Manufacturers are offering ever larger and more powerful wind turbines for utilising wind power. As the wind turbine sizes increase, the wind and weather take an increasing toil on the structures and turbine components. Hanover University’s Test Center Support Structures opened in 2014 to enable the components used for the tower and foundations to be tested and optimised in advance. Here components made of steel, concrete and other materials are tested to their limits.

In the Test Center Support Structures, forces equivalent to wind force 10 tug on wind turbine components and shake the material vigorously. In the hall itself, however, not the slightest breeze can be felt. The scientists use mechanical power in the test rigs to exert extreme loads on models of towers, masts and foundations as well as on components and screws. In practice, these loads are caused by the wind and the movement and twisting it induces in the rotor blades and nacelle. With offshore wind turbines, the waves, currents and the interaction of the wind and waves also come into play. Wind turbines need to reliably withstand all these forces for at least 20 years. The economic viability plays a role in this regard in two ways: the investment costs need to be minimised without sacrificing reliability, whereby components that are constructed too solidly and which also do not provide any additional stability incur unnecessary material and installation costs.

The new centre has two large test rigs: the foundation test pit and the clamping field. Support and foundation structures for offshore foundations and associated construction methods are investigated at a scale of 1:10 in the 10-metre-deep pit filled with sand. Models of support structures at a scale of 1:5 are clamped in the clamping field and subjected to multi-axial loading. One of the aims is to investigate the fatigue behaviour. The facilities at the centre are rounded off with special laboratories.
for concrete, fibre composite materials and geotechnical investigations along with a resonance testing machine and a climate chamber. This results in reproducible data for extreme and cyclic loading of components and materials. Three to four months are required in the hall to simulate the requirements during a wind turbine’s entire lifespan. The interplay of models, large-scale experiments and numerical calculations make it possible to design wind turbines more precisely and to validate simulation programmes. Leibniz Universität Hannover operates the Hanover Test Center Support Structures together with the Fraunhofer Institute for Wind Energy and Energy System Technology, IWES, as its cooperation partner.

Preventing failure through material fatigue

The rotary motion of the rotors transfers most of the forces acting on wind turbines. These have to be absorbed by the hub, nacelle, tower and foundations. In addition, loads are also exerted, for example, when nacelles rotate to track the changing wind direction and, offshore, through the force of the waves on towers and foundations. It is not so much extreme events such as severe storms but rather the large number of constantly changing loads that provide a particular challenge in terms of the structural loading. Examples include the gusts and wind turbulence that occur when the wind direction constantly changes within a short time and the rotors are exposed to widely varying loads.

The foundation structures of wind turbines are designed to meet three objectives:

- All components must remain break-proof when subjected to extreme loads.
- There should be no failures caused by material fatigue during the 20- to 30-year operation.
- Precise knowledge of the system’s stiffness is necessary to ensure that externally introduced oscillations do not stimulate the natural frequency of the system, which would cause increased swinging.

The design needs to take into account all the maximum operating conditions that can be expected, all fault combinations and the probabilities of the events occurring. To achieve this, the developers determine and calculate the design loads, whereby the structures are conceived so that they can withstand all loads. The data determined in the test centre will make it easier in future to predict the structural resistance more accurately.

Foundations buried in sand

The foundation test pit (Fig. 2 and 3), with a surface area of 126 m² and a depth of 10 metres, holds 1,250 m³ of sand. This is saturated with water, whereby four wells enable the moisture content to be varied. The test pit is used for testing construction methods and the anchoring of offshore wind turbine foundations to the seabed. Hydraulic actuators for applying loads are situated at the top of the test piece, which in reality corresponds to the base of the tower. One example is a combination of cyclical loads and large impulses, which in reality would correspond to continuous operation with individual high waves. Strain, tilt and acceleration sensors record all movements. The scientists are also using the pit to investigate the ground behaviour around the test pieces and the interactions between the ground and foundation. Another research area is concerned with developing and testing low-noise installation methods for the foundations. Possibilities include installing piles in the ground by vibration or using suction buckets. Here the wind turbine rests on a sort of upturned bucket, which is adhered to the seabed.

Clamping tests for components

In the clamping field (Fig. 4), the scientists test components and large models in terms of their material fatigue. The test rig consists of a 200-m² concrete
floor slab that is bounded along two sides by solid concrete walls positioned at right angles to each other. In order to check, for example, a hybrid connection element made of steel and concrete (grouted joint), this is clamped between the floor slab and the walls. Hydraulic cylinders then apply different loads to the test object. The cylinders generate forces between 250 and 2,000 kN and the test frequency varies between 0.1 and 50 Hz. Just as in reality, the tensile, shear and torsional forces are applied to the objects from different directions. Checks are conducted, for example, on steel nodes or the nodes of gravity foundations on which offshore wind turbines are built. All components can be tested in both upright and horizontal positions.

