NEW HYBRID^2-TOWERS OPTIMIZE THE CONSTRUCTION AND ASSEMBLING OF ONSHORE WIND TURBINES

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ABSTRACT

For the yield of renewable energies, wind offers many capabilities. The development and enhancement of wind turbines have a strong demand worldwide.
Especially, land-based turbines are in the need of immense hub heights (over 100m) to ensure economic operations. Involving that the turbines will become massive and require large transport plus assembly works.
A research project funded by the State of Hesse, Germany, represent the most economical solution for high towers of wind turbines- the hybrid²-towers. The hybrid²-towers combine the materials concrete and steel analogous to their properties and thus improve the performance of the whole structure. The construction consists of prefabricated quarter-circle shaped concrete elements, which are connected with each other by a framework of common rolled steel sections or concrete beams to accelerate the operations on-site. With this innovative construction principle, the self-weight of the concrete tower can be decreased up to 40 % in comparison to a full concrete tower and the costs for the assembling will be reduced tremendously.

Keywords: Research Project, External Prestressing, Hybrid-Towers, Onshore Wind Turbines, Precast Concrete Elements, Steel Framework

INTRODUCTION

SITUATION IN GERMANY

Shortly after the nuclear disaster in Fukushima, the German Federal Government decided to phase out nuclear power by 2022. Until then, all nuclear power plants are supposed to be shut down gradually. For this reason, Germany puts a special focus on the development of renewable energies like wind, solar energy, hydroelectric, biomass etc. Of these alternatives, wind power has the highest potential for the expansion of generated electricity by renewable forms of energy. According to Ender, C. (2014)[1] in Germany about 24.000 wind energy plants were built in 2013 with a total operation performance of about 35.000 MW. Thus, Germany is in the third place of the world's installed wind energy plants with a share of 10.9%, behind China and the USA.

The so-called *Repowering* features a special status in the extension of the wind energy. This concept describes the replacement of old wind turbines with new powerful ones in the same location. In 2013, around one-third of the newly installed onshore wind energy plants were built as repowering plants, according to Neddermann, B. (2014)[2]. With this process, in Germany about 340 wind turbines with a total operation performance of 226 MW were demolished and replaced by 256 new ones. More than the threefold performance could be reached with a new electricity production of 726 MW.

This gain in energy is the result of increasing hub heights, larger rotor diameters and the enhancing performance of the turbines. The development of wind turbines is currently a strong demand market. For this reason, the *Technische Hochschule Mittelhessen* develops a new tower construction, which reduces the material requirements and optimizes transport and assembly.

Fig. 1 Design of the hybrid²- towers

EFFICIENT OPERATION OF A WIND ENERGY PLANT

For the efficient operation of a wind turbine, an average wind speed of 5 to 6 m/s is required. The energy of the wind flow thereby changes with the third power of wind velocity. Accordingly, the tower height of a wind turbine is dependent on the location and the hub height ultimately determines the economy of a wind turbine. Therefore, a number of wind turbine manufactures create different combinations of rotor diameters and hub heights to offer an optimal wind turbine depending on the location. For interior sites, the following proportionality can be applied as a rule of thumb: the yield increases up to 1 percent per meter hub height of the wind turbine. For that reason, hub heights over 100 m are often desirable in interior sites of Germany, such as the state Hesse. Investigations of the wind potential in Hesse by *TÜV Süd* (2011)[3] show, that a wind speed of 5.5 m/s at 100 m height can be expected on an area of 30 % in Hesse. At a height of 140 m wind speeds of about 5.5 m/s are even expected in 65 % of the area of Hesse. This shows that the increasing hub height is the future in wind power generation. It is also confirmed by the trend of newly installed wind turbines in Germany. To reach the desired hub height, the construction of tower is of particular importance.

The tower is the largest and heaviest component of a wind turbine and carries a share of approximately 20 to 25 % of the total cost. Also the tower has a big influence on the assembling and transportation costs.

