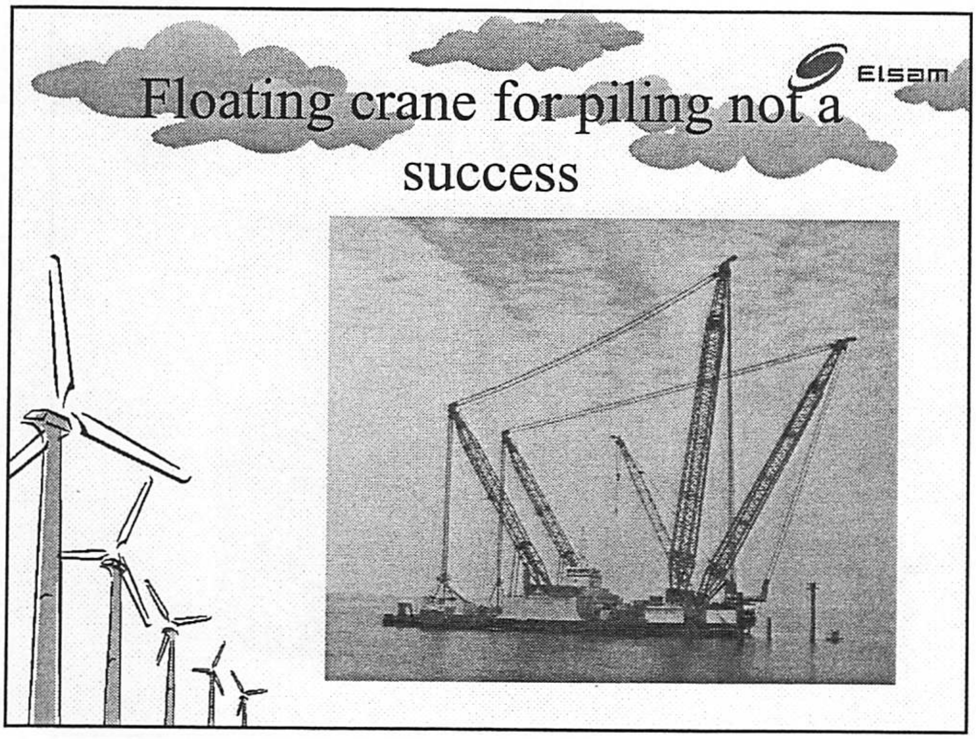
Self sailing Jack-up a success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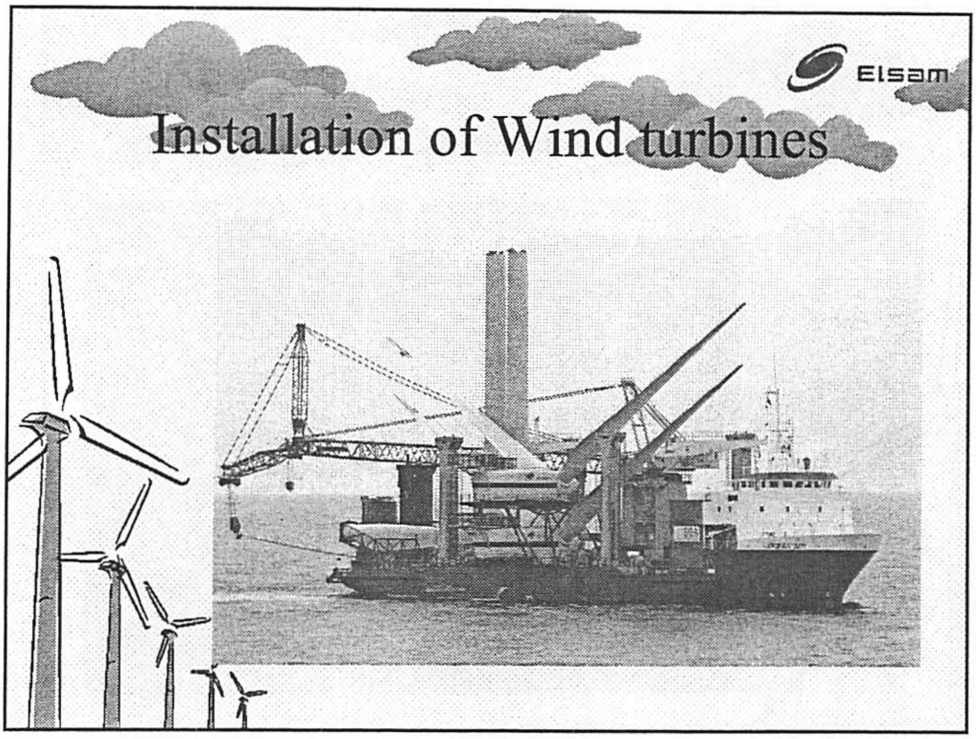
Floating crane for piling not a success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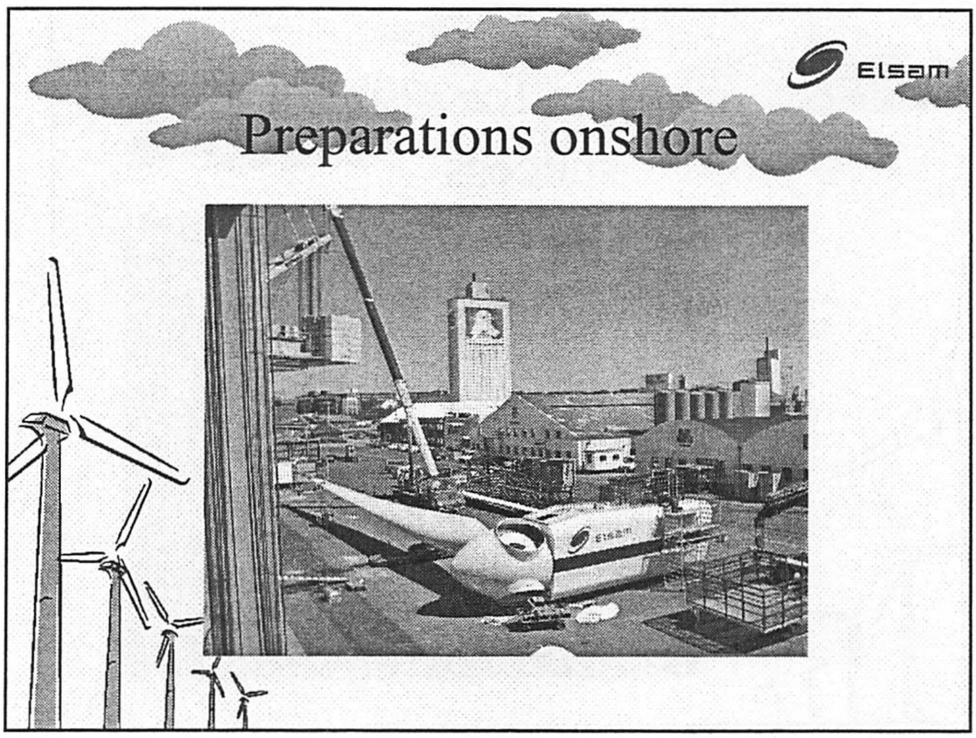
Installation of Wind turbines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Preparations onshore

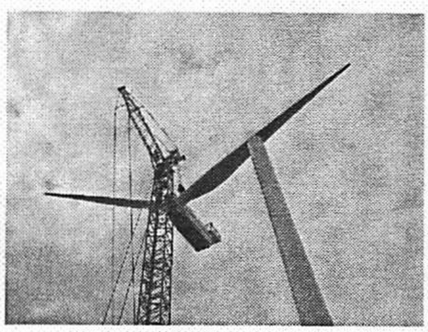
Elsam

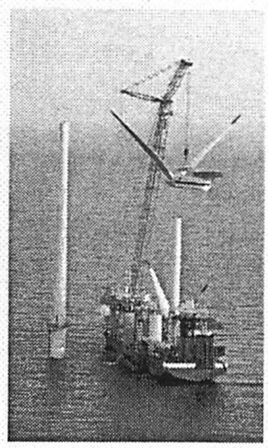
Preparations onshore

- There is not much room to work on at a quay, but it is still much easier than working offshore.
- There will be unexpected delays, plan for a buffer in the assembly line.
- QA is important, it is hard to change the plan when the vessel has been loaded.

Elsam

Installation of Wind turbines





Elsam

Installation of Wind turbine

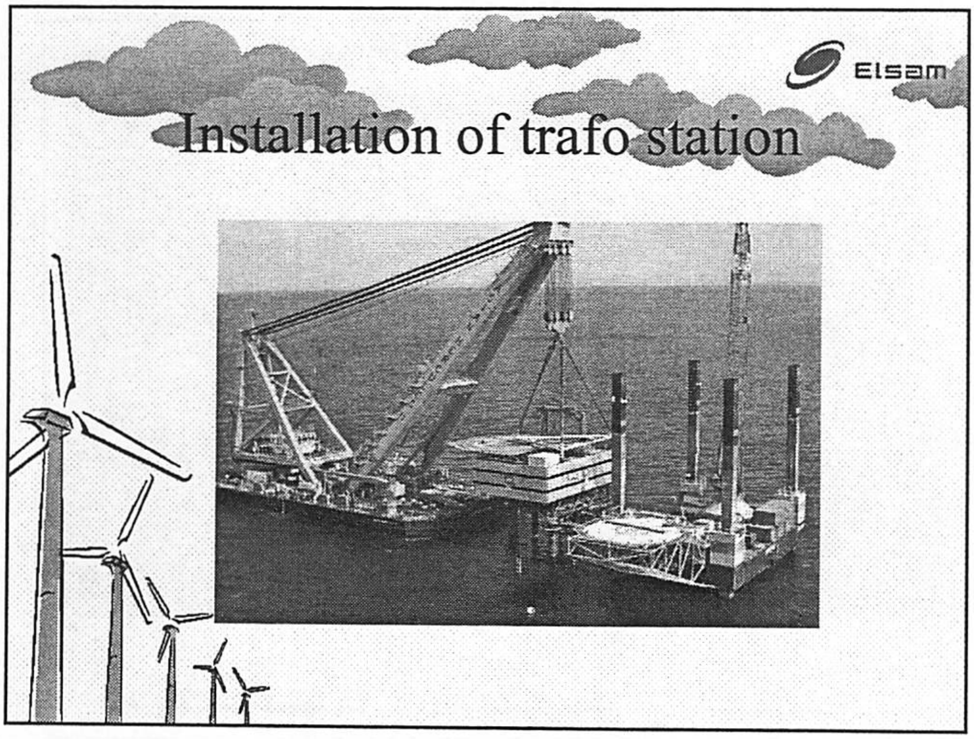
- Short lifting time offshore means that more weather windows can be utilized.
- Utilize the time in the turbine, create work packages that last the whole day, transport between turbines is a waste of time.

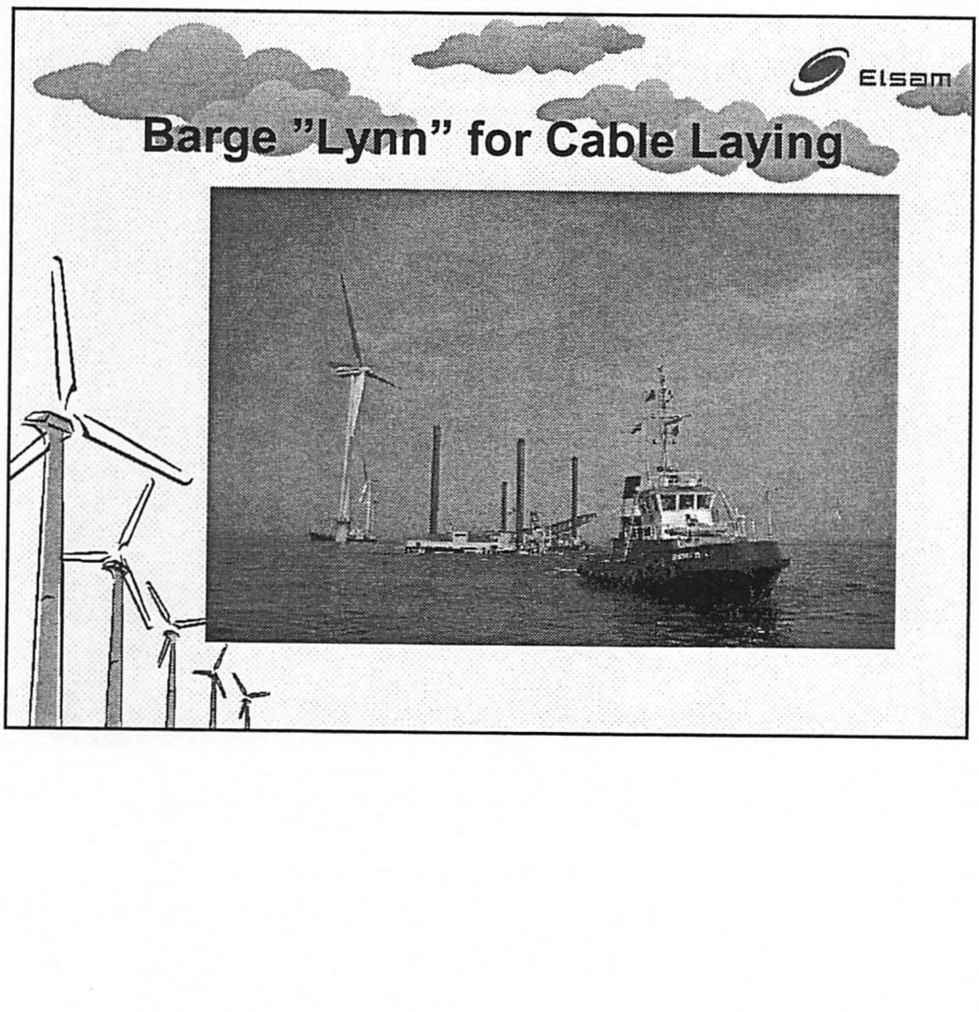
Elsam

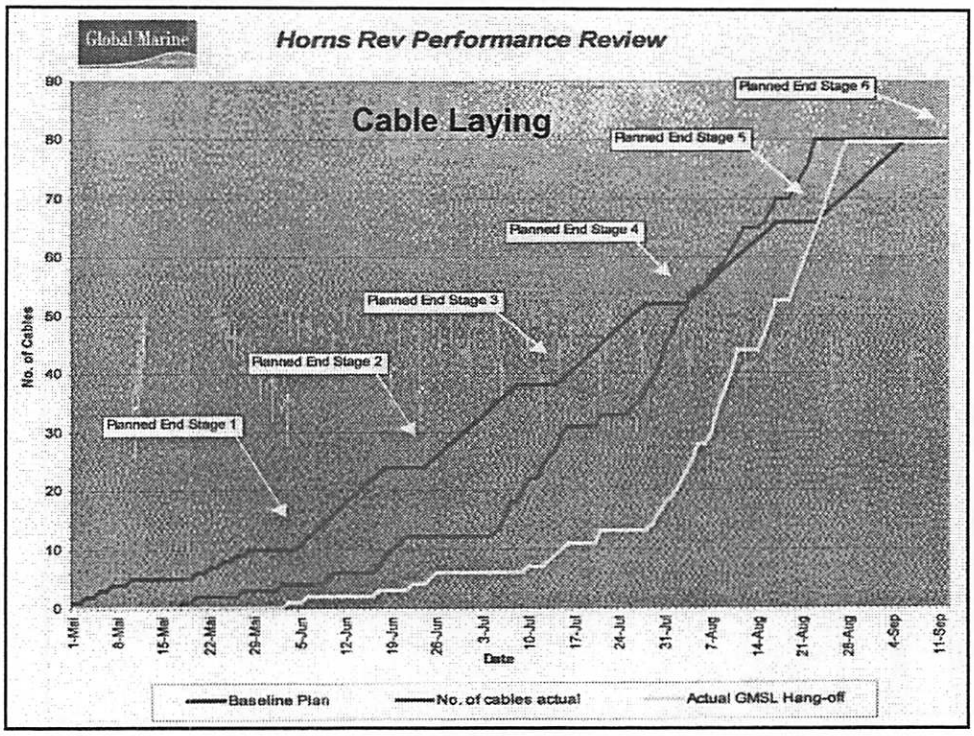
Installation of Wind turbine

Technology:

- Onshore turbines moved offshore.
- 5 MW WTG coming soon, but will it be more offshore than existing turbines.
- “Self-installing” suggested, but why extra cost on xxx turbines in stead of 1-2 good installation vessels.


Elsam
Installation of trafo station


Elsam
Barge "Lynn" for Cable Laying


Global Marine
Horns Rev Performance Review
Cable Laying
Planned End Stage 1
Planned End Stage 2
Planned End Stage 3
Planned End Stage 4
Planned End Stage 5
Planned End Stage 6
No. of Cables
0
10
20
30
40
50
60
70
80
90
1-Mai
8-Mai
15-Mai
22-Mai
29-Mai
5-Jun
12-Jun
19-Jun
26-Jun
3-Jul
10-Jul
17-Jul
24-Jul
31-Jul
7-Aug
14-Aug
21-Aug
28-Aug
4-Sep
11-Sep
Date
Baseline Plan
No. of cables actual
Actual GMSL Hang-off


Thank You for Listening
Elsam

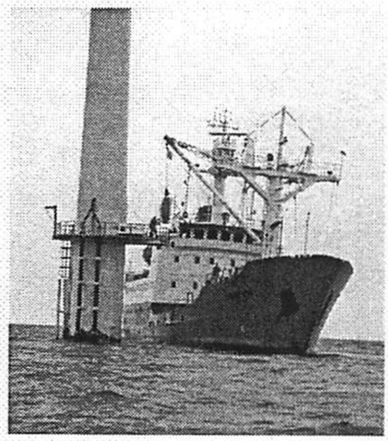
Elsam

The Horns Rev Offshore Project

Operation and Maintenance

O & M Manager

Søren
Vestergaard



Elsam

Operational conditions

- Service contract with Vestas for the first 5 years.
- Availability guiarantee on both each turbine and the hole park.
- Elsam take care of transport of personnel.
- Elsam take part in the maintenance work with 6 technicians.

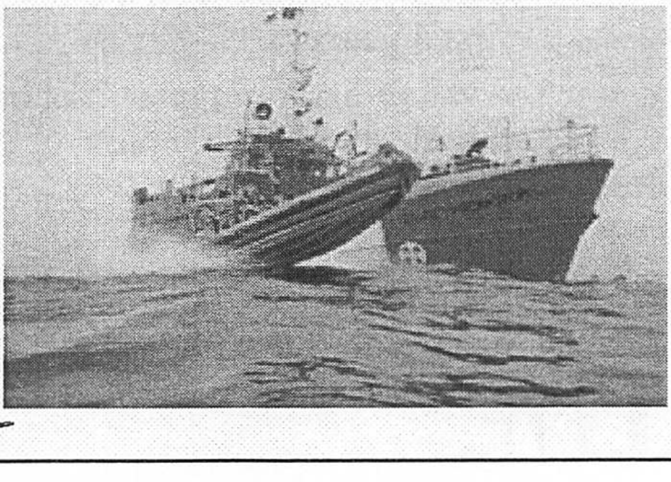
Elsam

Organization

- 24 hours surveillance at Elsam.
- 24 hours technical backup from Vestas.
- Vestas manage the work on the turbines.
- Elsam assist with 6 technicians.
- Elsam coordinate and deliver transport of personel to the park.

Elsam

TRANSPORT



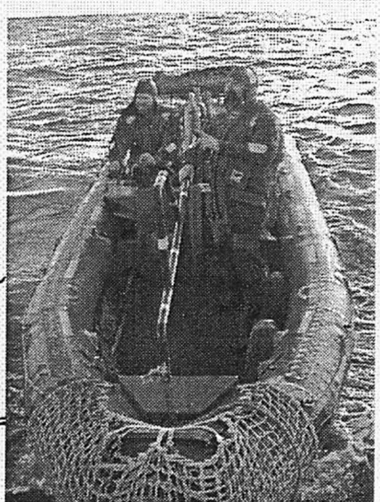
Elsam

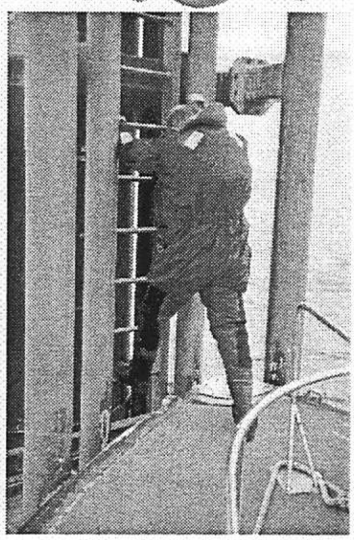
Data which limits the access from the sea

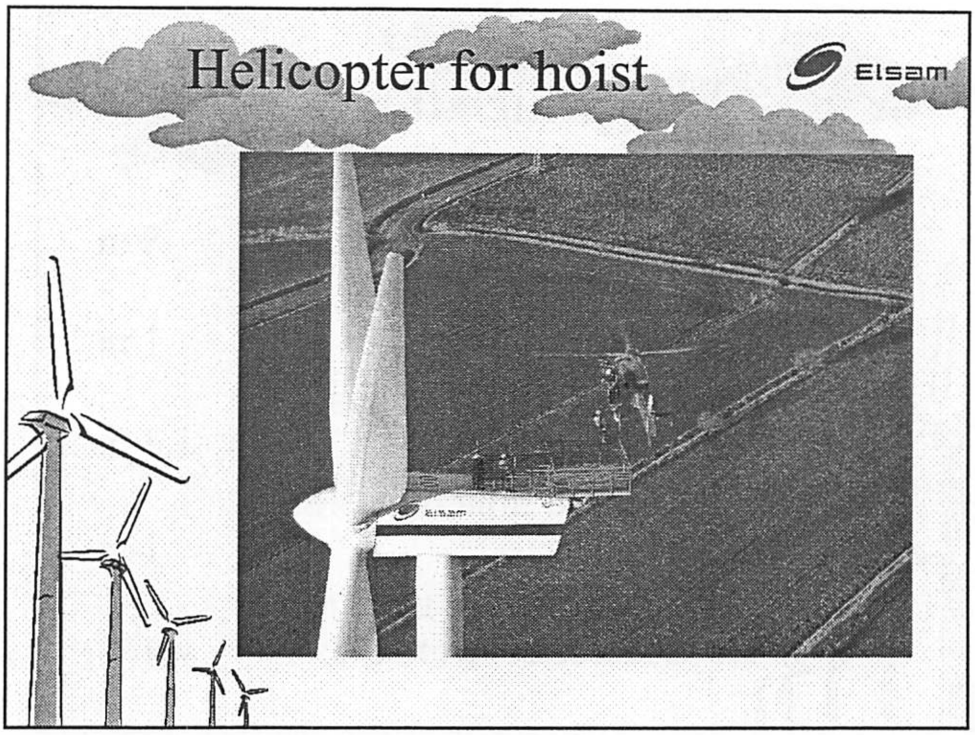
- Maximum Wave Height: 8 m
- Annual Average Significant Wave Height: 1 m
- Expected limit for access to the turbines: 1,3 m
- Experienced limit on Horns Rev: 1 m
- Part of year where the turbines are inaccessible from sea: 40 %

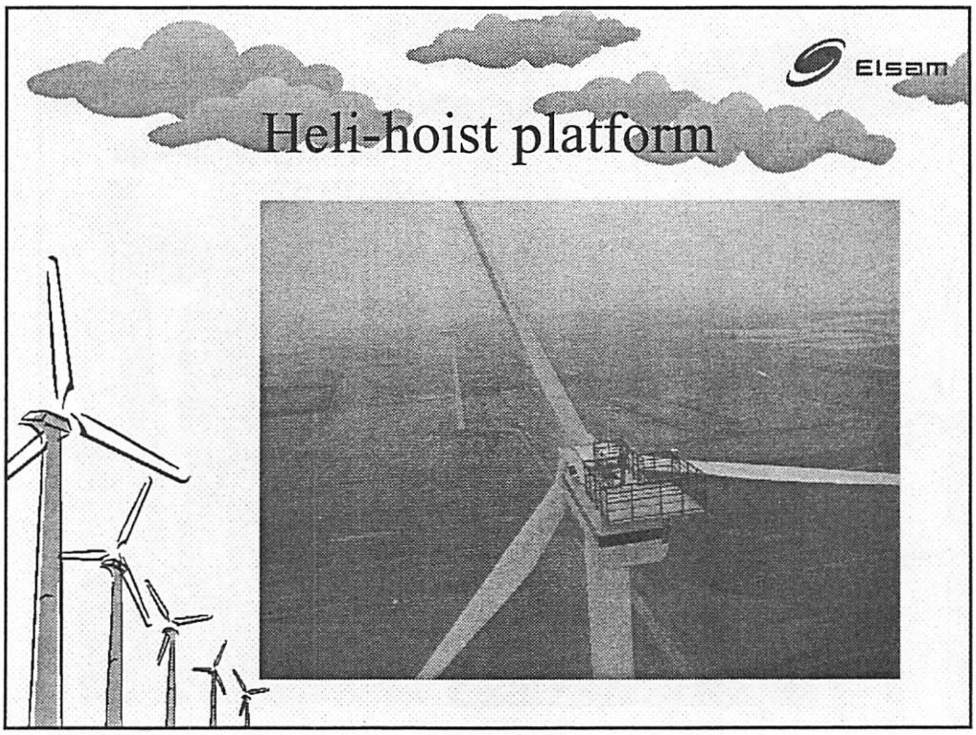
Elsam

Fast Rescue Boat






Helicopter for hoist
Elsam


Elsam
Heli-hoist platform

Elsam

"New" technology

Condition monitoring system, especially vibration monitoring:

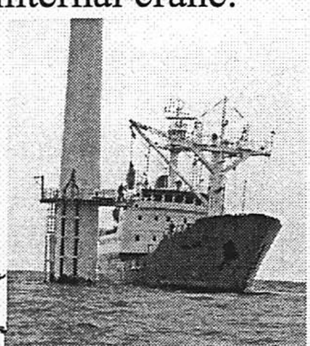
"Now it works, we have an alarm.... What does that mean?"

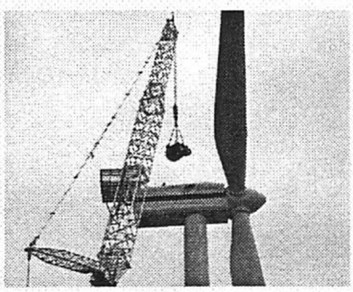
Research and work still needed.

Elsam

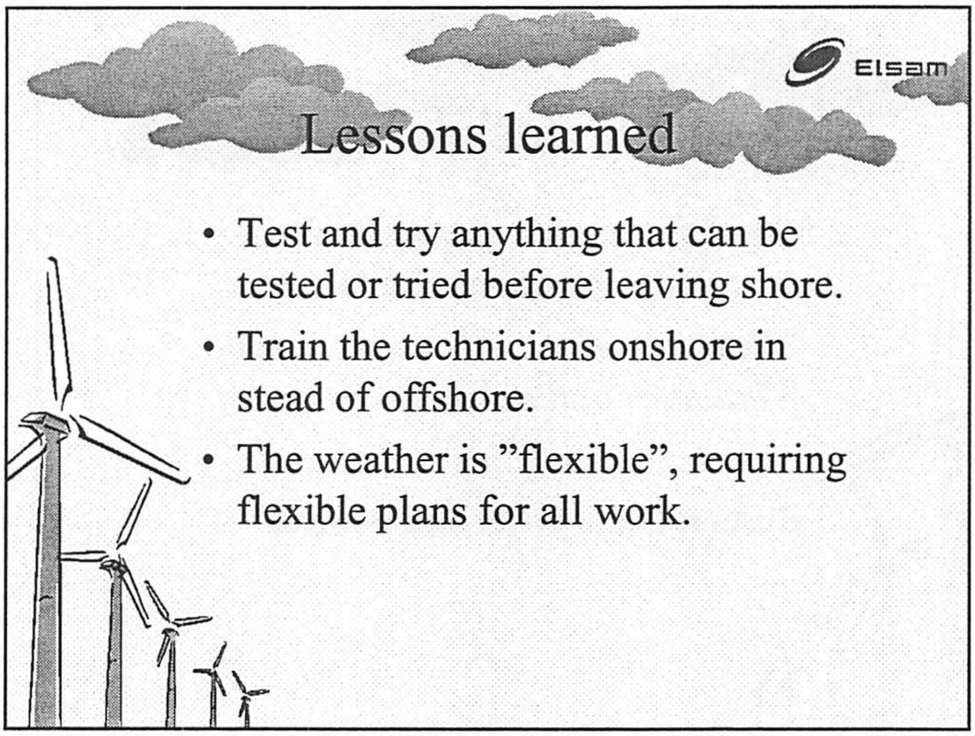
"New" technology

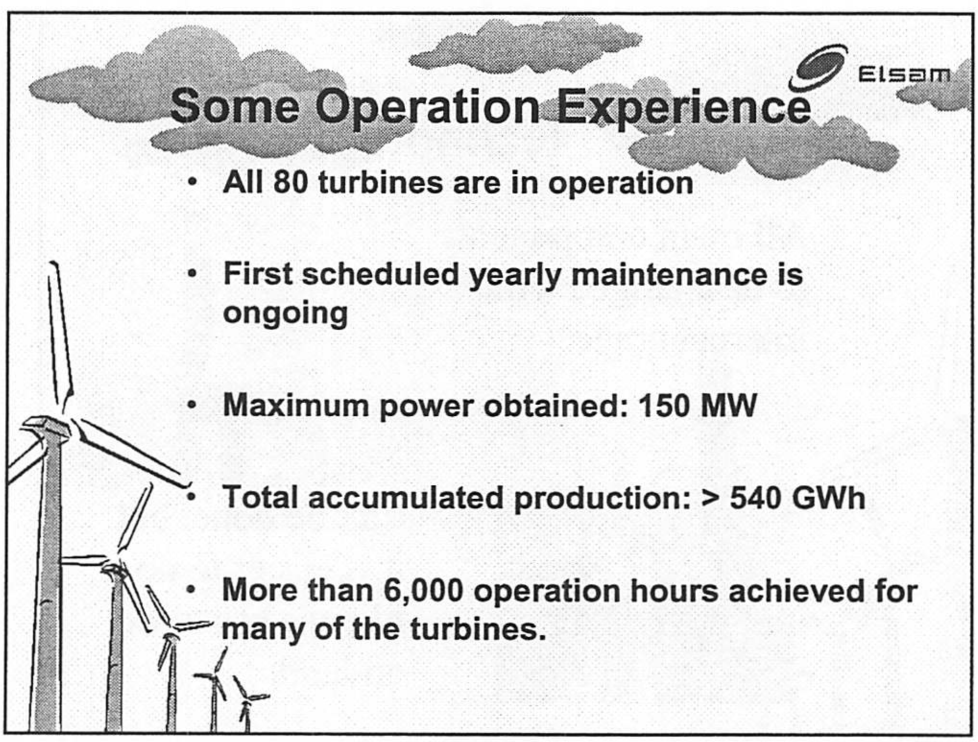
All main components to be changed with internal crane.

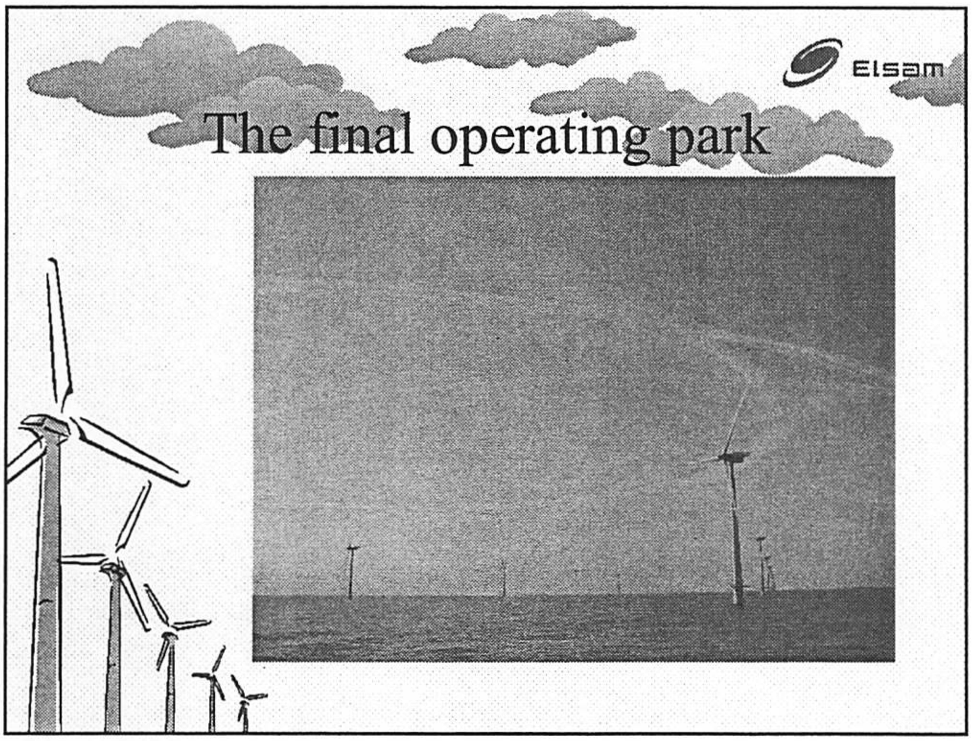




Can be done, but it is easier to do it like we use to do on land.


Elsam
Lessons learned
• Test and try anything that can be tested or tried before leaving shore.
• Train the technicians onshore in stead of offshore.
• The weather is "flexible", requiring flexible plans for all work.


Elsam
Some Operation Experience
• All 80 turbines are in operation
• First scheduled yearly maintenance is ongoing
• Maximum power obtained: 150 MW
• Total accumulated production: > 540 GWh
• More than 6,000 operation hours achieved for many of the turbines.


Elsam
The final operating park

WINDARC™
winds of change

Windarc – a new foundation, transportation and installation method for offshore wind turbines

IEA Topical Expert Meeting No. 43
"Critical Issues Regarding Offshore Technology and Deployment"

Elsam, Fredericia, Denmark, March 9-10 2004
Esa Holttinen, Managing Director, Windarc

WINDARC™
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Windarc is developed at the Mechanical Engineering Division of the Hollming Group

- Hollming Ltd. is a multi-business group that operates in three main sectors:
  - mechanical engineering
  - shipping
  - commercial refrigeration
- Founded 1945, Turnover EUR 160 million
- Hollming Mechanical Engineering Division:
  - Equipment supplier for the offshore and shipbuilding industry, energy production, mining industry etc.

WINDARC™
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Background

- Drawbacks of the traditional techniques for offshore wind turbine installation:
  - Require heavy and expensive equipment
  - Long working time offshore (cost, safety, environmental impacts)
- Experience from the offshore oil and gas and shipbuilding industries applicable to offshore wind projects

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The traditional way – an example

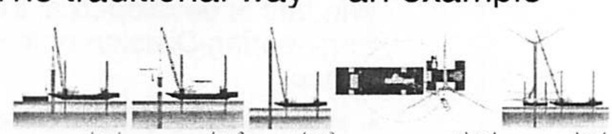

Fig. 1: Different phases of the project (5)

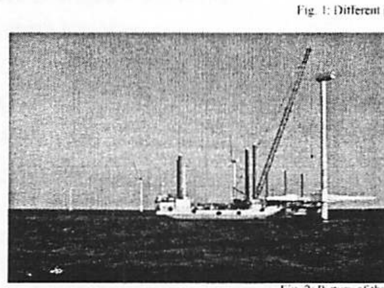

Fig. 2: Picture of the erection of the turbine

(Source: Luc Vandenbulcke, Hydro Soil Services n.v.,
The Utgrunden Windfarm project and future evolutions,
EWEA Special Topic Conference on Offshore Wind Energy, Brussels, Belgium, December 2001)

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Windarc - a pioneering installation concept for offshore wind power plants

- Significant cost savings
- Shorter delivery times
- Guaranteed production capacity
- Safe and ecologically sound

12/03/2004, 5

WINDARC™

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Windarc turn-key solution

Foundation	Design and manufacturing of foundations
Transport	Marine transport
Installation	Offshore installations
Monitoring	Monitoring and communication system
Development	Development services for offshore wind power projects
Financing	Financing services

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WINDARC™

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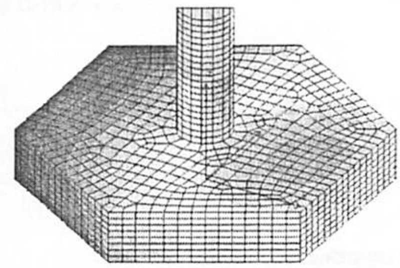
- Foundation
- Transport
- Installation
- Monitoring
- Development
- Financing

Offshore wind power assembled onshore

- Floating steel tank foundation with concrete ballast
- Foundation diameter 25-30 m for turbines at 2 MW size range
- Weight around 1300 t



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- Foundation
- Transport
- Installation
- Monitoring
- Development
- Financing

Installation site optimized manufacturing concept

- Individually designed according to turbine capacity, water depth and soil conditions
- Serially manufactured simple steel structure
- Wind turbine is assembled in port on top of the floating foundation
- The centre of gravity remains inside the concrete ballast also with the turbine assembled
- All mechanical and electrical installations inside the turbine can be performed in port

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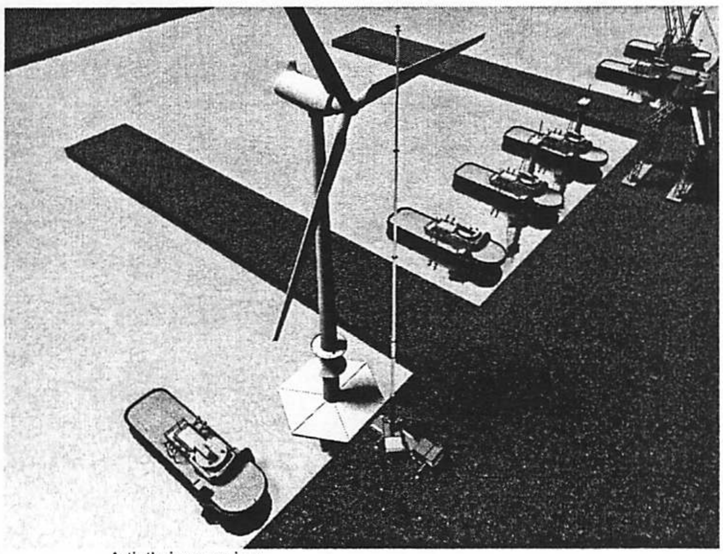

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Artist's impression

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- Foundation
- Transport
- Installation
- Monitoring
- Development
- Financing

Integrated towing system

- Turbines are towed afloat to installation site
- Specially designed barge for transporting several wind turbines simultaneously

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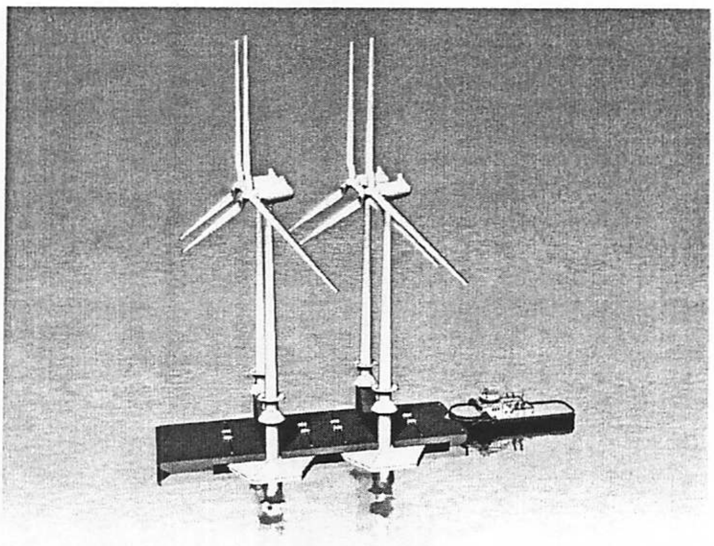

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Artist's impression

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winds of change

- Foundation
- Transport
- Installation
- Monitoring
- Development
- Financing

Minimal installation time offshore

- Windarc technology is best suited to water depths of 5-30 m
- Preparation of seabed is done in a similar manner to a traditional gravity foundation
- Foundation is filled with water and attached to prepared seabed in a controlled manner
- Installation of communication and power transfer cables, preparing of erosion protection
- In use the foundation behaves like a traditional gravity based foundation
- At the end of its lifespan the turbine can be towed back to the shore

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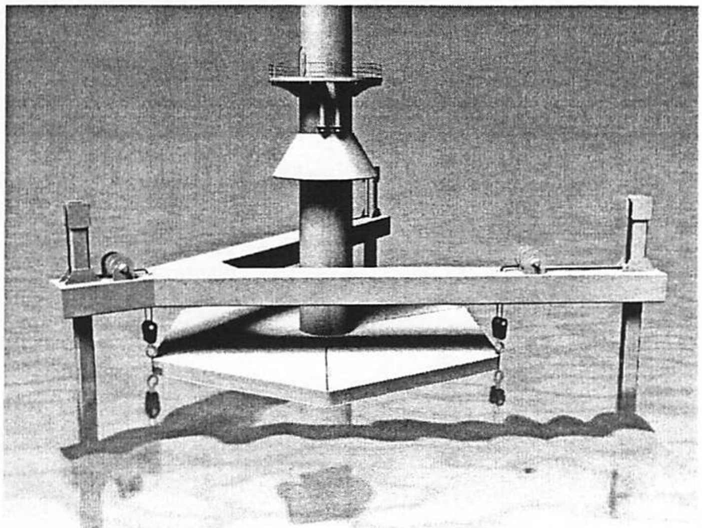

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Artist's impression

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- Foundation
- Transport
- Installation
- Monitoring
- Development
- Financing

Safe remote monitoring

- Monitoring system for analysing wind turbine stability and measuring load conditions
- Data transfer and online monitoring of wind turbine foundation during the transportation, installation and use
- Tower inclination, loads and vibrations on critical parts of the foundation and tower

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Product development

- A network of expertise utilized in the development of Windarc:

VTT

PI-RAUMA

ALFONS HÅKANS

STADIA HELSINKI POLYTECHNIC

IMMTECH OY

ELECTROWATT-EKONO
Jaakko Pöyry Group

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Milestones

- Patent application filed 1999
- Patent granted 2001
- Market assessment and feasibility study 2001
- Product development since summer 2002 in cooperation with PI-Rauma
- Conceptual design and preliminary model tests summer 2003
- Cost estimates and competitiveness analysis 2003
- Publishing of concept at Husum Wind in September 2003

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Present status and future plans

- Conceptual design ready for a 2 MW and a 2.3 MW turbine
- Contract negotiations for the first pilot project going on
- Further model tests have been performed
- Design Verification commenced in cooperation with Germanischer Lloyd
- Pilot installation late 2004 or early 2005
- Commercial production anticipated in 2005-06

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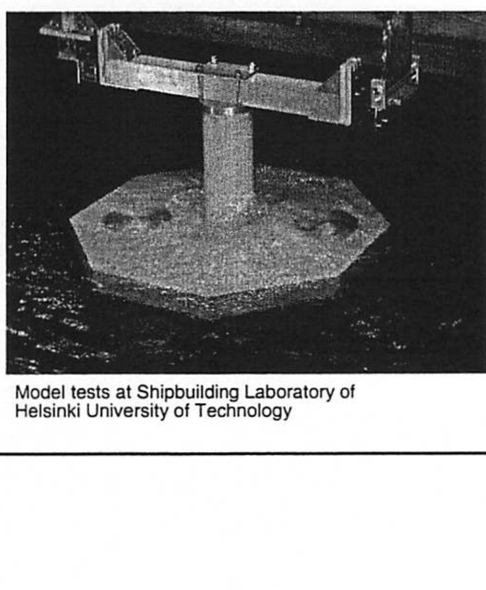
Snapshots from the product development



Model tests at Shipbuilding Laboratory of Helsinki University of Technology

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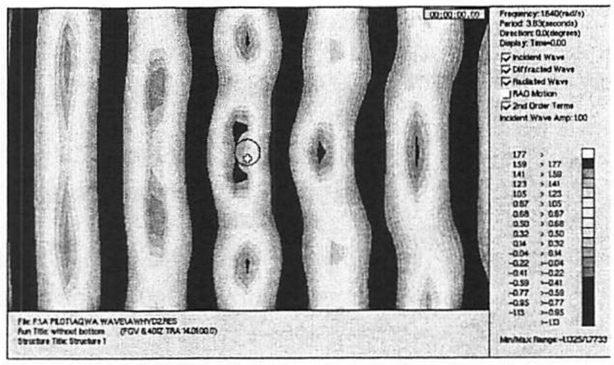
Snapshots from the product development



Wave motion analysis with AQWA software / PI-Rauma

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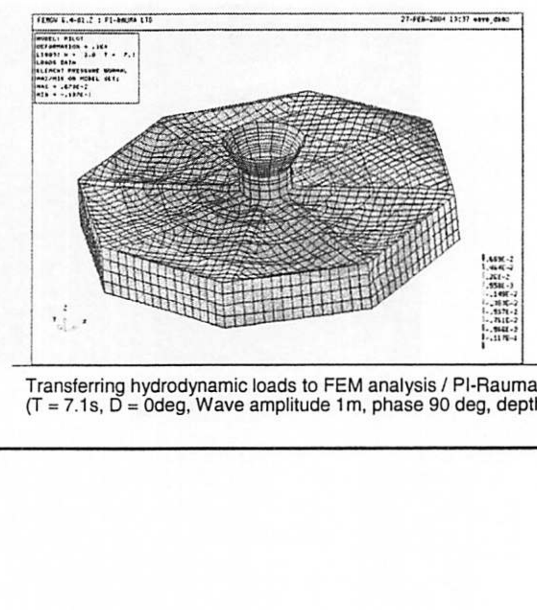
Snapshots from the product development



Transferring hydrodynamic loads to FEM analysis / PI-Rauma
(T = 7.1s, D = 0deg, Wave amplitude 1m, phase 90 deg, depth of water 8m)

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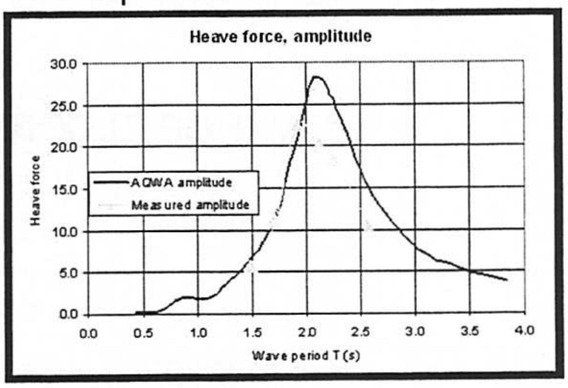
Snapshots from the product development



Comparison of model tests with hydrodynamic analysis / PI-Rauma

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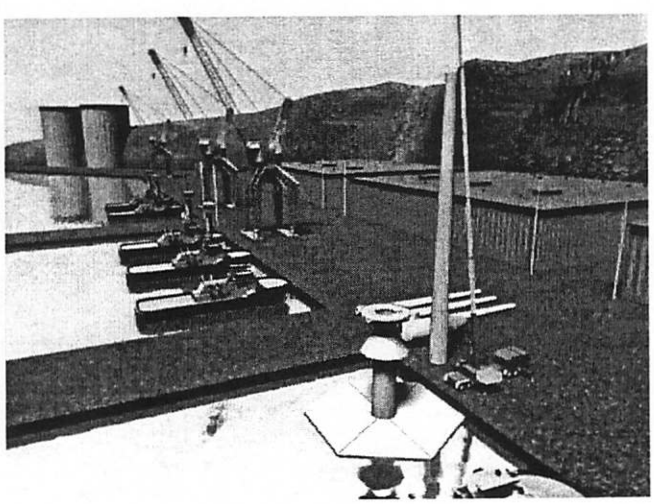

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Scour protection: a necessity or a waste of money?

