Scour Protection / Soil Mechanics

Wind farms will typically be placed on shallow reefs or offshore dunes. This keeps the foundation costs down and protects the wind farm from the ship traffic. Reefs or dunes, however, tend to shift position. This means that special scour protections capable of follow-ing the changing seabed must be installed. LICENGINEERING A/S has in the last decade developed protec-tion schemes for the offshore industry in environments with changing sea-bottoms.


Ship impact and scour protection, Eastern Bridge, Great Belt.

Offshore Measurements of Hydrodynamic Forces

LICENGINEERING has, for the offshore industry, conducted a large number of tests both in the laboratory and in the ocean in order to determine hydrodynamic forces from waves and currents. Especially the dynamic response has been studied. The measurements have been the basis for the development of analytical methods and computer programs.


Underwater Acoustic Sonar. Waves and turbulernce.

Ship Impact, Ice Forces, Boat Landing


Boat landing and ice cone for a navigational light in the Great Belt.

For maintenance of offshore wind turbines vessels will have to be moored close to or at the mono-pile foundation. In environments with strong waves and currents this warrants relatively large vessels. These vessel may either accidentally hit the foundation or be pressed up against the boat landing by wave actions. Further, there may be vessels from the normal traffic which goes astray and hits the foundation. Analysis of these scenarios leads to special designs of the boat landing, special maneuver constraints for the vessels and plans for naviga-tional light(s) in the case of shipping channel(s). LICENGINEERING A/S has executed several projects of this type for the Offshore Industry and Navigational Authorities.

Projects

OFFSHORE WIND FARM

LICENGINEERING A/S has contributed with expertise to the development, planning, and design of the following either completed or planned offshore wind farms:

- Tunø Knob (Denmark)
- Blyth (United Kingdom)
- Middelgrunden (Denmark)
- Scroby Sands (United Kingdom)

SCOUR PROTECTION

LICENGINEERING A/S has designed scour protections or made repair schemes of scour protections for the following clients:

- Mærsk Olie og Gas AS
- Statoil
- Dangas
- Great Belt Fixed Link
- Øresund Fixed Link

Who is LICENGINEERING?

LICENGINEERING A/S is an engineering company specialized in fluid and structural dynamics, subsea-, soil-, and marine engineering, and under-water acoustics. It delivers specialized services comprising analyses, design, project supervision, and project admini-stration. Further, it supplies complete systems of underwater acoustical equipment for monitoring of fish or for measurements of velocities, waves, currents and turbulence. A large part of the turnover comes from research and development for the industry. The

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Mono-Pile Wind Turbine Foundation

Januar 2009

Mono-Pile Foundation for Offshore Wind Turbines

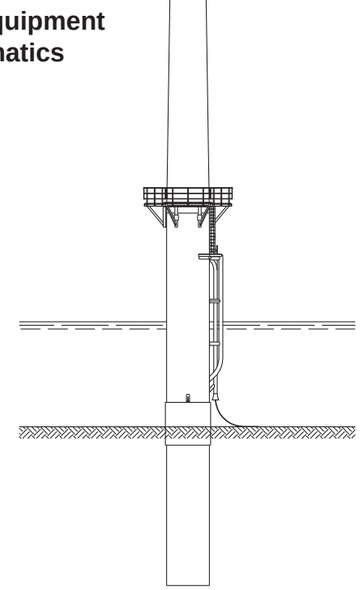
DISCIPLINES

- **Structural Analysis**
- **Dynamic Analysis**
- **Fatigue Analysis**
- **Soil Mechanics**
- **Installation**
- **Stress Concentration**
- **Pull-in System for Cables**
- **Wave, Current, and Ice Forces**
- **Erosion and Scour**
- **Material Selection**
- **Corrosion Protection**
- **Ship Impact**

LICENGINEERING A/S covers all disciplines within design and supervision of foundations for offshore wind farms.

DELIVERABLES

- **Planning**
- **Analysis**
- **Design**
- **Installation Schemes**
- **Site Supervision**
- **Underwater Acoustical Equipment for Wave & Current Kinematics**




Specifications for soil investigation at Scroby Sands north of Great Yarmouth, United Kingdom.

SCROBY SANDS

LICENGINEERING has made conceptual study, geotecnical specifications, ship impact, and sediment morpho-logic analysis for the Scroby Sand offshore wind farm.