DEVELOPMENT OF THE TOWER CONSTRUCTIONS

For the construction of higher wind turbines, self-supporting towers are mainly used. They can be built in various forms of construction. In addition to the hub height, the first eigenfrequency is also an important criterion for the efficiency of a wind turbine. The crucial objective for wind turbines is to reach the required tower height and the required stiffness with low construction costs. The most popular tower types are lattice towers, steel tube towers, concrete towers and for a few years, hybrid-towers.

Lattice towers are used for great hub height. Because of the transmittance, the lattice towers can integrate themselves easily into the landscape and are characterized by their high material and weight saving. However, the manufacturing and maintenance of these towers is very labor-intensive. With the high labor costs in Germany the lattice towers are decreasingly being built.

A further variant with a large amount of total towers of wind turbines are the *steel tube towers* with a total height of 60 to 120 meters. This tower variant usually consists of an upwards conically tapering cross-section. One can say: the higher the tower, the wider its base. Therefore, the producing of the tower height is limited to 100 m. This is mainly due to the portability and the limited thickness of the plates. German road bridges have a vertical clearance of 4.0 m and thus limit the diameter of the lower tower sections when it is delivered in one piece. Composite in-situ steel towers did not establish themselves, because of the high welding and assembly costs.

In addition to the steel tube and lattice towers, it is possible to build towers of concrete. However, there exist various construction concepts for concrete towers. The cheaply produced *centrifugal concrete towers* have the disadvantage of high transportation and assembling costs. *In-situ concrete towers* simplify transportation and assembly. For this purpose, it is possible to construct the towers with sliding or climbing formwork directly on site. The problem with in-situ concrete is the quality control of the concrete casting. In bad weather conditions, such as cold temperatures and strong winds, the assembly is time-consuming and costly with increasing altitude.

Because of these disadvantages, the production of concrete towers out of *precast concrete elements* got in place. The prefabrication of individual segments can be guaranteed in the factories for precast concrete at a cost-effective rate with continuous high quality. The prefabricated construction optimizes transport and assembly and the tower can be adapted to the corresponding local conditions. The aim is to manufacture the components without changes in series if possible. This enables a significant reduction in the formwork, and in the costs for large quantities per segment. After the precast concrete parts are assembled on site, they are suppressed by means of vertical pre-stressing bars across the entire height to protect the concrete from tensile stresses. Towers with bigger contact areas can be built easily with this construction method. An important advantage over the in-situ concrete towers is the easier deconstruction of prefabricated components after the wind turbine has reached its service life.

A combination of concrete towers and steel tube towers has been used increasingly during the last years. The so-called *hybrid-towers* consist of a concrete tower with precast elements in the lower part and an attached steel tube tower in the higher part. Large hub heights over 100 meters can be manufactured with comparable low costs with this variant. Furthermore, the variation of the height of the concrete and steel tube tower influences the eigenfrequency. Thus, the operating efficiency will be improved.

NEW HYBRID^2- TOWERS

CONSTRUCTION

The previously built hybrid-towers, which consist of a prestressed reinforced concrete tower and an attached steel tube tower, offer considerable potential for improvement. The development of hybrid-towers is quite young, which is why there is still a considerable need for further advancement in this field.

The lower part of concrete has a large self-weight. This should be optimized with regard to material requirements and assembly. Furthermore, the composite precast concrete towers are built of vertical and horizontal joints, which react prone to damage under dynamical loads. The idea was born to minimize these problems with a development of a new construction for hybrid-towers of precast reinforced concrete.

A framework replaces a part of the concrete section so that an open tower construction occurs. With the combination of precast concrete and framework, the concrete tower itself becomes a hybrid-tower, which is completed by an attached steel tube tower. Thus, a hybrid-tower in a double sense is created, the so-called hybrid^2-tower.