[1]M.B. Zaaijer, MSc, [2]J. van der Tempel, MSc
Delft University of Technology
Section Wind Energy, Interfaculty Offshore Engineering
Stevinweg 1
2628 CN Delft
The Netherlands
Fax +31 (0) 15 2785347
[1] *Tel. +31 (0) 15 2786426; M.B.Zaaijer@citg.tudelft.nl*
[2] *Tel. +31 (0) 15 2786828; J.vanderTempel@offshore.tudelft.nl*

INTRODUCTION

With 181 out of 295 foundations for offshore wind turbines, the monopile is currently the preferred foundation option. Of these foundations, 169 are driven in sandy soils, which can be more or less susceptible to a type of erosion called scour. Especially at sites with tidal currents, a significant section of the soil around the pile can be removed, due to the effect of the foundation on the local flow pattern and velocities. As a rule of thump, confirmed by experience with other structures, the scour hole can reach a depth of 1.5 times the pile diameter. The main disadvantages associated with this scour hole are:

- Reduction, uncertainty and variation of the supporting function of the seabed, relating to
  - Reduction of the stability of the foundation,
  - Increase of the maximum design moments in the monopile,
  - Decrease and variation in the natural frequency of the support structure,
- Novel and more complicated design requirements for transition of cable between turbine and cable trench.

As a result, the standard solution for monopiles at sites with sandy soils and tidal currents is the application of (costly) scour protection. This paper addresses the question whether scour protection is a necessity, or whether the effects of a scour hole can be mitigated in a cost-effective way. Although no unique answer can be given to this question, the background, effects, solutions and examples presented in this paper will help finding the best solution for a specific project and site. Much of the background information is taken from [7], whereas most of the other information is obtained from study projects in which Delft University has participated.

In addition to the type of scour caused by the influence of the structure on the local flow pattern causing local scour, natural instabilities in the seabed can cause rise and fall of seabed level. The effect can mean a variation and uncertainty of the seabed level of a few meters. Although this can have considerable effect on a structure, and consequently its design, this issue is hardly studied for offshore wind turbines and therefore only marginally addressed in this paper. So far, it is common practise to avoid sites with large moving sand waves.

BACKGROUND

Types of scour

As stated in the introduction, two main types of scour can be identified: one relating to influence of the structure on the flow pattern and one relating to overall seabed movement. Overall seabed movement, or *sand waves*, can be found in places where the upper soil layer consists of loose material that can be transported by sea currents. Without addressing the mechanisms that can cause variations in seabed level due to this soil transport, an example is given in Figure 1 to demonstrate the relevance. The left hand plot shows the location of the site *LN-7* that was selected for a desktop study of an optimum wind farm concept. The plot in the middle zooms in on the local variations of seabed level and the arrows indicate the direction in which the sand waves are migrating (unfortunately unclear in the picture). The right hand side of Figure 1 shows the soil profile at the site and the considerable variation that needs to be taken into account.

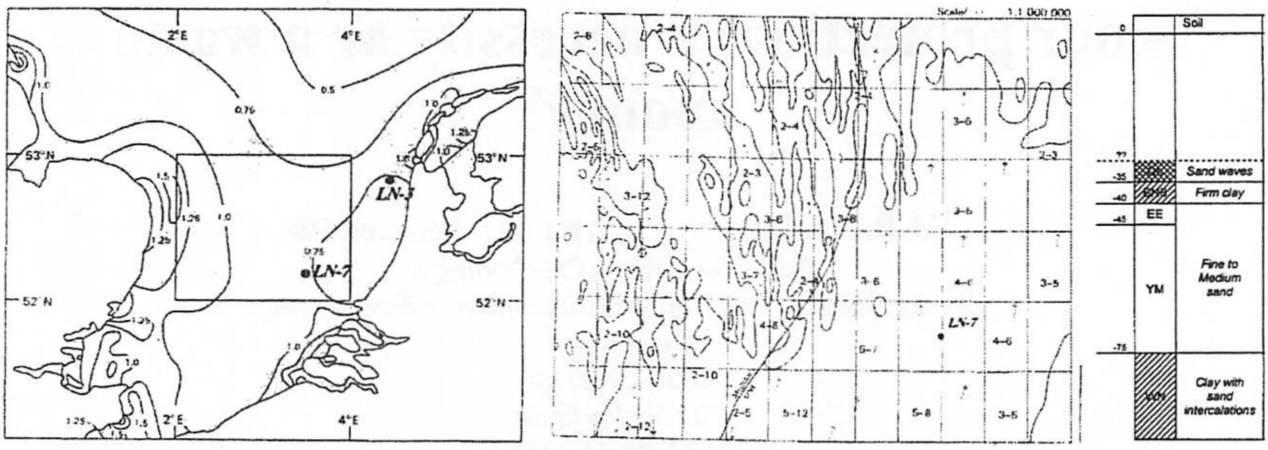

Figure 1 Sand waves with amplitude of around 8 m at a site selected for an offshore wind farm (desktop study) [3].

Figure 2 shows that the occurrence of a scour hole around a structure can be simply demonstrated at the beach. The alternating currents of waves washing ashore have caused a steep scour pit of more or less elliptical shape. This type of scour is called *local scour*.

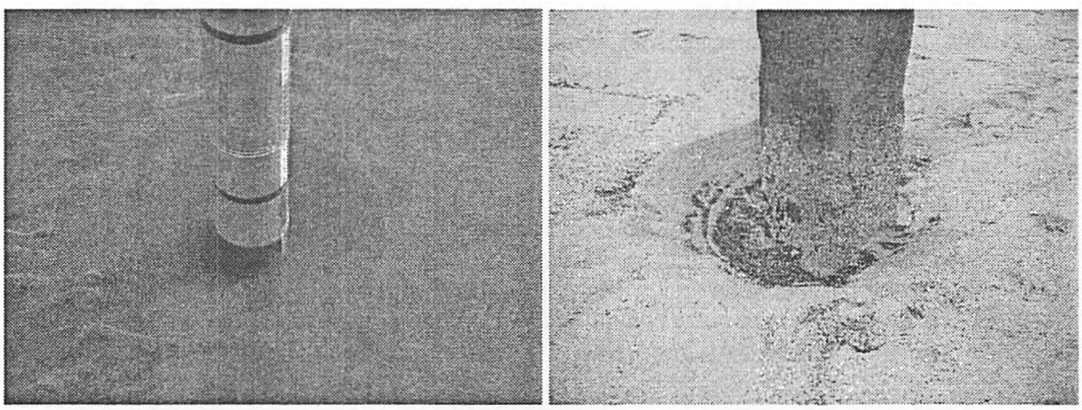

Figure 2 Local scour: steep-sided scour pits around single piles (pictures: J. van der Tempel).

Beside the scour effect at the position where the structure touches the seabed, a more general influence of the flow pattern is possible from the rest of the structure. The effect is typically a shallow and wide depression, as shown in Figure 3. This type of scour is called *global scour* or *dishpan scour*. As the effect of this type of scour on the structure often resembles that of sand waves, this paper will sometimes indicate both changes in seabed level with the term *general scour*.

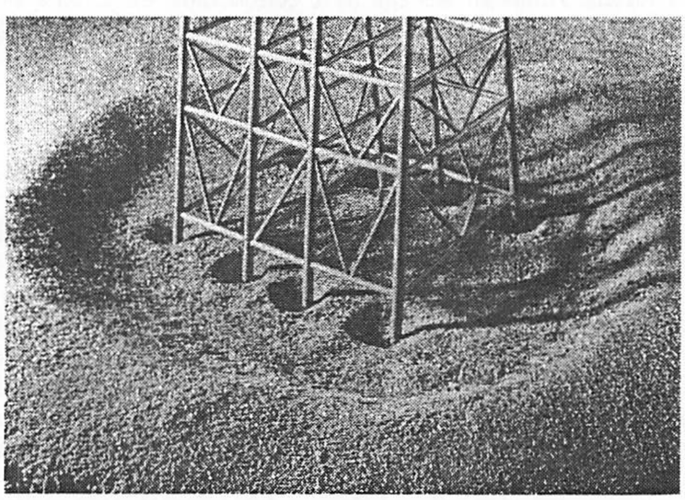

Figure 3 Global scour: shallow wide depression under and around installation [7].

As a further classification of types of scour the following distinctions can be made:

- Characteristic structures
  - Single pile: monopiles
  - Multiple piles: jackets, tripods
  - Large volume: gravity base structures and breakwaters
  - Pipelines.
- Sources of scour
  - Current: in rivers and estuaries
  - Waves: for seas with small tidal influence
  - Waves and current: normal for most offshore locations
  - Ship screws: manoeuvring vessels can cause large local flow velocities.

Development of local scour

The disturbance of the flow by the structure is visualised in the left-hand drawing of Figure 4. The oncoming flow is forced around the structure creating a down flow in front of the structure and a horseshoe vortex near the seabed. Behind the structure the flow is still turbulent. The horseshoe vortex is the main driver of the scour. The turbulent flow behind the structure has a lower velocity, which causes the floating sediment to settle again, creating a zone of deposition higher than the unscoured seabed as shown in the right-hand drawing of Figure 4.

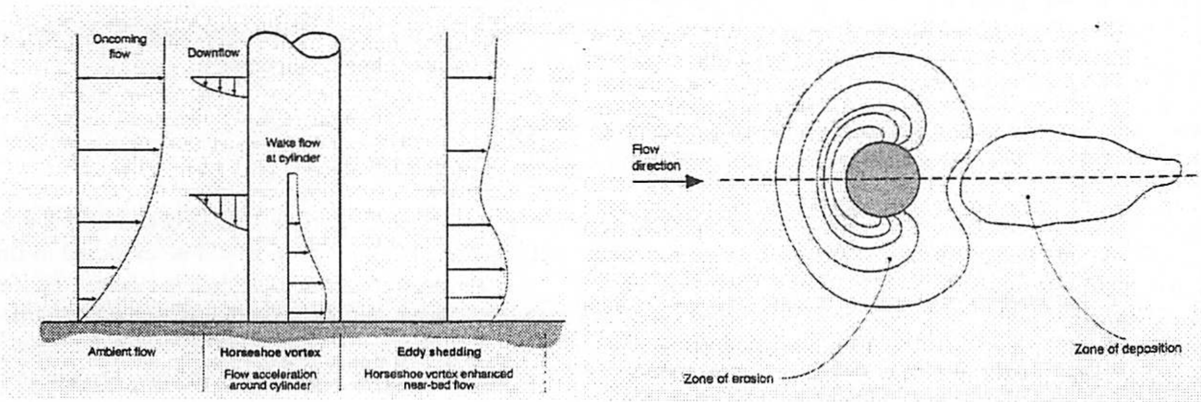

Figure 4 Flow-structure interaction for a vertical cylinder and characteristic scour hole and deposition pattern.

As a rule of thump, depth of the scour is normally taken to be between 0.8 and 2.5 times the pile diameter. However, little experience that does exist with larger piles indicates that the scour depth cannot be scaled linearly for larger diameters. According to personal communication, the scour hole of a 6 m diameter single pile platform in the North Sea was only about 0.6 times the diameter (platform installed by Genius Vos for the NAM in sector N7 north of Schiermonnikoog (NL)). In proceedings of a conference on monopiles, the scour depth for the Europlatform, with a 3.5 m diameter pile, was reported to be less than 1 times the diameter.

PROTECTION AGAINST SCOUR AROUND WIND TURBINES

Design approach and failure mechanisms

When the occurrence or uncertainties of a local scour hole around the wind turbine are not desired, preventive or remedial measures can be applied. This chapter focuses on the prevention of scour by rock dumping, but some alternative will be mentioned at the end. The design principle of this type of scour protection is to provide a filter layer that immobilises the sand and to stabilise this filter layer with one or more layers of rock that can sustain the action of current and waves. Typically, the scour protection will be realised using layers of natural, crushed rock, increasing in size when going up from the seabed. The lowest layer of rock, which is small enough to restrain the soil, may be replaced by a geotextile. The four main failure mechanisms of this type of scour protection are shown in Figure 5, leading to the following design issues:

- Grading of the armour rock to get a stable top layer under design conditions.
- Grading and thickness of filter layers to avoid washing out of soil or intermediate rock layers.
- Horizontal dimension of the scour protection to secure the soil that provides stability to the foundation, including consideration of shear failure and flow slide at the edge.

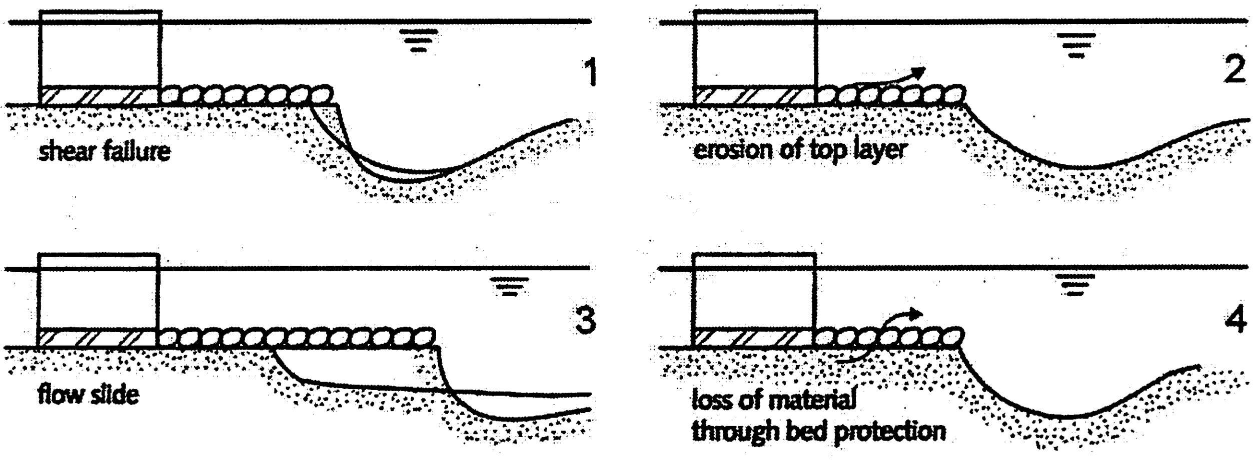

Figure 5 Failure mechanisms of scour protection [1].

Example of baseline solutions

In [1] a design study of scour protection for a 3 MW wind turbine with a 3.5 m diameter monopile is performed. Designs were made for the four possible combinations of the following two conceptual variations:

- Rock layers on top of the seabed or embedded in the seabed
- An armour layer combined with two filter layers or one filter layer and geotextile

For specification of site conditions, the reader is referred to the original report. Under the specified conditions a scour hole with a maximum equilibrium depth of approximately 7 m and a radius of around 20 m would be expected to finally develop without protection. As no shear failure or flow slide of the scour protection are expected, the horizontal extent of the second filter layer is set at 25 m (from the pile outside), providing nearly 100% protection of the active soil. The technical parameters of these designs are presented in Table 1. Including considerations for installation, the design with three rock layers on top of the seabed appeared to be the most economic solution in this case, with approximate costs of € 350,000 per turbine. This design is illustrated in Figure 6.

Table 1 Theoretical scour protection quantities (no losses) for 3 MW turbines.

Description	3 rock layers on top of seabed	3 rock layers embedded	2 rock layers and geotextile on top of seabed	2 rock layers and geotextile embedded
Layer thickness (m)	1.5	1.3	1.2	1.0
Rock quantity (ton)	6500	5500	5400	4400
Geotextile area (m2)			2000	2000
Dredging quantity (m3)		5000		37000

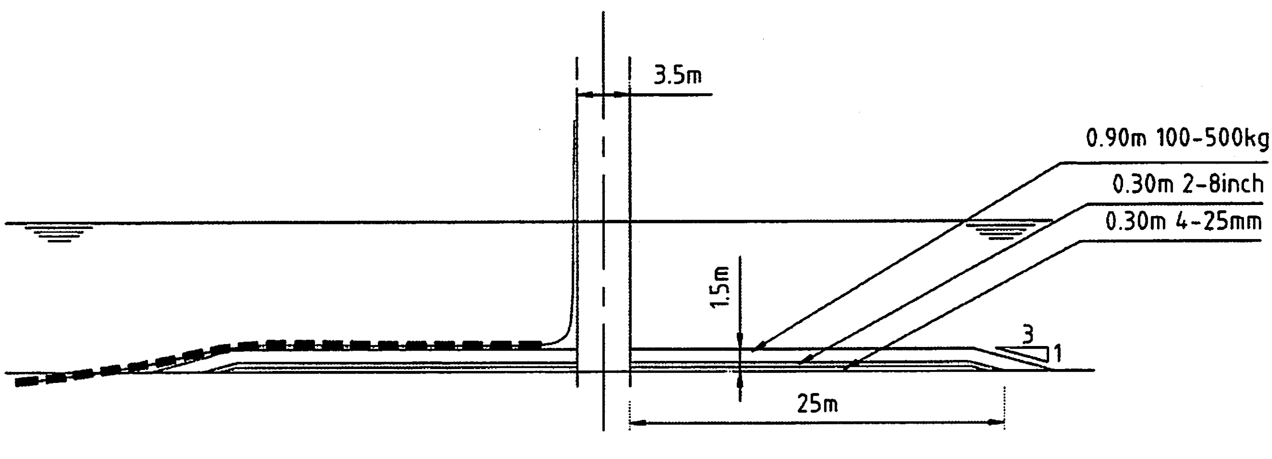

Figure 6 Design solution: three rock layers on top of seabed [1].

Advances in protection design

The cost of a baseline scour protection as presented above is a rather large portion of the total investment. In a follow-up design study for a 6 MW turbine with a 6 m diameter monopile a new protection concept was used, in which the horizontal extent is reduced to a minimum to secure only the soil level near the pile [2]. Due to shear failure the scour protection slopes down to a circular scour hole outside its edge, see Figure 7. The stability of the scour protection and the 'moat' around it determine the minimum required extent of the scour protection. A lower limit is set at 2 times the pile diameter, which is considered to be the region with influenced current. Based on the outcome of the protection design for the 3 MW turbine only designs for rock layers on top of the seabed are made. Some results are shown in Table 2 for various water depths. No clear and monotone relation could be found, due to counteracting mechanisms. The new design concept results in far smaller rock quantities than for the 3 MW turbines. When this type of limited protection is applied, geotechnical evaluations of the pile must consider that the scour protection slopes down at a rate of 1:8 and that some of the active soil outside the protected area is washed away.

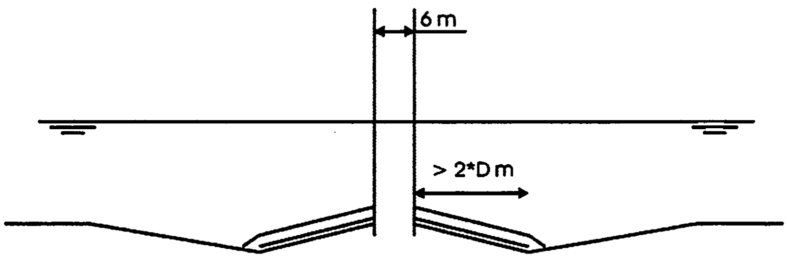

Figure 7 Scour protection of limited area.

Table 2 Theoretical scour protection quantities (no losses) for 6 MW turbines.

Water depth (m)	Horizontal extent (m)	Layer thickness (m)	Rock quantity (ton)
20	13.5	1.1	1000
25	16.9	1.0	1300
30	20.2	0.75	1300
35	23.6	0.7	1600

In [5] several alternative methods of scour protections are analysed, leading to the following conclusions:

- Rock dumping in the scour hole after it has been developed is technically possibly and might be an economic solution.
- Bottom protection with integrated geotextile and concrete block mattresses is difficult to install and too expensive.
- A protection wall with concrete filling is technically difficult and too expensive.
- Seabed improvement by gluing the sand is risky and little experience is available.

It is noted that scour protection requires inspection and maintenance. As an alternative to commonly applied procedures, [5] concludes that application of optical fibres to monitor scour protection or the development of a scour hole by temperature measurements is technically unfeasible.

CONSEQUENCES OF (LOCAL) SCOUR

Overview

The effect of scour on the structure is schematically presented in Figure 8. The left-hand side of Figure 8 illustrates the pile and the change in seabed geometry and the right-hand side shows the increase of vertical effective soil pressure with depth below the mudline. The vertical effective soil pressure is directly determined by the weight of the soil in higher layers and is a measure for the strength and stiffness of the soil. Evidently, in the scoured region the pile is no longer supported by soil. In case of general scour (either due to sand waves or global scour), the effective soil pressure at all depths is reduced with the weight of the scoured soil. In case of local scour, the effective soil pressure near the pile and near the bottom of the scour pit is also reduced to zero, but further down the pile the weight of the upper layer of soil farther away from the pile also presses down on the soil near the pile. At very large depths the effect of the local scour hole on the effective soil pressure is no longer present. The transition is commonly modelled by a linear decrease of the effect of the local scour hole over a region that is called the overburden reduction depth. A typical value for the overburden reduction depth is 6 times the pile diameter.

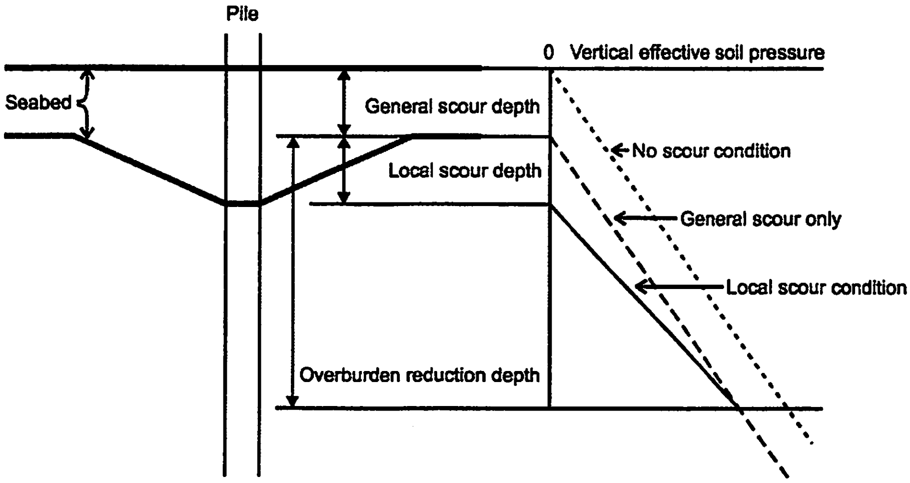

Figure 8 Reduction of effective soil pressure due to scour.

For offshore wind turbines, the consequences of the disappearance of soil support in the scoured region and of strength and stiffness below the mudline can be summarised as follows:

- Reduction of soil support and strength requires a larger penetration depth for piles to provide a stable foundation,
- Increase of the lever arm of wind and wave loading increases the bending moments in the pile, leading to a larger required diameter or wall thickness,
- Reduction of soil support and stiffness results in lower natural frequencies of the support structure,
- Geometrical variation of the mudline leads to novel and more complicated design requirements for transition of the cable between turbine and cable trench.

These consequences are further discussed in the next sections.

Static strength and stability

As stated in the overview, the effect of scour needs to be considered in the design of pile length and cross-sectional properties. Table 3 provides a comparison of the design parameters of monopiles for 3.6 and 6 MW turbines with or without scour protection. This data is taken from [4]. As can be seen, omission of scour protection may result in increase of material for the pile of over 20% of the material used in case of scour protection. A similar study for a tripod for a 6 MW turbine in [8] showed that pile material needed to be doubled when no scour protection was applied, but this conclusion relates to the much lower masses of tripod piles.

Table 3 Comparison of monopile designs with and without scour protection in 21 m water depth.

Configuration	Diameter (m)	Wall thickness (mm)	Embedded length[1] (m)	Mass[2] ($\cdot 10^3$ kg)
3.6 MW				
Scour protection	4.6	46	30	310
Scour hole 7.5 m	4.9	49	37.5	396
6.0 MW				
Scour protection	5.8	58	35.9	541
Scour hole 9.3 m	6.2	62	40.7	664

[1] Below the unscoured seabed at 21 m water depth
[2] Pile extends to 9 m above MSL

Dynamic behaviour

The natural frequencies of the wind turbine determine to what extent external excitations are picked up and translated to stresses in the structure. Of primary importance are the relations between the first natural frequency of the support structure on the one hand and wave, rotational and blade passing frequencies on the other. As the natural frequency of the support structure drops when scour occurs, it will normally get closer to wave frequencies and pick up more wave loading. Whether the distance to rotational or blade passing frequencies decreases or increases differs for different turbine and support structure designs. Since the level of scour is uncertain and may vary in time, the possibility of resonance due to variation and uncertainty of the natural frequencies needs careful consideration. In [9] the effect of general and global scour on several support structures for a 3 MW turbine is determined. The results are summarised in

Table 4. The natural frequency in case of general scour relates to a scour level of -2 m, while the natural frequency in case of local scour relates to 2 times the pile diameter. The natural frequency of the monopile is most susceptible to scour. The tripod and lattice tower are more sensitive to general scour than to local scour, given the small local scour hole associated with the small pile diameters.

Table 4 Sensitivity of first natural frequency of the support structure of a 3 MW turbine to scour.

	Tubular tower - monopile		Tripod - piles		Lattice tower - piles	
	1st n.f. (Hz)	Difference (%)	1st n.f. (Hz)	Difference (%)	1st n.f. (Hz)	Difference (%)
No scour	0.29055		0.45516		0.72470	
General scour	0.28360	2.4	0.45185	0.7	0.70191	3.1
Local scour	0.27771	4.4	0.45375	0.3	0.71424	1.4

In [8] a similar study for a tripod and monopile design of a 6 MW turbine is presented. The result, including an analysis of the second natural frequency, is shown in Figure 9. General scour is not considered for the tripod, since that had also not been considered in the design phase. The results show the same tendency as Table 4, but in addition demonstrate a considerable sensitivity of the second natural frequency, particularly for the tripod. It is expected that the large sensitivity is caused by the lateral flexibility of the unsupported pile section in the scour hole.

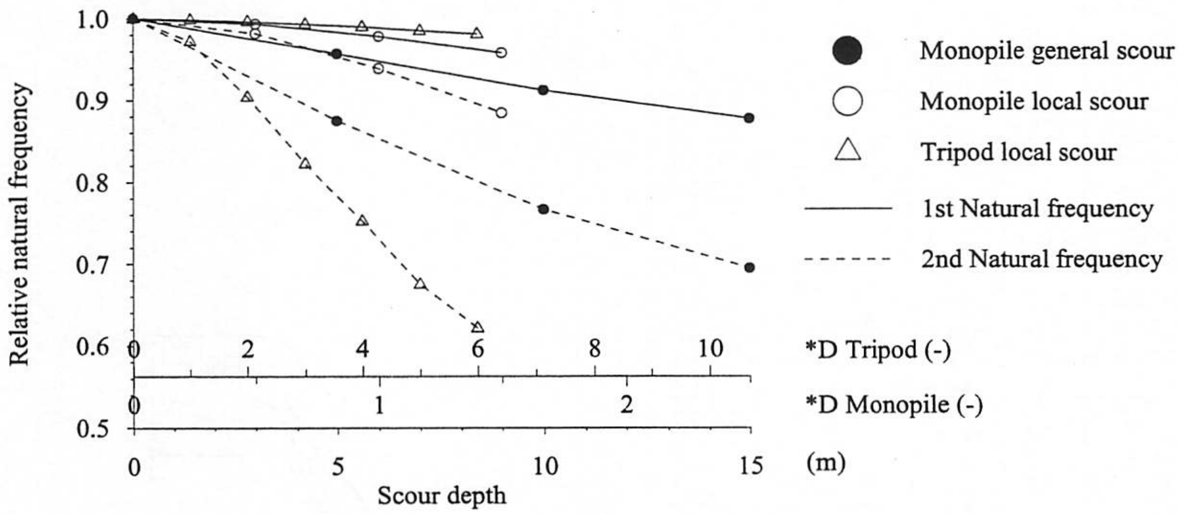

Figure 9 Sensitivity of natural frequencies of the support structure of a 6 MW turbine to scour.

Cable feed-in

As a reference, Figure 10 shows the cable feed-in of the Horns Rev wind farm. A PVC J-tube facilitates the transition between turbine and cable trench and at the exit of the J-tube the cable is stabilised by armour rock.

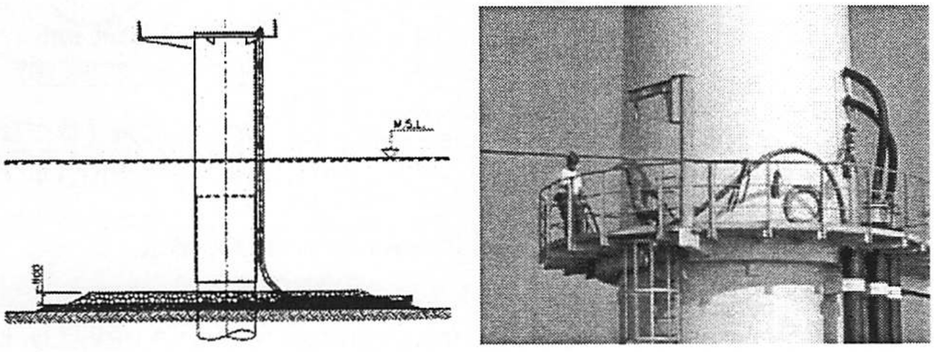

Figure 10 Principle of J-tube cable feed-in with scour protection.

Without extra measures, the cable exiting the J-tube will hang loose in the scour hole and will fail due to the continuous action of currents and waves. Figure 11 shows an extended J-tube, which might be a straightforward solution to this problem as presented in [6]. The right-hand drawing in Figure 11 shows intermediate piles that are proposed to support the cable over a span.

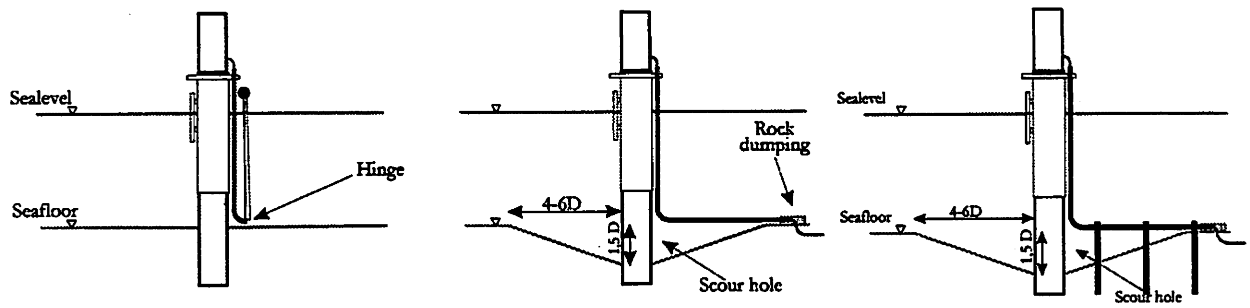

Figure 11 Extended J-tube to cover the transition of a scour hole.

[6] also proposes the more advanced solution of directional drilling, thus avoiding a J-tube and the scour hole as illustrated in Figure 12. Although this set-up has some clear advantages, it is noted that no experience exists with a cable installation procedure using a well with 90° intrusion angle, horizontal directional drilling units cannot easily be used and offshore oil drillers are not used to resurface their wells, so mud handling problems at the exit point have yet to be solved. Besides the technical feasibility, the economic viability of this solution has to be established.

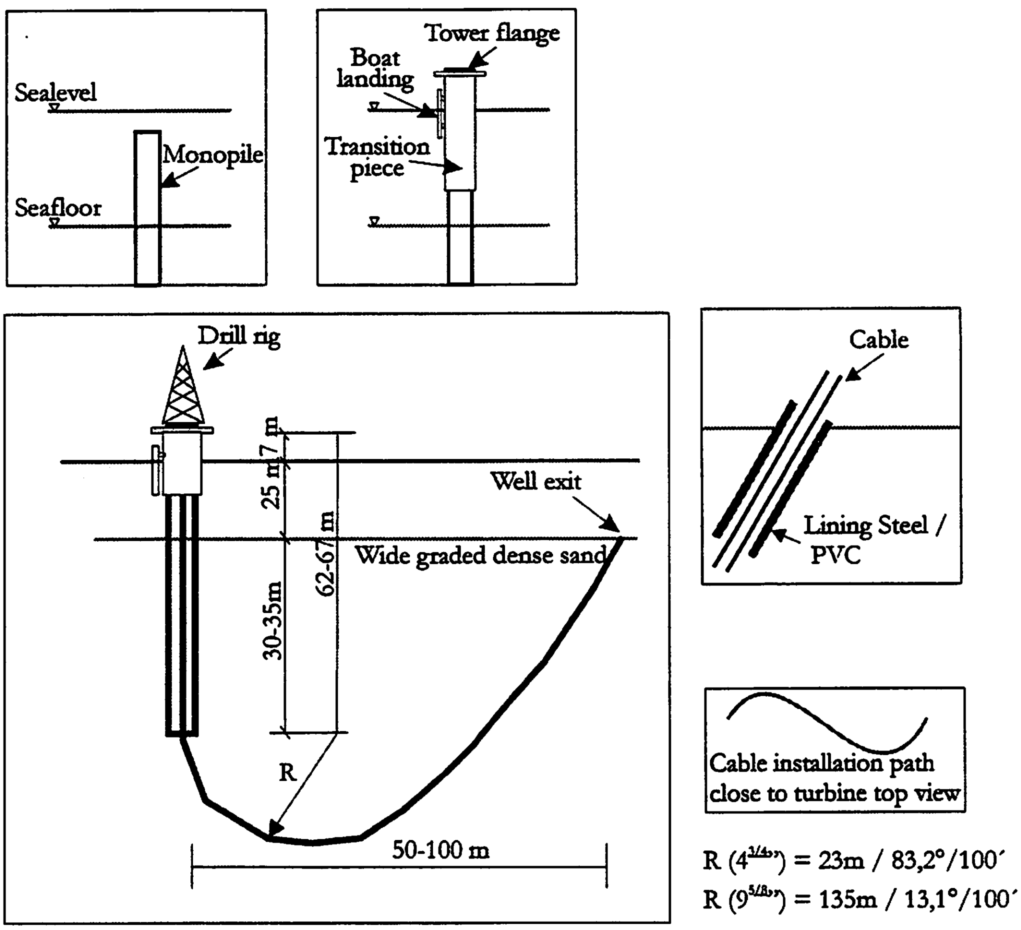

Figure 12 Transition of scour hole by means of directional drilling.

SCOUR PROTECTION OR NOT: TECHNOLOGICAL CHALLENGE AND DEVELOPERS CHOICE

Although it is common practise to apply scour protection at sites with a potential for local scour, the analysis of the issues indicate that the omission of protection is likely to provide a technically acceptable solution. The design solutions with and without scour protection have to be compared with respect to

- Technical feasibility of the solutions
- Risks
- Costs

In general, the technical feasibility of the slightly larger pile for a design that allows scour will not differ significantly from that of the protected case, unless the latter is designed at the limit of manufacturing or installation capabilities. Currently, technical feasibility of the solutions to create a reliable cable transition of the scour hole is untested, although many solutions can be designed that are technically rather straightforward. Last but not least, the variation of the natural frequency as the scour hole develops may be in conflict with the rotor speed range. If this conflict occurs, it has to be resolved by a mechanism that can adapt the natural frequency or the rotor speed controller. However, the examples presented show acceptably small sensitivity of the natural frequency to scour depth.

The main risk of unprotected wind turbines is associated with the uncertainty and variation of the depth of the scour hole around wind turbine structures. With respect to stability of the foundation, risks can be eliminated to the same level as obtained with scour protection by assumption of a conservative (equals deep) scour hole. The same is not true for the dynamic behaviour, as the assumption of a deeper scour hole may increase the predicted response to wave loading, but could lead to underestimation of response to wind loading. As a consequence, several scour depths should be analysed, but still some effects might be missed in the process.

The case study of the 6 MW turbine that is used as an example at various places in this paper resulted in nearly equal additional costs to sustain a scour hole as the original costs for scour protection. This demonstrates that the question whether or not to apply scour protection is legitimate from an investor's point of view. As uncertainties in scour depth have to be translated to additional margins, part of the costs may be reduced in future, when more knowledge and experience are obtained. In addition to direct costs, it is noted that adaptation of the rotor speed range to avoid resonance may result in reduced energy production.

The preference for monopiles is likely to persist for future wind farms, many of which will be at exposed sites with water depths of around 20 m. For these foundations the omission of scour protection is going to be a likely alternative when the aforementioned uncertainties and design considerations are effectively addressed. The reduction of the relative scour depth for larger piles would be in favour of the omission of protection for larger sized turbines in deeper waters. Nevertheless, this advantage can only be exploited when the reduced scour depth for larger piles can be predicted with sufficient safety. Existing theoretical models, tank tests and experiences can form a basis for this prediction, but have to be extrapolated and validated for the conditions and sizes of offshore wind turbine foundations.

Although the subject is not extensively addressed in this paper, the reader is reminded that sand waves may result in additional complications for offshore wind turbine design. Predictability of sand waves is limited, due to limited theoretical and practical knowledge of the phenomenon. In addition, as the phenomenon cannot be prevented, mitigation of the effect on the structure has to be investigated.

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[9] Zaaijer, M.B., e.a., Design methods for offshore wind turbines at exposed sites (OWTES) - Sensitivity analysis for foundations of offshore wind turbines, Section Wind Energy, WE 02181, Delft, March 2000.

Scour protection: A necessity or a waste of money?