The Scroby Sands owner: PowerGen Renewables, Vestas A/S, and Econet Ltd.

BLYTH WIND FARM

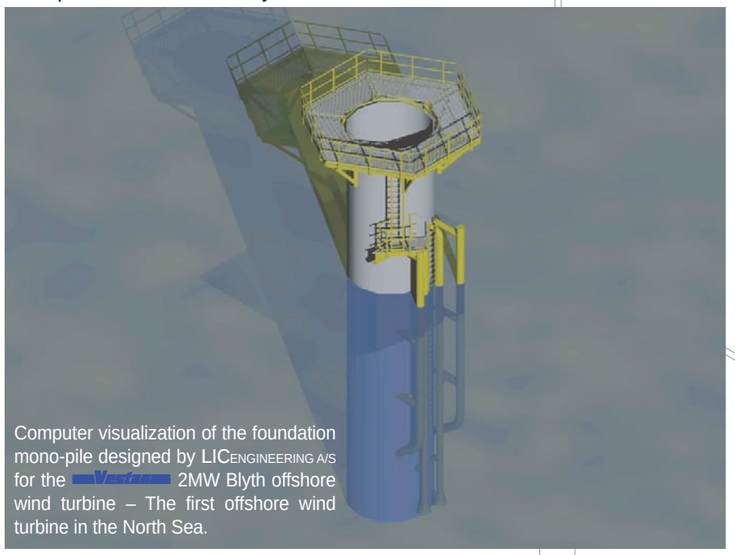
UK's first offshore wind farm in the North Sea on 8m water depth completed Summer 2000 near Blyth, Northumberland.

Mono-pile foundation, access platform, J-tubing and tower flanges for the Vestas 2MW turbine has been designed by LICENGINEERING A/S.

Blyth owner: PowerGen Renewables, Shell Renewables, Nuon UK, and Border Wind.

Mono-Pile Design and Analysis

Mono-pile foundations for large offshore wind turbines are attrac-tive and cost effective solutions. They are, however, very dynamical swaying back and forth in their eigenmodes. Which means that special vibrational analyses are warranted to cover the situations with strong dynamical amplifications. This particular behavior means that both wind and wave loads interact hereby amplifying the response



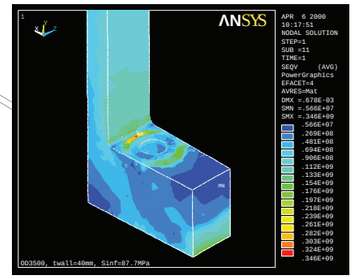
Computer visualization of the foundation mono-pile designed by LICENGINEERING A/S for the Vestas 2MW Blyth offshore wind turbine – The first offshore wind turbine in the North Sea.

- STRUCTURAL ANALYSES
  - o 3-Dimensional, Full Transient, Dynamic Analysis (Time Simulation)
  - o Wind, Wave, and Ice Load Interaction
    - ∗ Breaking Waves in Shallow Waters
  - o Soil / Structure Interaction
  - o Rainflow Counting Fatigue Assessment
  - o Flange Design
- INSTALLATION ANALYSES
  - o Vibrated/Driven or Drilled/Grouted Mono-Pile with Pre-Fitted Flange
  - o Dynamic Motion Simulation of Installation Barge / Weather windows
- SOIL MECHANICS
  - o Analysis of scour and scour protection
  - o Analysis of ground erosion
  - o Soils behavior for dynamic loads
- HYDRODYNAMICS
  - o Wave and Current Kinematics
  - o Hydrodynamic Loads
  - o Hydroelastic Vibrations
- SHIP IMPACT ANALYSIS
  - o Accidental Collisions
  - o Boat Landing maneuvers

LICENGINEERING A/S have developed methods for calculating the joint response. Using these refined methods the foundation and tower design can be weight op-timized.