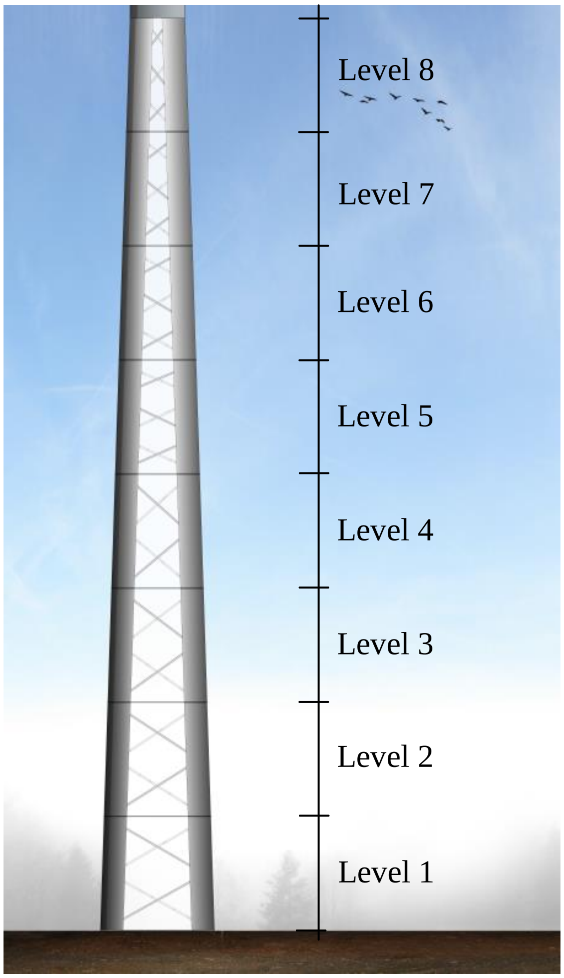


Fig. 2 View of the tower

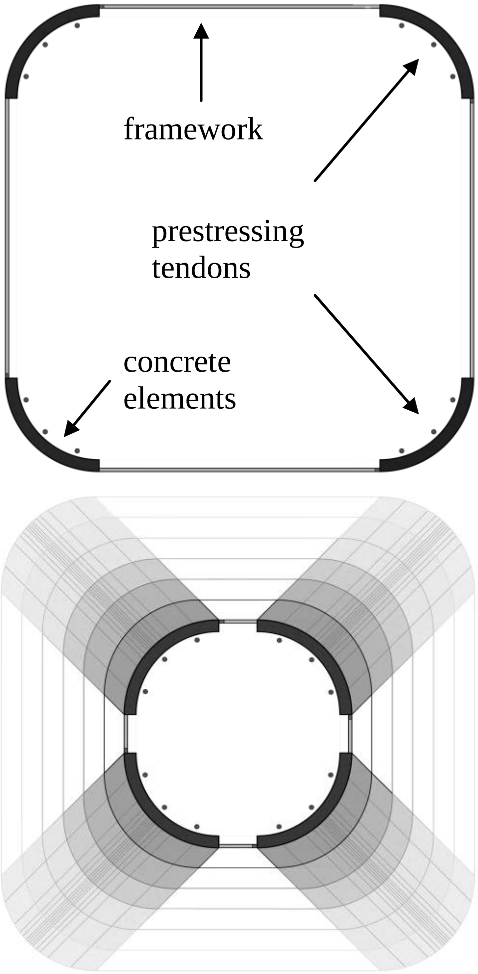


Fig. 3 Lower and upper cross-section of the tower

These hybrid²-towers are currently in development by the University of Applied Sciences *Technische Hochschule Mittelhessen* (Giessen, Germany) together with the precast company *Oberhessisches Spannbetonwerk* (Nidda, Germany). This project (HA project no. 352/12-42) is funded within the framework of Hessen ModellProjekte, financed with funds of LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz, Förderlinie 3: KMU-Verbundvorhaben (State Offensive for the Development of Scientific and Economic Excellence).