Michiel Zaaijer
Jan van der Tempel

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Background information

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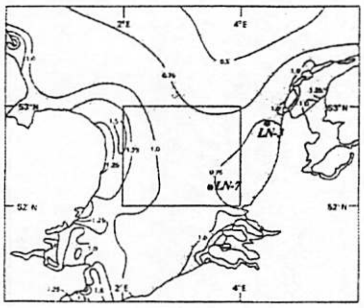
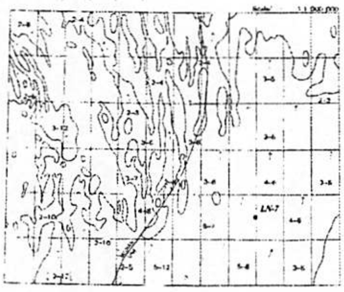
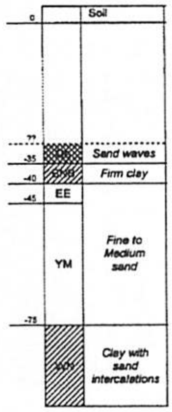
Sand waves







Overall movement of the seabed

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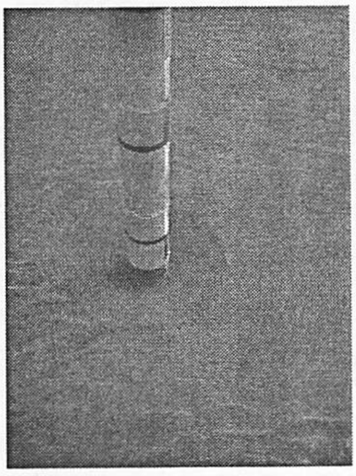
Local scour



Steep-sided pits around single piles

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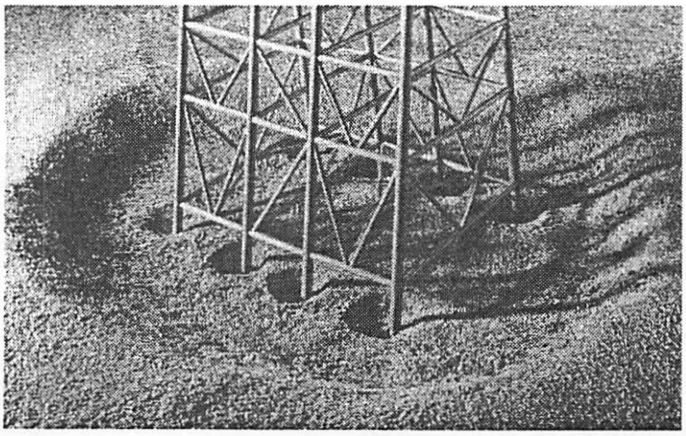
Global scour



Shallow wide depressions under installations

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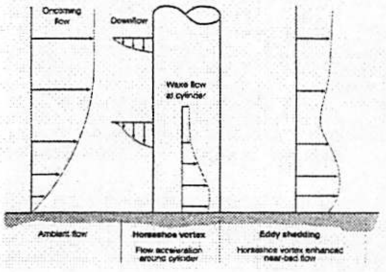
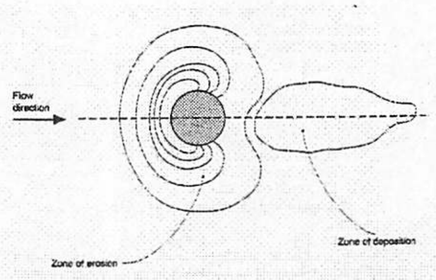
Development of local scour





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Scour protection

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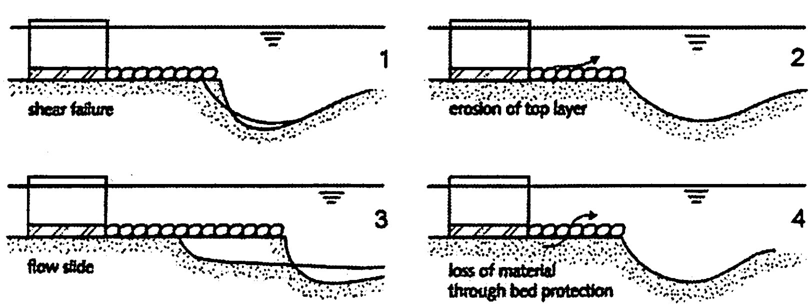
Failure mechanisms



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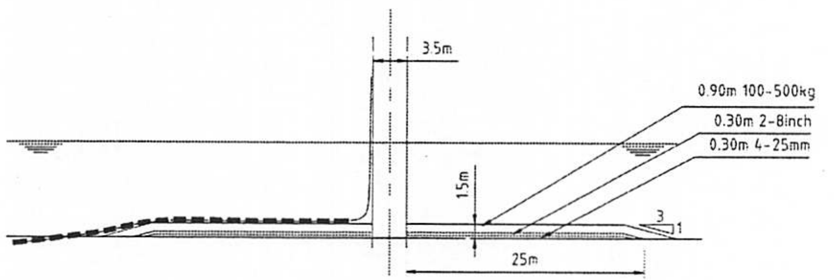
Baseline solution – full protection



3 MW turbine
3.5 m diameter monopile
Protection of active soil up to 25 m from pile
3 layers of rock – 6500 ton

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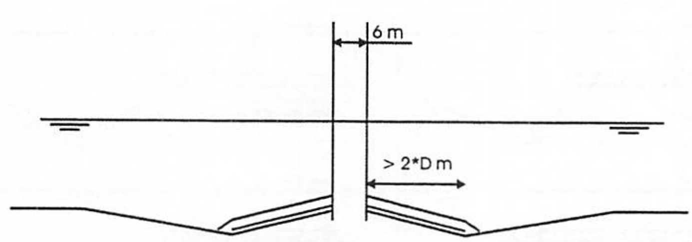
Advanced solution – limited protection



6 MW turbine
6 m diameter monopile
Smallest possible stable protection area (> 2*pile diameter)
1000 ton

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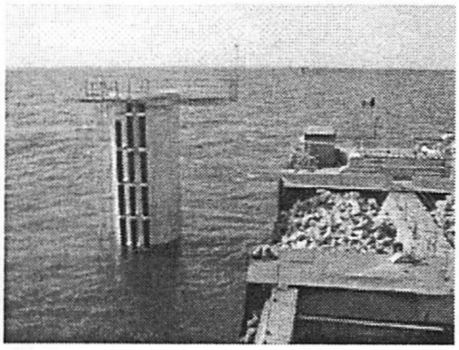
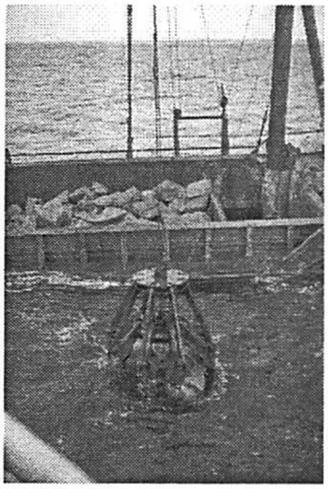
Installation





Alternative concepts of protection

- Rock dumping in hole after development
- Integrated geotextile and concrete mattresses
- Protection wall with concrete filling
- Seabed improvement by gluing

Consequences of (local) scour

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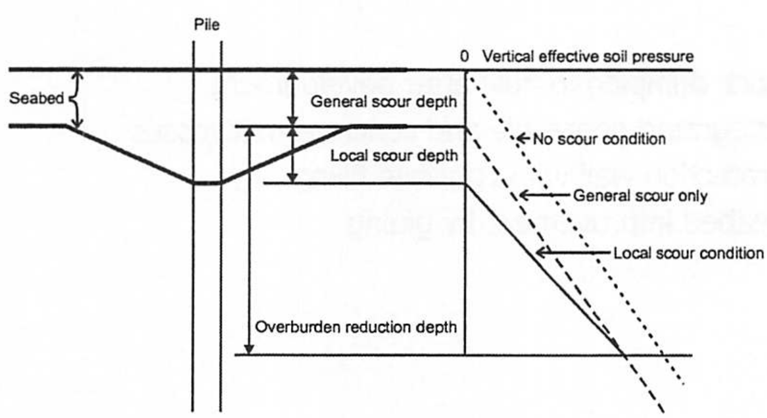
Reduction of effective soil pressure



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Four effects of scour on pile design

- Increase of pile length
- Increase of pile diameter and or wall thickness
- Decrease and uncertainty of natural frequency
- Complication of cable transition (structure to trench)

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Increase of pile material

Configuration	Diameter (m)	Wall thickness (mm)	Embedded length (m)	Mass ($\cdot 10^3$ kg)
3.6 MW				
Scour protection	4.6	46	30	310
Scour hole 7.5 m	4.9	49	37.5	396
6.0 MW				
Scour protection	5.8	58	35.9	541
Scour hole 9.3 m	6.2	62	40.7	664

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Decrease of natural frequency (1)

	Tubular tower - monopile		Tripod - piles		Lattice tower - piles	
	1st n.f. (Hz)	Difference (%)	1st n.f. (Hz)	Difference (%)	1st n.f. (Hz)	Difference (%)
No scour	0.29055		0.45516		0.72470	
General scour	0.28360	2.4	0.45185	0.7	0.70191	3.1
Local scour	0.27771	4.4	0.45375	0.3	0.71424	1.4

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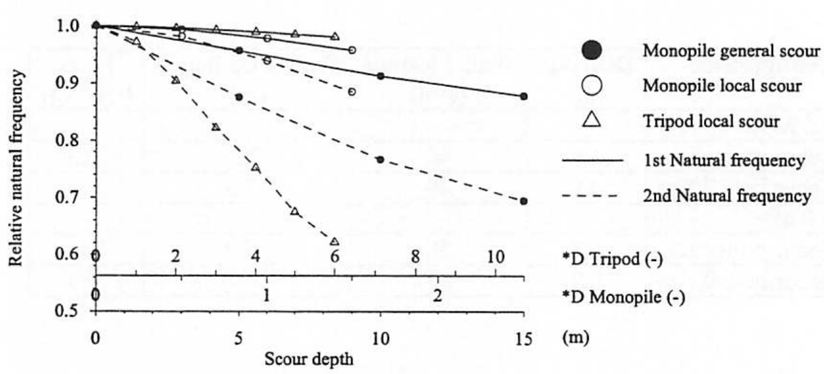
Decrease of natural frequency (2)



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Cable feed-in

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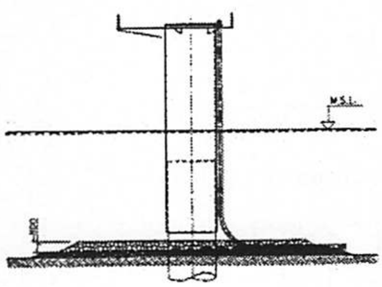
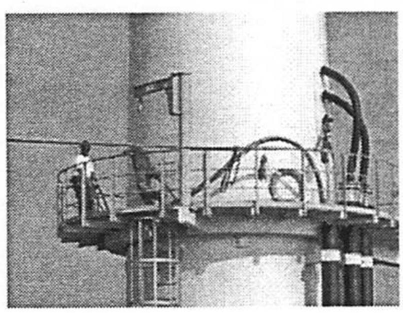
Reference: Scour protection / J-tube





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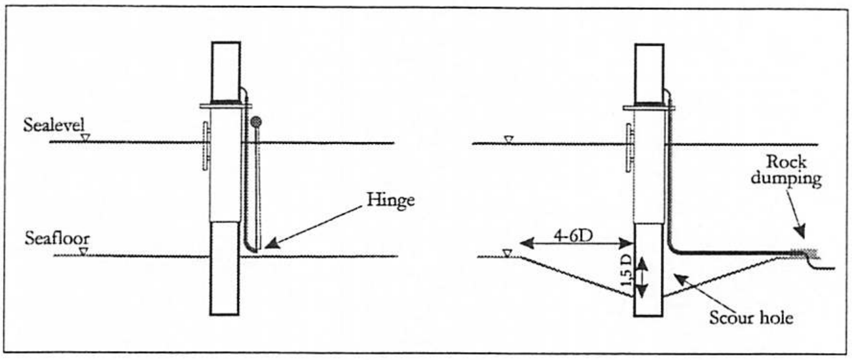
Transition of scour hole (1)



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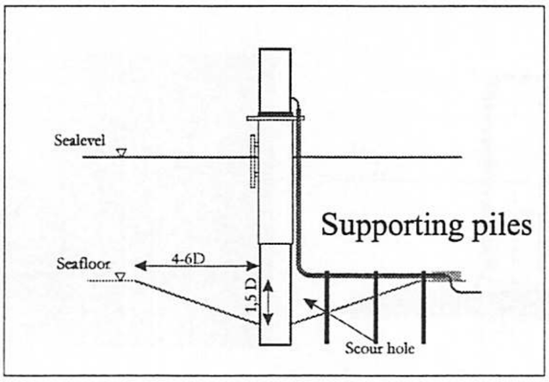
Transition of scour hole (2)



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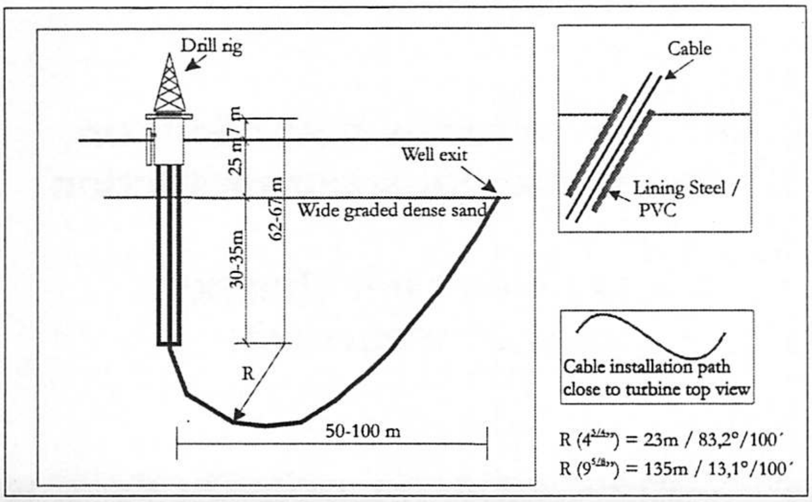
Transition of scour hole (3)



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Scour protection or not?

- Scour protection not always necessary
- Comparison of
  - Technical issues
  - Risks
  - Costs
- Accelerators for omission of scour protection
  - Better prediction of scour pit depth
  - Solutions for cable transition

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Proposition for discussion:

All future effort is best spent on solutions without scour protection

-

Rocks won't get cheaper, new concepts will

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Differentiating Integrated Design

J. van der Tempel
Delft University of Technology
Section Wind Energy, Interfaculty Offshore Engineering
Stevinweg 1
2628 CN Delft
The Netherlands
Fax +31 (0) 15 2785347
Tel. +31 (0) 15 2786828; J.vanderTempel@offshore.tudelft.nl

SYNOPSIS

While offshore wind energy outgrew its demonstration character over the last decade, a recurring theme found throughout most studies was the need for "integrated design". The explicitness with which this requirement was emphasised is remarkable, considering the highly multi-disciplinary nature of both wind turbine and offshore engineering. Even more remarkable is the fact that to date real integrated design of offshore wind turbines has not really made it to the designer's desk. Although turbines are "marinized" they are still extensions of the onshore versions. And in the design a strict division line still runs between the foundation and the turbine.

This paper investigates the origin and initial intention of integrated design for offshore wind energy: the methodology, the numbers and the details. The practical design and installation of Horns Rev is then used to test the proposed methodology. The results of the measurement program on the turbines at Blyth are used to validate the numbers. Finally, the Delft University of Technology has finished their first exam in offshore wind farm design. The results of the student exercises give a remarkable insight in the details of applied integrated design.

It can be concluded that integrated calculation of dynamic wind and wave loads is crucial for a proper offshore wind turbine design. But the understanding of the underlying principles of both engineering fields is even more essential. This understanding will enable designers to optimise sub-components that result in an optimised total design.

THE ORIGIN OF "INTEGRATED DESIGN" IN OFFSHORE WIND ENERGY

During the 1970-ies, '80-ies and early '90-ies, a number of studies were conducted in the field of offshore wind energy. Offshore and shipbuilding as well as renewable energy groups drafted reports on how to effectively harness the offshore wind energy potential. The first designs were mainly based on the multi-megawatt prototype turbines built in the 1970-ies: 3MW and more. The structures were large, heavy and stiff: based on the accumulated experience of offshore construction in the North Sea for oil & gas exploitation. Figure 1 shows examples of a design from the British RES study and a Heerema tripod design.

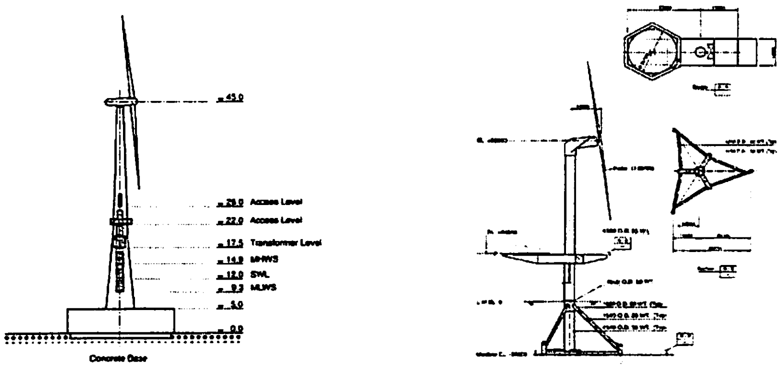

Figure 1. Offshore wind turbine design from the RES and the Heerema study

The design did incorporate combined wind and wave loading, but only on a basic level for extreme load case calculations. The stiffness of the structure prevented heavy dynamic response, so fatigue was not a big issue. For the subject operation and maintenance a direct copy of offshore platforms was made: the addition of a complete helicopter deck.

In 1995 the Joule I "Study of Offshore Wind Energy in the EC" was published. The study gave an overview of the wind potential offshore as shown in figure 2. The study described the design of offshore wind turbines in a more generic way with example designs for different types of offshore wind turbines. It was found that for one turbine wave loads could be dominant while for the other wind was the dominant load source. One of the main issues found was the benefit of aerodynamic damping on the dynamic behaviour of the structure when the turbine is in operation. It was also stated that a softer support structure would further enhance the aerodynamic damping effect, but at the cost of increased tower motion.

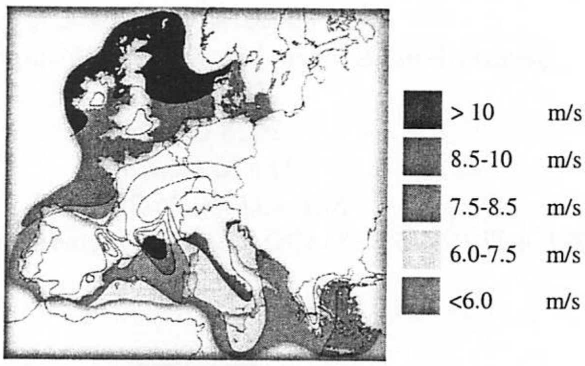

Figure 2. Yearly average wind speed at 100m height for the European Seas

The Joule III Opti-OWECS report finally made a complete design focussing on the integrated dynamic features of flexible offshore wind turbines. The design incorporated the entire offshore wind farm with all its features from turbines to operation and maintenance philosophy to cost modelling. Figure 3 gives an overview of all subjects covered in this integrated design scheme.

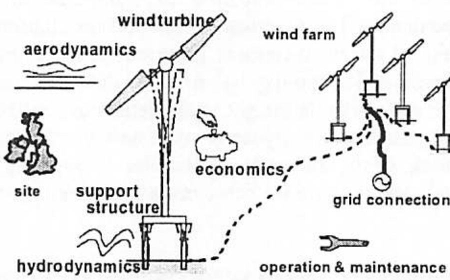

Figure 3. Subjects covered in the integrated design approach of the Opti-OWECS study

The Opti-OWECS study explored the possibilities of flexible dynamic design further. Although several types of support structures were reviewed, it was decided to make a full design of a soft monopile structure to benefit in full from the aerodynamic damping and assess the potential negative consequences of large structural motion. It was found that a structure could be designed with a natural frequency below both the rotation and the blade passing frequency of the turbine, a so-called soft-soft structure. The frequency distributions are shown in figure 4.

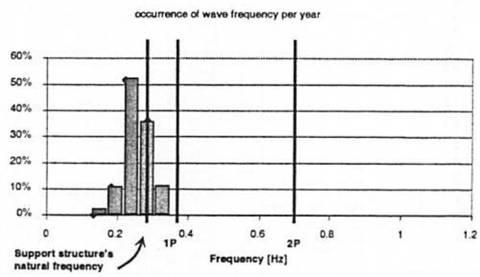

Figure 4. Rotation (1P) and blade passing frequency (2P) of the Opti-OWECS turbine with the structure's natural frequency and a histogram of the occurring wave frequencies

The fact that the structure's natural frequency coincided with a large portion of wave frequencies was further investigated. The aerodynamic damping of the turbine was found to reduce fatigue significantly, doubling the structures fatigue life when taken into account. To enable the analysis of this feature, full non-linear time domain simulations were found to be necessary of simultaneous wind and wave loading. Should wind and wave loads be analysed separately, the effect will not become visible by just adding the separate analyses as can be seen in figure 5.

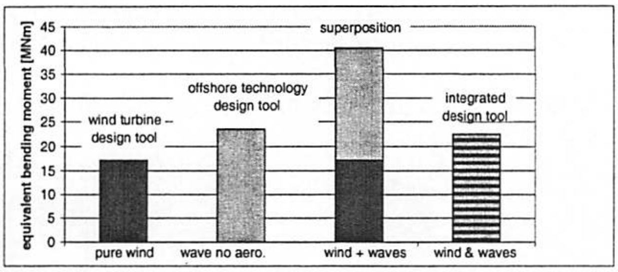

Figure 5. Comparison of fatigue calculations for wind only, wave only, wind and wave combines from separate analyses and wind and wave loads treated simultaneously

Next to the detailed investigation of the dynamic behaviour in the design, a large number of practical issues were addressed in an integrated way. For installation it was found that onshore pre-installation would cause large cost reductions. For the correction of misalignment of the driven foundation pile, a transition piece was proposed. Installation of fully operational turbines and the misalignment correction are shown in figure 6. It was concluded that large-scale offshore wind energy application would require purpose-built vessels because existing vessel were either too large (offshore cranes) or too small.

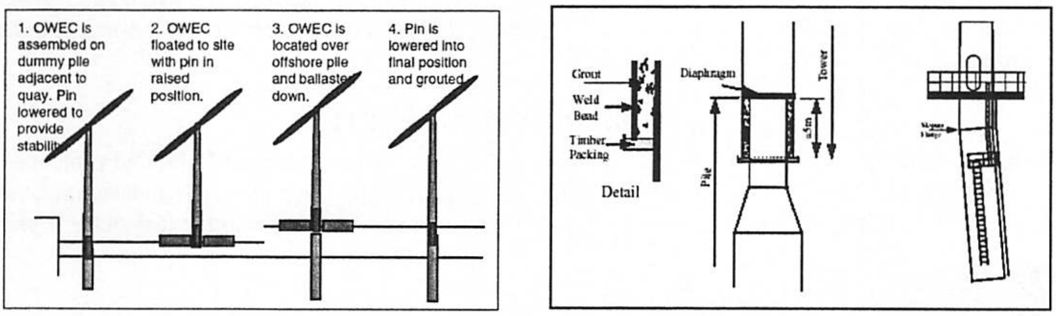

Figure 6. Installation of fully operational turbine and connection details between foundation pile and tower with misalignment correction

FROM THEORY TO PRACTICE: HORNS REV

The installation of Horns Rev in 2002 was the largest practical test of all theoretical findings. The installation of the foundation pile was done on a rather traditional manner: a small jack-up with a crane. For the installation of the turbines however two ships were entirely converted to purpose-built turbine installation vessels. Choosing a normal ship would ensure high sailing speed from and to port. A jacking system was added which only pre-stressed the legs without lifting the entire vessel out of the water. Two blades were already connected to the nacelle before placing it on the deck of the installation vessel. The method was chrissened "bunny ears" for obvious reasons. The installation of the tower and turbine was reduced to 4 lifts; 2 tower sections, nacelle with 2 blades and the final blade.

All appurtenances were pre-fitted in port to the transition piece: boat landing, J-tube, platform and the transition piece was grouted to the foundation pile. Figure 7 shows the "bunny ears", the A2Sea installation vessel, the transition piece being pre-fitted with a J-tube and the installation of the transition piece.

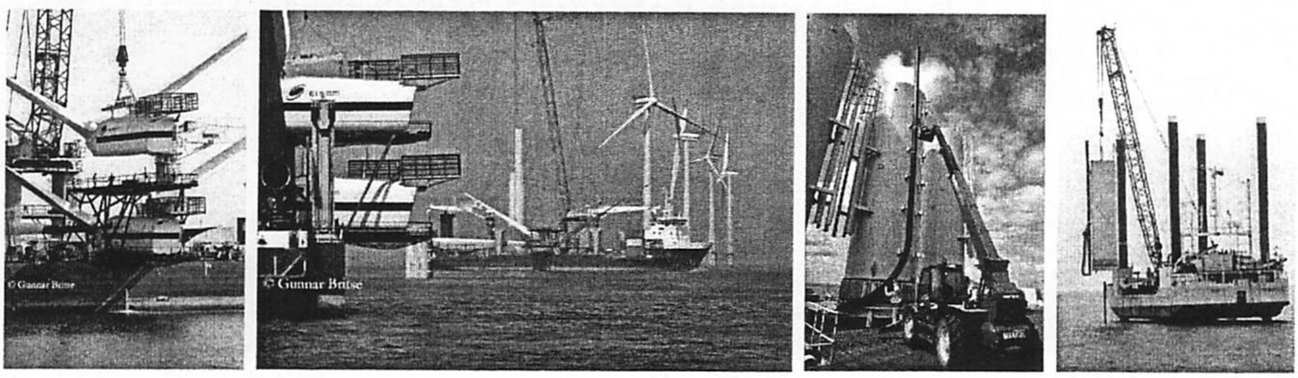

Figure 7. Bunny ears pre-fitting of two blades, purpose-converted installation vessels, pre-fitting of J-tube to the transition piece and the installation of the transition piece

The design for the support structures on Horns Rev was fully covered by the owner of the wind farm: Elsam supplied all contractors with a complete pre-design, which was to be prized and for which an installation method was to be drafted. The design was well documented and integrated. The contractors were also invited to give their own alternative design. The amount of information for this part however was much less: the support structure was to end at 9m above the mean

sea level and the only interaction from the turbine was a static load and moment at this 9m level. It can be argued that no contractor at that time would have any time for more detailed integrated turbine-foundation interaction analysis as all engineering went into "getting the things there".
For maintenance all nacelles are equipped with a heli-hoist platform onto which mechanics can be lowered even when boat access is not possible due to high waves, figure 8.

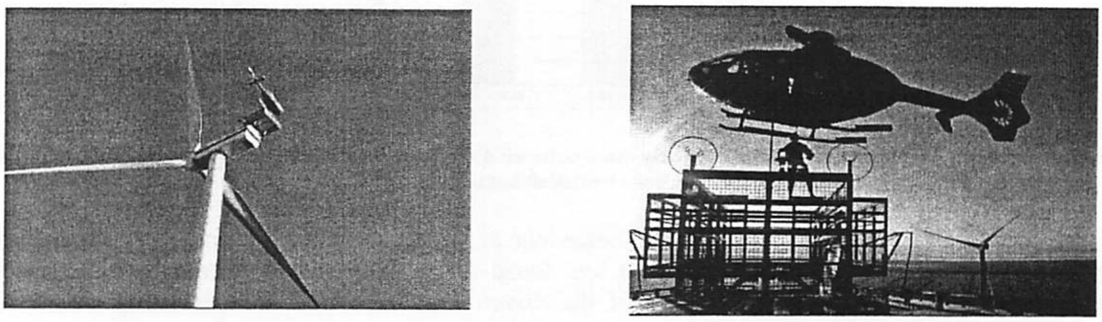

Figure 8. Heli-hoist platforms are installed on all turbines to lower a mechanic for maintenance

The Horns Rev project proved that many practical issues addressed in the paper studies were applicable in real offshore wind. The amount of overall integration, or even the need for it is not crystal clear: many individual optimisations could be done without affecting the entire system.

THEORY BEHIND PRACTICE

The installation of the two turbines offshore of Blyth in the UK was part of a large EU-funded project to study Offshore Wind Turbines at Exposed Sites (OWTES). One of the turbines is fitted with a complete measurement system to record external conditions and structural response. A picture of the turbines and the measurement systems is shown in figure 9.

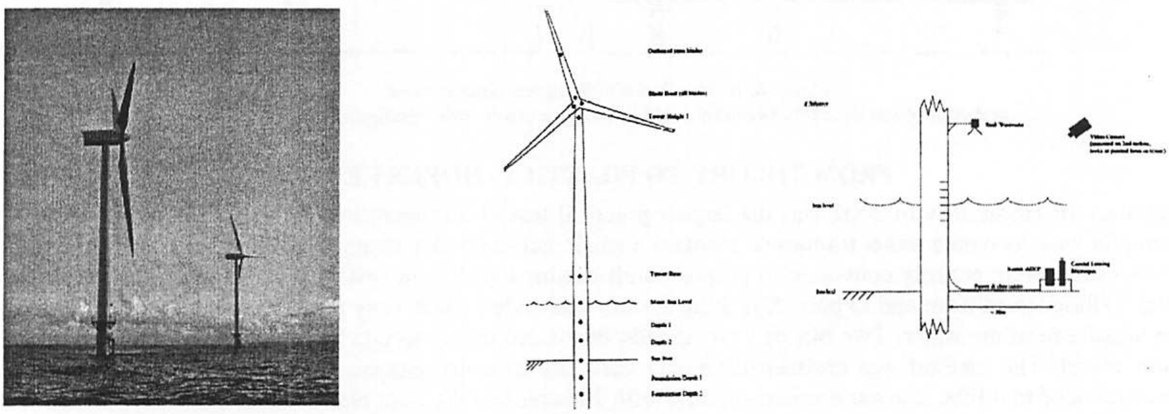

Figure 9. Turbines at Blyth with complete measurement system for external loads and responses

The measurements were used to validate the current design tools for offshore wind turbines. It was found that present-day tools are very able to model the offshore wind turbine behaviour induced by wind and waves simulations. Figure 10 shows the comparison of measured and modelled mudline bending moment per wind speed.

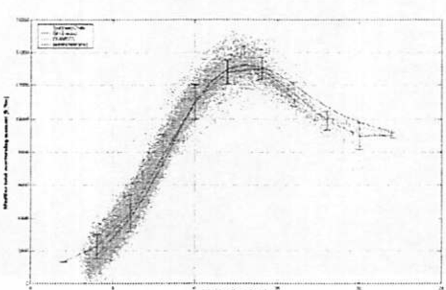

Figure 10. Comparison of mudline bending moment form measurements and modelling

It was found that offshore wind turbine design is very dependant on site-specific features like the wind and wave climate. At Blyth the local bathymetry is such that near the turbines breaking waves are a common phenomenon. Although their influence did not affect the design dramatically in this particular case, they prove the importance of taking all details of a site into account.

Although the natural frequency of the structure is rather high at 0.48Hz, the effect of both wind and wave loading on resonance is significant, as is the aerodynamic damping. Figure 11 shows the response spectrum for the mudline bending stress for equal environmental condition with an idling rotor (left) and a turbine in operation (right). The significant resonance peak in the wave-only case is damped dramatically when the turbine is operating.

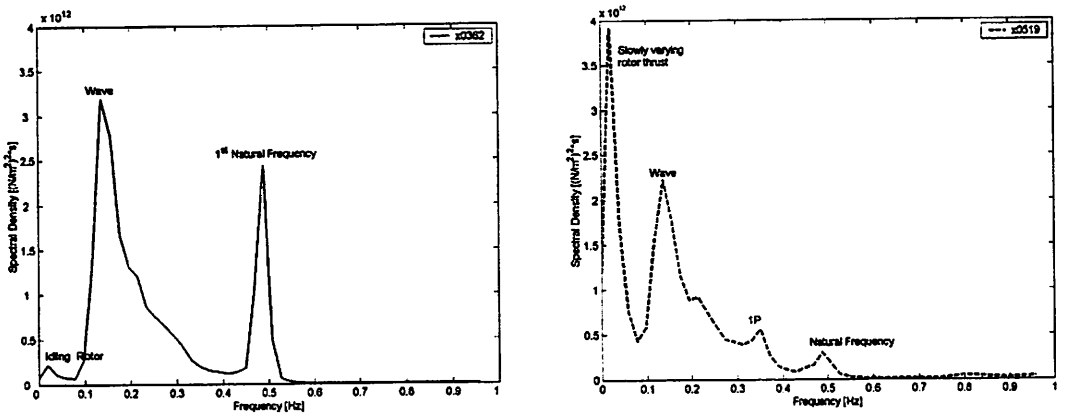

Figure 11. Response Spectrum for mudline bending stress for idling (left) and operating (right) turbine

From the measurements at Blyth it can be concluded that current modelling techniques are able to represent the critical features of offshore wind turbines properly, especially when on hindsight all structural and environmental parameters are known. It has also been shown that monopile structures are very dynamically sensitive, even in this case with relatively high natural frequency and that therefore proper analysis of resonant behaviour and aerodynamic damping deserve special attention.

OFFSHORE WIND FARM DESIGN, A STUDENT COURSE

In the autumn of 2003 the sections of Wind Energy and Offshore Engineering of the Delft University of Technology started a new student course in Offshore Wind Farm Design. The course is for fifth year offshore students who have already finished exams in Bottom Founded Structures and Wind Energy. The course focuses on the offshore side of design and installation. The turbine is treated as an "of-the-shelf" part of the design: its influence is taken into account fully, but its characteristics cannot be altered. The course consists of 40 hours of lectures including guest lectures by people from A2Sea, Shell Wind, Ballast Nedam and Essent. After the lectures, the students are to design an offshore wind farm in groups of 3-4.

The only restrictions given for the exercise are that offshore wind turbines are to be built in the North or Irish Sea. The groups are to select:

- location
- number of turbines
- type of turbines
- support structure
- cable layout
- shore connection.

To facilitate the exercise a large amount of tools and data was made available:

- digital sea maps
- access to waveclimate.com for wind, wave and current data
- electricity grid layout maps
- design standards: API, Germanischer Lloyd, DNV
- Bladed, with models of 2, 3, 5 and 6 MW turbines
- and all literature available.

The first group was focussing on the Irish Sea. With the available information they were able to do a very rapid site selection, comparing the wind and wave climate for 3 sites as well as nearest port, location of load centres and water depth. In a day they concluded that the most profitable site would be north of Wales: high wind speeds but smaller wave activity than on sites more exposed to the southern infiltration of Atlantic waves. The design method for the support structures was mainly based on extreme load design. This resulted in a very large and stiff structure, which proved to be very able to take all extreme and fatigue loads but which might have been largely over-dimensioned. Although the group functioned very effectively, the outcome of the design was not ideal and would require large adjustments in next design steps (for which no time was available).

The second group consisted of 4 persons including 1 non-offshore expert. The group had large difficulty in defining a proper scope for their design. They selected a site in the German Bight above Hamburg with no specific site selection criteria. The group focussed very intensely on non-critical features like the sediment transport and the foundation

modelling but failed to come to an agreement about design load cases. Where the load cases were concerned, the non-expert in the group took the lead without much correction from his more experienced teammates. Intervention by the course leaders finally resulted in at least a list of agreed-upon load cases. The main pitfall the group continuously encountered was the inability to discern the amount of detail required for certain design steps: simplifying critical data and over-investigating side effects.
The design process however was much more successful. The group pursued a structure with fitting dynamics for the selected turbine and site. Both fatigue and extreme checks were within a safe and economically acceptable range.

It can be concluded from this exercise that the group process is as critical for success as using the right approach. Being able to understand the critical issues is much more critical than doing a final integrated wind and wave load calculation. A final remark about the exercises: the functioning of the student teams showed striking parallels with real offshore wind farm design teams. The exercise is being revised for next year's course to give more guidance without imposing restrictions to the design freedom.

DISCUSSION

When reviewing all study reports and real offshore wind farm designs, one feature of integrated design keeps coming back: simultaneous wind and wave loading on a dynamically sensitive structure must be analysed in an integrated way to take all interactions into account. But reviewing the entire scope of offshore wind farm design, many subjects can be designed and optimised quite separately from the overall design. However, a thorough integrated understanding of the entire system does aid the sub-component optimisation and it is this integrated understanding that should be pursued more than the integrated design.