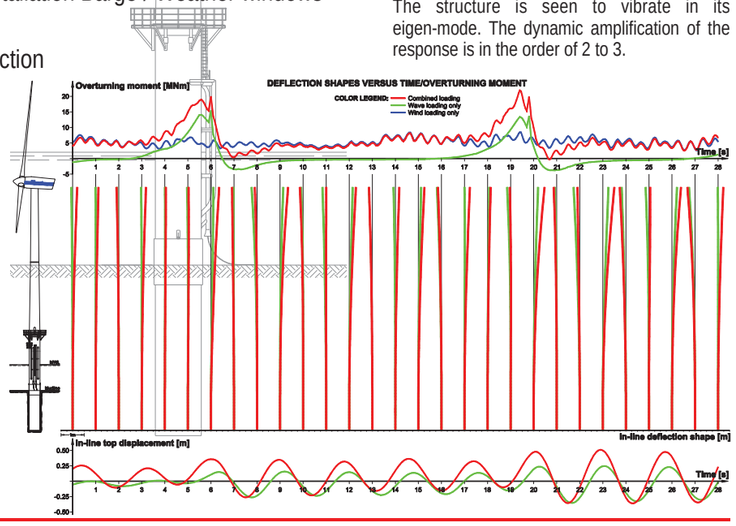
FLANGE DESIGN

Being fatigue – rather than extreme load – dominated structures, detailed analysis of the flange connections for 2MW class offshore wind turbines offers the possibility of fatigue life optimization.



Above: Flange design using the finite element program ANSYS®. The model includes the effect of bolt pre-stressing together with a correct modeling of the contact boundary between the two flanges (Only one shown).

Below: Transient dynamic response of a 2MW wind turbine. The response to a sequence of two extreme breaking waves is comparatively shown for wind-, wave-, and combined loading. The structure is seen to vibrate in its eigen-mode. The dynamic amplification of the response is in the order of 2 to 3.



Drivability of Mono-Piles

PROBLEM

A substantial part of the cost of a mono-pile foundation is the steel price. It is therefore highly beneficial for the projects to optimize the steel structure.

This shall be done both for ultimate forces and for fatigue life. 2MW class mono-piles may be vibrated down the first distance. The last meters, however, they will normally have to be driven in order to obtain the necessary penetration.

The most economical procedure will be to drive the pile with the flange for the turbine tower welded on. However, this opens up for risks such as deformation of, or exces-sive fatigue damage to, the flange during driving resulting in extensive repair work before the wind turbine tower can be installed.

LICENGINEERING A/S has therefore committed substantial resources to research the possible damages occurring during driving of large-diameter mono-piles with pre-fitted connection flanges.

The research is made both with large scale field tests and with advanced numerical calculations.

The objective is to define the flange which can sustain direct driving and to define safe procedures and equipment for driving to avoid deformations of pile and pre-fitted flange.

Driving of Ø1620mm mono-pile at Horns Rev using a MENCK MHF 10-15 hydro hammer.
Picture courtesy of ELSAM PROJEKT A/S.

POWER CABLE PULL-IN

LICENGINEERING A/S has developed and tested special systems for the pull-in of power cables into driven mono-piles.

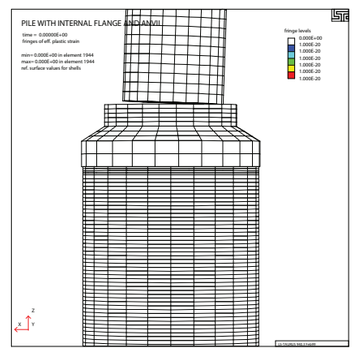
DRIVING ANALYSIS

LICENGINEERING A/S are conducting an extensive analysis scheme of numerical simulations of the driving process for piles with a pre-fitted flange.

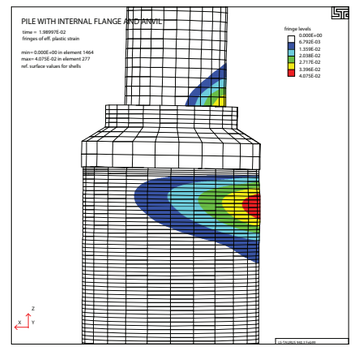
The effect of the impact loading on pile and flange are determined using the state-of-the-art Finite Element programs LS-DYNA3D™ and ANSYS®.

An exploded view of a Finite Element model of a pile, anvil and hammer is shown to the left.

The two plots to the right shows the analysis results of an extreme scenario where the the pile wall may be too thin for the driving.



Initial stress-free situation just before the



Plastic stain distribution 2ms after impact seen

The kind cooperation of the Livermore Software Technology Corporation (LSTC) on this research project, through the use of their LS-DYNA3D™, software is greatly acknowledged.