The new hybrid²-towers are built out of four prefabricated quarter-circle shaped concrete elements in the cross-section, which are connected by a framework. The quarter-circle shaped elements are 10 m high and constructed identical over the complete height. Thus, it is possible to produce these elements in series with the same formwork in precasting factories. The weight of one element is less than 20 tons. They can be delivered to the building site without expensive special transports.

The desired hub height determines the horizontal distance between each concrete element. It is to bear in mind that the higher the tower, the greater the contact area needs to be. The framework connects the concrete elements, thus the distances are variable.

Moreover, the concrete elements are constructed with a slight inclination, in such that the distance and the framework taper upwards.

A hub height of e.g. 145 meters, which is usual for hybrid-towers in Germany, requires a contact area of 10 x 10 meters. Towers of this dimension are built up of a concrete tower including a foundation and an adapter ring with a height of 85 meters and the attached steel tube tower with 60 meters. Due to the modular construction concept of the hybrid²-tower and a height of 10 meters for each level, different heights can be implemented easily. Because of the taper, the conventional steel towers with a diameter of about 4 meters can be attached flush to the concrete tower with the help of the adapter ring.

Different materials have been tested for the framework construction. The use of commercial steel profiles is the simplest option. However, a structure made of concrete beams is another variant, which is still under examination and might effect some pros.

The assembling of each level takes place on the ground. One level consists of four corner elements and the trussed beams. The lower and upper end of each level is a steel ring, to which multiple tasks are assigned. During assembly, the steel ring stabilizes the quarter-circle shaped concrete corner elements and ensures an accurate installation of the trussed beams. In addition, it can adjust the tolerances in the corner elements. The steel ring is similar to the tower cross-section of four quadrants. The distances in between are arranged straight, so they are extended flush with the reinforced concrete corner elements. After each level is assembled on the ground, it is placed on top of another and aligned with the aid of the steel ring. The horizontal joint between the overlapping steel rings is filled with grout. The surrounding steel constrains the lateral expansion of the grout and secures a force-fit connection.

Vertical external prestressing steel tendons are inside the tower, which set the concrete elements under compressive stresses and thus counter the occurring tensile forces. The anchoring of the prestressing tendons is in the foundation and in the adapter ring. The adapter ring is an important link between the concrete tower and the steel tube tower.

The open structure of the framework further offers creative advantages. In the standard version of the open framework, the tower is transmittance and can be integrated into the landscape. The open areas between the concrete elements can also be used for the design of the tower. The use of illuminated films offers many creative possibilities and space for advertising. Alternatively, the intermediate gaps can be filled with films, trapezoidal sheet metals etc. to get a uniform surface.

CONSTRUCTION OF THE FRAMEWORK

To connect the precast elements to each other, trussed beams of steel or precast concrete are arranged. This framework construction gives the hybrid²-towers the low weight and the open structure. In addition, the trussed beams have the task to strut the tower.

Therefore, the execution of the beams is an important component of the tower. The trussed beams have to absorb resulting tensile- and compressive forces in order to transmit them to the next precast concrete corner element.

If the use of steel profiles applies, they will be made out of conventional profiles, like square hollow profiles, circular hollow profiles, I-profiles, etc. First, a factory cuts the profiles to their correct length and delivers them easily to the construction site. The connection of the steel framework and the precast concrete elements is carried out by a common grouting connection, well-established in precast and composite constructions. For this purpose, gaps are in the precast elements in which the trussed beams can be placed in-situ and be adjusted in the right position for the construction in progress. Head bolts or anchor plates are provided at the end of the trussed beams to permit a force-fit and permanent connection to the precast elements. A good connection can also be realized with the use of concrete dowels made of cut-outs in the steel profiles or welded plates. The advantage of this type of mounting is the insensitivity to manufacturing tolerances. The trussed beams can be grouted to the corner elements after alignment.