Differentiating

Integrated Design

Jan van der Tempel

DUWIND

TU Delft

Integrated Design

of
Support Structures
for
Offshore Wind Turbines

DUWIND

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Integrated Design of Offshore Wind Turbine Support Structures

Goals:

- Create a "basis for design"
- Description of quick & dirty design tools
- Requirements of detailed design checks

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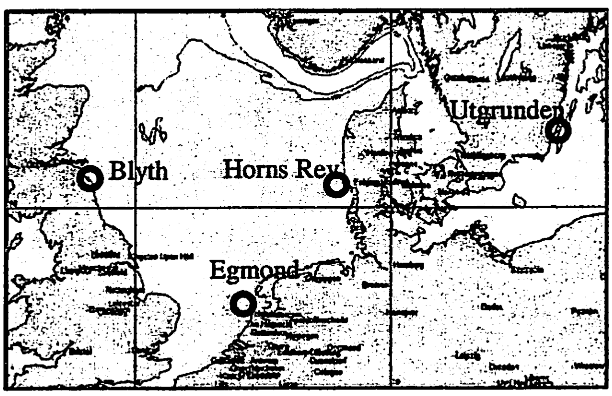
Integrated Design of Offshore Wind Turbine Support Structures



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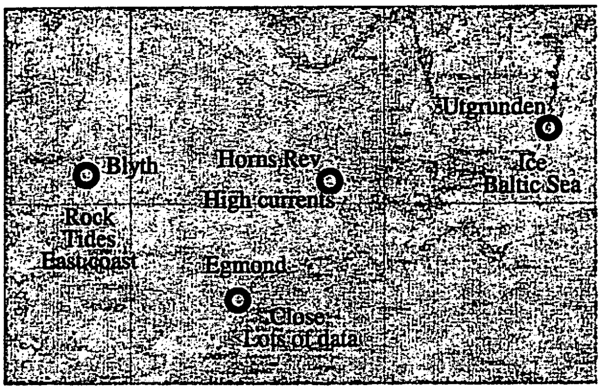
**Integrated Design of
Offshore Wind Turbine
Support Structures**



DUWIND TUDelft

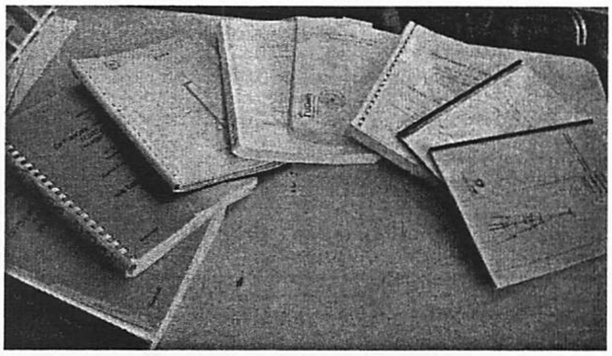
Contents

- The history of integrated design
- Practical examples on Horns Rev
- Checking the numbers at Blyth
- Focus on details: student exercise

DUWIND TUDelft

History

RSV/Hydronamic
Heerema
RES
Phase IIC
Blekinge



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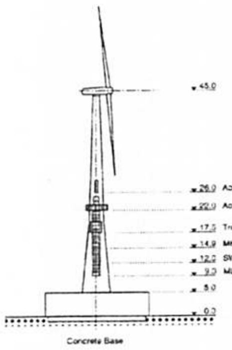
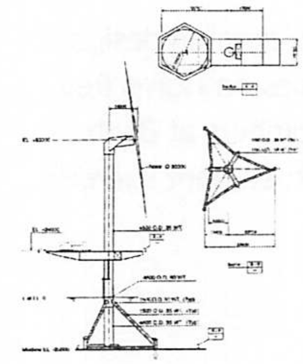
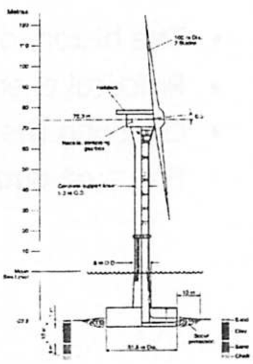
History





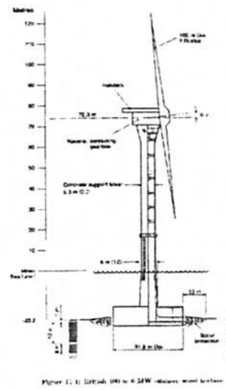


DUWIND TUDelft

History

Characteristics:
- Robust: steel, concrete, stiff
- Large turbines
- "Deep" water
- Helidecks

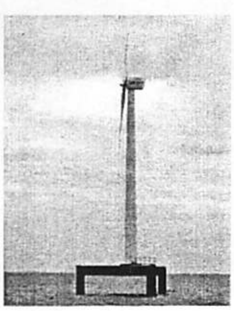
- Combining wind and waves but only for extreme loads



DUWIND

TU Delft

History



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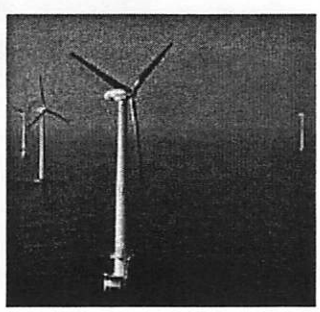

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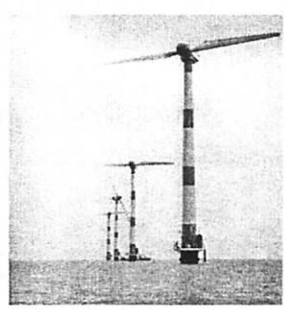

Lely

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History

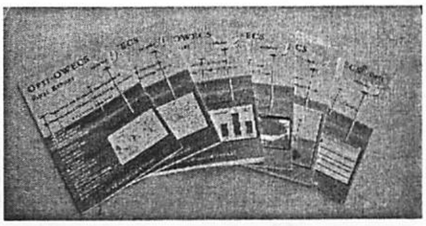
Joule I

- Resume of previous studies
- Energy potential in Europe
- Finding critical design issues

→ Aerodynamic damping important

DUWIND TUDelft

History



Joule III, Opti-OWECS

→ Integration of all aspects

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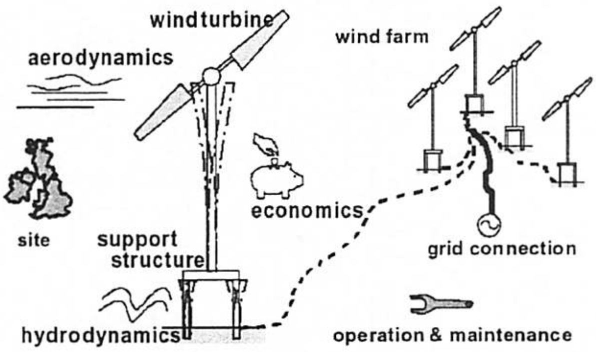
History



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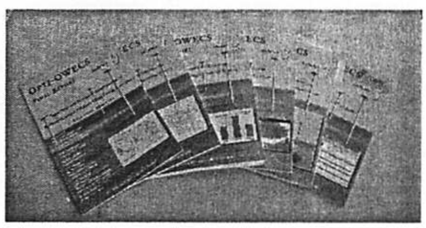
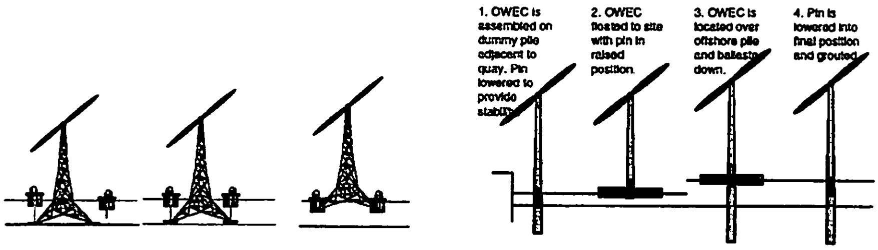
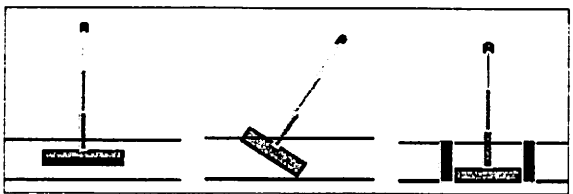


Joule III, Opti-OWECS

→ Integration of all aspects
→ Installation: as much as possible onshore

History





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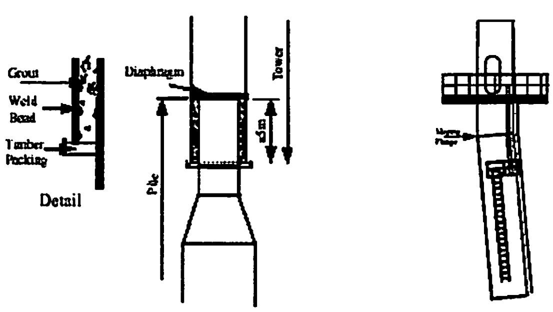
History



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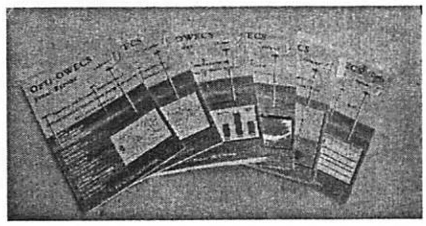
History



Joule III, Opti-OWECS

→ Integration of all aspects
→ Installation: as much as possible onshore
→ Aerodynamic damping more important
→ Soft-Soft structures benefiting from damping

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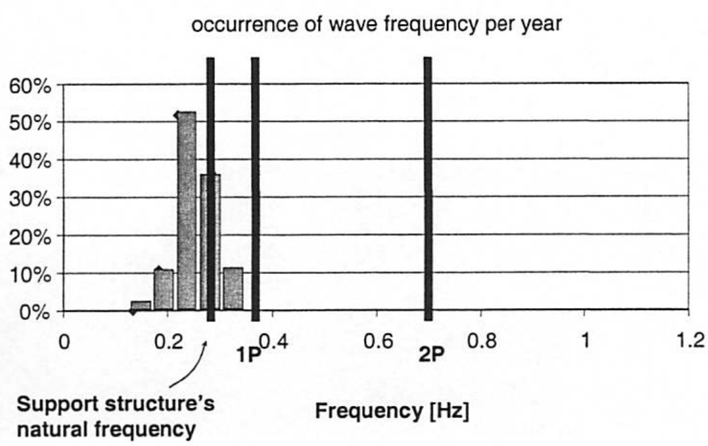
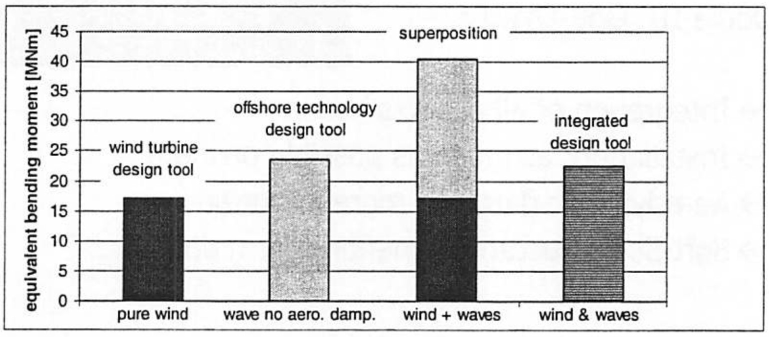
History



DUWIND

TU Delft

History



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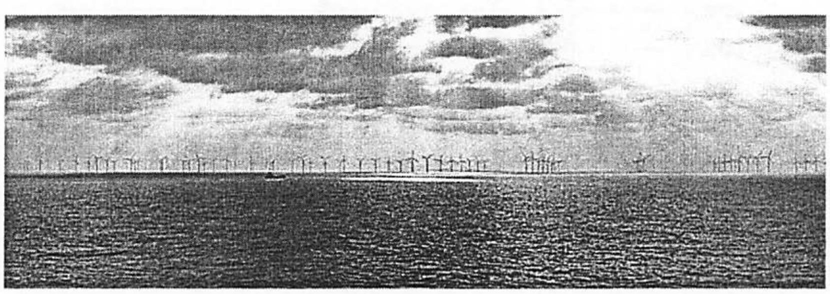
Practice

Horns Rev



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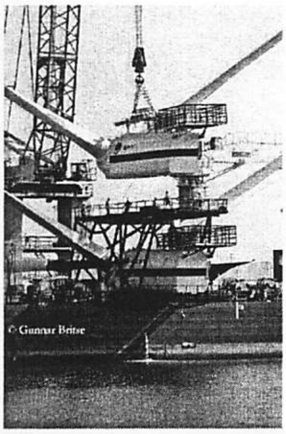
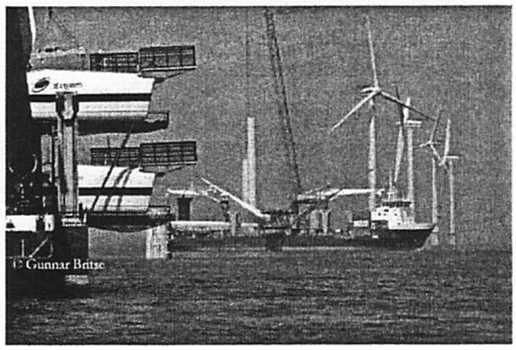
Practice





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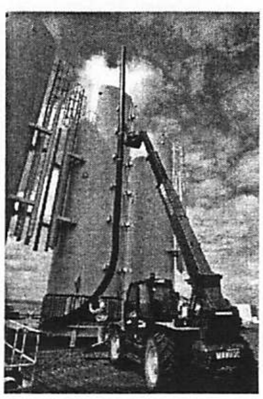
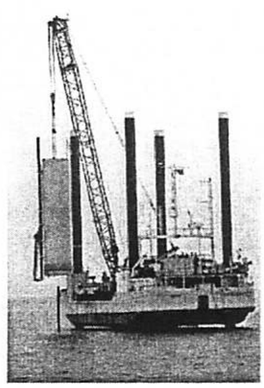
Practice





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Practice

DUWIND

TUDelft

Practice

Horns Rev

Overall pre-design: integrated

Design data for installation contractor: not!

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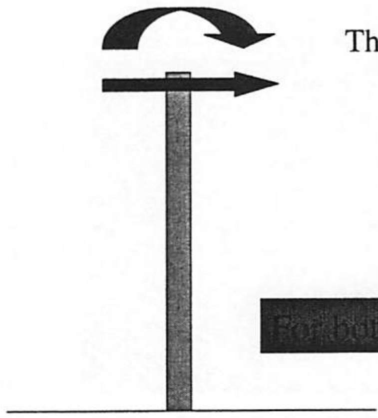
Practice



The only interaction between support structure and turbine:

Force F = ... kN

Moment M = ...kNm

[redacted]

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Practice

Horns Rev

Conclusion:

- It is going OK
- Minor details require adjustment

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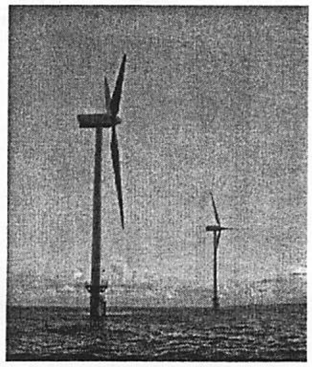
Theory behind Practice

OWTES Blyth



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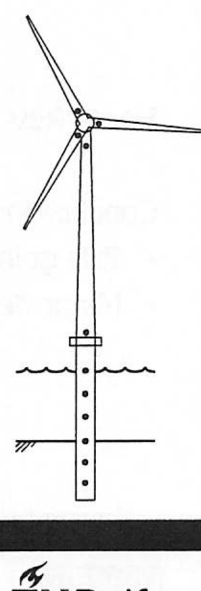
Theory behind Practice

- Blade root flapwise and edgewise bending moments
- Bending moments & torsion of low-speed shaft
- Bending moments at tower top & base plus torsion at tower top
- Torsion at MSL
- Bending moments at:
  - Mean sea level (MSL),
  - 2 stations between MSL and mudline,
  - 2 stations between mud-line and pile base.



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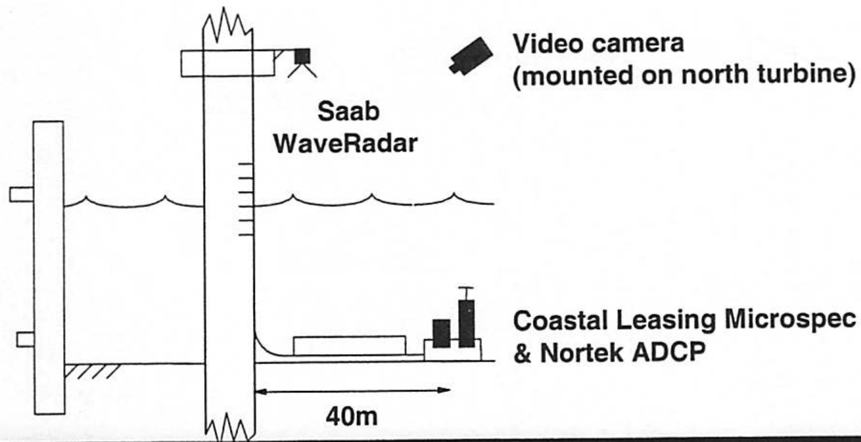
Theory behind Practice



DUWIND

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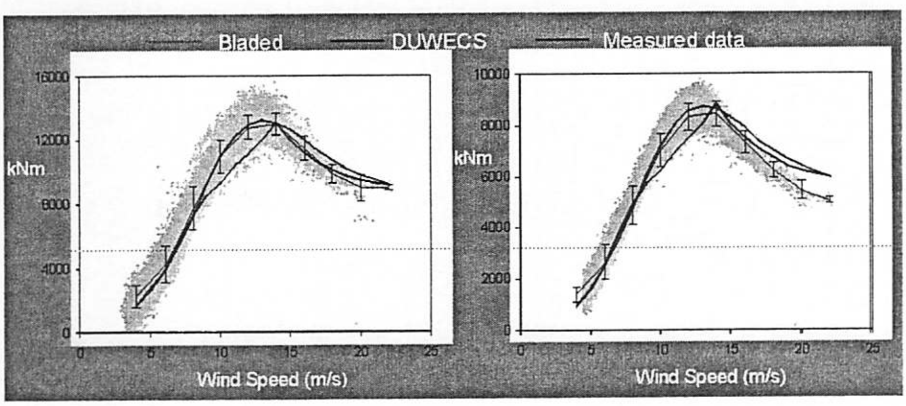
Theory behind Practice



Mudline bending moment

Tower base bending moment

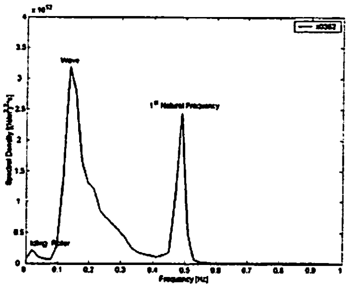
DUWIND

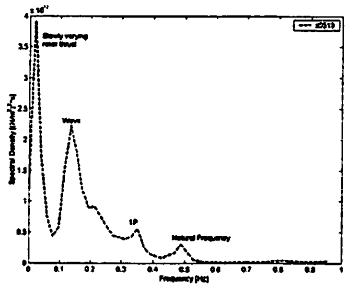
TUDelft

Theory behind Practice

Details: Aerodynamic damping

Even with stiff structure: high resonant loads





DUWIND

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Theory behind Practice

OWTES Blyth

Conclusions: Turbine is not influenced by offshore

Structure <u>is</u>

DUWIND

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Offshore Wind Farm Design

a student course

- 5th year students of the Offshore curriculum
- Requirements: Bottom founded structures, wind energy
- Focus on the offshore design

- 7 participants
- 40 hours lectures
- 80 hours design exercise
- Guest lectures by Shell, Ballast Nedam, A2Sea and Essent

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Offshore Wind Farm Design

a student course

Exercise

- Design an Offshore Wind Farm in the North or Irish Sea

- Digital sea maps
- Access to waveclimate.com: wind, wave and current data
- Bladed, with 2 3 5 6 MW turbine models
- Design Standards: API, DNV, GL
- And all other literature

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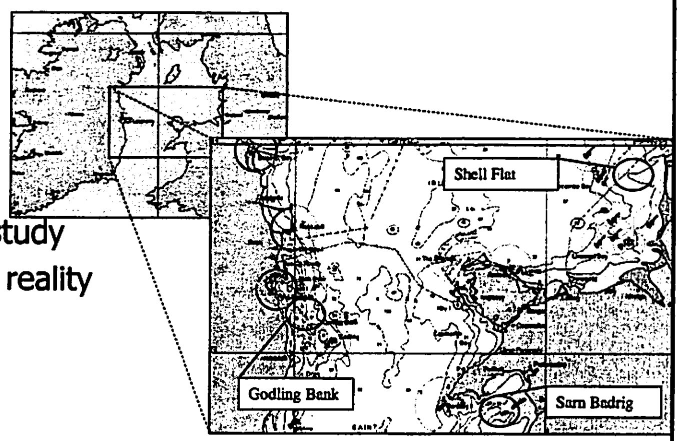
Offshore Wind Farm Design

a student course

Group I



Site selection study

→ agrees with reality

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Offshore Wind Farm Design

a student course

Group I

Design on extremes with crude rule of thumb

→ Very big tower, too much steel

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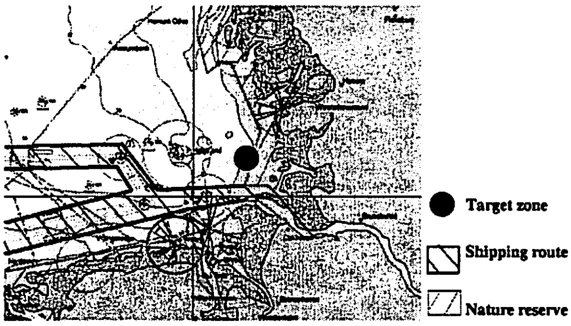
Offshore Wind Farm Design
a student course

Group II

→ Selected "the other site"



DUWIND

TUDelft

Offshore Wind Farm Design
a student course

Group II

Very difficult group process

3 offshore students, 1 mechanical engineering student

The non-expert took the lead

Detailed investigation of non-important issues

Not able to arrive at critical design parameters

Reduction of perfectly digestible data

DUWIND

TUDelft

Offshore Wind Farm Design

a student course

Group II

But:

When challenged: design on estimated critical issue: resonance and fatigue

Result: better preliminary design

DUWIND

TU Delft

Offshore Wind Farm Design

a student course

Conclusions

Group functioning critical

Group members have to be and accept "experts"

Not so much the design, but the understanding must be INTEGRATED

DUWIND

TU Delft

Differentiated Integration

- Turbines are "off-the-shelf" not much tuning
- Support structure can be tuned
- Understanding of the origin, nature and effects of dynamic interaction implicitly results in integrated design

DUWIND TUDelft

Differentiated Integration

All other sub-components can be designed (nearly) separately

- Transition piece/welded flange/slip-joint
- J-tube
- Scour and protection against it
- Access
- Tripods

DUWIND TUDelft

So

- Uncover critical relations
- De-mystification
- Understanding

DUWIND TUDelft

$$\frac{\partial \int design \, \mathrm{d}t}{\partial t} = \int understanding \, \mathrm{d}€$$

DUWIND TUDelft

RISØ

Database on Load Characteristics www.WindData.com and example applications

G.C. Larsen and K.S. Hansen

Outline

RISØ

- **"Database on Wind Characteristics"**
- **Design turbulence intensity at offshore shallow waters**
- **Statistics of offshore wind speed gusts**
- **Outlook**

"History"

RISØ

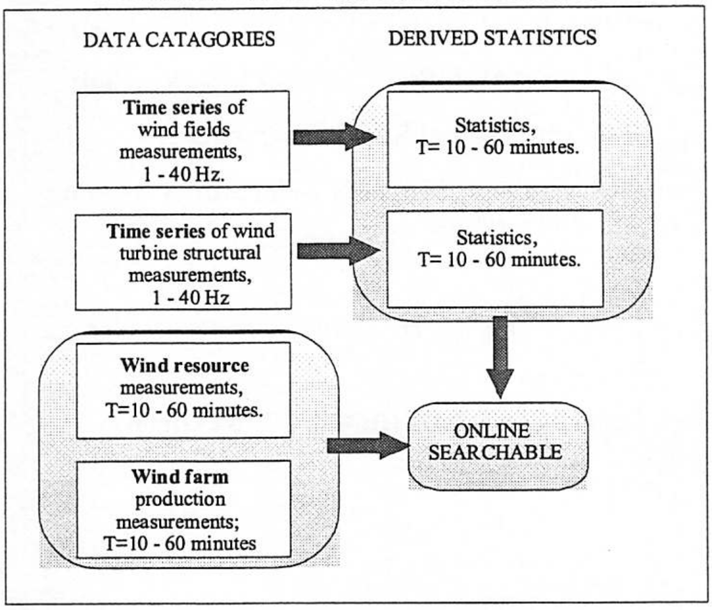
- "Database on Wind Characteristics"
  - ➢IEU-DG XII (JOULE) project "Database on Wind Characteristics": 1996 - 1998
  - ➢IEA Wind R&D; Annex XVII; phase 1: 1999 – 2001
  - ➢IEA Wind R&D; Annex XVII; phase 2: 2001 – 2003

Goal

RISØ

The main purpose of Annex XVII has been to provide wind energy planners, designers and researchers, as well as the international wind engineering community in general, with a source of quality controlled wind field data (time series and resource data) observed in a wide range of different wind climates and terrain types, and stored in a common file format.

CONTENTS OF
THE DATABASE ON WIND CHARACTERISTICS



Data - offshore

- **Ressource data**
  - **➢48.000 hours (Restricted access)**
- **Time series data**
  - **➢Wind data: 20.300 hours**
  - **➢Wave data: 2.090 hours (of the 20.300 hours)**

Analysis (1) – Offshore Design Turbulence Intensity

RISØ

- **Turbulence standard deviation assumed Log-Normal;**
- **Best fit based on the Normal Scores method;**
- **Fatigue design turbulence intensity determined from a simple heuristic expression:**

$$\sigma_{d,10}(U_{10}) = \left[\int_0^\infty P_\sigma(\sigma_{U,10} \mid U_{10}) \sigma_{U,10}^m \times d\sigma_{u,10} \right]^{1/m}$$

- **Two Wöhler curve exponents (m = 4, 12) has been investigated.**

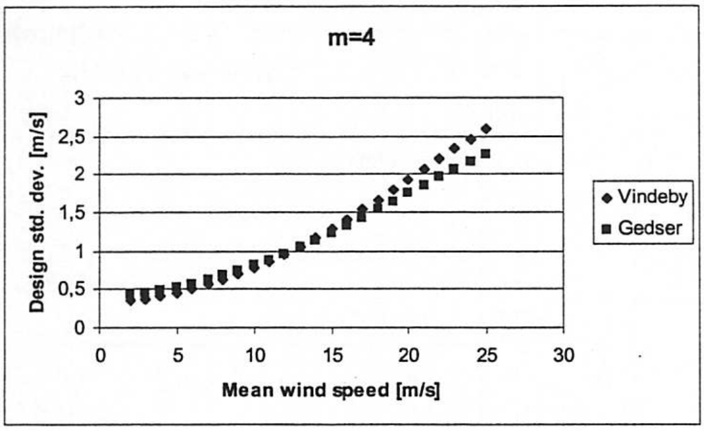
Analysis (1) – Offshore Design Turbulence Intensity

RISØ

- **Data material:**
  - **Gedser site: 22419 10-minute time series with an overall mean wind speed equal to 7.87m/s;**
  - **Vindeby site: 5015 10-minute time series with an overall mean wind speed equal to 7.92m/s.**

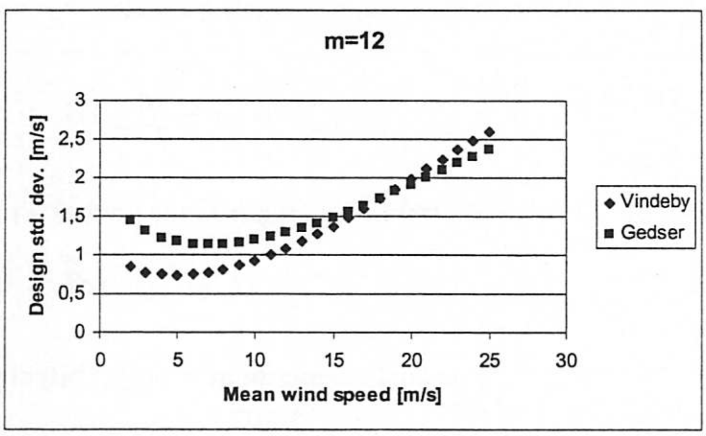
Analysis (1) – Offshore Design Turbulence Intensity

RISØ



Analysis (1) – Offshore Design Turbulence Intensity

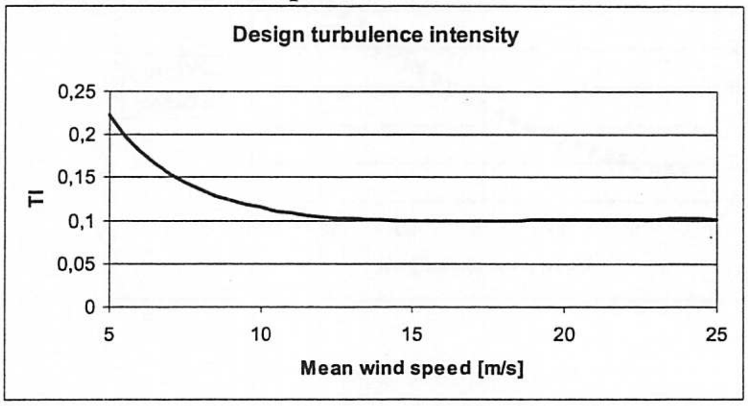
RISØ



Analysis (1) – Offshore Design Turbulence Intensity

RISØ

- ***The ambient*** **fatigue design turbulence intensity, applicable for shallow water off-shore sites, as function of the 10-minute mean wind speed**



Analysis (2) - Statistics of offshore wind speed gusts

RISØ

- **Gumbel CDF conditioned on the mean wind speed (recurrence period T)**

$$F_{eg}(x;\alpha,\beta_{eg}|U) = \exp(-\exp(-\alpha(x-\beta_{eg}))) \ ,$$

- **Unconditional extreme distribution (recurrence period T)**

$$f_{uc}(x;k,\beta_U) = \int_0^{\infty} f_{eg}(x;\alpha,\beta_{eg}|U) f_U(U;k,\beta_U) dU \ .$$

- **Monte Carlo simulation used to transform to an arbitrary return period (typically 1 year or 50 years)**

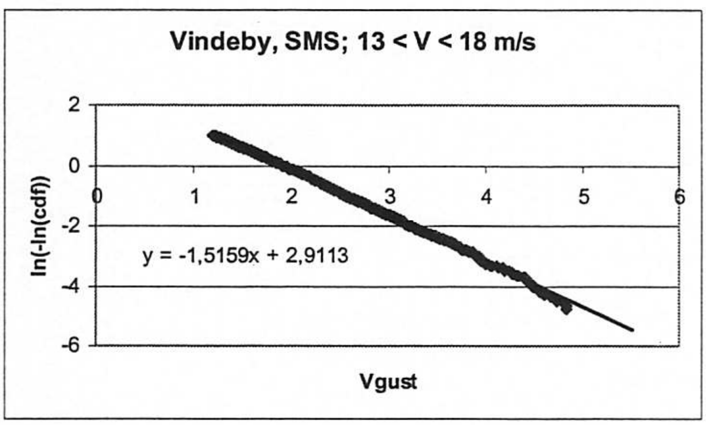
Analysis (2) - Statistics of offshore wind speed gusts

RISØ

- **Data material:**
  - **Horns Rev site: by 9737 10-minute time series with mean wind speeds ranging up to 20.5m/s supplemented with approximately 660 days of resource measurements;**
  - **Vindeby site: 5615 10-minute time series with mean wind speeds ranging up to approximately 20m/s supplemented with 250 days of resource measurements.**

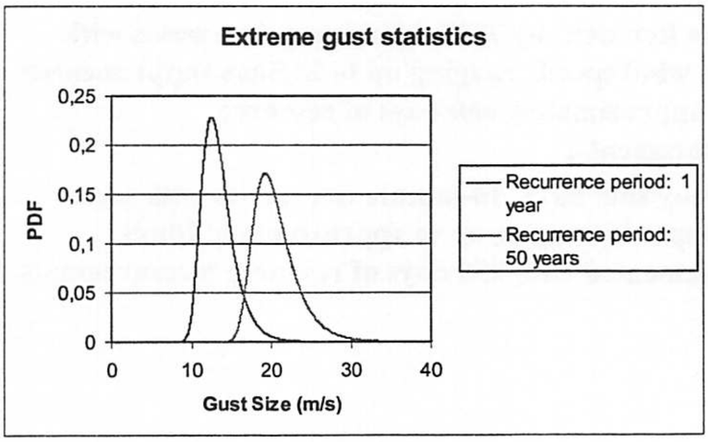
Analysis (2) - Statistics of offshore wind speed gusts

RISØ



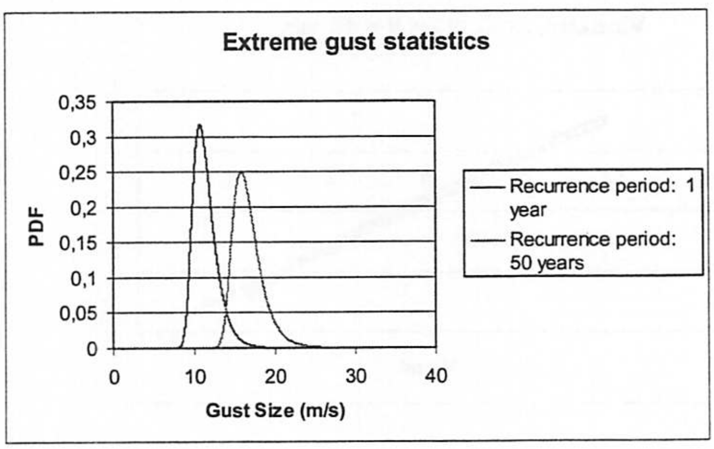
Analysis (2) - Statistics of offshore wind speed gusts

- **Horns Rev**



Analysis (2) - Statistics of offshore wind speed gusts

- **Vindeby**



Analysis (2) - Statistics of offshore wind speed gusts

RISØ

- **Conclusion:**
  - **Most likely 1Y gusts at Vindeby and Horns Rev are estimated to 10.7m/s and 12.4m/s, respectively;**
  - **Most likely 50Y gusts at Vindeby and Horns Rev are estimated to to 15.8 m/s and 19.2m/s, respectively;**

Analysis (2) - Statistics of offshore wind speed gusts

RISØ

- **Possible explanation:**
  - **Horns Rev site is characterised by having conditional extreme gust amplitude distributions with smaller mean values than the Vindeby site (larger roughness ??);**
  - **The mean wind speed distributions for the two sites have approximately the same mean value, but the Weibull shape parameter is less for the Horns Rev site yielding enhanced probability of large mean wind speeds compared to the Vindeby site;**
  - **The estimated one-year and fifty-year extreme gust distributions combine these two opposite directed effects.**

Outlook

RISØ

- **Use the present content of the database bank to further analyses of offshore wind turbine loading;**
- **Expand the present content of the database with more offshore wind data (e.g. 3D time series measurements, measurements at higher levels, additional "open water" measurements, ...);**
- **Expand the present content of the database with more offshore wave data (e.g. Bockstigen data, NL data, ...).**

DTU

Database on Wind Characteristics
www.WindData.com

Kurt S. Hansen
Department of Mechanical Engineering,
Technical University of Denmark
ksh@mek.dtu.dk

IEA Expert meeting on Offshore Technology
9-10 Mar. 2004 at ELSAM, DK

DTU

Objectives

The main purpose of Database of Wind Characteristics has been to provide wind energy planners, designers and researchers, as well as the international wind engineering community in general, with a source of quality controlled wind field data (time series and resource data) observed in a wide range of different wind climates and terrain types, and stored in a common file format.

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Database on Wind Characteristics www.WindData.com

- Initial period 1996 - 1998, funded by EU, Joule 3 program.
- Continuation: IEA Wind Energy Implementing Agreement, Annex XVII 1999-2003 (S, N, NL, US, JP and DK)

  Operating agent: Gunner Larsen, Risø Nat. Labs.,DK

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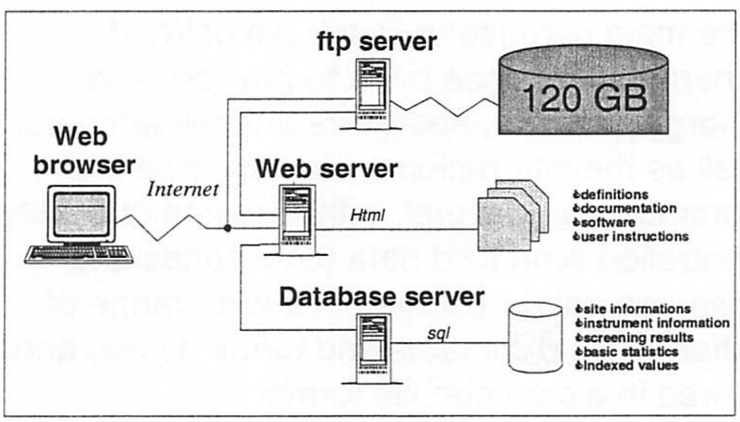
Structure of www.winddata.com



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Database on Wind Characteristics contents

DTU

- Raw time series sampled with a frequency > 0.8 Hz of wind speed and direction.
- Indexed values (mean, st.dev., turbulence, min, max, skewness, kurtosis, quality params...) for all time series, searchable through the query system.
- Resource statistics for wind speed & dir., temp, humidity, wave height,..
- Windfarm production statistics, wake effects,..

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Search facilities

DTU

•"Simple query" in runs (=time series) are based on either country,site terrain, orography, wind speed, turbulence and wind direction logging time.
The results can be viewed e.g. as time series plots or downloaded from the ftp-server.

•"Resource query" in 10-minute statistics are based on a site. The result from can be downloaded as mean, st.dev., min, max... values for a selected period.

•"Site-Channel" in run statistics are based on a channel from a specific site. Choose value between mean, st.dev, min,max, range, stationarity and turbulence.

•The results can be viewed e.g. as time series plots or downloaded from the ftp-server.

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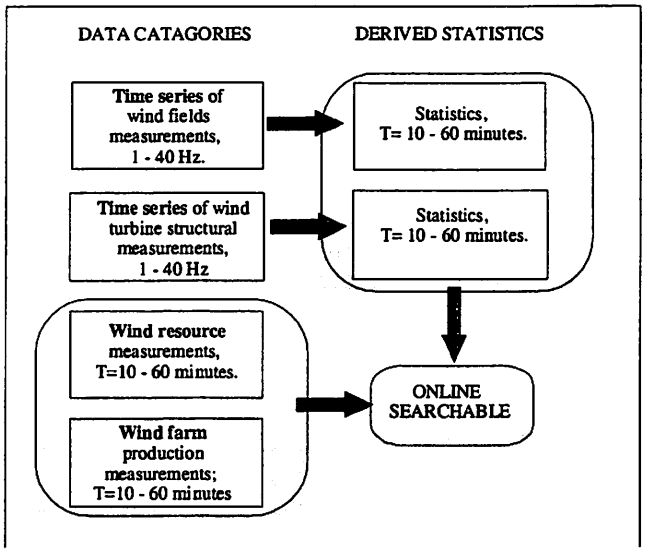
CONTENTS OF
THE DATABASE ON WIND CHARACTERISTICS



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DTU

Access to the "Database on Wind Characteristics"

•Users from SE, NL, & DK can obtain free, unlimited access to all data and the query system, but registration is necessary!
(US & NO has not validated yet)

•Other users can obtain free, unlimited access to all data and the query system for an annual administative fee, but registration is necessary!

•Browsing the information system and simple queries is possible as guest user, but registration is necessary.

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Contents of the Database of Wind Charateristics Primo 2004

DTU

165.000 hours of time series representing 59 different sites in 17 countries

1.200 hours of wind turbine structural measurements representing 3 different sites In 2 countries

825.000 hours of resource data representing 28 different sites in 10 countries

19.100 hours of wind farm data representing 2 sites in 2 countries

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Contents of the Database of Wind Charateristics OFFSHORE data - primo 2004

DTU

20.000 hours of time series representing 6 different sites in 2 countries

2.090 hours of time series with combined wind and wave measurements

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Available offshore measurements in WindData.com

DTU

Time series:

- •Horns Reef, 20 Hz, sonics (3-D),13.500 hours,
- •Vindeby, 5&20 Hz, cup, sonics (3-D) & wave, 2.400 hours
- •Rødsand (Nysted), cup and sonics(3-D), 618 hours
- •Middelgrunden, cups, 2.000 hours,
- •Gedser Reef, cups, 600 hours,
- •Bockstigen, cups (+wave), 1.200 hours

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Offshore resource data with resticted access

DTU

Horns Rev, 1999 – 2004 (ELSAM)
Horns Rev, Wave measurements, 1999 – 2002 (ELSAM)
Horns Rev, Wake measurements (ELSAM)
Læsø Syd, 1999 – 2002 (ELSAM)
Vindeby, 48.000 hours (Risø)

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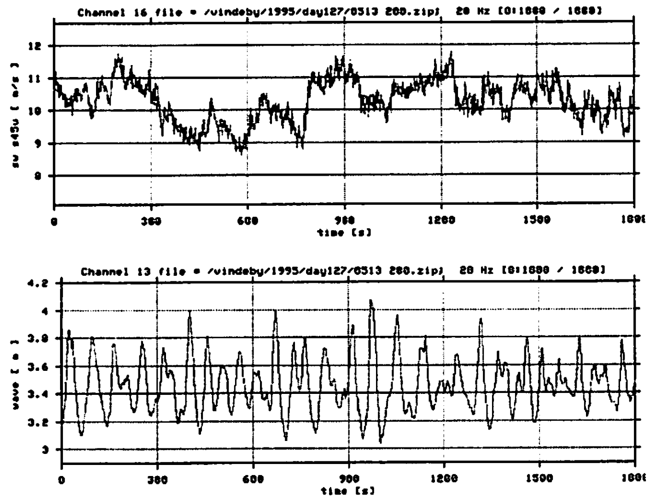
Example wind & wave

DTU



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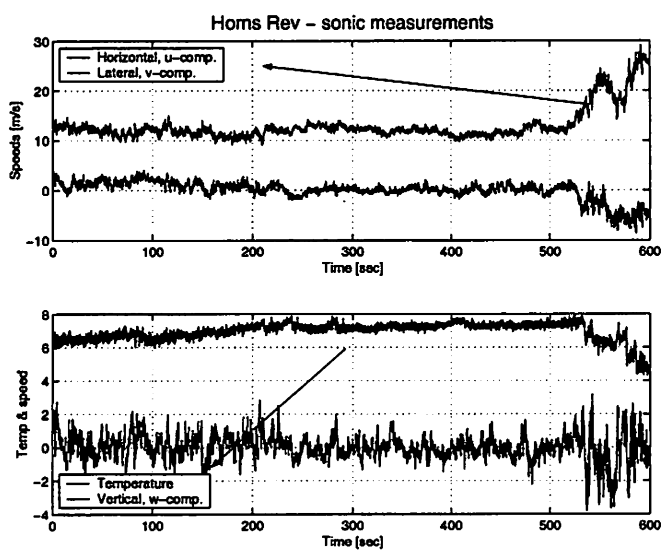
Example of measured 3-D time series from Horns Rev

DTU



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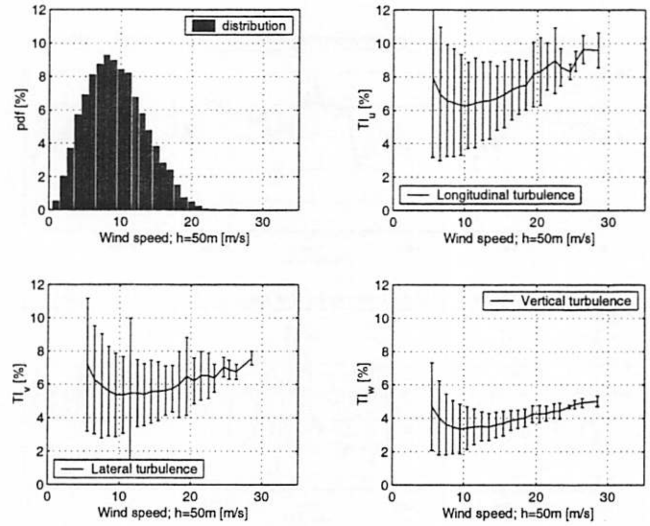
Mean 3-D turbulence at Horns Reef

DTU



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9-10 Mar. 2004 at ELSAM, DK

RISØ

IEA Meeting 9/10 March 2004
Uncertainties in power prediction offshore

Rebecca Barthelmie et al.
Risø

www.wasp.dk

Uncertainties

RISØ

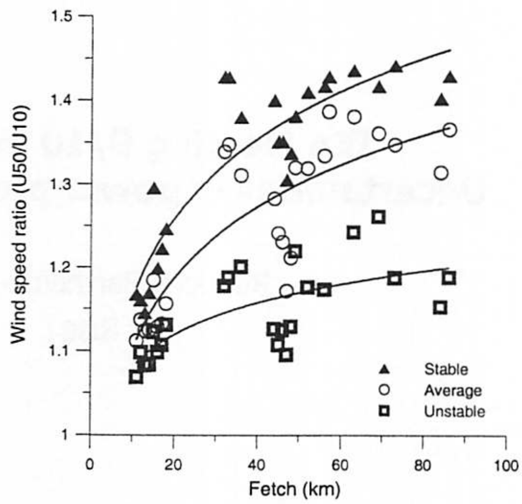
- Atmospheric stability – important due to lower z_0
- Reducing measurement uncertainty & making representative measurements at remote sites
- Extrapolating from measurement to turbine hub-height
- Time scales: Short-term prediction $\rightarrow$ climate variability
- Modelling wind and turbulence in coastal areas (< 50 km), spatial variability over large wind farms
- Individual and collective wind turbine wake propagation

Barthelmie et al.

Coastal zone

RISØ

- The coastal zone (distance in which the effects of land can be detected on U) is ~50 km
- At 50 m height U increases by:
  2 km ~5 %
  11 km ~24 % higher



Barthelmie et al.

Wake Models

RISØ

Complexity/ Computing requirement ↓

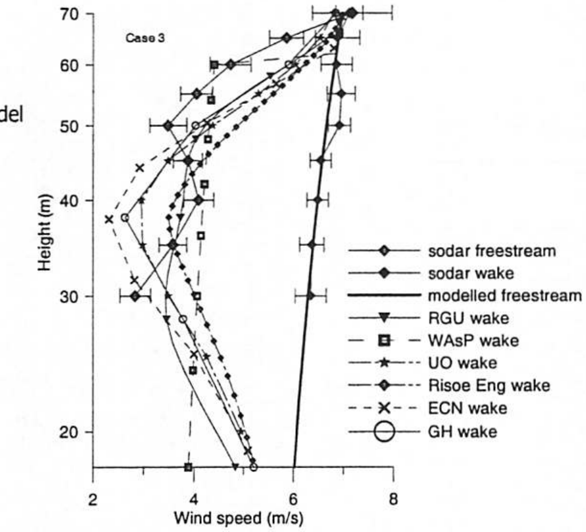
Empirical/ highly parameterised	GL empirical model WAsP/Park Sten Frandsen	Gaussian deficit Top-hat profile For loads inside a wind farm
Ainslie Group	ECN (NL) Garrad Hassan FLaP (University of Oldenburg)	Based on UPMPARK Turbulence parameterised Stability parameterised
CFD type	Robert Gordon University	Least parameterised – based on Navier stokes

Barthelmie et al.

Wake models vs. SODAR

RISØ

- Wake models
  - Empirical
    - GL empirical model
    - WAsP/Park
  - Ainslie Group
    - ECN
    - Garrad Hassan
    - FLaP (BL)
  - CFD type
    - RGU
- 6 Sodar profiles



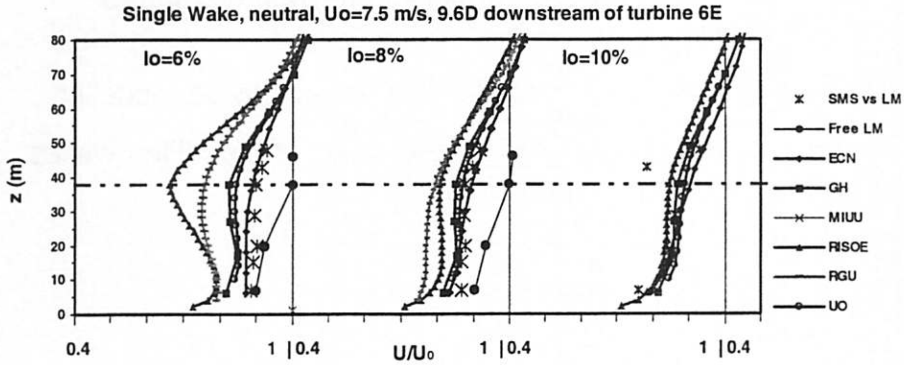
Barthelmie et al.