Climate chamber and laboratories
The durability of the materials is tested in the climate chamber (Fig. 5). Causes for corrosion and other forms of material degradation, which include long-standing thermal changes, salt spray or continuous exposure to UV light, are investigated in time-lapse tests in the chamber. These investigations enable the behaviour, for example during the last quarter of a wind turbine’s lifespan, to be tested in advance in the laboratory, whereby tests with condensation and salt spray can be conducted in accordance with different standards. The investigations are also aimed at studying the course of the grouting process over time. This is the name given to the process for joining the piling tube to the base of the tower for offshore wind turbines. The concrete laboratory makes it possible to check the quality of fresh and hardened concrete as well as test samples made of high-performance concrete. In the structural health monitoring laboratory, detailed analyses are conducted on the breakpoints of components that have failed in test pieces. A composite laboratory makes it possible to develop methods for repairing damaged components made of fibre composite materials. The investigation spectrum is supplemented with a resonance testing machine. This enables quick and inexpensive tests with large number of samples in order to verify calculations statistically. It is also used to determine the fatigue strength of fasteners such as screws. The machine has an axial force of 1,000 kN and works in a frequency range of up to 120 Hz.

Higher and higher
The towers represent about one-fifth of the total cost of wind turbines. Structures are therefore sought that reach the desired height with the necessary stiffness and at the lowest possible cost. One of the four following structures are mostly used with onshore wind turbines: tubular steel towers (with or without bracing), concrete towers made of either precast elements or in-situ concrete, lattice or truss masts as used with high-voltage transmission lines, and hybrid towers. These consist of a concrete tower at the base on which a tubular steel tower is constructed. All foundations are anchored to the ground with foundations made of reinforced concrete, which depending on the ground conditions are built on piles.

Offshore wind turbines predominantly rest on monopiles, tripods or a jacket structure (Fig. 6). The latter two are anchored with smaller piles into the ground, whereas monopiles are themselves rammed into the ground. Researchers are currently working on developing low-noise construction methods and new foundation concepts.

Fig. 4 The loads are transferred in the clamping field via the anchor points and abutment brackets.

Fig. 5 Exterior of the 4.2-metre-wide and 2.8-metre-deep climate chamber in which fresh- and saltwater tests are conducted.

Fig. 6 Monopile, tripod and jacket (from left to right)
GIGAWIND project group

Following the Competence Center Rotor Blades and the DyNaLab Dynamic Nacelle Testing Laboratory, another testing facility has now begun operation in Germany with the Test Center Support Structures. The German Federal Ministry for Economic Affairs and Energy has spent almost 50 million euros on constructing these facilities as part of its energy research programme. These will be supplemented by the BladeMaker Demo Centre at the end of 2015. New methods for automatically producing rotor blades will be tested here.

Offshore wind farms are only economically successful if the wind turbines are on a firm footing. For more than 15 years, the GIGAWIND project group at Leibniz Universität Hannover has been researching the structural and environmental principles for foundations and towers. The scientists have studied the influence of ocean currents, sea states and waves, and developed evaluation criteria for geotechnically assessing the subsoil. Thanks to the investigations, the design of the foundations can now be based on reliable data. This is a prerequisite in order to further reduce wind turbine costs through the increased series production of the foundations.

As part of the accompanying research conducted as part of the RAVE research initiative, the project group also monitored structural aspects regarding Germany’s alpha ventus offshore test field, whereby one of their focus areas was on scouring. Scouring occurs when fixed structures, such as wind turbine foundations, are anchored in water. The current pattern changes near the structures, which leads to increased erosion on the seabed. This creates depressions in the ground around the structures known as scouring. In order to investigate this phenomenon, models of foundation structures were tested in the world’s largest wave channel in Hanover and compared with echo-sounder measurements taken near wind turbines in the test field. The investigations revealed that the stability of the wind turbines is not threatened by scouring.

With the ongoing GIGAWIND life project, which is continuing until 2016, the focus is on researching the lifespan of the supporting structures. The data derived from the worldwide unique long-term measurements made on the wind turbines at alpha ventus will be used to develop validated methods and structural models. These in turn will be used for both investigating individual wind turbines as well as for further optimising the design of foundations for future offshore wind turbines.