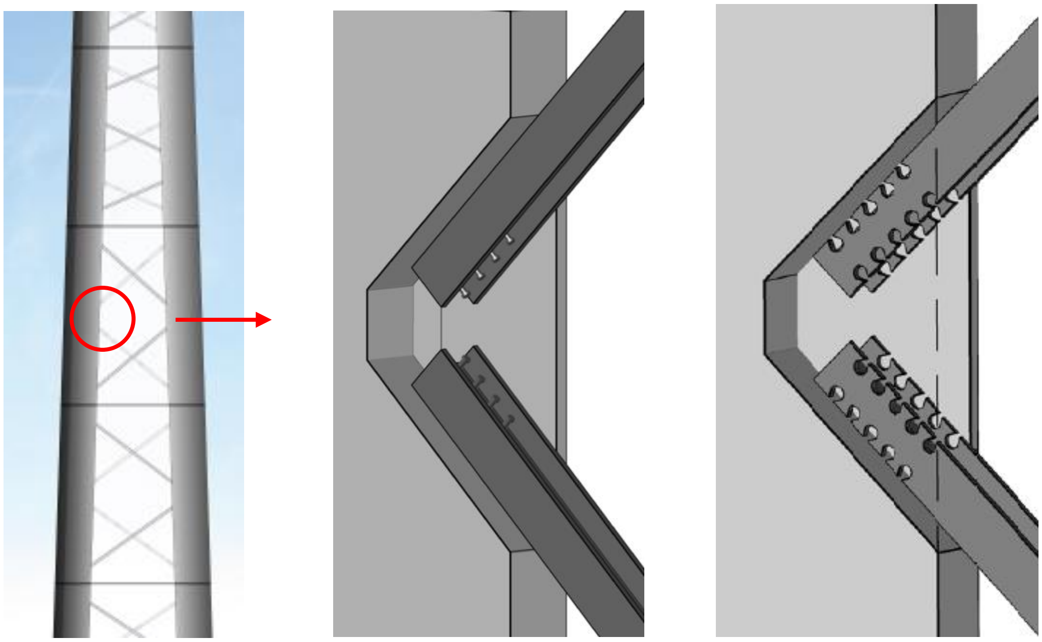


Fig. 4 Connection of trussed beams with head bolts (left) and concrete dowels (right)

JOINTS OF THE PRECAST CONCRETE ELEMENTS

Previously constructed hybrid-towers consist of a complete concrete cross section in the lower part. Especially for precast constructions, horizontal and vertical joints cannot be avoided. A butt-jointed concrete joint can only be realized with complex and expensive equipment. Therefore, the use of grout in the joints is an easier alternative. However, the post-grouting of the vertical joints affords big problems in bad weather conditions and advanced height, so there is often a blemish in not complementary filled joints. This results in serious problems in durability and density of joints. An efficient force transmission cannot be guaranteed and in view of the dynamic load it is critical. The hybrid²-tower is without vertical joints by the use of a framework, which improves the construction.

The horizontal joints are less problematic than the vertical joints. The vertical prestressed tendons are adapted to avoid tensile stresses in the horizontal joint during the dynamical load. There only occurs a gap in the joint between two overlapping steel rings in the ultimate limit state. The prestressed steel tendons absorb the resulting tensile forces. The big problem with the use of grouts is the dependence on the weather. Especially in colder regions, a use of grout without special measures is not possible. An alternative connection e.g. of elastomer supports, needs to be researched yet.

FOUNDATION AND ADAPTER RING

Foundations of prestressed concrete towers for wind turbines are made of a circular ring shape and will be built with in-situ concrete. In the middle opening of the foundation is the place where the prestressed steel tendons are anchored. In this so called cellar the prestressing jack must be set in order to apply vertical prestressing for the concrete tower. The required working space is very large and the tendons must be anchored in the foundation. For this reason, foundations for wind turbines with a height of 4 meters are not uncommon. The elaborate formwork and the time-expensive concreting make the foundation a significant cost factor. Therefore, it is desirable to reduce the material requirement for the foundation in order to build it economically.