Single wakes: Vindeby

RISØ

- Wake models agree in 'moderate' conditions

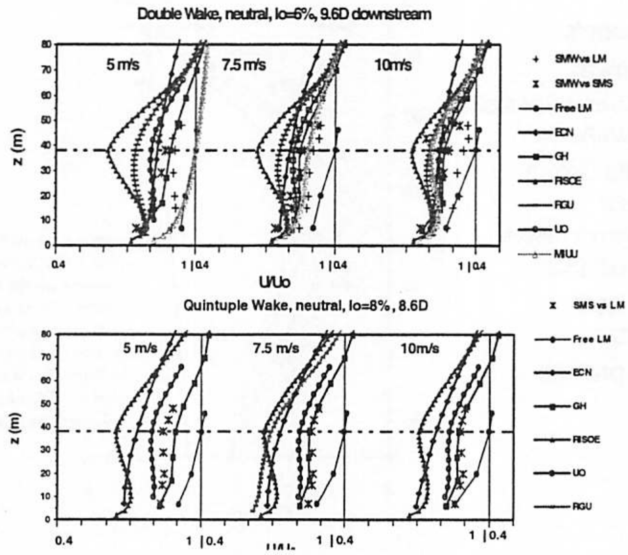
Single Wake, neutral, Uo=7.5 m/s, 9.6D downstream of turbine 6E



Barthelmie et al.

Multiple wakes: Vindeby

RISØ



Barthelmie et al.

Linking wake and boundary-layer models

RISØ

- The effect of large wind farms is more than the sum of single wakes.
- Wake impacts on the boundary-layer have to be modelled
- Storpark project – examining new ways of modelling wakes & large wind farm interactions

Barthelmie et al.

Boundary-layer models

RISØ

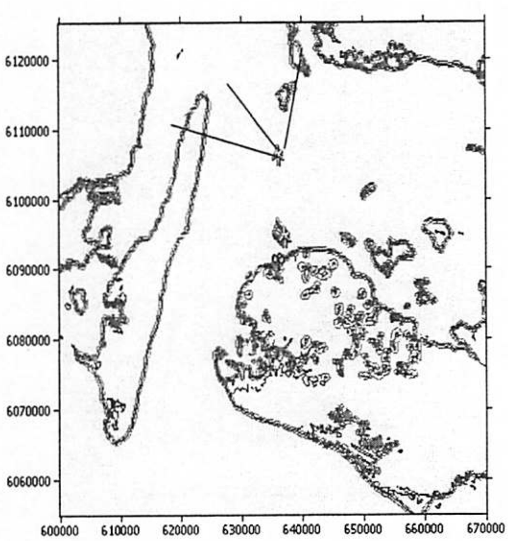
Complexity/ Computing requirement ↓

Coastal Discontinuity Model	Simple, has stability	No advection scheme, no wind farm model
WASP/ PARK	Simple, easy to set up wind farm	No stability/dynamic roughness, difficult to insert new models, cant use momentum deficit approach
KNMI	No wind farm representation	Better physics than WAsP, can couple wind-wave models
Mesoscale (e.g. KAMM)	Difficult to set up/run, wind farm representation ?	'Best' physics/stability/dynamics roughness Could use momentum deficit

Barthelmie et al.

Empirical analysis

RISØ

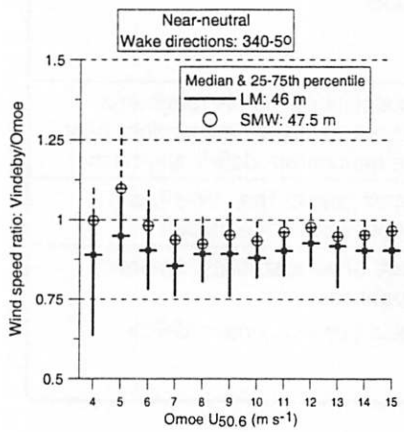


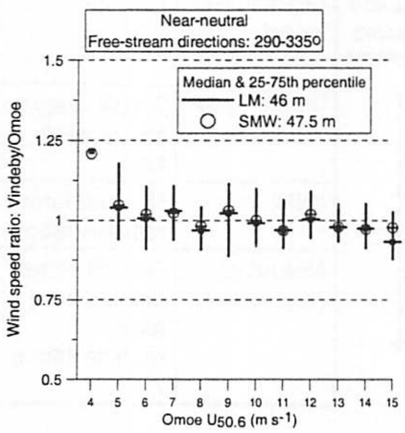
- Comparison of concurrent wind speeds at Omø, Vindeby SMW & LM
- Wake 340-5°/Free-stream 290-335°
- At 2 km downwind ~6% (48m height)
- Cf WAsP prediction ~2.8% power loss

Barthelmie et al.

Comparison of ratios

RISØ



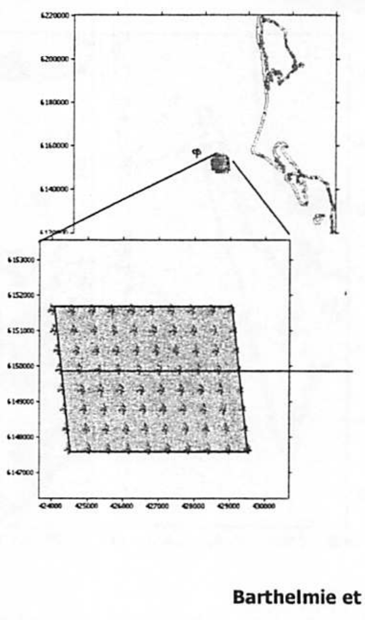


Barthelmie et al.

Predicting downwind flow

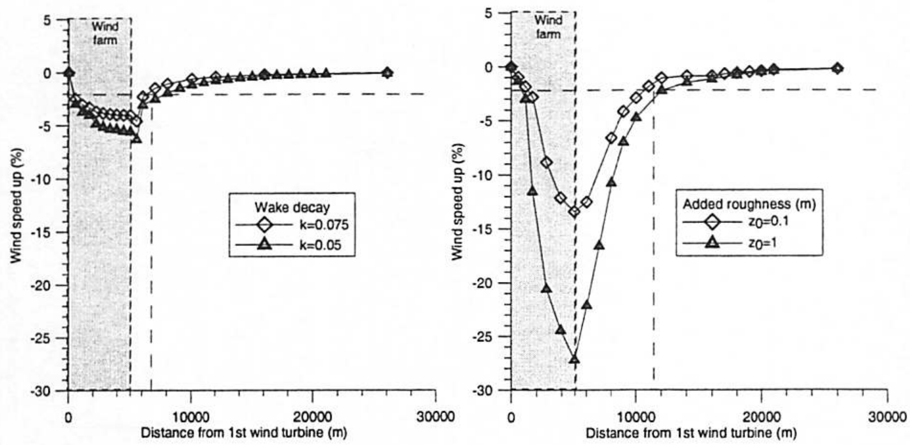
RISØ

- WAsP
  - PARK
    - k=0.075, 6.7% wake loss
    - k=0.05, 8.7% wake loss
    - 'Virtual turbine' downwind
  - Roughness element (block)
    - Z_0 0.1, 0.5, 1m
- WAsP, FLaP & Windfarmer
  - 6-10% wake losses
  - depends on assumptions



Barthelmie et al.

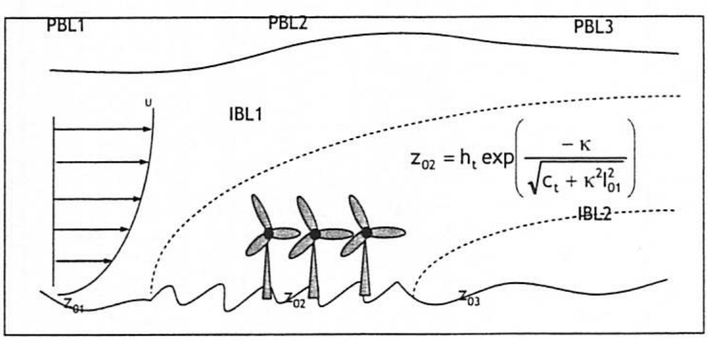
WAsP/PARK WAsP roughness



Barthelmie et al.

Preliminary 'whole wind farm' model

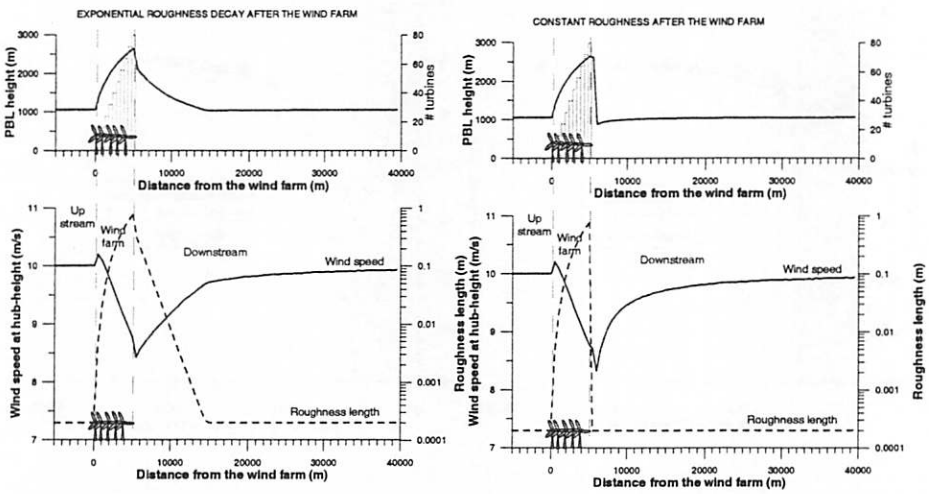
- Turbines added in rows
- Turbulence Intensity from Stens eqn
- Neutral Boundary-layer
- z_{03} – exponential decay or constant



Barthelmie et al.

Exponential or constant roughness?

RISØ



Barthelmie et al.

Recovery distances for U (2%)

RISØ

		km from the wind farm
Zo (block) (m)	0.1	6
	0.5	7
	1	8
WASP	k 0.075	2
	0.05	3
Added roughness	exp	9
	constant	14

Barthelmie et al.

Summary

RISØ

- Storpark
  - Comparison of different wind farm models from WAsP to CFD
  - New approaches to multiple wakes
- Uncertainty in single wake models should be addressed
- Feedback between wakes and the boundary layer appears to be important for large wind farms but is not incorporated in current models
- There is an urgent need for data from large wind farms
- Models have to be improved

Barthelmie et al.

Influence of hydromechanics on the dimensions of an offshore wind floater

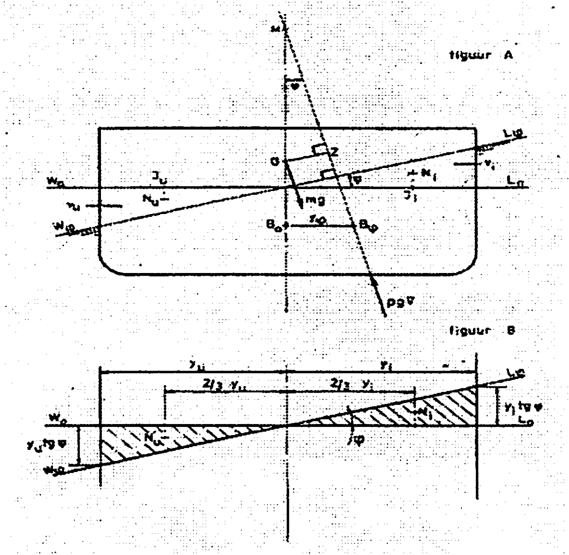
Johan Peeringa

ECN

Contents

ECN

Explanation of stability



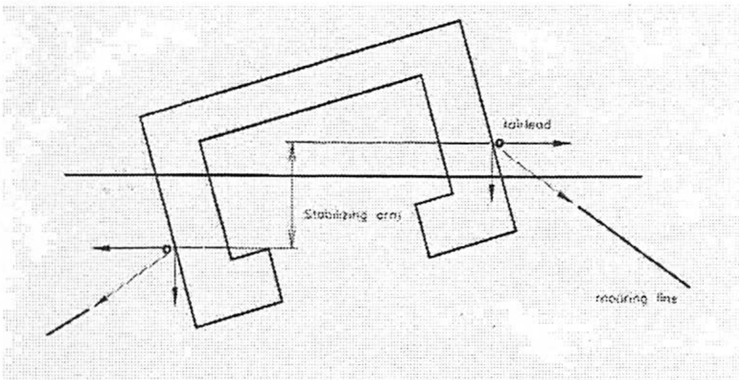
Righting arm GZ

GZ = GM *sin(φ)

GM = KB + BM -KG

BM = inertia of area/displacement

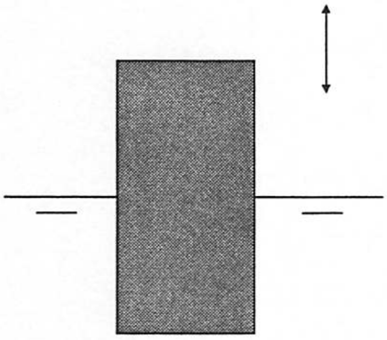
Effect of mooring on stability



Heave motion

$$Fz = \rho g A_w dz$$

$$T = 2\pi \sqrt{\frac{M + A}{\rho g A_w}}$$



Selection of heave period

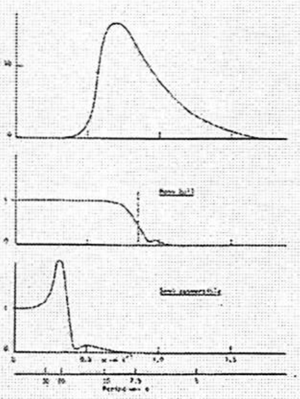
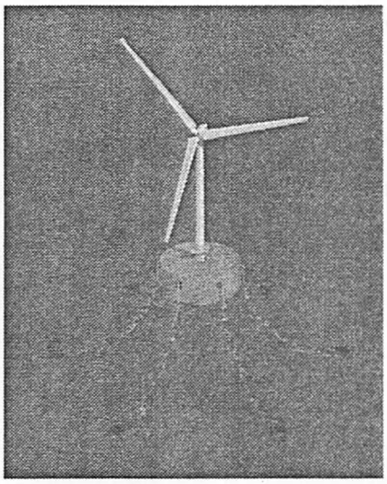


Figure 10
Frequency characteristics for a monohull and a semi-submersible

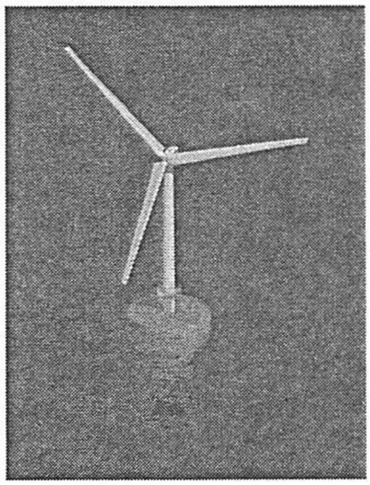
Candidate Concepts [1]

- Single Cylindrical Floater
  - Difficulty in achieving stability
  - Large motion response
  - Size & Cost
- With Skirt
  - Natural periods in heave & roll



Candidate Concepts [2]

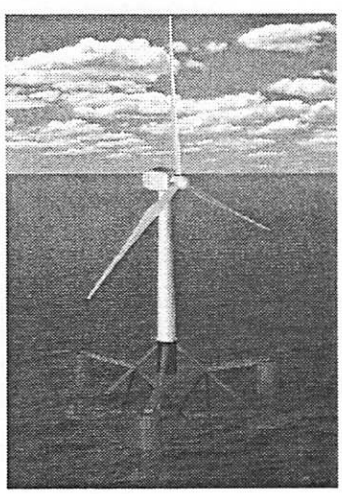
- Cylindrical Floater with Tension-Leg
  - This type of mooring is most suitable for deeper waters
  - Difficulty in achieving stability
  - Size & Cost



ECN

Candidate Concepts[3]

- Tri-Floater
  - Damping-plates needed to increase natural periods (and hence reduce motion response)
- Turbine on one floater
  - Likely heavier structure
- 4-Floater
  - Likely heavier structure



ECN

Future research topics

- Coupling between hydrodynamics and wind turbine dynamics
- Design of shallow water mooring system
- Connection of electricity cables

Acknowledgements

Partly funded by NOVEM within the TWIN-2 program under contract 224.721-0003

Partners in the *Floating Windfarms for Shallow Offshore Sites* Project

- Delft Technical University
- ECN
- Lagerwey (part-time)
- MARIN
- TNO (coordinator)
- Marine Structure Consultants

NoordzeeWind

Het Near Shore Wind Park
Status en Planning

Ing. Henk Kouwenhoven
Manager Monitoring and Evaluation program
NoordzeeWind

NoordzeeWind

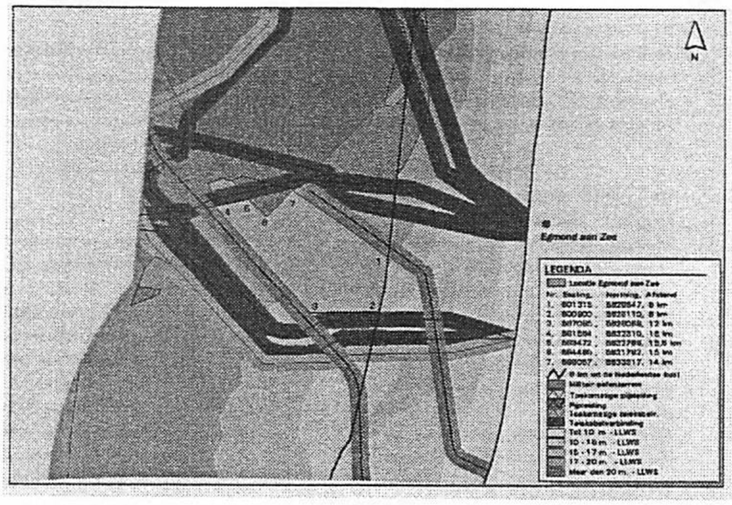
Important project parameters:

- 36 wind turbines
- 1 meteo mast
- NEG Micon NM92/2750
- 2,75 MW each
- Hub height 70 m LAT
- Three 34 kV cables to shore
- 34 -> 150 kV on shore
- Electricity for 110.000 households

NoordzeeWind

NUON

Site of the wind farm



NoordzeeWind

NUON

NoordzeeWind C.V.

Sponsors

- **Shell WindEnergy**
- **Nuon Renewable Energy Projects**

Construction consortium

(Bouw Combinatie Egmond)

- **NEG Micon**
- **Ballast Nedam**

Advisors

- Norton Rose
- etc

NoordzeeWind

Project history (1)

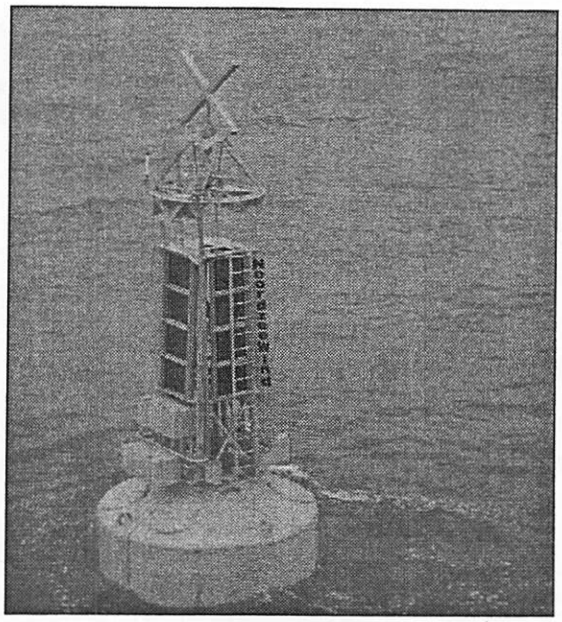
- 1997: Feasability study (Novem)
- 2000/2001: PKB Procedure (EZ, VROM)
- 2002: Selection of NoordzeeWind (EZ)
- 7/2002: Signing contract with Government (EZ, Finance)

NoordzeeWind

Project history (2)

- 7/2002: Project team established (12 people)
- 10/2002: Wind buoy installed on site
- 5/2003: Soil investigation
- 7/2003: Final steps licensing procedures started
- 12/2003: Meteo mast installed on site
- 1/2004: Concept Permit published
- 1/2004: Project team expanded (20 people)

NUON



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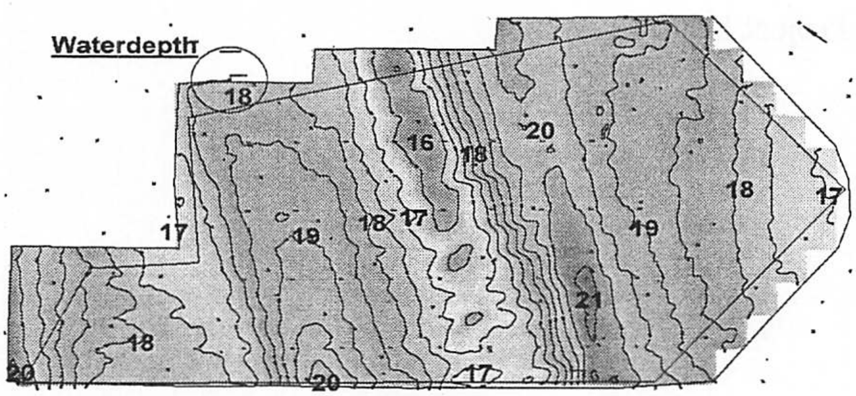
NoordzeeWind NUON



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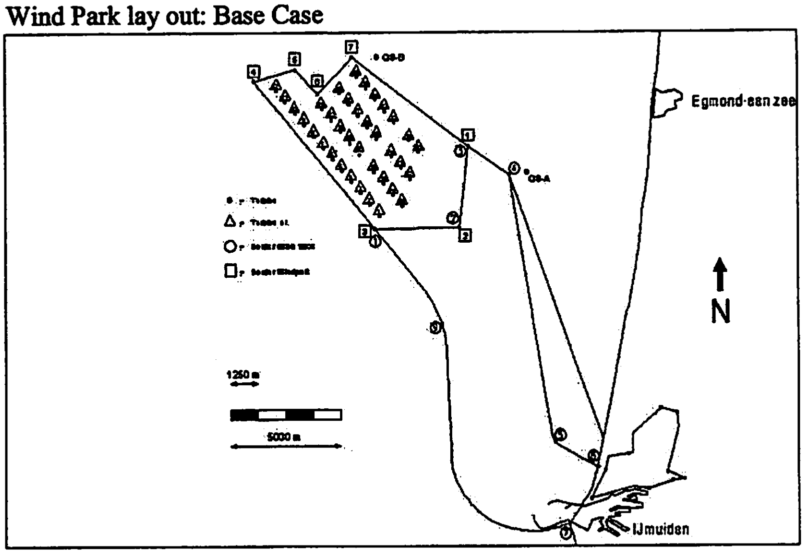
NoordzeeWind NUON

Wind Park lay out: Base Case



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NoordzeeWind NUON

Planning

- 6/2004: Final Investment Decision
- 6/2004: Notice to proceed to BCE
- 7/2004: Start monitoring Ecology
- 10/2004: Start monitoring Technology
- 2005: Construction of the wind farm

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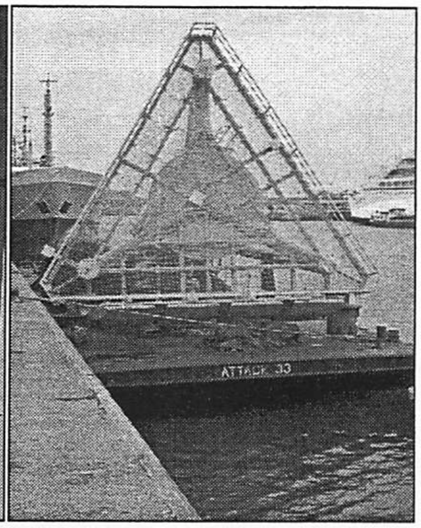
NoordzeeWind NUON



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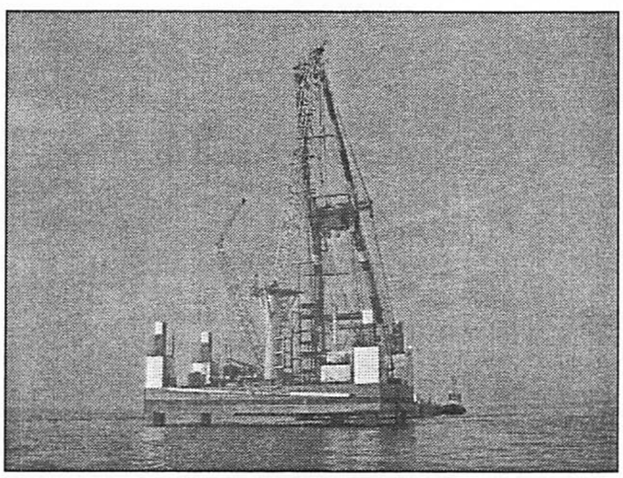
NoordzeeWind NUON



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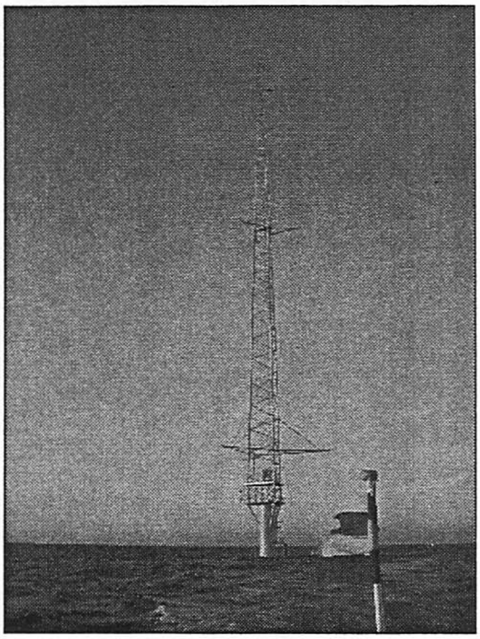

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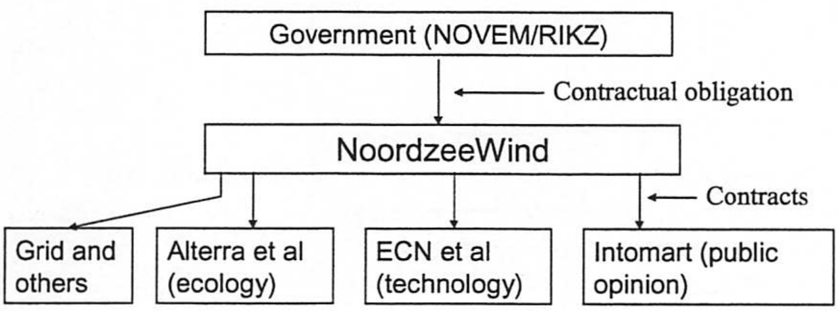
NoordzeeWind

Demonstration Program set up



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NoordzeeWind

ENVIRONMENTAL ASPECTS:

- Birds
- Sea mammals
- Fish and benthos
- Landscape (public opinion and related issues)
- Shipping and Safety

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NoordzeeWind

TECHNOLOGY:

- Wind and waves
- Scour (if possible)
- Corrosion (where technology specific)
- Performance turbines (power curve, control systems etc)
- Logistics construction and operations
- Predictability of generated power
- Power quality
- HSE
- Economics

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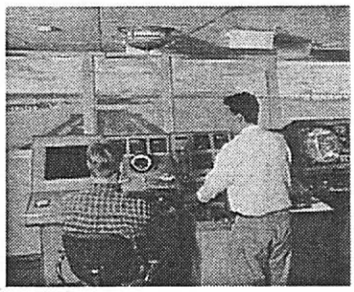
NoordzeeWind NUON

Disruption of the shipping radar
An experiment on MARIN's simulator



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NoordzeeWind NUON

Time schedules

- Environmental aspects:
  - Start immediately after FID
  - Finish 3 – 5 yrs (under discussion)
- Technology:
  - Start 1 yr before start operations
  - Finish 4 yrs later
- Public opinion:
  - Start immediately after FID
  - Finish 3 yrs later

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NoordzeeWind

Any questions?

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NoordzeeWind

Installation of the Near Shore Wind farm metmast

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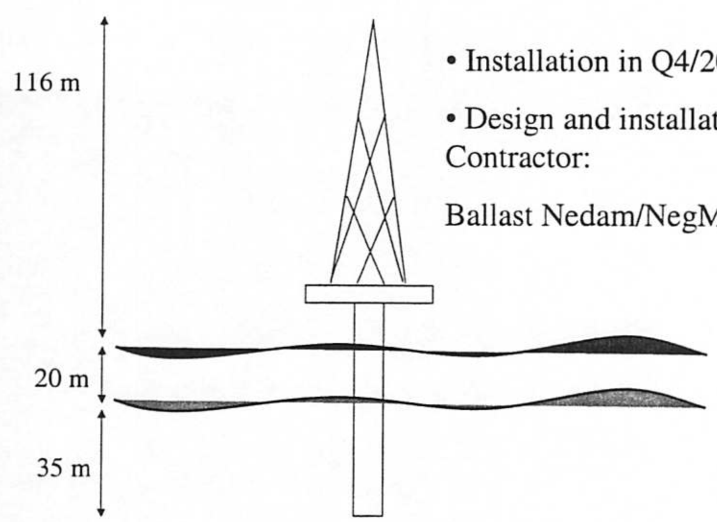
NoordzeeWind



- Installation in Q4/2003
- Design and installation Contractor:

Ballast Nedam/NegMicon

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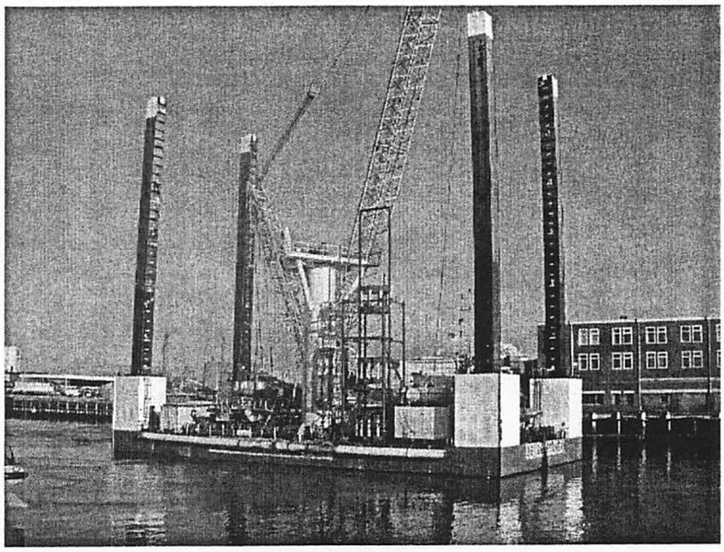
NoordzeeWind



The 'Zeebouwer' mobilising from Ijmuiden harbour

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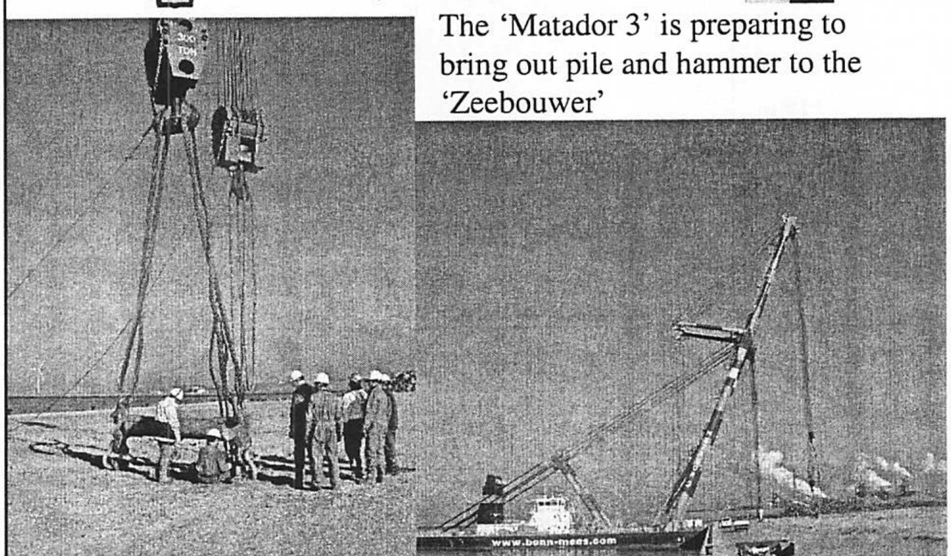
NoordzeeWind

The 'Matador 3' is preparing to bring out pile and hammer to the 'Zeebouwer'



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Specific HAZIDs and training courses were run to prepare all contractors for the 'sea access'

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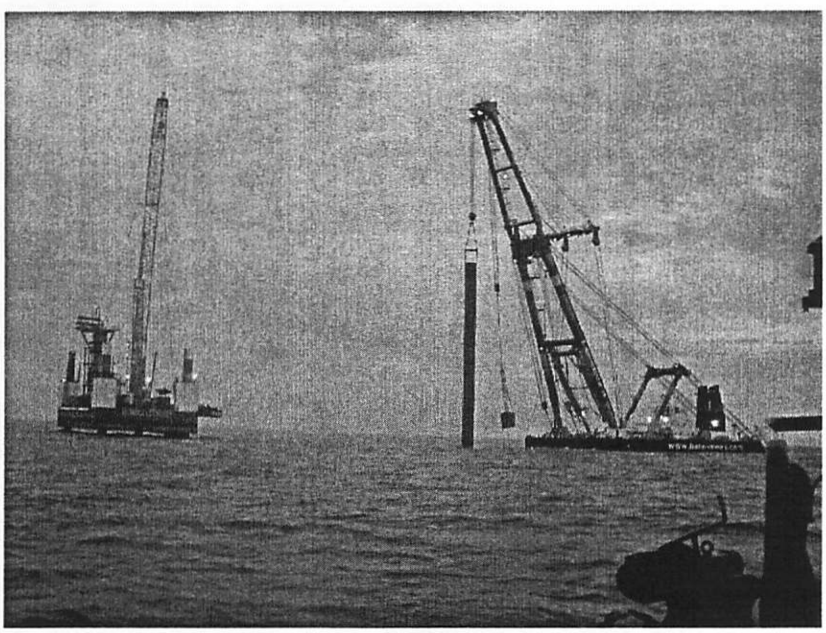
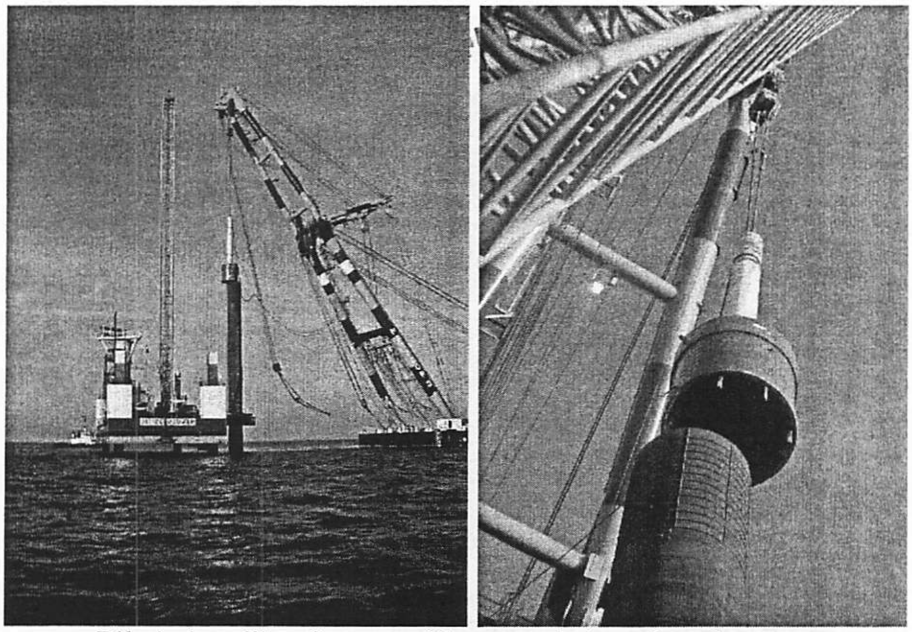


Hammer and pile moving towards the Zeebouwer

IEA Wind Expert Meeting 9./10.3.2004



Pile in handling frame and hammer being placed on top

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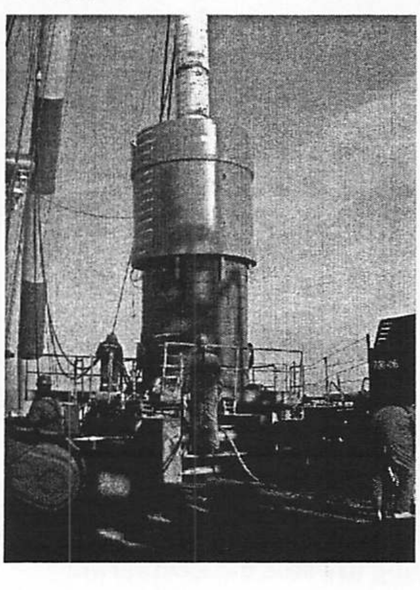
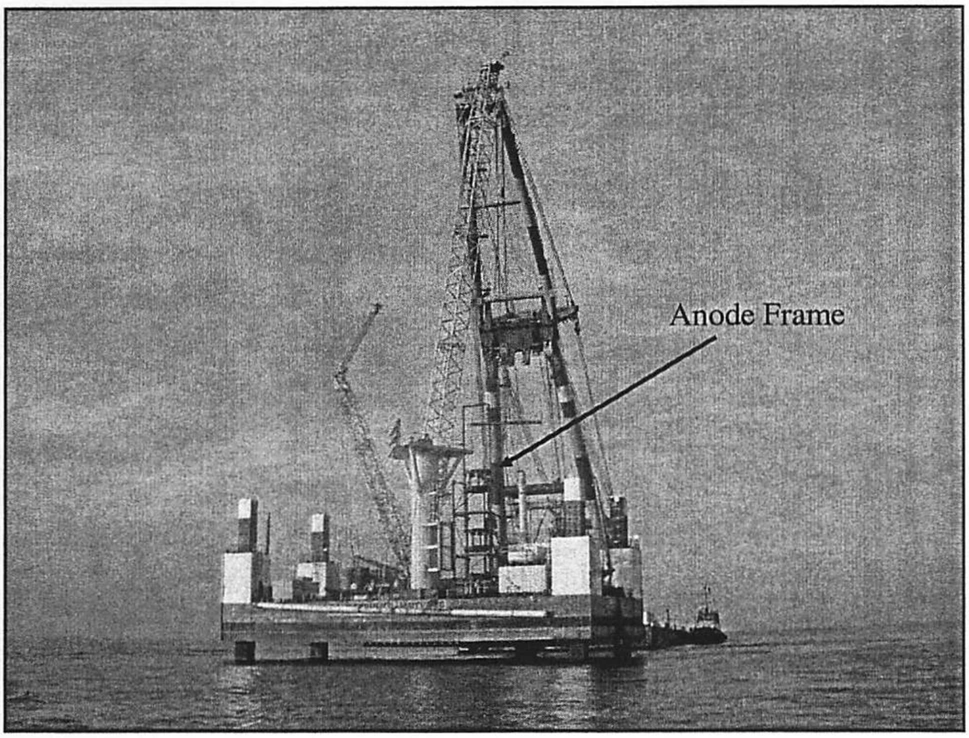
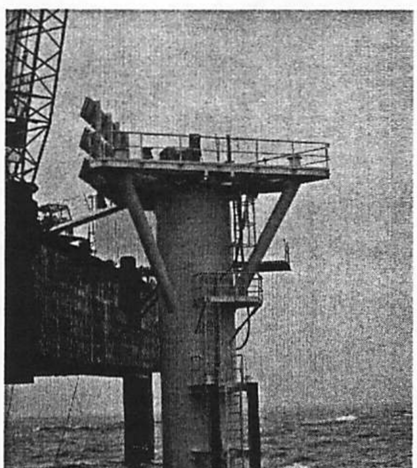
NoordzeeWind NUON



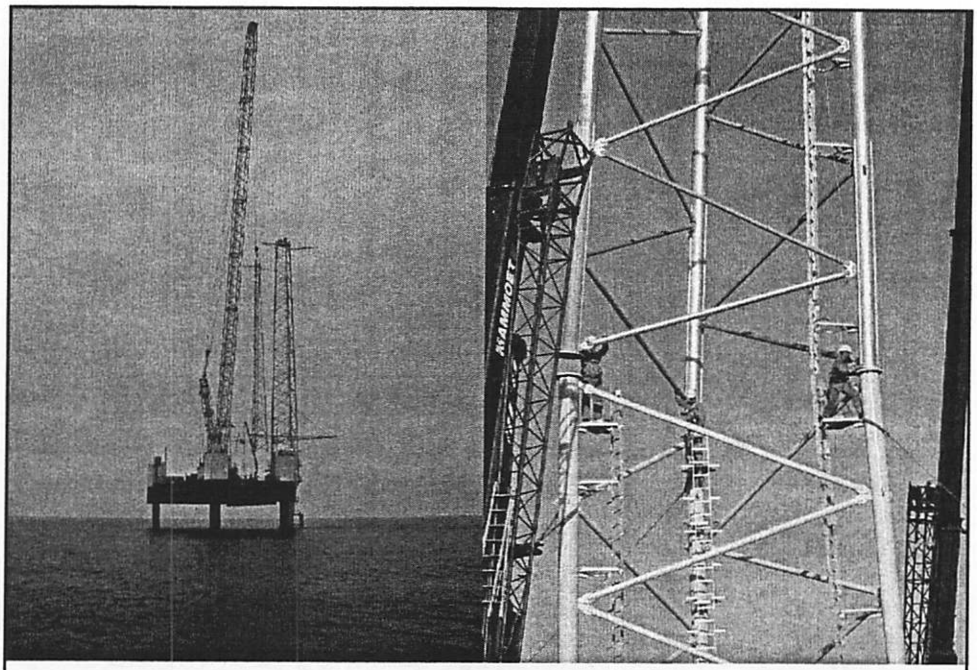
Half way down;
pile is hammered
into seabed to more
than 30m of depth

IEA Wind Expert Meeting 9./10.3.2004





The transition piece on top of the pile



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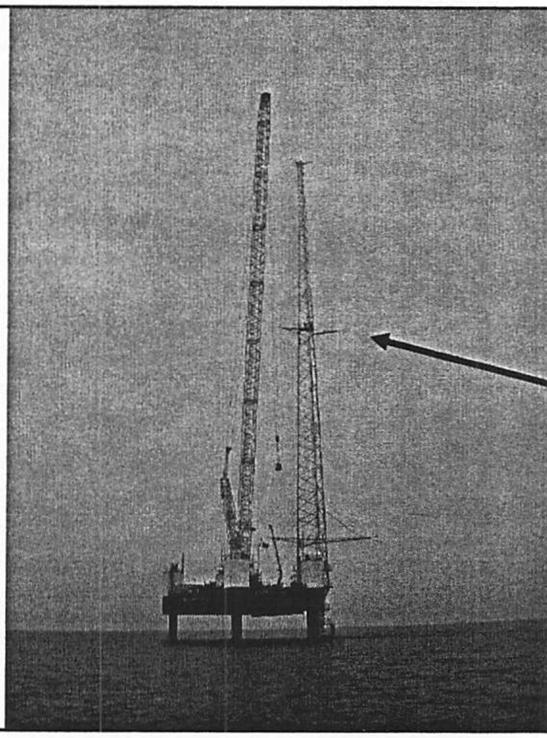
The metmast being assembled



The metmast construction completed (5/12/03).

Note the scale - there are people working on the second level

E-Connection

EXPERT MEETING IEA #43
CRITICAL ISSUES OFFSHORE
DENMARK, MARCH 9&10 2004

SAFESHIP

REDUCTION SHIP COLLISION-
RISKS OFFSHORE WINDPARKS
IN 20-25 M DEEP SEAWATER

IR. HENK DEN BOON
E-CONNECTION
NETHERLANDS
www.e-connection.nl

E-Connection

E-CONNECTION

- INDEPENDENT
- PROJECTS NETHERL: 150 MW
- PROJECTS UK: 50 MW
- PROJECT OFFSHORE: 120 MW
- CONTRACTS: > 100 million EURO
- DUE DILIGENCE
- WIND RESOURCE
- RISK ASSESSMENT

E-Connection

Paper describes EU supported project in connection with 120 MW Q7-WP offshore windfarm:

SAFESHIP

partners:
- E-Connection Project BV
- VESTAS Wind Systems A/S
- Technical University of Denmark, Section of Maritime Engineering
- Technical University Delft, Section Marine Technology
- Germanischer Lloyd AG
- Germanische Lloyd Windenergie
- Maritime Research Institute Netherlands MARIN

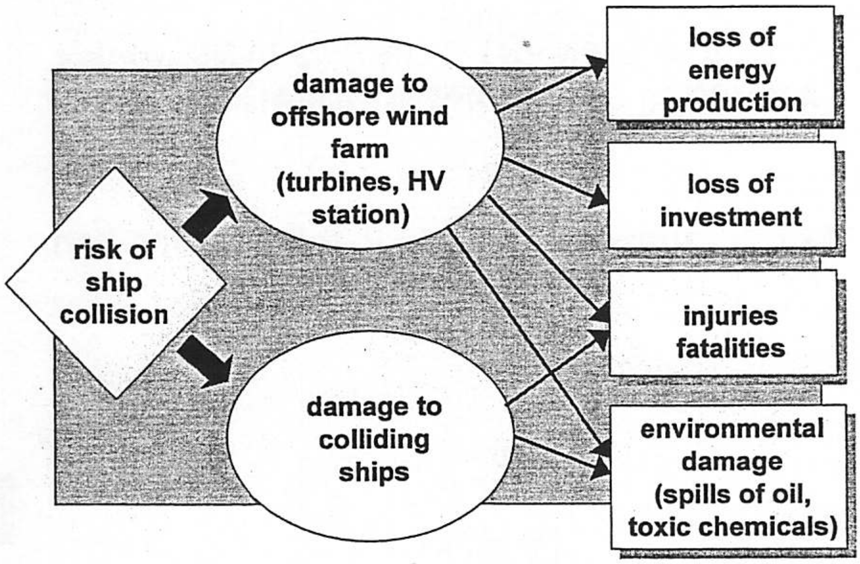
E-Connection

SAFESHIP project (EU contract NNE5/2001/521):

⇨ to reduce the risks of ship collisions with offshore wind farms by development of technologies and assessment methodologies

E-Connection

potential effects from ship collision with wind farm

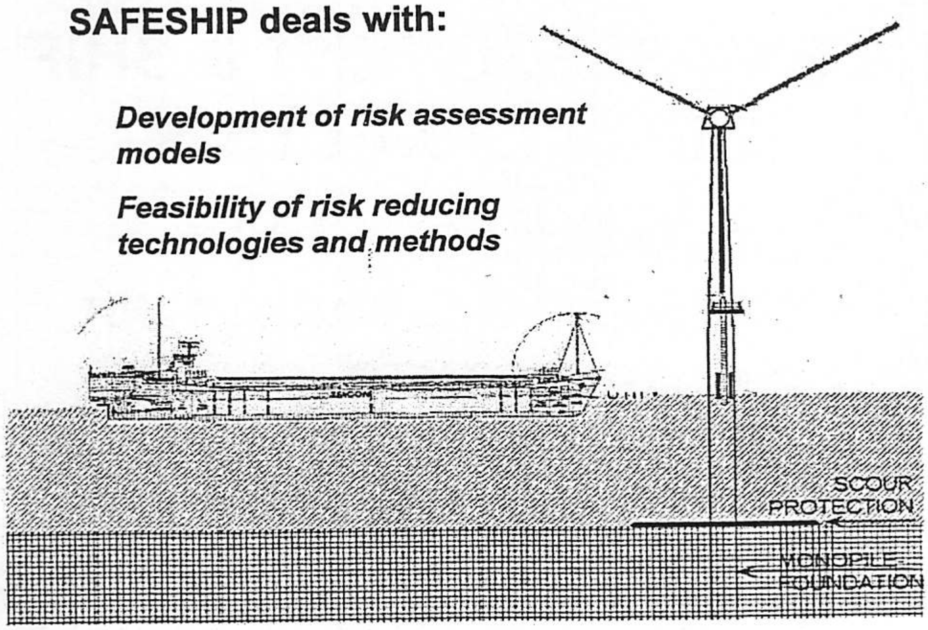


E-Connection

SAFESHIP deals with:

Development of risk assessment models

Feasibility of risk reducing technologies and methods



E-Connection

development of risk assessment models
further development of:

RISK ASSESSMENT & SHIP IMPACT ANALYSIS OFFSHORE WINDPARK Q7-WP

➡ **further described in this presentation**

E-Connection

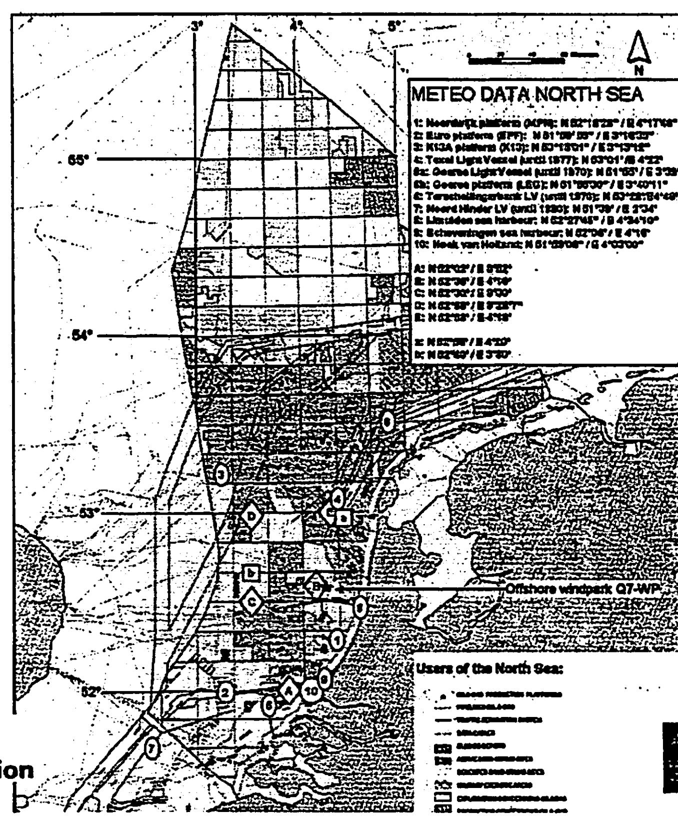
RISK ASSESSMENT & SHIP IMPACT ANALYSIS

- E-CONNECTION
- OFFSHORE WINDPARK Q7-WP
- RISK-ASSESSMENT
- SHIP IMPACT ANALYSIS
- CONCLUSIONS

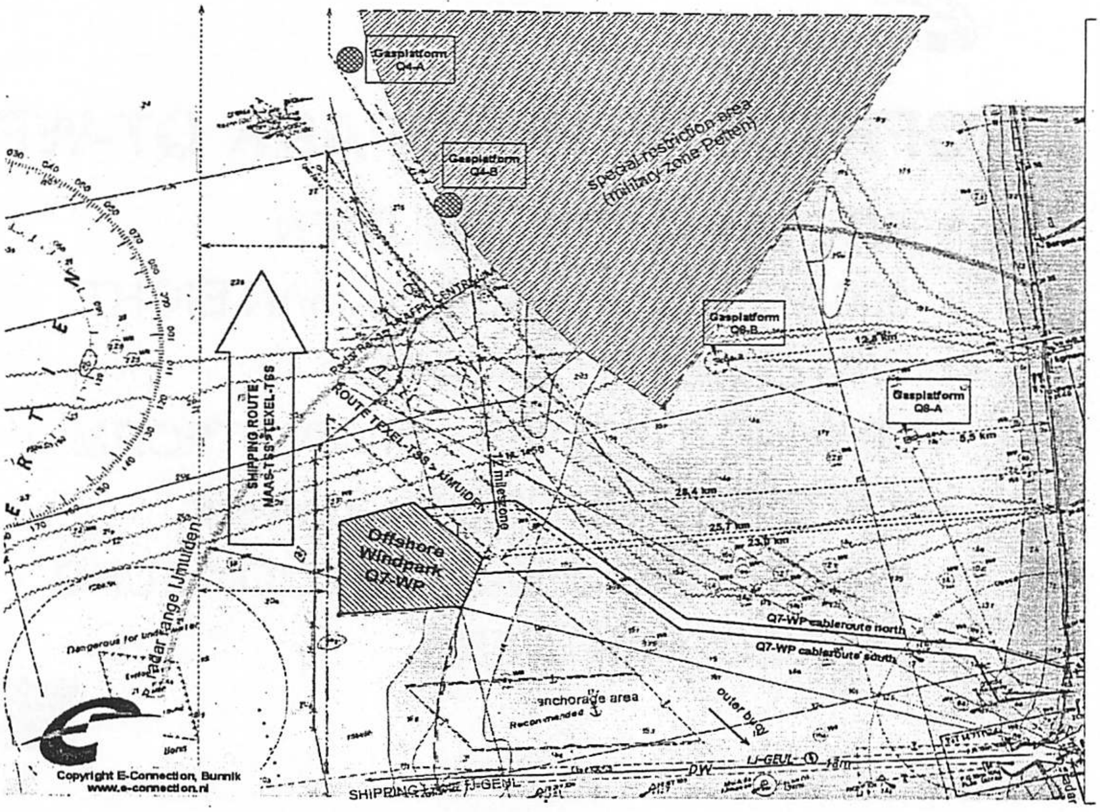
E-Connection

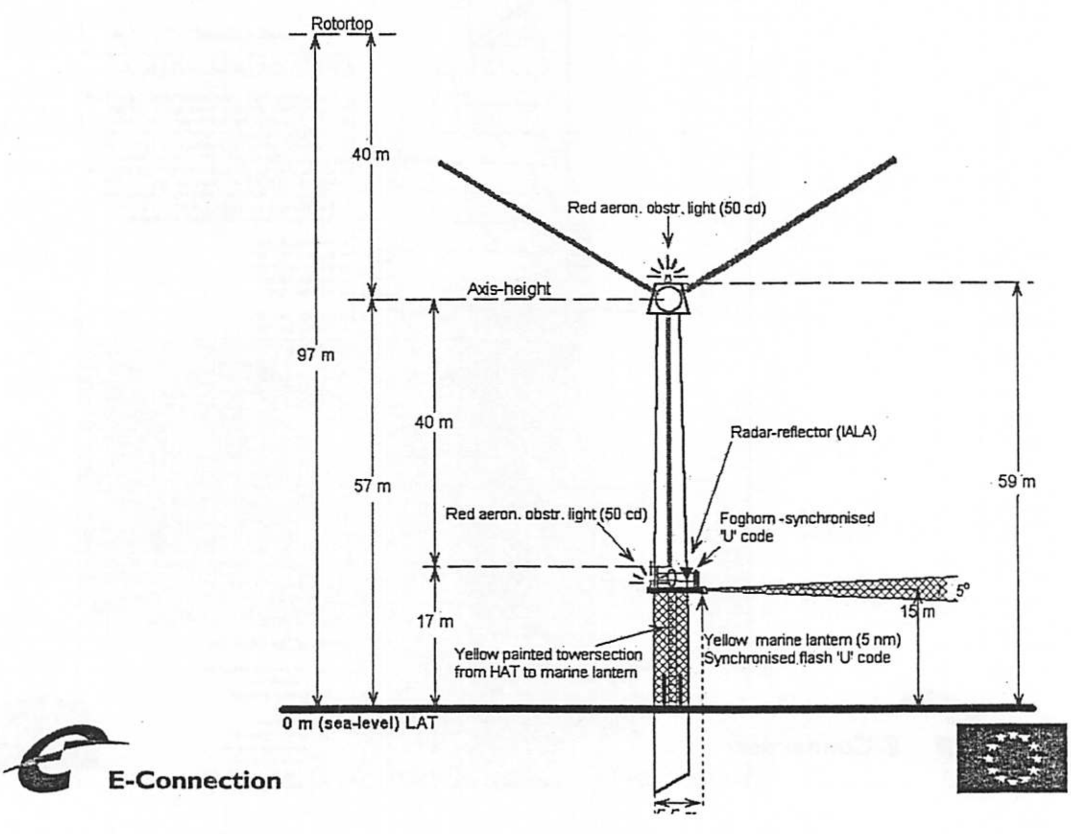
OFFSHORE WINDPARK Q7-WP

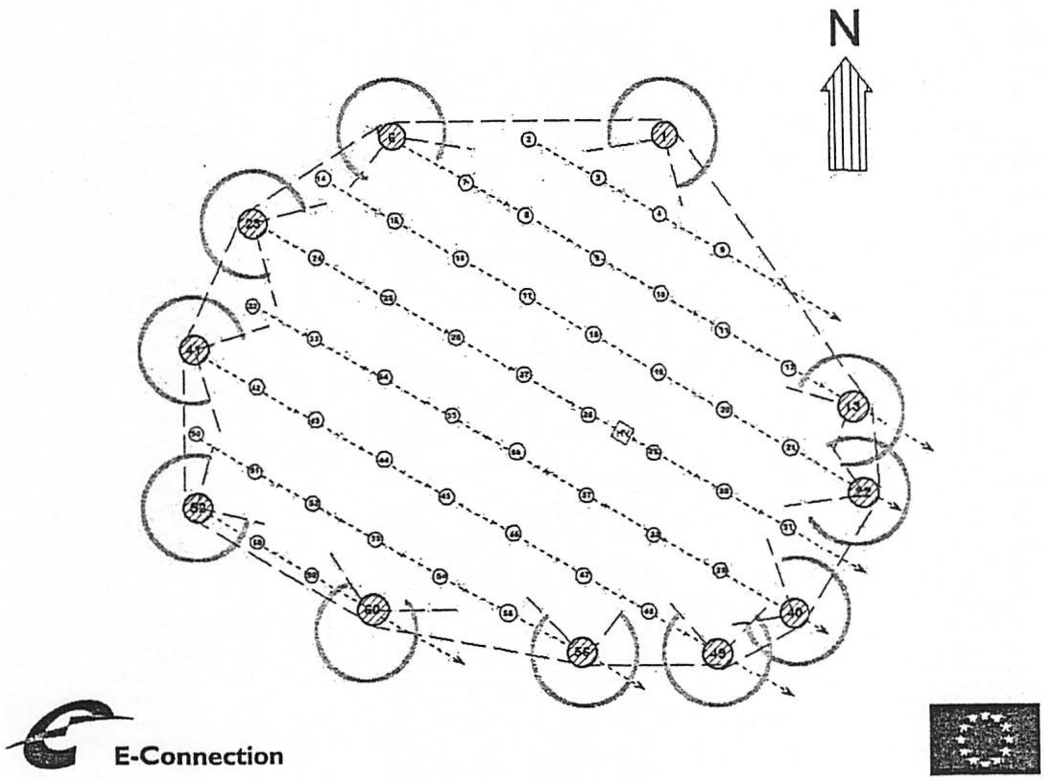
- SITE 23 KM WNW IJMUIDEN
- 500 M SHIPS MAAS-GERMAN BIGHT
- WATERDEPTH 20-24 M
- 60 WINDTURBINES + HV-PLATFORM
- 120 MW & 438.000.000 kWh/year
- INVESTMENT 250-300 MILLION EURO
- PROJECTPARTNERS

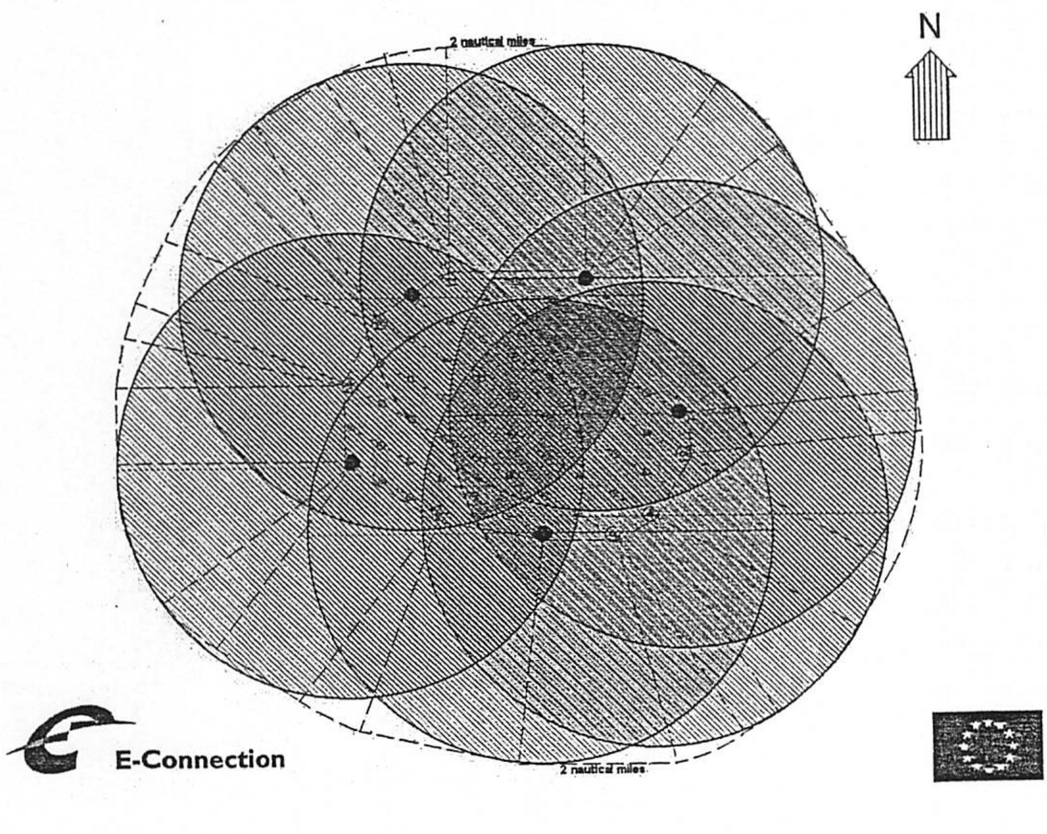


E-Connection


Gasplatform Q4-A
Gasplatform Q4-B
special restriction area (military zone Petten)
Gasplatform Q8-B
Gasplatform Q8-A
SHIPPING ROUTE MAAS-TSS - TEXEL-TSS
ROUTE TEXEL-TSS > IJMUIDEN
Offshore Windpark Q7-WP
Q7-WP cableroute north
Q7-WP cableroute south
anchorage area
outer buoy
Radar range IJmuiden
Copyright E-Connection, Bunnik
www.e-connection.nl


Rotortop
40 m
Red aeron. obstr. light (50 cd)
Axis-height
97 m
40 m
57 m
Radar-reflector (IALA)
59 m
Red aeron. obstr. light (50 cd)
Foghorn - synchronised 'U' code
5°
17 m
15 m
Yellow painted towersection from HAT to marine lantern
Yellow marine lantern (5 nm) Synchronised flash 'U' code
0 m (sea-level) LAT
E-Connection


N
E-Connection

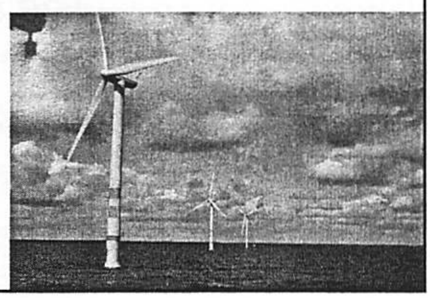

N
2 nautical miles
2 nautical miles
E-Connection

Netherlands

IEA Annex XI

8 - 9 March 2004
Skearbeck
Denmark

Ing. Jaap L. 't Hooft
(Novem)



Critical Issues OS NL

- Wind farms and environment
- Grid integration
- Wind forecasting

- Remarks on floating offshore

2

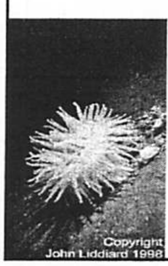
Influence environment

- Environment on wind farm
- Wind farm on environment
  - migrating and foraging birds
  - pelagic and non-pelagic fish
  - benthos and epi-benthos
  - sea mammals
- Base line measurements
  - On behalf of the government
  - 1-st results benthos, end sept. 2004
  - website **www.mep-nsw.nl**
- Effect measurements NoordzeeWind

3

COD

- Environmental impact offshore wind farms
  - collect and benchmark data from environmental monitoring programmes
  - guidelines and best practices for EIA's
- Legislation, consents procedures
  - collect and benchmark legislation procedures
  - guidelines and best practices
- Electrical infrastructure
  - inventory, need for EU wide studies

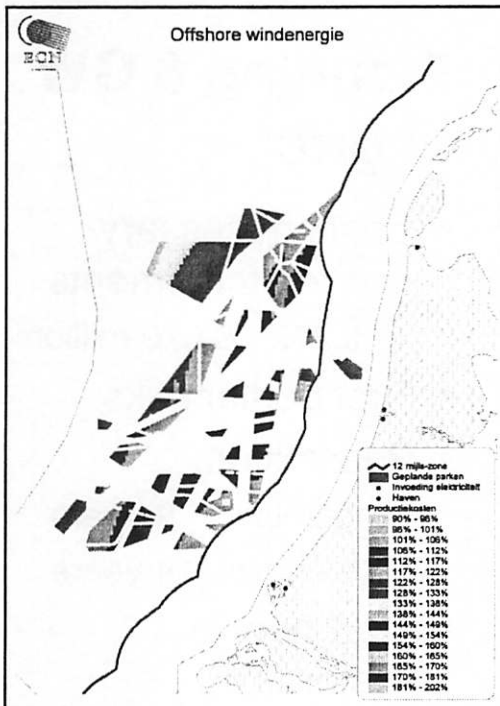


4

Concession regime.

- Entire North Sea EEZ (> 12 miles)
- Exception of excluded areas
  - shipping lanes and military practice areas etc.
- Max 50 km^2 ?
- End 2004

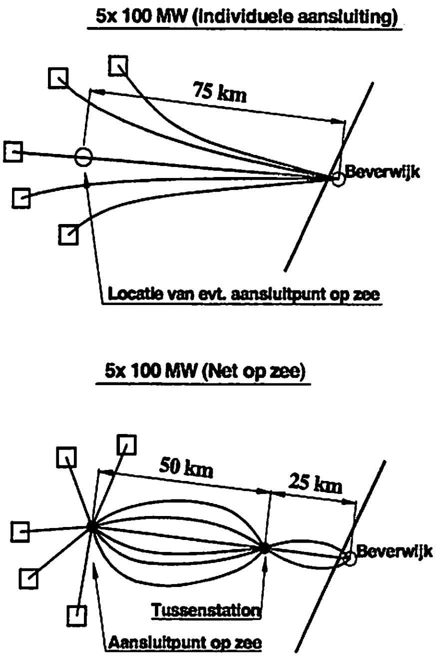
5



Connect 6000 MW

- Objective: develop vision on integration 6 GW wind
- Clarify responsibilities tasks and authority of:
  - Government,
  - TenneT (TSO)
  - Regulator (DTe)
  - Market parties.

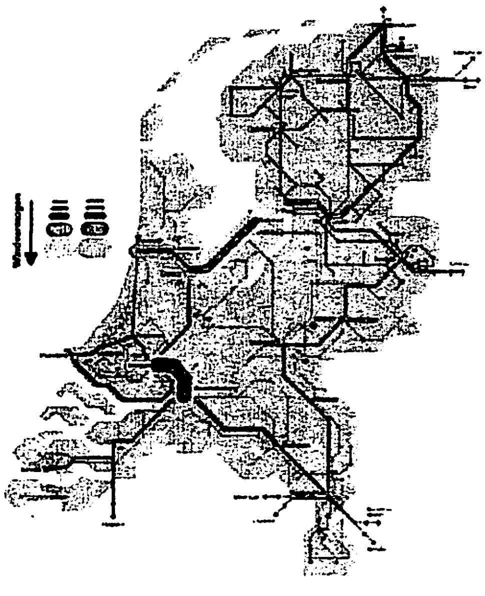
6



Offshore cables.

- Comparison AC and HVDC
- Grid at sea
- Economic benefits uncertain
- Non-economic, mainly planning consents, less cables landfall
- 2.7 G€ or 0.7 G€

7



Figuur 2 Knelpunten en fasering

Planning 6 GW in grid

- Costs necessary grid reinforcements
  - € 275 - € 570 million
- First bottlenecks
- Realisation:
  - optimistic 9 years
  - pessimist 14 years
- Start now or yesterday

8

Research subjects (1)

- Dynamic analyses Dutch grid
  - short circuit behaviour and transient stability
- Dynamic behaviour of large wind farms
  - Annex XXI

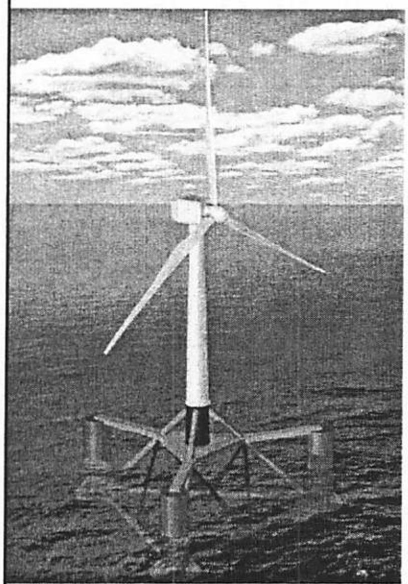
9

Research subjects (2)

- Short term power fluctuations, normal and storms
  - Early warning forecast loss of power
- Influence on conventional power generation
  - required control reserve and emergency power
- Study maintenance of power balance
  - Program Responsibility, load rejection, trade on spot market based on wind forecasting

10

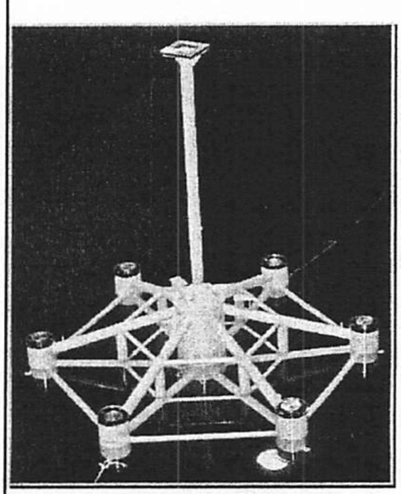
Floating offshore WTB's



- Extensive feasibility study
- 50 m water depth
  - 1% of NL North Sea
- 500 MW farm
- 100 km from shore
- LPC 0.07 €/kWh
  - uncertainties
    - floater 10%
    - mooring 50%
    - O&M 50 %
  - pfd available

11

Floating offshore WTB's



Tank Test Model (1/50)

- Hitachi Zosen Corp.
- Design for 5 - 10 MW
- Tank model
- Central floater and 6 sub-floaters
- Dynamic motion compensation through pumping of ballast water

12

Offshore wind - critical issues for the UK

Colin Morgan

IEA Meeting Fredericia 9-10 March 2004

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Strategic questions

Can the wind deliver?
- Offshore wind load factors

Can the industry deliver?
- Supply chain constraints

Will it be consented?
- Consents

Can it be connected?
- Grid connection considerations

Will it be affordable?
- Cost of energy

Can it be financed?

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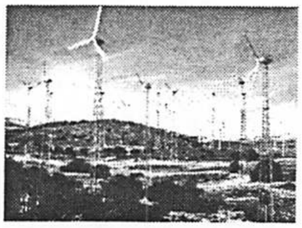
Garrad Hassan and Partners Ltd

Industry-leading wind energy engineering consultancy

Founded in 1984

Independent - no equity stake in wind farm or wind turbine



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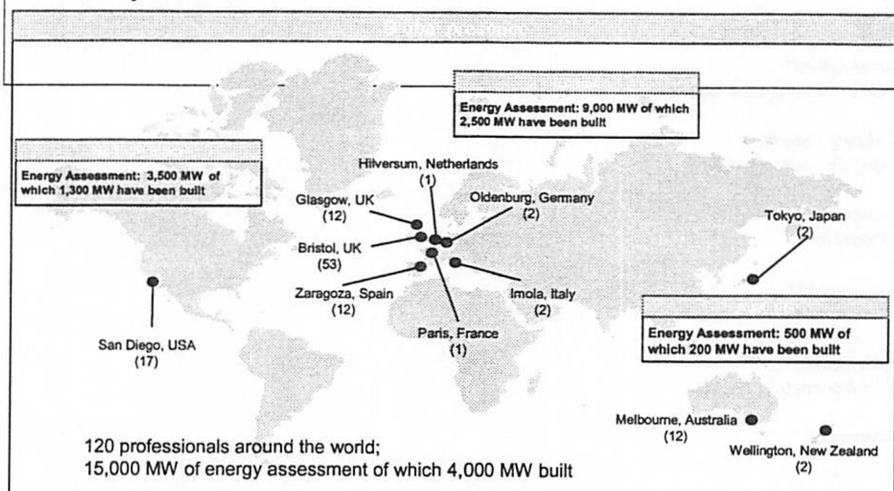
GH activity around the world



Note: Number of professionals per location in parenthesis.

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GH offshore activity – UK & Ireland.

Plus projects in Belgium, Denmark, France, Italy, Sweden and USA

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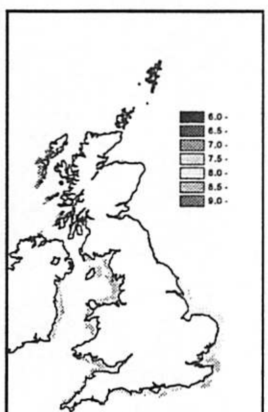
Offshore wind – estimated load factors

UK Offshore Wind Map

Estimate for UK Round 1 sites
- 8.5m/s to 9.5m/s at 90m AMSL
- current market leading turbines
- 20% total losses
- net load factor 33% to 38%

Estimate for UK Round 2 sites
- wind speeds higher than Round 1 on average
- 35% load factor – supportable



Annual mean wind speeds 60m AMSL [1995 GH/GL]

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Offshore wind – actual load factors

Project	Net load factor	
Delabole Wind Farm, Cornwall (4MW)	30 %	Elevation 240m AMSL, Cornwall, based on Nov 1991 to date (12 years)
Burradale Wind Farm (4 MW)	51 %	Elevation 150m AMSL, Shetland, based on 2001 to 2003 (3 years)
Middelgrunden Offshore Wind Farm (40MW)	29 %	3km offshore Copenhagen, based on only full year since commissioned (2002)

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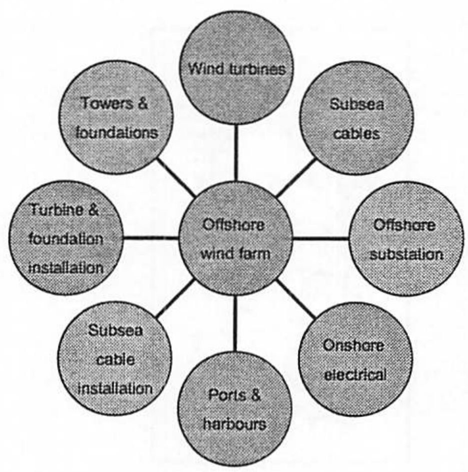
The offshore wind engineering supply chain



Assumptions:
Required capacity 1 to 2 GW/annum 2008 onwards
- Other markets drawing resource - especially Germany
- Onshore wind still much larger market than offshore

Key requirement - consistent stable market – to facilitate investments with 3-5 year lead time

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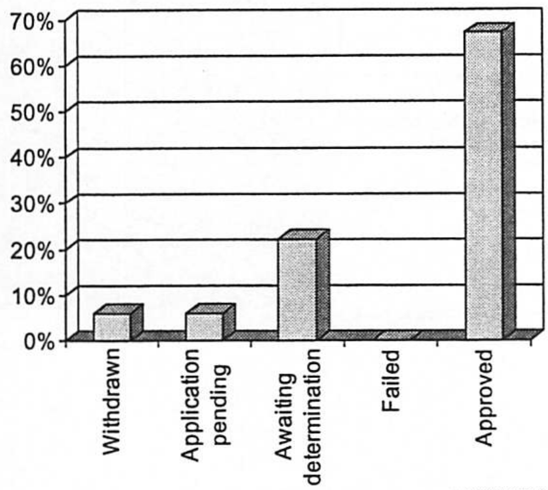
Planning UK Round 1 - a success story



Grid connection

Connections:

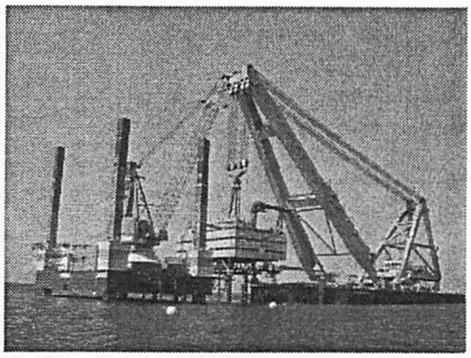
- Mostly NGT 400/275 kV system.
- Some DNO 132/33 kV system.

Issues:	**Actions:**
Wind turbines to become more "grid-friendly"	Evolution of Grid Code, modelling and hardware
Grid to become more "wind-friendly"	System management measures, reserve capacity
Predictability of wind power output, for scheduling other plant, enhancing value of wind	Improved forecasting of wind farm output

Source : DTI/ABPmer

Grid connection

Issues:	Actions:
North to south power flows are a major issue in the UK - thus new offshore wind in the south is preferable.	NGT will probably penalise generation located in the north via a locational charge – more important for onshore wind
Major onshore transmission system works – 5-10 year lead time	Early move – especially on consenting
Extension of transmission network offshore - Who pays?	Transmission system operator permitted to build out offshore. "Connection hubs"?



Source : Elsam

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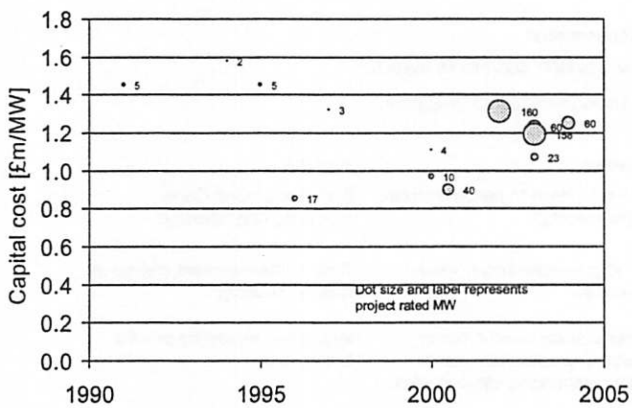
Capital costs – existing projects

Experience to date - 500MW

Downward cost trend

Early, demonstration projects
- Small
- Sheltered, shallow waters
- Risk allocation non-commercial

Since 2000
- Larger
- More demanding sites
- More commercial



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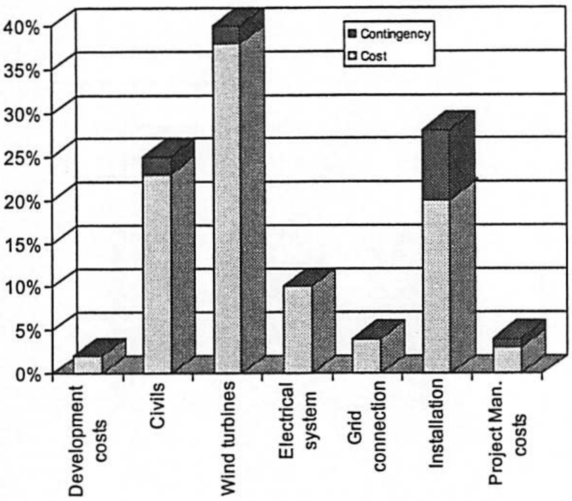
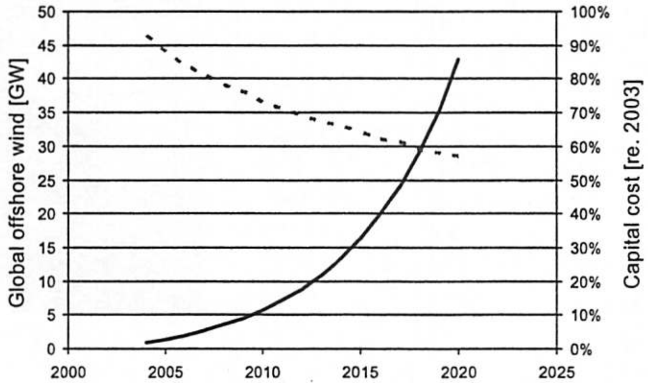
Capital costs – breakdown



Capital costs – scope for improvement

Assumptions :

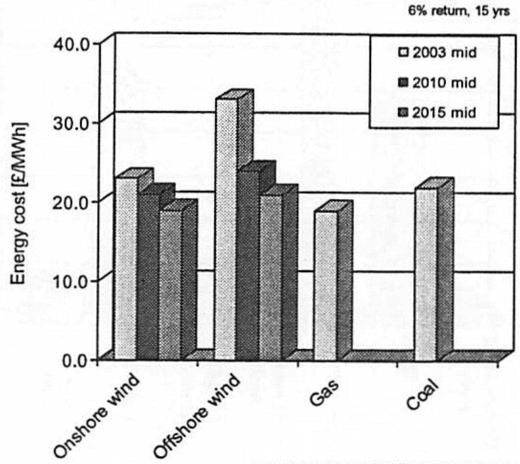
- 20% annual growth in installation rate [IEA]
- 8% reduction in capital cost with doubling of installed capacity [ISET – Germany]



Energy costs

Range on all technologies

"External cost" effects?



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Financing

Critical ingredients:

- Viable economics
- Solid parties
- Offtake confidence
- Risks understood, quantified and allocated
  - in construction
  - in operations

- ..... experience

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A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

OFFSHORE WIND ENERGY RESEARCH IN THE UNITED STATES

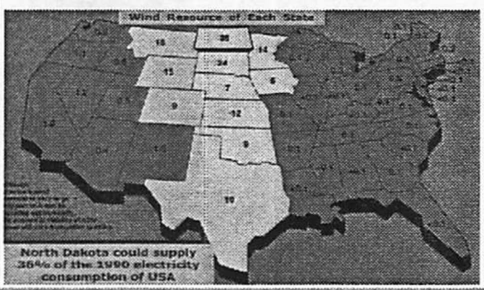
Walt Musial
National Renewable Energy Laboratory
Golden, CO USA
Walter Musial@nrel.gov

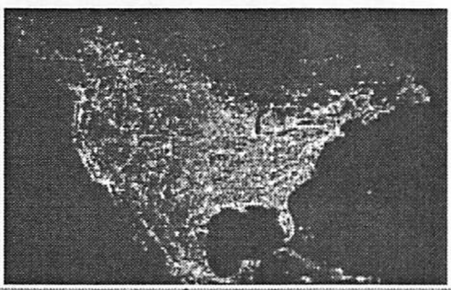
IEA Topical Experts Meeting #43
Critical Issues Regarding Offshore Technology and Deployment
March 9-10, 2004
Elsam, Fredericia, DK

NREL is operated by Midwest Research Institute • Battelle

US Wind Resource – Development Strategy

- *Land-based resource can provide all US electricity*
- *Grid is not set up for long inter-state electric transmission.*
- *Load centers are not near best wind sites*
- *DOE/NREL strategy – Low Wind Speed Turbine Program*





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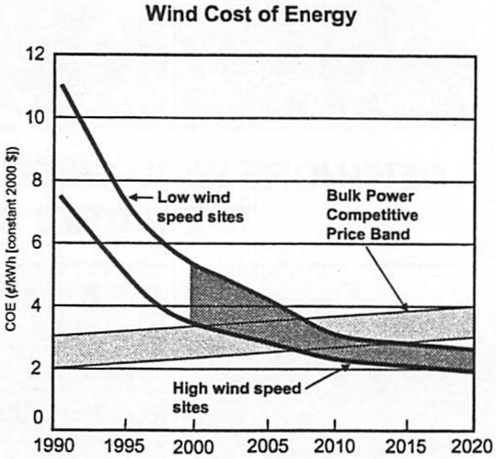
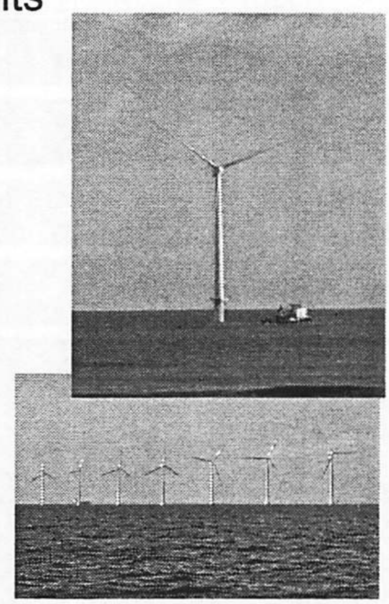
Low Wind Speed Technology

- Current Situation
  - Wind energy viable at higher wind speed sites (Class 6)
  - Subsidies important
  - Good wind sites are far from load centers
- Future Focus
  - Achieve competitive turbine costs of \$.03/kWh at Class 4 (avg. 5.8m/s @ 10m) sites on-land.
  - 20x land area
  - Diminish need for subsidy
  - Closer to load centers
  - Achieve competitive offshore turbine costs of \$0.05/kWh by 2012.
  - Develop technology for deep water wind turbine deployment.