On the upper side of the concrete tower, the adapter ring must absorb the prestressed steel tendons. It also has the function to transfer the forces from the steel tube tower to the concrete tower; thus a massive adapter ring of reinforced concrete is used. The adapter ring with a weight of often more than 50 tons also has demand for improvement.

ASSEMBLING OF THE HYBRID^2-TOWER

The first step of the tower assembling is to build up the foundation including the cellar and the anchor for the prestressing steel tendons. To realize a fast build-up, the concrete corner elements and the trussed beams will be delivered in time to the building site. The constantly repeated formwork provides an optimal pre-production in the precast factories and guarantees a delivery in time. The first corner elements will be placed and aligned on grout on the foundation and fixed with the aid of the steel ring. In the next step, the trussed beams will be inserted and secured in the right position. The gaps in the precast elements will be filled. This construction section is the first level.

At the same time, a mobile foundation of prefabricated concrete plates will be arranged next to the actual tower. There, the pre-assembly for the next levels takes place with the same work steps as described for the first level. In cold regions, the pre-assembly can also be done under a housing which allows a temperature-independent assembly of the individual level and provides optimum conditions for the grout. Each level of the hybrid^2-tower will be lifted and placed on grout on the underlying steel ring and be aligned by a hydraulic devise. The same concept is repeated for the next level. The upper end of the hybrid^2-tower is built by the adapter ring. This ring is also placed and aligned on grout. After the completion of the concrete tower, the external prestressed steel tendons can be installed from the foundation to the adapter ring. The prestressing cables have no anchor points on the reinforced concrete corner elements to avoid unbalanced forces. After the desired prestressing force for the concrete tower has been applied, the installation of the steel tube tower can begin. This is equal to the usual way of assembled wind turbines.

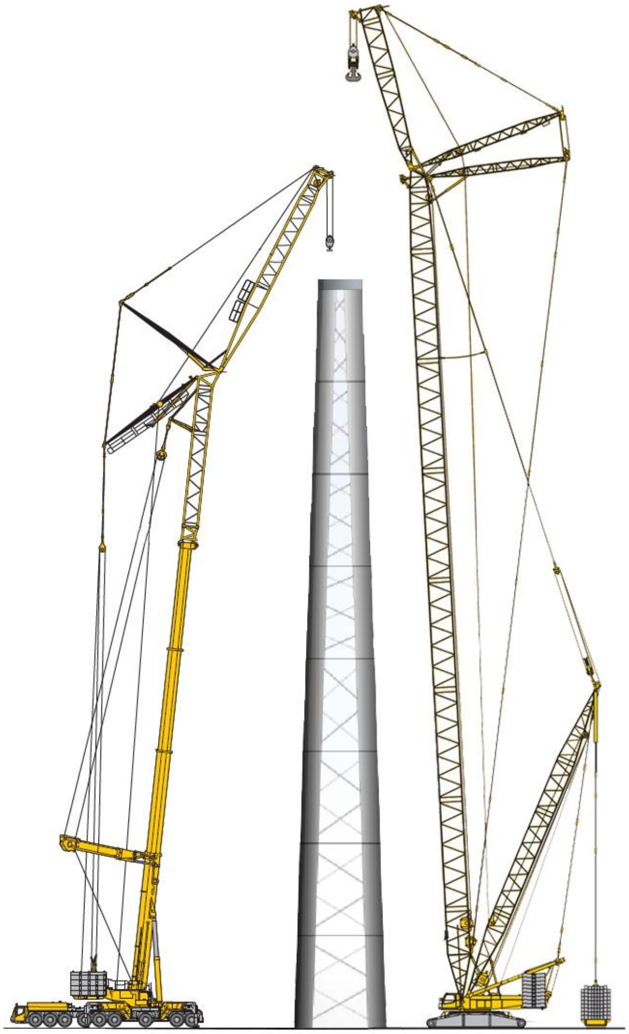


Fig. 5 Comparison of a mobile crane and a crawler crane for a wind turbine[4]