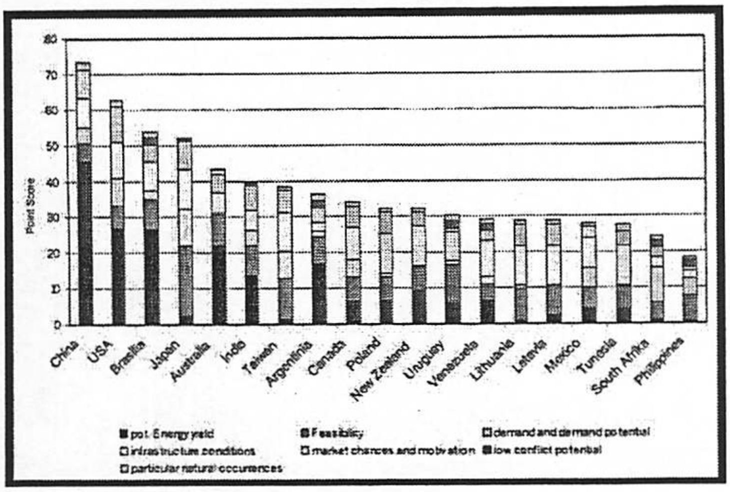


Offshore Wind Benefits

- Higher-quality wind resources
  - Reduced turbulence
  - Increased wind speed
- Avoid constraints on turbine size
- Proximity to loads
  - Many demand centers are near the coast
- Increased transmission options
  - Access to less heavily loaded lines
- Potential for reducing land use and aesthetic concerns



Offshore Wind Energy Potential Outside the European Union



Source: Siegfriedsen, Lehnhoff, & Prehn
aerodyn Engineering, GmbH
Conference: Offshore Wind Energy in the Mediterranean and other European Seas
April 10-12, 2003 - Naples, Italy

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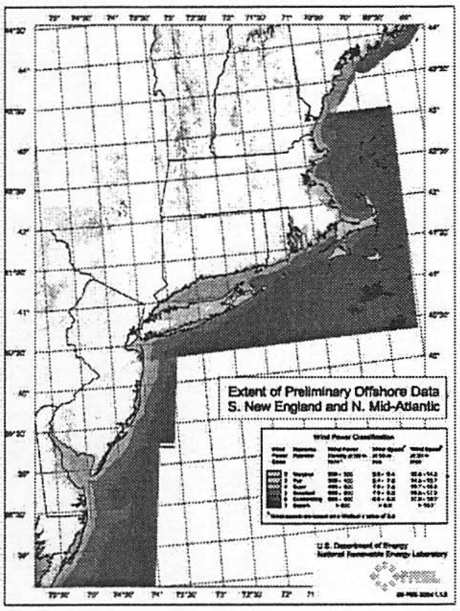
Estimate of US Resource Offshore



Offshore Resource Estimates in MW
5 - 20 Nautical Miles

Region	Shallow Water < 30 m	Deep Water > 30 m	% Exclusion
New England	9,900	41,600	67%
Mid Atlantic States	46,500	8,500	67%
California	2,650	57,250	67%
Pacific Northwest	725	34,075	67%
Totals	59,775	141,425	67%

Offshore Resource Estimates in MW
20 - 50 Nautical Miles

Region	Shallow Water < 30 m	Deep Water > 30 m	% Exclusion
New England	2,700	166,300	33%
Mid Atlantic States	35,500	170,000	33%
California	0	238,300	33%
Pacific Northwest	0	93,700	33%
Totals	38,200	668,300	33%

Preliminary Analysis

- Inside 5nm – 100% exclusion
- 33% exclusion– 20 to 50 nm
- 67% resource exclusion to account for avian, marine mammal, view shed, restricted habitats, shipping routes & other habitats.
- By comparison, total U.S. electrical generation capacity for all fossil, nuclear and renewable generation is 914 GW

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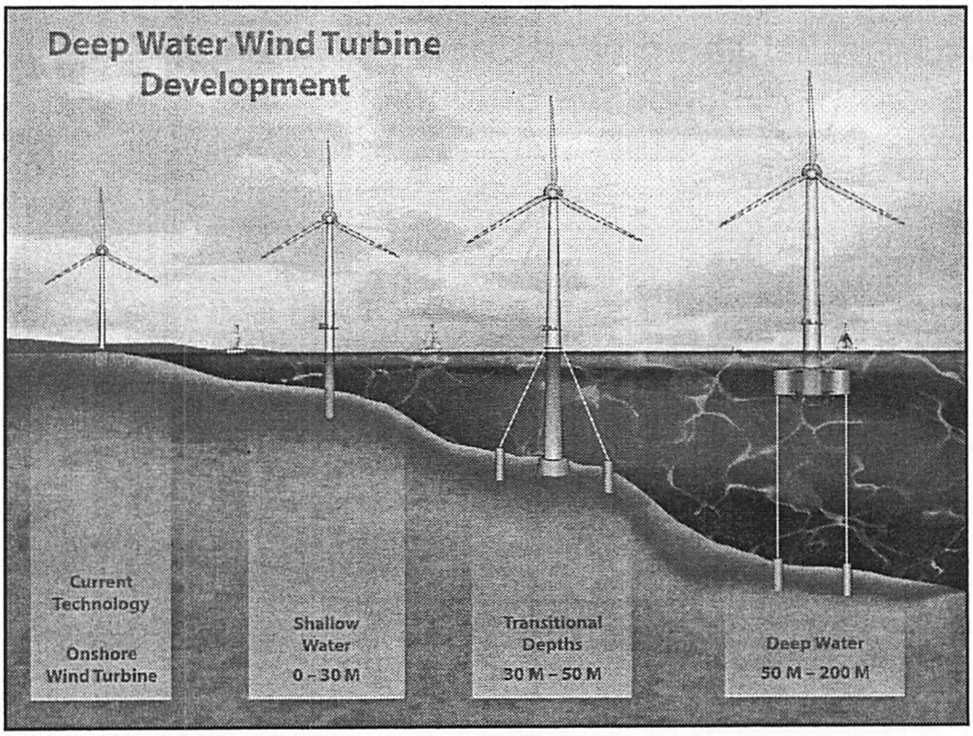
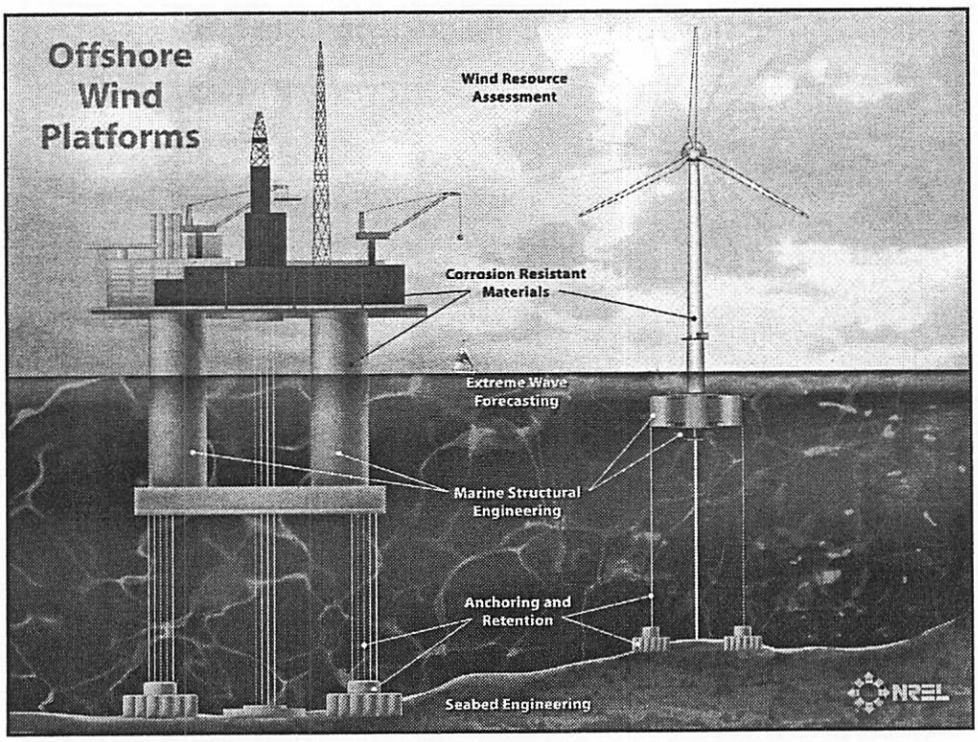

Deep Water Wind Turbine Development
Current Technology
Onshore Wind Turbine
Shallow Water
0 - 30 M
Transitional Depths
30 M - 50 M
Deep Water
50 M - 200 M


Offshore Wind Platforms
Wind Resource Assessment
Corrosion Resistant Materials
Extreme Wave Forecasting
Marine Structural Engineering
Anchoring and Retention
Seabed Engineering
NREL

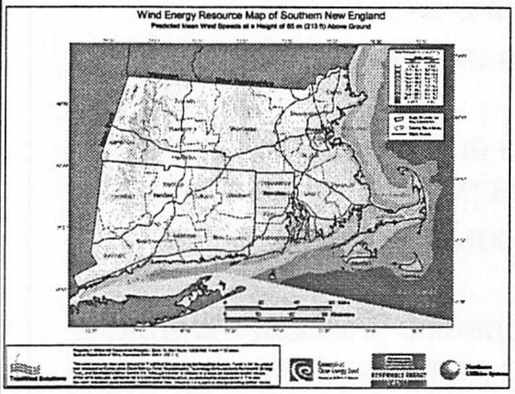
Cost Reduction Strategies for Floating Offshore Platforms

- Use oil and gas baseline experience.
- Delete whole systems that are unnecessary for wind application.
- Develop standardized and modular designs (uncoupled) and mass produce platforms.
- Minimize installation costs – simplify all tasks done at sea.
- Develop application specific low-cost mooring systems from existing marine options.
- Minimize weight.
- Minimize O&M costs

NREL/DOE Research Initiatives

- Resource Assessment
- Environmental and Permitting Issues
- Floating Platforms
  - Dynamic Modeling
  - Cost Modeling
- Technology Development Contracts
- Standards Development Support

NREL Resource Assessment



- **Validate offshore wind maps (TrueWind Solutions) developed as part of onshore mapping projects**
  - New York - New England
  - Mid-Atlantic
- **Support production of new offshore maps where needed**
  - Oceans (up to 200 nautical miles from coast)
  - Great Lakes
- **Explore methodology for calculating offshore potential**
  - Obtain relevant GIS datasets
  - Define exclusion areas
- **Workshop with resource assessment and mapping and offshore experts**
  - Purpose is to provide guidance to NREL for future offshore analysis

Floating Offshore Turbine Dynamics
NREL's Near-Term Plans

•Jason Jonkman – PhD student at NREL

•Collaboration with Massachusetts Institute of Technology - Department of Ocean Engineering.

• Implement platform motion DOFs to FAST and ADAMS:

• Add wave loading dynamics. Interface with SML code.

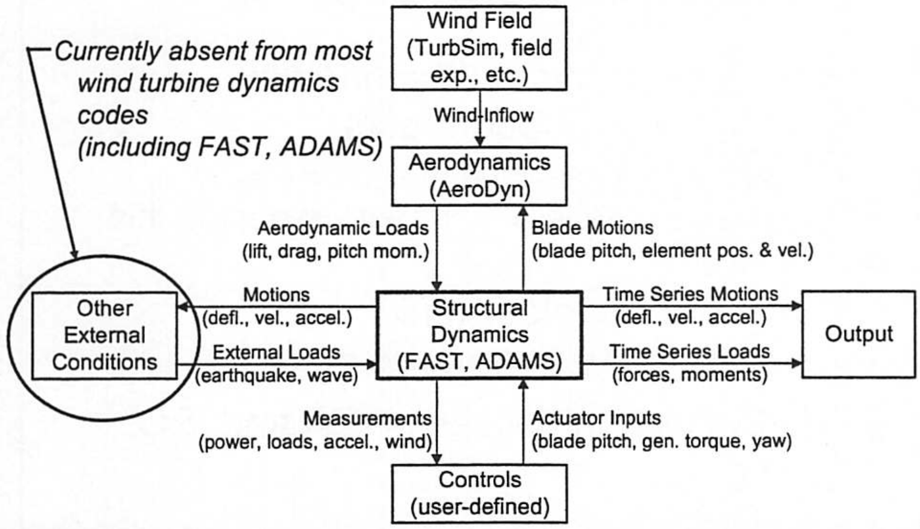
• Compare load case simulation results with and without wave loading dynamics.

Is power performance lost?
How much do waves increase loads for offshore floating turbines?
Which floater concepts result in smallest loads?

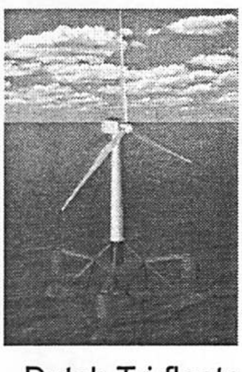
• Examine stability issues through linearization and eigen-analysis

• Develop controllers to reduce loads and deflections and improve stability

Floating Offshore Turbine Dynamics
Aeroelastic Analysis Flowchart

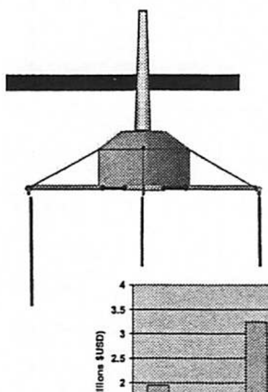


Floating Platform Cost Comparison



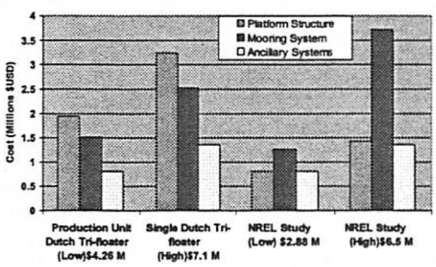
Dutch Tri-floater

Studie narr haalbaarheid van en randvoorwaarden voor drijvende offshore windturbines. ECN, MARIN, Lagerwey the Windmaster, TNO, TUD, MSC, Dec. 2002.



NREL Mono-column TPL Cost Study Concept

- **5-MW Turbine**
- **Steel Buoyancy Tank**
- **Three Radial Arms – 60-m spacing**
- **Vertical moorings**
- **2 tendons per arm**
- **SF=2.0 buoyancy**



Musial, W.D, Butterfield, C.P. and Boone, A.,"Feasibility of Floating Platform Systems For Wind Turbines" Proceedings of AIAA/ASME w\Wind Energy Symposium, AIAA-2004-1007, January, 2004.

NREL Technology Development and Standards Support

- DOE/NREL Phase II Technology Development Subcontracts
  - Targeted Research and Hardware for Offshore – Several contracts expected this year.
- Standards Development
- Support IEC Working Group 3
- Support new initiatives in IEA and IEC.

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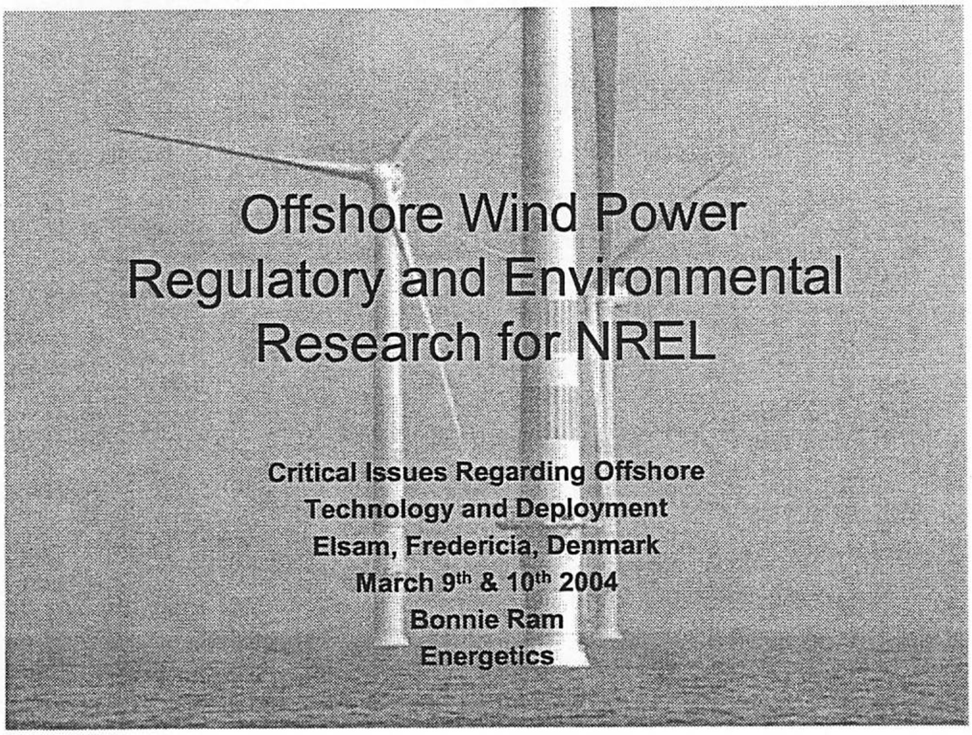


NREL Subcontract
November 2002 to present

- Assist NREL in supporting the Office of Wind and Hydropower Technologies with technical services related to environmental policies and laws associated with offshore wind systems in the U.S. and Europe
- Review existing research and conduct a gap analysis
- Assist in organizing various technical workshops

Results to Date

- Literature review and reference listing
- Federal/state environmental regulations compiled
- European environmental studies identified & analyzed
- Technical Workshops held in 2003
  - NWCC Offshore Stakeholder Dialogue Meeting (July)
  - Boston Technical Tutorial Meeting (September)
  - Deep Water Technologies Workshop (October)
- Tracking new national energy legislation and local permit applications
- Reviewing U.S. land-based studies and guidelines and their application for offshore projects

DOE Public Meeting On Offshore Wind - July 2003

- Over 100 stakeholders
- Presented analysis: Offshore Wind Developments in the U.S. -- Regulations and Jurisdictions
- Identified universe of potential environmental and socio-economic issues
- Recommendation to have technical dialogue with regulators
- Information available on website
  - http://www.nationalwind.org/events/offshore/030701/default.htm

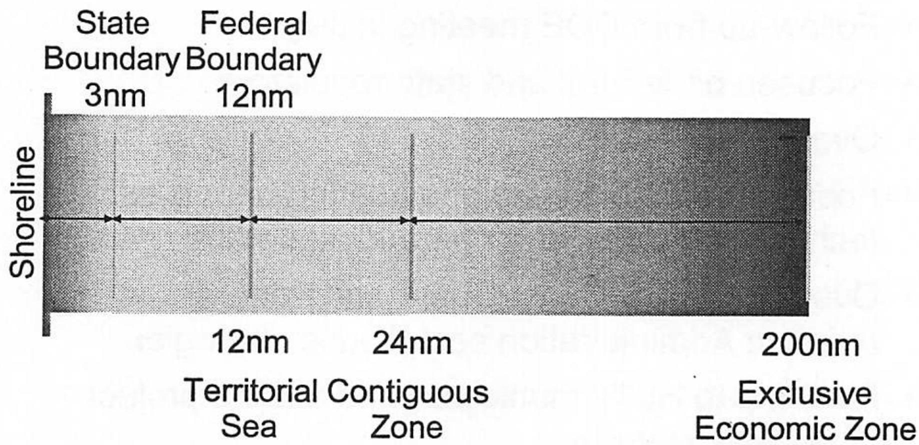
NREL Technical Tutorial in Boston — September 29-30, 2003

- Follow-up from DOE meeting in July
- Focused on federal and state regulators
- Over 65 attendees
- Focus on offshore wind engineering principles, technology status, and operational details
- Overview of US Coast Guard and Federal Aviation Administration compliance strategies
- Field trip to Hull's municipal wind turbine project
  - http://www.hullwind.org

NREL Deep Water Technologies Workshop — October 15-16, 2003

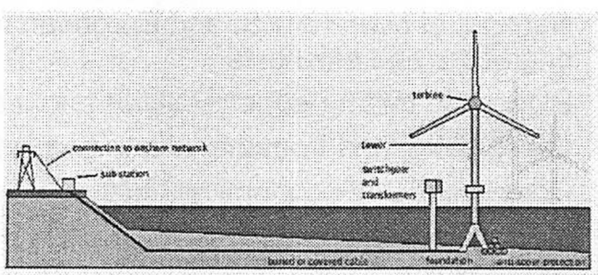
- Network of over 40 U.S. and European wind & oil & gas engineers and scientists
- Discussed cutting-edge research and technologies
- Lessons learned from the oil and gas industry
- Consensus that economical, floating offshore applications are achievable
- Next steps:
  - Identify R&D directions for the U.S. Department of Energy
  - Obtain environmental data needed to characterize operating conditions
  - Develop integrated models to understand system dynamics
  - Consider integrated workshop between engineers and marine scientists
  - http://www.nrel.gov/wind_meetings/offshore_wind/

Ocean Jurisdictions



Not to Scale

Factors Determining Applicable Regulations

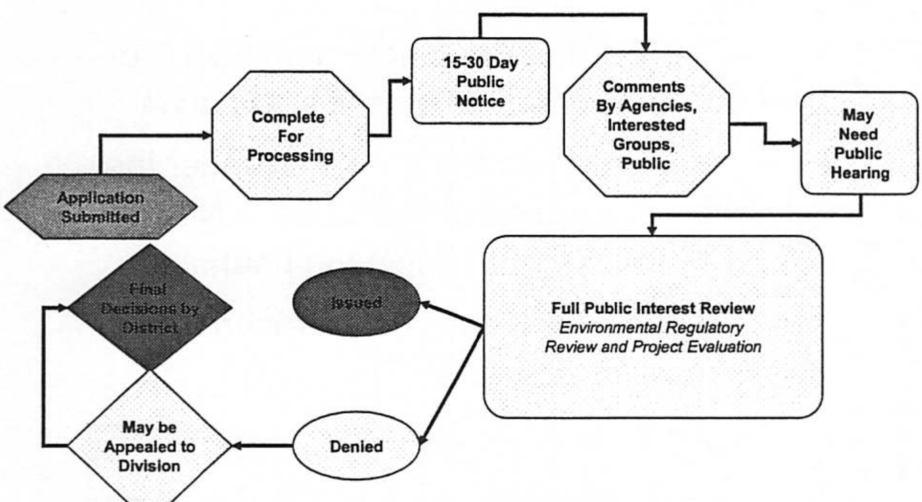


- Project Size, Location and Construction
- State/Federal Ocean Boundaries
- Landfall Grid Connection
- Sensitive Marine/Land Areas
- Avian and Marine Species
- Activities and Uses of Project Area

Selected Federal Regulations

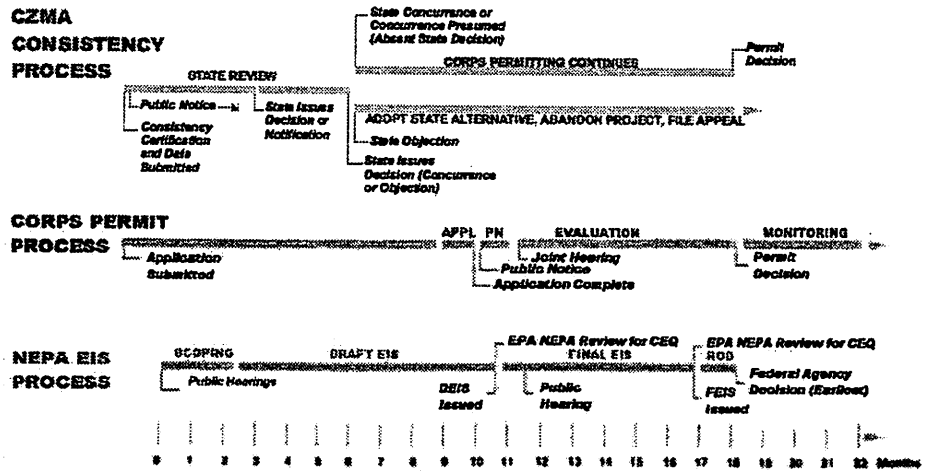
Legislative Authority	Major Program/Permit	Lead Agencies
Rivers And Harbors Act - Section 10	Prohibits the obstruction or alteration of navigable water of the U.S without a permit	U.S. Army Corps of Engineers (District Office)
National Environmental Policy Act (NEPA)	Requires submission of an environmental review for all major federal actions that may significantly affect the quality of the human environment	U.S. Army Corps of Engineers (District) Council on Environmental Quality
Coastal Zone Management Act	Consistency determination with the coastal program of the affected state	NOAA State Coastal Zone Management Agencies
Navigation and Navigable Waters	Navigation aid permit (markings and lighting)	U.S. Coast Guard
Navigational Hazard to Air Traffic	Determination of the safe use of airspace from construction start (lighting)	U.S Federal Aviation Administration (Regional Administrator)

U.S. Army Corps of Engineers Individual Permit Process



Reference: Adapted from USACE presentation, Christine Godfrey

U.S. Army Corp of Engineers Permit and EIS Process



Reference: Adapted from USACE presentation, Karen Adams

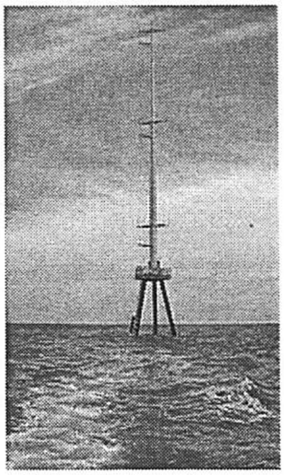
A Significant Objective of the Permit is Public Involvement

- U.S. Army Corp of Engineers authorized to hold public hearings on permit application
- Environmental Impact Statement (under the National Environmental Policy Act – NEPA) process requires public scoping hearings
- EIS requires interagency cooperation and review (local, state, federal)
- Citizen lawsuits

Cape Wind -- Nantucket Sound Massachusetts

- First project in the nation – 468 MW
- 130 - 3.6 MW GE turbines
- About 24 square miles
- Meteorological tower installed in 2003
- Draft environmental impacts statement (EIS) schedule delayed – 3 year process?
- Two lawsuits
  - Ten Taxpayers Citizen Group vs. Cape Wind Associates (8/03)
  - Alliance vs. US Army Corp of Engineers (9/03)
- Extensive public involvement

  http://www.mtpc.org/offshore/index.htm



Long Island Power Authority – Jones Beach

- Feb. 2003 LIPA issued competitive RFP
- Decision expected soon
- 100-150 MW
- LIPA, a municipal utility, is guaranteeing purchase power agreement
- Substation construction subsidized
- Public involvement process
- State political support
- See http://lioffshorewindenergy.org/

What Have We Learned from Cape Wind

- First U.S. project is a result of a market-driven process
  - Developer responsible for the EIS process
  - Negative perception of the use of public resource without a national policy in place
- Multiple jurisdictions for the same marine resource
  - Uncertainties about the scope of environmental analysis needed
- Timeframe for federal permitting and approvals is a minimum of 3 years
- Public involvement & state leadership are central to success (e.g.,LIPA)
- Need for renewable energy in New England is thwarted by "not in my backyard" attitude

What Have We Learned

- Workshop Dialogue
  - Concerns from government agencies & communities because ecological impacts are not understood
  - Uncertainties about best available data & standards
  - Benefits are not well established or communicated
- Institutional issues are dynamic
  - Energy Bill would change jurisdictional control of the outer continental shelf
- Market-driven development requires due diligence
- Lack of national leadership is a serious impediment to development

What Have We Learned From the Europeans

- Governments funding of environmental studies provides valuable data and tested methodologies
  - Horns Rev and Nysted five-year program
  - U.K.'s Strategic Environmental Assessment
- Preliminary conclusions across sites & resources are lacking
- Establishing zones of development is a reasonable approach for U.S. coastal waters
- Viewshed perspectives are still controversial

Future Activities

- Continue analyzing European environmental studies
- Follow-on to 2004 workshops
  - Technical Tutorial for New York regulators after LIPA project awarded
  - Deep water and environmental issues workshop (Sept. 9-10, 2004 in Woods Hole,MA)
- Assist in reviewing the Cape Wind Draft Environmental Impact Statement
- Support the IEA proposed offshore annex

RISØ

IEA expert meeting Skærbæk March 9-10 2004

Standards for structural design of offshore wind turbines and related research

Sten Frandsen
RISØ National Laboratory

RISØ

Standards:

- Design basis for offshore wind turbines – type approval
- Danish standard, **DS472**: revision per 2001
- On its way: **IEC61400-3** (Working Group 03)

RISØ

Content of presentation:

ABOUT THE COMING IEC STANDARD:

– Core of IEC offshore standard

SOME TECHNICAL ISSUES:

– Combination of wind and wave loads

– Base time period for dynamic calculations

– Extreme extrapolation

CONCLUDING REMARKS:

Where do we want to go?

(*)Mere herom

RISØ

Core of IEC offshore standard: IEC61400-**3**
(Safety requirements for offshore wind turbines)

- From Scope: ...This standard is to be used together with other IEC/ISO standards. *"In particular, this standard is fully consistent with, but not duplicating the requirements of IEC 61400-1"*

- "-3" document may be independent or an annex to "-1"

RISØ

Core of IEC offshore standard:
wind turbine classes

Table 1 - Basic parameters for wind turbine classes[1]

Wind Turbine Class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values Specified by the Designer
A	I_{ref} (-)		0,16		
B	I_{ref} (-)		0,14		
C	I_{ref} (-)		0,12		

Table 1 - Basic parameters for wind turbine classes[1]

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B	I_{ref} (-)		0,14		
C	I_{ref} (-)		0,12		

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Core of IEC offshore standard:
Generic wind turbine classes and extent of calculations

- A special offshore wind turbine class?
  No, but:
  - *"The design of the support structure of an offshore wind turbine shall be based on environmental conditions, including the marine conditions, which are representative of the specific site at which the offshore wind turbine will be installed. In general therefore, the* ***foundation and tower of the offshore support structure shall require wind turbine class S design****"*
- How many extra load cases?
  - Including waves: expansion from 20 to 35-40 load cases.
  - In addition ice load cases

Core of IEC offshore standard:
Number of load cases

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"-1" standard 20 have become 35-40 in "-3" draft

Table 2 - Design load cases (The table is based upon MT14(Madsen)102 which is not up to date)

Design situation	DLC	Wind condition		Sea condition	Other conditions	Type of analysis	Partial safety factors
1) Power production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$	...normal...	For extrapolation of extreme events	U	N
	1.2.1	NTM	$V_{in} < V_{hub} < V_{out}$	...normal...	Assumed to exist for 90% of the lifetime	F	•
	1.2.2	STM	$V_{in} < V_{hub} < V_{out}$		Assumed to exist for 10% of the lifetime	F	•
	1.3	ECD	$V_{hub} = V_r - 2$ m/s			U	N
	1.4	NTM	$V_{in} < V_{hub} < V_{out}$	...normal...	External or internal electrical fault	F	•
	1.5	EOG_1	$V_{hub} = V_r$ or V_{out}		External or internal electrical fault	U	N

Core of IEC offshore standard:
Safety factors and extent of description of design methods

RISØ

- How should safety factors be determined for combinations of wind and wave loads and wind and ice loads?
  - Obviously not a problem if the coefficients are identical.
  - If not, a separate calculation which weights the influence of the load contributors.
- Should the standard contain detailed descriptions of design calculations?
  - Present mood in WG03: yes – and maybe not.

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IEC-WG3: Support for the designer

Annex G
(informative)
Wave spectrum formulations

Annex H
(informative)
Appropriate wave theories

Annex I
(informative)
Shallow water hydrodynamics and breaking waves

Annex J
(informative)
Guidance on calculation of hydrodynamic loads

Annex K
(informative)
Sea ice loads

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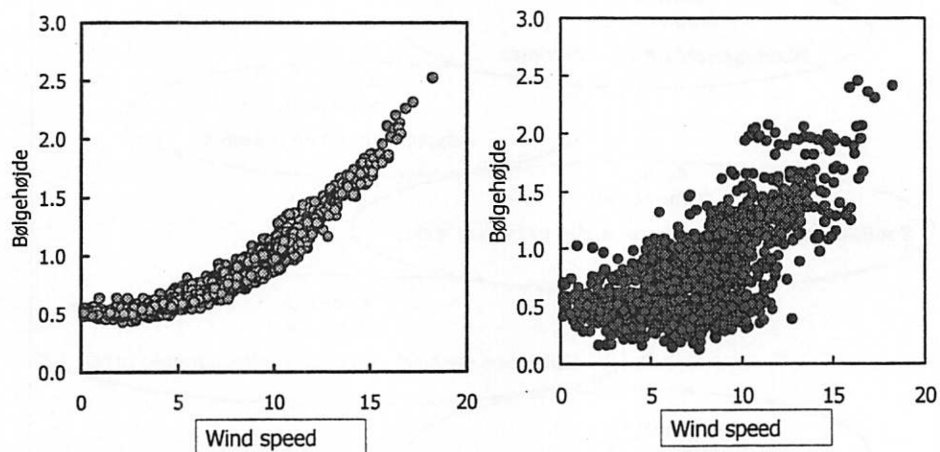
Core of IEC offshore standard:
Struktur beregningsmetoder

- Can "wind turbine" and "support structure" calulations be separated?
  - *"Depending on the dynamic properties of the support structure and the assumed design marine conditions, the designer may in some cases demonstrate by means of an appropriate analysis that the marine environment has a negligible influence on the structural integrity of the rotor – nacelle assembly"*

Combining wave and wind loads



fordeling

$$F(x) = \int\int F(x|U, H_S) f(U, H_S) dU dH_S$$

betinget
fordeling

Waves/wind - 3hours/10min?

- Tradition in wave loading: base period for dynamic calculations: 3h – 1000 waves
  - This because over that period get a stable estimate of $H_S(4 \cdot \sigma_{surface})$, and because a storm last 3(-6) hours
- Tradition in wind loading: base period for dynamic calculations: 10min
  - This because it was thought that there were a spectral gap at approx. 1/600Hz
- A common base period is needed: what should it be?
  - Probably **1hour**

In wind loading: from 10min statistics to gust:

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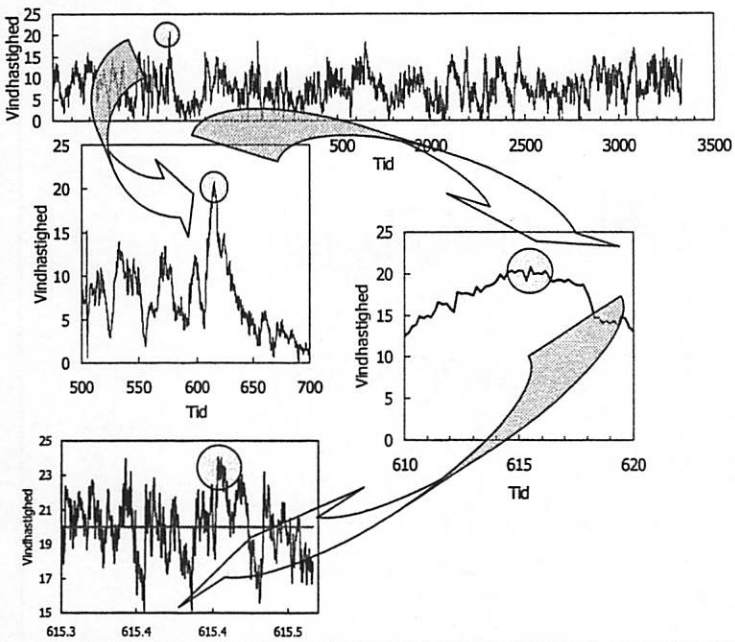
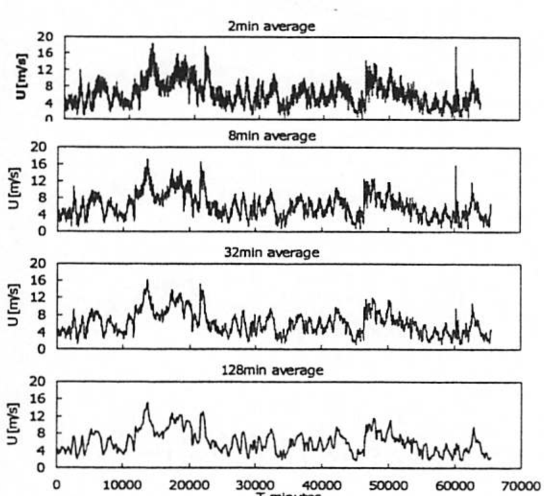


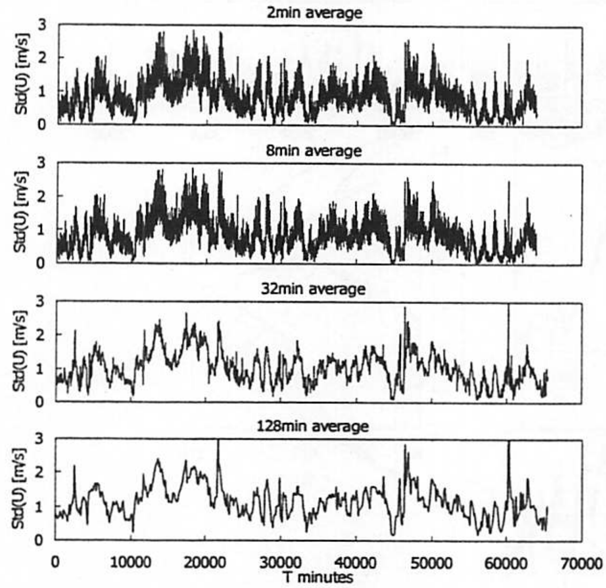
Re-calculation of std(U) from one base-period to another

RISØ

Mean wind speed for different pre-averaging

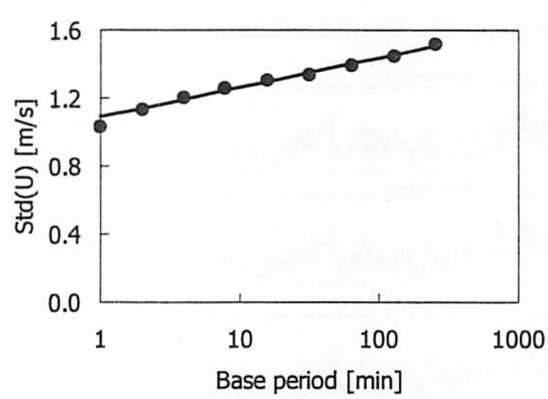


Std(U) for different base-periods



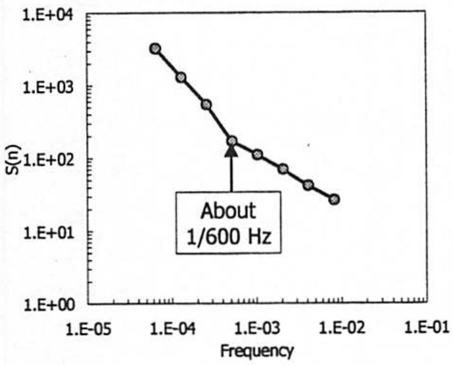
Std(U) as function of period in which it was determined

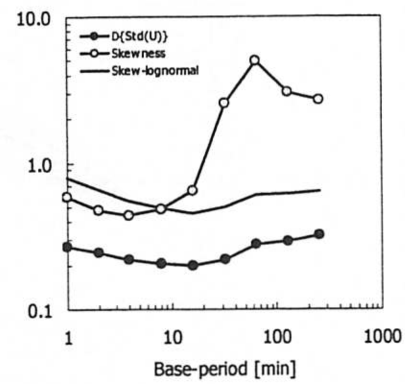
7<U<9 m/s



$$\sigma_u = 0.075 \cdot \ln(T) + 1.087 \approx 0.075(\ln(T) + 15)$$

Interesting statistics:
"Second-order" spectral gap at 1/600- 1/1800 Hz?





Proposition for conversion of std(U) from one base-period to another:

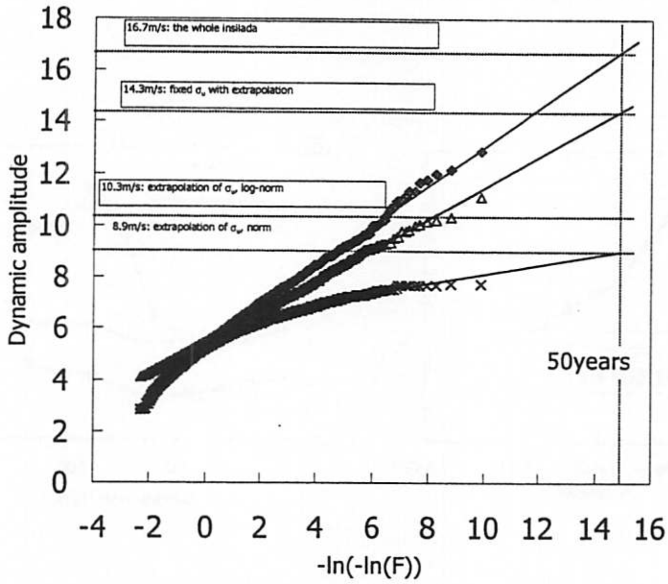
$$\sigma_{new} = \frac{\ln(T_{new}) + 15}{\ln(T_{old}) + 15} \sigma_{old}$$

T in units "minutes"

Upcrossing frequency probably increasing with T

Load extrapolation – more than one way?

RISØ



RISØ

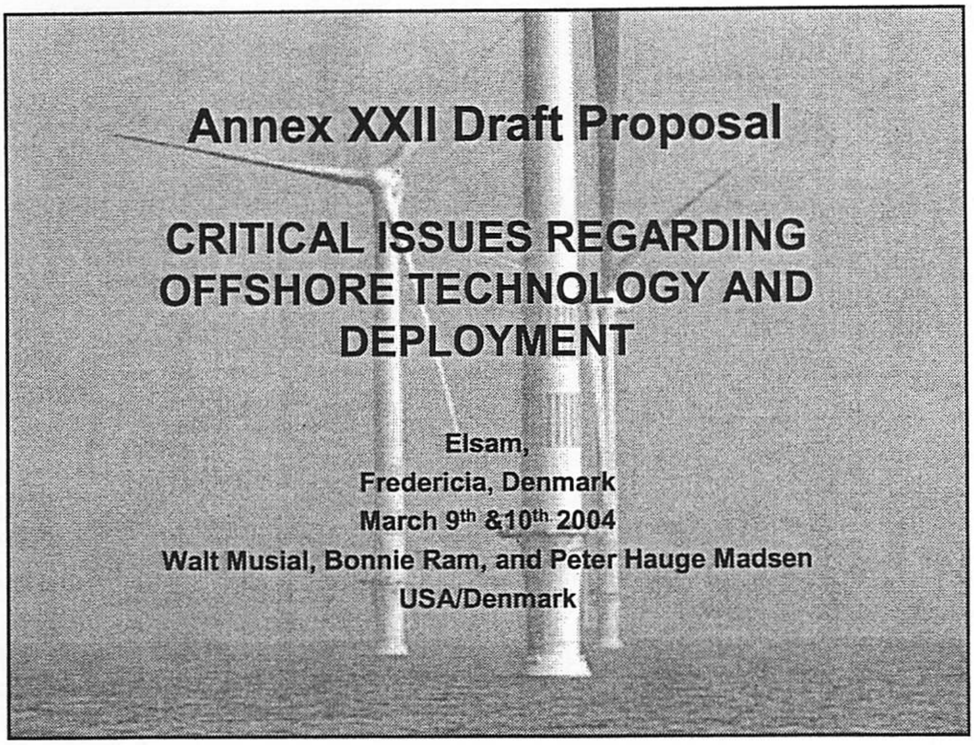
Where do we want to go?

Calculations are getting too complex relative to the inherent general uncertainty

What can be done?

- Slimming number of load cases
  - Individually and in combination these should as well as possible reflect actual loading
  - Reliable methods for reduction of number of simulations should be developed

- Wind climate: large wind farms tend to generate their own wind climate for operational wind speeds
  - Therefore, for wind loads the wind climate may e.g. be described by the thrust coefficient of the wind turbines



Proposed Annex Overview

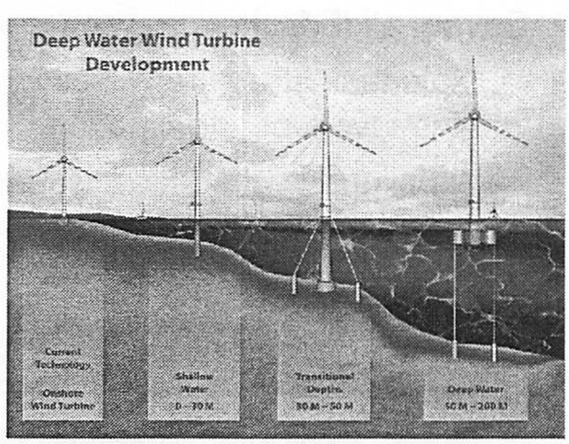
- IEA annex XXII
- Covers all IEA offshore wind energy activities
- Multiple task structure will allow sub-topics at varying levels of participation.
- Tasks aligned with critical issues based on mutual interest and participation.
- Proposed tasks:
  - Task 1 – Experience with current facilities
  - Task 2 - Alternative base structures for deepwater.
  - Task 3 - Ecological issues and regulations
  - Task 4 - ???

PROPOSED SUBTASK 1: OPERATING OFFSHORE WIND FACILITIES AND TECHNOLOGY APPLICATIONS Joint Action Symposium – Exchange on Information and Experience

- Annual Meeting to Exchange Information and Experience
- Possible Topics for Collaboration
  - Layout and array effects
  - External conditions
  - Technology
  - Standards and Certification Research
  - Operation and maintenance
  - Construction and infrastructure
- Possible Outcome: Meeting Proceedings, other reports?

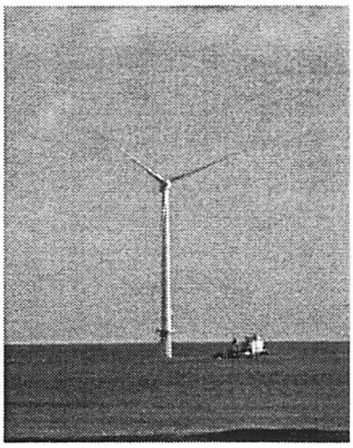
PROPOSED SUBTASK 2: ENABLING RESEARCH - ALTERNATIVE BASE STRUCTURES FOR DEEPWATER OFFSHORE WIND

- Collaborative Long-term Research Focus
- Possible subtopics:
  - Low cost moorings
  - Cost modeling trade-off studies
  - Dynamic modeling
  - Other topics to be determined.
- Possible Outcome:
  - Gap Analysis of R&D Needs
  - Report on Findings



PROPOSED SUBTASK 3: ECOLOGICAL ISSUES AND REGULATIONS

- Baseline data and research methods
- Environmental Impact Assessment experience
  - Site specific effects on marine ecology
  - Methodologies and data from existing studies.
  - Avian and mammal surveys.
  - Post and pre-construction monitoring strategies
- Permitting process
  - Streamlining planning and approval procedures
  - Educating the regulators and facilitating interagency cooperation
- Monitoring of operating wind facilities
- Public involvement and acceptance
- Possible outcome:
  - Common methods
  - Gap analysis
  - Report?



Schedule

• This Meeting: – Critical Issues and Recommendations – Poll national interest	March 04
• Proposal Draft to Topical Meeting #42 participants.	April 04
• Proposal Presentation to Executive Committee	May 04
• Annex ExCo approval	??
• Anticipated Annex duration	5 years

Offshore Critical Issues

- Compile critical issues from topical experts meeting #43.
- Roughly prioritize critical issues > 1,2,3
- Solicit input on sub-tasks based on national interest (informal).
- Rank collaborative interests based on confidential data issues.
  - Are some areas inappropriate due to proprietary data issues?
- Distribute results in spread sheet with minutes.

Discussion

Summary of IEA R&D Wind – 43rd Topical Expert Meeting on

CRITICAL ISSUES REGARDING OFFSHORE TECHNOLOGY AND DEPLOYMENT

March 2004 Elsam, Fredericia, Denmark
Sven-Erik Thor

Background

The market-driven up-scaling and offshore application requires better understanding of a number of issues. In 2003, the worldwide installed capacity of grid-connected wind power exceeds 30GW corresponding to an investment of approximately 30 billion Euro. The global wind energy installed capacity has increased exponentially over a 25 year period and in the process the cost of energy from wind power plants has been reduced by an order of magnitude. In Germany, approximately 5% of electric energy is now produced by wind turbines and in Denmark, the fraction of energy coming from the wind is close to 20%. In most other countries the contribution is less than 1%.

There are several compelling reasons to move the technology offshore, including:

- Higher-quality wind resources (Reduced turbulence and increased wind speed)
- Proximity to loads (Many demand centers are near the coast)
- Increased transmission options
- Potential for reducing land use and aesthetic concerns
- Reduced scaling concerns for transportation and erection

Two larger demonstration wind power plants have already been constructed in Denmark, each with a capacity of 160MW. In all, on a regional basis wind power has developed from being a marginal "alternative" energy source to a quickly maturing mainstream technology. On a global scale, the wind power technology is still in its adolescence and has much growing and maturing in front of it, and it is believed that a sizable fraction of the growth will happen offshore.

Summary

A primary goal of the meeting was to give the participants a good overview of the challenges encountered in offshore applications and to identify areas that needs more R&D attention in the future, "identify white spots". The objectives were summarized as follows:

- Overview of challenges in offshore wind energy
- Summary and assessment of issues
- Identification of critical issues, suitable for an international cooperative R&D effort
- Outline of an IEA annex
- Prioritizing subtasks

The meeting gathered 18 participants, representing Denmark, Finland, the Netherlands, UK, USA. Presentations covered both detailed research presentations and more general descriptions of current situations in Denmark, UK, the US and the Netherlands.

As a part of the introduction to the meeting an inspiring presentation was given on experiences from the Horns Rev wind farm. Lessons learned were summarized as:

- Test and try anything that can be tested or tried before leaving shore
- Train the technicians onshore in stead of offshore
- The weather is "flexible", requiring flexible plans or all work

Notes from final discussion

Reasons for going offshore

The most obvious reason is that the wind resource is usually higher than on land. Other important factors are:

- Proximity to electric loads (demand centres near the coast)
- Increased transmission options
- Potential for reducing land use and aesthetic concerns
- Reduced scaling concerns for transport and erection

Possible R&D areas Offshore wind technology

During the presentations a number of research topics were mentioned:

- Environmental impact of near- and far-shore projects
- Potential conflicts of interest (fishing, defence, oil and gas exploration etc)
- Legal research in offshore ownership in coastal waters, exclusive economic zones etc
- New design, higher tip speeds, less noise concern
- Minimization of O&M downtime
- Systems and components for erection, access and maintenance
- Design of >5 MW systems (incl. Multirotor systems)
- Offshore meteorology, short- and long term forecasting
- Alternative and deep water support structures
- Combined wind and wave loading

The Danish strategy for wind energy research contains the following items:

- Loads and safety
- Monitoring and maintenance
- Support structures, also for more than 15 m water depth
- Total system dynamics modelling, from soil-structure to blade tips
- Environmental impact
- Forecasting
- Regulation and transmission of production
- Integration in energy system

Potential issues:

- Layout and array effects (impact on loads, cost and energy production, mutual shadow effect of large, closely spaced wind farms)
- Specific loads and load combinations (e.g. extreme wind / wave load combinations)
- External conditions (e.g. Instrumentation for site assessment, siting and energy prediction)
- New design drivers offshore (e.g. personnel safety requirements, increased personnel access)
- Reliability and statistical design procedures
- R&D needed to support new requirements on standardization and certification
- Streamlining consent agreement (permitting) and public involvement
- Operation and maintenance
- Innovative approaches to offshore construction and infrastructure
- Economics
- Quantifying Risk assessment
- Deepwater offshore issues (e.g. moorings, floating platform design, stability, power cabling, dynamic stability), see also www.nrel.gov/wind_meetings/offshore_wind/

A number of R&D topics were mentioned in the presentations:

- Condition monitoring system, especially vibration monitoring, [Vestergaard]
- Scour protection or not? "All future efforts is best spent on solutions without scour protection – rocks won't get cheaper, new concepts will", [Zaaijer]
- Simultaneous wind and wave loading on a dynamically sensitive structure must be analysed in an integrated way to take all interactions into account. [Tempel]
- IEA Wind data base needs more data from wave and wind conditions, [Larsen]
- Feedback between wakes and the boundary layer appears to be important for large wind farms but is not incorporated in current models, [Barthelmei]
- There is an urgent need for data from large wind farms, [Barthelmei]
- Coupling between hydrodynamics and wind turbine dynamics, [Peeringa]
- Design of shallow water mooring system, [Peeringa]
- Connection of electricity cables, [Peeringa]
- Risk assessment (ship collision etc), [den Boon]
- From the Dutch horizon ['tHooft]:
  - Dynamic analyses of the Dutch grid - short circuit behaviour and transient stability
  - Dynamic behaviour of large wind farms
  - Short term power fluctuations, normal and storms - Early warning forecast loss of power
  - Influence on conventional power generation - required control reserve and emergency power
  - Study maintenance of power balance - Program Responsibility, load rejection, trade on spot market based on wind forecasting

Regarding International standards Frandsen mentioned that:

Calculations are getting too complex relative to the inherent general uncertainty

What can be done?

- Slimming number of load cases
  - Individually and in combination these should as well as possible reflect actual loading
  - Reliable methods for reduction of number of simulations should be developed
- Wind climate: large wind farms tend to generate their own wind climate for operational wind speeds
  - Therefore, for wind loads the wind climate may e.g. be described by the thrust coefficient of the wind turbines

Priority of R&D Tasks

At the end of the discussion the different R&D topics were grouped in different categories and prioritized as follows. "1" is highest.

Topic/subtask	Priority	Information Exchange	R&D action	Potential country participation
1. Operating offshore wind facilities and technology applications – joint action symposium - exchange of experience	1	1		All
2. Alternative support structures for deep water (30m) wind energy (Deepwater offshore issues moorings, floating platform design, stability, power cabling, dynamic stability)	2	2	1	US, JP?
3. Ecological issues and regulations LCA, decommissioning, consent agreement (permitting) and public involvement	1	1	2	All
Layout and array effects (energy production, mutual shadow effect of large, closely spaced wind farms)	2	1	1	DK, NL, S, UK
Specific loads and load combinations for standardization (e.g. extreme wind / wave load combinations, wake loads)	2	1		All
External conditions (e.g. Instrumentation for site assessment, siting and energy prediction)	1	1	2	S, US, DK
Safe operation offshore (personnel safety requirements, increased personnel access)	2	1		All
Reliability and statistical design procedures – calibration of safety, Risk assessment (see annex 11)	2	1	1	All - NL
Condition monitoring, inspection, reliability, operation and maintenance, forecasting of conditions)	1	1	1	All
Cost development, economic risks, Financing and insurance	2	1	2	All
Electric system integration (dynamic behaviour, controllability and stability, power balance, reserves, see annex 21)	1	1	1	All
Ship collision	2	2		S, NL
Technology, project, operation and decommissioning uncertainties – effect on costs (TEM)	2	1		All
Integrated dynamic modelling af WT/support structure	2		1	DK, NL, UK

New Annex proposal

At the end of the meeting there was a presentation of a proposal for creating an annex dealing with critical issues regarding offshore technology and deployment. The proposal was prepared by Bonnie Ram, Walter Musial and Peter Hauge Madsen, see also presentation #19. The proposal served as basis for a discussion on making a prioritized inventory of challenges going offshore. The discussion resulted in an updated proposal, prepared after the meeting, which is attached at the end of this document. The new draft will be submitted to the next meeting of the IEA R&D Wind Executive Committee in Chester in May.

The objective of the proposal is to:

- lower cost of energy
- reduce uncertainties
- increase value of electricity.

Interesting links

Cape Wind USA www.mtpc.org/offshore/index.htm
Long Island Project USA www.lioffshorewindenergy.org
Baseline measurements in the Netherlands (in Dutch) www.mep-nsw.nl
US websites dealing with challenges offshore
www.nationalwind.org
www.hullwind.org
www.nrel.gov/wind_meetings/offshore_wind/

List of participants

IEA R&D Wind Annex XI Topical Expert Meeting
Critical Issues Regarding offshore Technology and Deployment,
March 9-10, Skærbæk, Denmark

No	NAME	COMPANY	ADDRESS 1	ADRESS 2	ADRESS 3	COUNTRY	CC	PHONE	E-mail
1	Kurt Hansen	Danish Technical University	Fluidmekanik	Rum 218, Byggn 404	DK-2800 Lyngby	Denmark	45	45254318	ksh@mek.dtu.dk
2	Peggy Friis	Elsam	Overgade 45	7000 Fredericia		Denmark	45	5139 4612	pf@elsam.com
3	Charles Nielsen	Elsam	Overgade 45	7000 Fredericia		Denmark	45	7622 2406	chn@elsam.com
4	Søren Vestergaard	Elsam Engineering	Overgade 45	7000 Fredericia		Denmark			sve@elsam-eng.dk
5	Rebecca Barthelmie	Risø National Laboratory	Department of Wind Energy	4000 Roskilde		Denmark	45	46775020	r.barthelmie@risoe.dk
6	Sten Frandsen	Risø National Laboratory	Department of Wind Energy	4000 Roskilde		Denmark	45	46775072	Sten.Frandsen@risoe.dk
7	Gunner Larsen	Risø National Laboratory	Department of Wind Energy	4000 Roskilde		Denmark	45	46775020	Gunner.Larsen@risoe.dk
8	Peter Hauge Madsen	RISØ National Laboratory	Wind Energy Department, Building 118	P.O.Box 49	DK-4000 Roskilde	Denmark	45	4677 5011	peter.hauge@risoe.dk
9	Esa Holttinen	Managing Director, Windarc	Tehtaankatu 10,	P.O. Box 56	FIN-38701 Kankaanpää	Finland	358	405 063 632	esa.holttinen@windarc.com
10	Sven-Erik Thor	FOI, Aeronautics - FFA	Dept. of Windenergy	172 90 Stockholm		Sweden	46	8 55 50 4370	trs@foi.se
11	Johan Peeringa	ECN	Unit Wind Energy	1755ZG PETTEN		the Netherlands	31	224 564 189	peeringa@ecn.nl
12	Henk den Boon	E-Connection Project B.V.	P.O. Box 101	3980 CC Bunnik		the Netherlands	31	30 659 8000	den.boon@e-connection.nl
13	Henk Kouwenhoven	Noordzeewind/NUON	P.O. Box 413	8901 BE	Leeuwarden	the Netherlands	31	58 267 62 62	henk.kouwenhoven@nuon.com
14	Jaap 't Hooft	Novem	P.O. Box 8242	3503 Utrecht		the Netherlands	31	30 2393 468	j.t.hooft@novem.nl
15	Matt Haag	Shell Wind Energy	P.O Box 3800	10308 N Amsterdam		the Netherlands	31	20630 3585	m.haag@shell.com
16	Michiel Zaaijer	TU Delft	TU Delft - Wind Energy Department	Stevinweg 1	2628 CN Delft	the Netherlands	31	152 786 426	M.B.Zaaijer@CiTG.TUDelft.nl
17	Jan van der Tempel	TU Delft	TU Delft - Wind Energy Department	Stevinweg 1	2628 CN Delft	the Netherlands			j.vandertempel@offshore.tudelft.nl
18	Colin Morgan	Garrad Hassan & Partners Ltd.	St Vincents Works	Silverthorne Lane	Bristol BS2 0QD	UK	44	117 972 9939	morgan@garradhassan.com
19	Bonnie Ram	Energetics	901 D Street S.W. Suite 100	Washington DC 20024		USA	1	202-406-4112	bram@energetics.com
20	Walt Musial	National Renewable Energy Lab.	1617 Cole Boulevard	Golden	CO 80401	USA	1	303-384-6956	walter_musial@nrel.gov

Henk den Boon

Rebecca Barthelmie

Peggy Friis

Henk Kouwenhoven

Bonnie Ram

Gunner Larsen

Colin Morgan

Jan van der Tempel

Matt Haag

Michiel Zaaijer

Jaap 't Hooft

Sven-Erik Thor

Esa Holttinen

Johan Peeringa

Sten Frandsen

Peter Hauge Madsen

Kurt Hansen

Missing
Charles Nielsen
Sören Vestergård
Walt Musial

IEA Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems

PROPOSED
Annex XXII

OFFSHORE WIND ENERGY TECHNOLOGY AND DEPLOYMENT

DRAFT

23 April 2004

Walt Musial, Bonnie Ram, and Peter Hauge Madsen

1. BACKGROUND

In 2003, the worldwide installed capacity of grid-connected wind power exceeded 40GW, corresponding to an investment of approximately 40 billion Euro. The global wind energy installed capacity has increased exponentially over a 25-year period, and in the process the cost of energy from wind power plants has been reduced by an order of magnitude. In Germany, approximately 5% of electric energy is now produced by wind turbines and in Denmark; the fraction of energy coming from the wind is close to 20%. In most other countries, wind contributes less than 1%, but current growth suggests that wind will soon become an important part of the energy mix on a global scale. Most of the development thus far has taken place on land-based sites, but future development will involve an increasing offshore fraction. Two larger offshore demonstration wind power plants have already been constructed in Denmark, each with a capacity of 160MW. At the end of 2003, the total installed capacity of offshore wind energy was 529 MW.

Installing wind turbines offshore has a number of advantages compared to onshore locations. The growth of onshore turbines is constrained by transportation and erection limits, as well as the undesirable visual appearance of massive turbines in populated areas. At a sufficient distance from the coast, visual intrusion is minimized and wind turbines can be larger, thus increasing the overall installed capacity per unit area. Transportation and erection problems are also mitigated offshore where the capacities of marine shipping and handling equipment still exceed the installation requirements for multi-megawatt wind turbines. Similarly, less attention needs to be devoted to reduce noise emissions offshore, which entails additional costs for onshore wind turbines. Also, the wind tends to blow faster and more uniform at sea than on land. A higher, steadier wind means more electricity generated per square metre of swept rotor area. While onshore turbines are often located in more remote areas, where the electricity must be transmitted by relatively long power lines to densely populated regions, offshore turbines can be located in close proximity to high-value urban load centers thus simplifying transmission issues.

On the negative side of offshore development, investment costs are higher and accessibility to the turbines is more difficult, resulting in higher maintenance costs. Also, environmental conditions at sea are more severe: more corrosion due to salt water and additional loads from waves and ice. And obviously, offshore construction is more complicated.

Despite the difficulties of offshore development, it holds great promise for expanding wind generation capacity. In Europe, the amount of space available for offshore wind turbines is many times larger than onshore. The potential for wind energy is therefore also considerably greater. As an example, for the Netherlands there is room for roughly 3 GW of wind power based on the area available outside the 12-mile zone (about 22 km) with a water depth of less than 20 metres. The North Sea, bordering the Netherlands, has the advantage of a relatively shallow sea; nearly the entire Netherlands Exclusive Economic Zone (delimitation of the Netherlands Continental Shelf) is less than 50 metres deep. The Netherlands shares this advantage with countries such as Belgium, Denmark, the United Kingdom, and Germany. Figure 1 shows the cumulative installed offshore capacity to date.

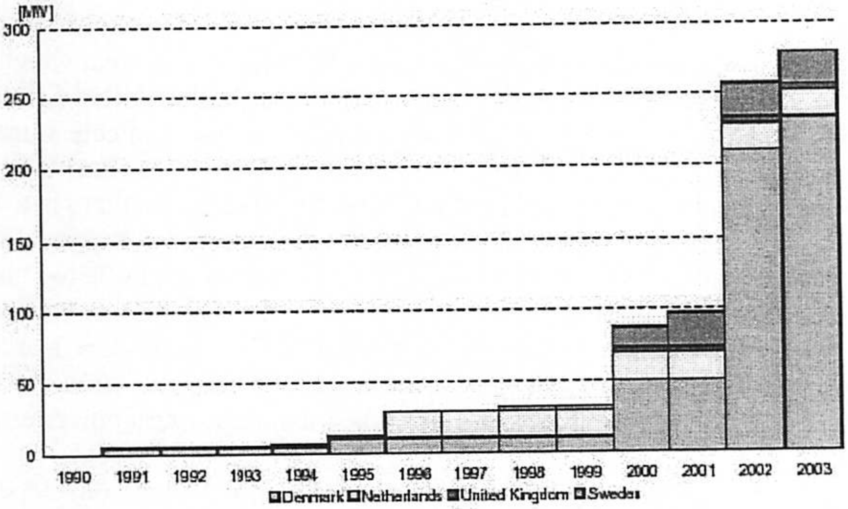


Figure 1 - Realised offshore wind power through February 2003

Those nations with long coastlines but without shallow seas within their continental shelf will be interested in exploring technology relating to installing wind turbines in deeper water. EU countries such as Ireland, Spain, Italy, and Portugal have a relatively small sea area with water depths less than 30 metres and will need to consider deep-water locations for wind turbines. Figure 2 shows that outside the EU, China and the U.S. have the highest potential, followed by Brazil and Japan.

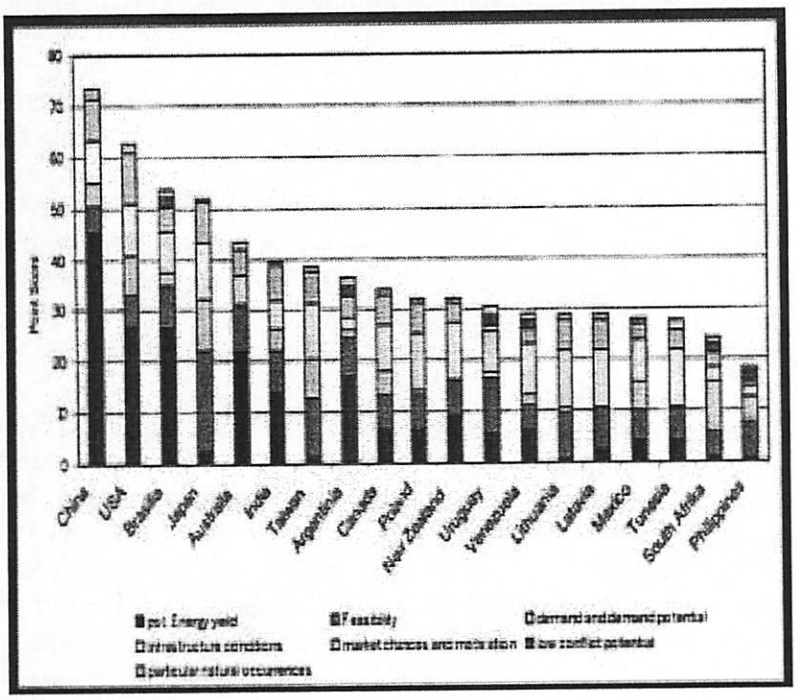


Figure 2 – Offshore Potential for Non-EU Countries

Source: Siegfriedsen, Lehnhoff, & Prehn aerodyn Engineering, GmbH, Conference Proceedings of Offshore Wind Energy in the Mediterranean and other European Seas, Naples, Italy April 10-12, 2003.

In October 2003, a deep-water technologies workshop was held in Washington, D.C. with participants from the US and Europe, see: http://www.nrel.gov/wind_meetings/offshore_wind/. From this workshop, it was evident that there is a keen interest in this area, which compliments the recent commercial progress of shallow water installations. In the United States, preliminary estimates of wind resources offshore for recently mapped regions indicate immense areas of Class 5, 6, and some Class 7 winds at distances from 5 nautical miles (nm) offshore to 50 nm offshore. These preliminary estimates indicate that for the United States there is over 800 GW of offshore wind resource in deeper waters (30-m to 100-m and greater) compared to less than 100 GW in shallow water (0-m to 30-m), and some shallow water sites might be too close to land for public acceptance. Opening these vast windy areas of deep-water ocean for electric power generation will require new technologies to be developed. In the US onshore markets, where the burden of electric transmission is great, the development of offshore wind would reduce the burden of supplying electricity to coastal cities from the inland transmission system.

Along with the technical challenges relating to technology applications, developers of offshore wind projects are required to analyze environmental conditions of the specific site location. The range of analyses involves submitting permitting applications, conducting baseline data collection, preparing an environmental impact assessment (European Directive for licensing and the US federal requirement for permitting), and conducting pre- and post construction monitoring studies. The methodologies employed to carry out these analyses are varied both in scope, timeframe and funding depending on the national regulatory requirements and location. At this stage of offshore development, there are dozens of environmental studies (possibly upwards of 120 studies) available that have been prepared by both government and private consultants. For example, there are some preliminary conclusions from the extensive work completed in Denmark for the Horns Rev, Nysted and Middlegrunden offshore wind parks. The UK has prepared a Strategic Environmental Assessment designating zones of potential development in three areas of the country and findings are expected soon from the Germanischer-Lloyd research platform in the North Sea. Participants in the IEA Topical Experts Meeting #40 in Husum, Germany (September 23-24, 2002) on "Environmental Issues of Offshore Wind Farms" discussed the possibilities of a future role for the IEA and provided input to the European Commission's initiative Concerted action for Offshore wind energy Deployment (COD). COD has prepared several work packages focusing on establishing a database of environmental baseline data, regulatory analyses, and grid integration issues. The objectives of COD may compliment the proposed environmental subtask proposed below.

There is a recognized need to compile credible ecological data across offshore sites and explore how the existing, site-specific data can be disseminated to facilitate streamlined planning and approvals in other countries and/or within regions (regional marine boundaries). Clearly, environmental analyses will become more important to the offshore wind industry as the technology matures and greater numbers of deployments are proposed. In addition to needing a better understanding of environmental effects of offshore facilities in different ecological systems, permitting and monitoring studies will have cost and schedule impacts as well as influence public acceptance.

This annex will give the participants an overview of the technical and environmental assessment challenges encountered in offshore applications and help them to understand the areas of further R&D needed.

2. OBJECTIVES

The objectives of this annex are:

a) To gather and exchange information on R&D topics of common interest relating to wind turbine facilities operating in offshore environments in order to reduce costs and uncertainties.
b) To propose joint research tasks among interested members based upon the critical issues to offshore wind development identified at the Technical Experts Meeting # 43 (see description in Section 3).
c) To share information on the ecological effects of placing wind turbines in different marine environments and identify R&D gaps in the existing areas of work.
d) To explore and share information on alternative technology applications relevant to wind turbines in deeper offshore sites (including floating platforms).
e) Through mutual exchange of ideas, perform an R&D gap analysis, identifying the deficiencies between the established offshore knowledge base and what is required for a mature offshore wind industry in both shallow and deep water.

3. MEANS TO ACHIEVE OBJECTIVES WITH PROPOSED SUBTASKS

This annex is comprised of two subtasks with dual operating agents, one for each subtask. The first subtask will cover an exchange of information and execution of collaborative research targeted in critical technical areas identified during discussions that took place at Technical Experts Meeting #43, "Critical Issues Regarding Offshore Technology and Deployment, " held in Fredericia, Denmark on March 9-10, 2004 (hereafter referred to as the Fredericia TEM # 43). These top-ranked areas, selected from a larger list of potential technical areas, share a high degree of mutual interest among the participants at the meeting, as well the potential to conduct collaborative R&D with a minimal amount of intellectual property concerns. This annex will draw primarily upon experience from shallow water (less than 30-m water depth) wind projects, both planned and operating. Other research topics can be added depending on the interest of the participants (For a complete list of the critical issues identified at Fredericia TEM # 43, please see Appendix 1).

The second subtask will be primarily focused on issues pertaining to deployment of wind turbine in water depths greater than 30 m. Primarily, this will include support structures that deviate from the present monopile technology. Because many European countries currently involved with offshore development have abundant shallow water sites, participation in this subtask may be limited to countries with a scarcity of shallow water sites.

SUBTASK 1
OFFSHORE WIND – EXPERIENCE WITH CRITICAL DEPLOYMENT ISSUES

Current experience with offshore wind turbine installations is providing valuable technical information that will aid future offshore wind developments. In general, many wind installations face the same technical issues, but variability in the local conditions for each individual wind power project can add a high degree of uncertainty. This variability, which includes a wide range of issues, may influence the success of a particular project. To accelerate the successful proliferation of offshore wind worldwide, timely exchange information and lessons learned from existing offshore facilities will be essential. This mutual exchange will lead to a better understanding of offshore siting and design requirements. Moreover, an objective for sharing information is to perform an R&D gap analysis, identifying the deficiencies between the established offshore knowledge base and what is required for a mature offshore wind industry in both shallow and deep water. Ultimately the annex would focus on reducing the costs and uncertainties of offshore wind facilities.

Year one of this annex the participants will exchange information on the critical issues identified during the Fredericia TEM #43 and then narrow down the number of topics listed under the Research Areas below. One meeting for each research area will be held in the first year of the annex and proceedings will be published from these working groups. (The Operating Agent may decide to combine two or more Research Areas into a single meeting for convenience.) R&D areas of common interest, agreed upon by member countries, will be selected for further investigation in year two of the annex.

Below are the four critical issues ranked as priorities for either R&D or information exchanges from the Fredericia TEM #43. The "suggested areas of collaboration" are potential R&D projects that could be pursued by member countries with a common interest. Subtask 1 is not limited to these research areas, however, as new areas can be added with the willing participation of two or more member countries.

Research Area #1 - External Conditions

Suggested areas of collaboration:

- Exchange wind resource data and wind maps specific to regions with high potential for wind development.
- Share databases for marine buoys pertaining to long-term sea-state and MET-Ocean data.
- Technical exchange of wave loading methods and validation experience of wave loading on wind turbine structures.
- Share experience with long-term measurement techniques and instrumentation at offshore stations.

Research Area #2 - Operation and Maintenance

Suggested areas of collaboration:

- Exchange experience with offshore wind turbine design practices benefiting O&M
- Compare experience with remote condition monitoring sensors and SCADA integration facilitating wind turbine O&M.
- Share service and inspection experience for O&M
- Share safety and reliability data to help validate codes and standards.
- Exchange technical experience with offshore forecasting to predict wind plant output.
- Exchange data on human factors related to offshore wind installation to ensure safe working environments.

Research Area #3 - Ecological Issues and Regulations [1]

Suggested areas of collaboration:

- Baseline data and research methods

[1] The first four bullets are from the IEA Technical Experts Meeting # 40 in Husum, September 2002.

    - Develop methods to share baseline data and research methods for pre- and post-construction studies
- Impacts on the environment (assessment criteria)
    - Experience and application of Environmental Impact Assessments
        - Summarize preliminary conclusions from environmental impact assessments among nations that have offshore facilities (this area is similar to one of the objectives of Concerted action for Offshore wind energy Deployment [COD]. This annex will collaborate with these activities whenever appropriate).
    - Potential cumulative effects to the marine ecology
    - Comparative methodologies and preliminary conclusions from avian and mammal surveys
- Permitting process
    - Streamlining planning and approval procedures
    - Educating the regulators and facilitating interagency cooperation
- Pre- and post-construction monitoring of operating wind facilities
- Public (stakeholder) involvement and acceptance
- Decommissioning processes and procedures

Research Area #4 - Electric system integration

Suggested areas of collaboration:

- Compare local data on grid dynamic behaviour and controllability.
- Exchange data on grid stability and fault requirements to develop reasonable performance standards.
- Exchange experience on wind plant power balance on the grid.
- Reserves, see Annex XXI

SUBTASK 2
OFFSHORE WIND – TECHNICAL RESEARCH FOR DEEPER WATER (Greater Than 30m)

All of the significant experience with offshore wind turbine foundations and support structures has been with either monopiles or gravity based foundations in water depths less than 30-metres. Some member countries are interested in alternative technology applications that will allow turbines to placed in water depths greater than 30 metres because they do not have abundant sites with shallow water (e.g. Japan, Italy, Spain, Ireland, Portugal, UK, and the USA), and some countries may be interested in deeper sites to mitigate potential visual impacts from the coastlines. To successfully deploy wind turbines in these depths, alternative fixed-bottom support structures or floating platforms may be necessary. There is no significant offshore wind industry experience with floating platforms yet. The oil and gas industries, however, have deployed thousands of floating oil-drilling platforms in depths up to 1-kilometer. Drawing from this experience, the wind industry can develop floating platforms by building on these offshore technologies. Some of the proposed R&D work that may be considered for alternative platforms and structures are:

- Development of low cost anchoring and moorings systems suitable for offshore wind installations in varying water depths.
- Optimization studies to determine lowest-cost options for floating platforms.

- Coupled platform dynamic modeling – understanding research requirements.
- Exchange data on manufacturing and materials benefits arising from floating platform requirements.
- Share experience and technical data pertaining to marine ecology, regulatory requirements, and permits in deep water and installations far from shore.

4. RESULTS EXPECTED

The results of the Tasks will be:

(a) Collect and distribute information related to offshore wind technology applications directed primarily in the four Research Areas pertaining to external conditions, operation and maintenance, ecological studies, and grid integration. Proceedings for each technical area will be published in a report and presented to the Executive Committee. In addition, the results will be presented at various national and international conferences.
(b) Innovative research exchange on alternative platforms and structures for turbine system optimization for deeper water applications, particularly foundations and support structures. This information may include code development and validation, platform cost tradeoff studies, deep-water ecological studies, or resource maps.

5. TIME SCHEDULE

The Annex will enter into force on ____________and shall continue for a period of three years.

The Annex may be extended by either subtask for such additional periods as may be determined by two or more participants, acting in the Executive Committee and taking into account any recommendation of the Agency's Committee on Energy Research and Technology (CERT) concerning the term of the Annex. Extensions shall thereafter only apply to those Participants

6. OBLIGATIONS AND RESPONSIBILIITES OF PARTICIPANTS

(TO BE DETERMINED)

7. SPECIFIC RESPONSIBILITIES OF THE OPERATING AGENT

(a) In addition to the responsibilities enumerated in Article 4 of the Agreement, the Co-Operating Agents shall be responsible for the performance of their subtask and will report to the Executive Committee.
(b) After one year of entry into force of the Annex, the Operating Agents in co-operation with the other Participants shall propose and submit for approval by the Executive Committee a detailed Program of Work and Budget for the Subtasks.
(c) The Operating Agent shall integrate all results of their Subtask into a final report and an executive summary and distribute the reports and supporting documentation to each participant.

8. FUNDING/ EXPENSES OF THE OPERATING AGENT

This Annex will operate without a common fund or a work plan for the first year.

Proposed funding obligations for the first year: The host country of the first technical exchange on the Research Areas will provide the logistics funding (without travel) for the member countries participating. All costs for this Annex for year one will be "in-kind" costs. Those R&D projects identified for further investigation will be covered by the overall Operating Agent of the Subtask and member countries choosing to participate.

After year one, a common fund for each of the Subtasks and R&D areas of common interest will be agreed upon by interested members. Thereafter a detailed Program of Work and Budget will be submitted for each subtask.

The total costs of the Operating Agent (s) for co-ordination, management and reporting will be _____ over three years and may not exceed such level except with the unanimous agreement of the Participants, acting in the Executive Committee.

Expenses of the Operating Agent (s)		
Salaries		
Travel	Meetings	
Expenditures	Information, publication	
Total		

9. SPECIFIC RESPONSIBILITIES OF THE PARTICIPANTS

In addition to the obligations enumerated in Article 7 of the Agreement:

(a) Each Participant shall bear its own cost for the scientific work, including travel expenses;
(b) The host country shall bear the costs of workshops and meetings of experts;
(c) The total costs of the Operating Agent shall be borne jointly and in equal shares by the Participants (in year 2);
(d) Each Participant shall transfer to the Operating Agent its annual share of the costs in accordance with a time schedule to be determined by the Participants, acting in the Executive Committee (in year 2);
(e) Each Participant shall collect and submit national statistics and other relevant information;
(f) Each Participant shall submit information from monitored installations, as available;
(g) Each Participant shall account for adapted design being used, as available.
(h) Each Participant shall bear its own costs related to monitoring and collecting data from wind turbines in operation, including background and foreground costs.
(i) In addition the individual Participants will carry out the following tasks:

COUNTRY PARTICIPATION TO BE DETERMINED AT THE IEA WIND AGREEMENT ExCo Meeting in Chester, UK, May 2004.

10. PROPOSED OPERATING AGENTS

This annex will have dual operating agents corresponding to each of the two subtasks.

SUBTASK 1
OFFSHORE WIND – EXPERIENCE WITH CRITICAL DEPLOYMENT ISSUES
(proposed) Operating Agent – Denmark

SUBTASK 2
OFFSHORE WIND – TECHNICAL RESEARCH FOR DEEPER WATER (> 30m)
(proposed) Operating Agent – USA

11. LEGAL ISSUES OF NEW PARTICIPANTS

Any Contracting Party may, with the agreement of and under conditions determined by the Executive Committee, acting by unanimity, become a Participant in this Task.

12. INFORMATION AND INTELLECTUAL PROPERTY

(a) **Executive Committee's Powers.** The publication, distribution, handling, protection and ownership of information and intellectual property arising from activities conducted under his Annex, and rules and procedures related thereto shall be determined by the Executive Committee, acting by unanimity, in conformity with the Agreement.

(b) **Right to Publish.** Subject only to copyright restrictions, the Annex Participants shall have the right to publish all information provided to or arising from this Task except proprietary information.

(c) **Proprietary Information.** The Operating Agent and the Annex Participants shall take all necessary measures in accordance with this paragraph, the laws of their respective countries and international law to protect proprietary information provided to or arising from the Task. For the purposes of this Annex, proprietary information shall mean information of a confidential nature, such as trade secrets and know-how (for example computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) which is appropriately marked, provided such information:

(1) Is not generally known or publicly available from other sources;

(2) Has not previously been made available by the owner to others without obligation concerning its confidentiality; and

(3) Is not already in the possession of the recipient Participant without obligation concerning its confidentiality. It shall be the responsibility of each Participant supplying proprietary information and of the Operating Agent for arising proprietary information, to identify the information as such and to ensure that it is appropriately marked.

(d) **Use of Confidential Information.** If a Participant has access to confidential information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent but shall not become part of reports or other documentation, nor be communicated to the other Participants except as may be agreed between the Operating Agent and the Participant that supplies such information.

(e) **Acquisition of Information for the Task.** Each Participant shall inform the other Participants and the Operating Agent of the existence of information that can be of value for the Task, but which is not freely available, and the Participant shall endeavour to make the information available to the Task under reasonable conditions.

(f) **Reports on Work Performed under the Task.** Each Participant and the Operating Agent shall provide reports on all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information, to the other Participants. Reports summarizing the work performed and the results thereof shall be prepared by the Operating Agent and forwarded to the Executive Committee.

(g) **Arising Inventions.** Inventions made or conceived in the course of or under the Task (arising inventions) shall be identified promptly and reported to the Operating Agent. Information regarding inventions on which patent protection is to be obtained shall not be published or publicly disclosed by the Operating Agent or the Participants until a patent application has been filed in any of the countries of the Participants, provided, however, that this restriction on publication or disclosure shall not extend beyond six months from the date of reporting the invention. It shall be the responsibility of the Operating Agent to appropriately mark Task reports that disclose inventions that have not been appropriately protected by the filing of a patent application.

(h) **Licensing of Arising Patents.** Each Participant shall have the sole right to license its government and nationals of its country designated by it to use patents and patent applications arising from the Task in its country, and the Participants shall notify the other Participants of the terms of such licenses. Royalties obtained by such licensing shall be the property of the Participant.

(i) Copyright. The Operating Agent may take appropriate measures necessary to protect copyrightable material generated under the Task. Copyrights obtained shall be held for the benefit of the Annex Participants, provided however, that the Annex Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee, acting by unanimity.

(j) **Inventors and Authors.** Each Annex Participant will, without prejudice to any rights of inventors or authors under its national laws, take necessary steps to provide the co-operation from its inventors and authors required to carry out the provisions of this paragraph. Each Annex Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the law of its country.

13. PARTICIPANTS

The Contracting Parties that are participants in this Annex will be determined later.

Appendix 1. Topics identified for further work at IEA Wind R&D TEM # 43

Topic/subtask	Priority	Info. Exchange	R&D action	Potential country participation
1. Operating offshore wind facilities and technology applications – joint action symposium - exchange of experience	1	1		All
2. Alternative support structures for deep water (30m) wind energy (Deepwater offshore issues moorings, floating platform design, stability, power cabling, dynamic stability)	2	2	1	US, JP?
3. Ecological issues and regulations LCA, decommissioning, consent agreement (permitting) and public involvement	1	1	2	All
4. Layout and array effects (energy production, mutual shadow effect of large, closely spaced wind farms)	2	1	1	DK, NL, S, UK
5. Specific loads and load combinations for standardization (e.g. extreme wind / wave load combinations, wake loads)	2	1		All
6. External conditions (e.g. Instrumentation for site assessment, siting and energy prediction)	1	1	2	S, US, DK
7. Safe operation offshore (personnel safety requirements, increased personnel access)	2	1		All
8. Reliability and statistical design procedures – calibration of safety, Risk assessment (see annex 11)	2	1	1	All - NL
9. Condition monitoring, inspection, reliability, operation and maintenance, forecasting of conditions)	1	1	1	All
10. Cost development, economic risks, Financing and insurance	2	1	2	All
11. Electric system integration (dynamic behaviour, controllability and stability, power balance, reserves, see annex 21)	1	1	1	All
12. Ship collision	2	2		S, NL
13. Technology, project, operation and decommissioning uncertainties – effect on costs (TEM)	2	1		All
14. Integrated dynamic modeling of WT/support structure	2		1	DK, NL, UK