For the assembly of the hybrid²-towers a mobile truck crane instead of a currently required crawler crane is necessary, because of the weight optimization. A comparison of these two cranes is shown in Fig. 5. This provides significant advantages for the choice of location of the wind turbine and considerable cost savings. The crawler crane will be transported to the building site with several special transports and has to be assembled on site. In contrast, the mobile crane is self-propelled and the significantly lower equipment can be delivered with normally loaded trucks. Additionally, the effort of the road construction to the building site will be reduced. Because the large wind turbines are built particularly in rural areas or forests, an optimization of the access way is also ensured. For example, one hybrid²-tower with 8 levels will be assembled in 5 days. The crawler crane for a complete concrete cross-section costs over 100.000 €, including assembly and dismantling, without personal costs. In contrast, the mobile crane has less than half of the costs because of the low assembly time. Furthermore, considerable costs arise for assembling interrupts because of bad weather conditions and high wind speeds for construction of single wind turbines as well as wind farms. An average of 10 lost days per tower can arise during the construction of only one wind turbine. The daily rate for one lost day of the mobile truck crane is only about 65 % as compared to the crawler crane. In addition, the smaller mobile crane allows a lifting with higher wind speeds and minimizes the downtimes.

DESIGN OF THE HYBRID²-TOWERS

STANDARDS AND GUIDELINES

Several standards and guidelines are available for load determination and design of wind turbines. In general, the design requirements for wind turbines are regulated in *IEC 61400-1:2011-08* respectively in the German version *DIN EN 61400-1:2011-08*[5]. Part one of the DIN EN 61400 involves the essential design requirement for the technical components of a wind turbine. This standard applies in addition to the structure system for the operational management and security systems, internal electrical systems and mechanical systems. In Germany the DIBt- Guideline (*DIBt- Richtlinie für Windenergieanlagen* published in *October 2012*[6]) obtains for the static proof of the stability of the tower and the foundation. This includes regulations for actions based on the specifications of DIN EN 61400. The guideline describes the safety factors associated to the actions, as well as the internal forces from the turbine to the tower and the foundation.

Furthermore, the *Guideline for the Certification of Wind Turbines* from *Germanischer Lloyd industrial services GmbH*[7] is also very important for the development of wind turbines in Germany and other European countries. It includes regulations for the design, examination and certification for the complete system. These regulations are more detailed than those in IEC 61400. In the further course of this paper, the fatigue calculations according to the DIBt- Guidelines will be assumed. For the proof of concrete it is referred to the current Eurocode- standards *DIN EN 1992-1-1:2011-01: Design of concrete structures*[8] and the *CEB-FIP Model Code 1990*[9].

DETERMINATION OF THE EIGENFREQUENCIES

For the stiffness of the tower, particularly the first eigenfrequency is very important for the development of the tower structure. The first tower eigenfrequency will be determined from the complete construction, foundation, tower and machine including its rotor, and should be in a sufficient distance to the excitation frequency. According to the current guidelines, a safety value of +/- 10 % is observed to the excitation frequencies. For these reasons, the range of the eigenfrequencies is severely limited. A wind turbine obtains many different dynamical loads during the normal operation. The periodic excitation of the single rotation number (1P- excitation) as well as the periodic excitation from the blade pass, with three times the rotation number (3P- excitation), are very important for the design of the tower's eigenfrequency. An example is shown in Fig. 6. The load applications to the tower and the mechanical components increase the closer the eigenfrequency is located to the excitation frequency. Towers of wind turbines are classified in three categories: "soft-soft", "soft-stiff" and "stiff-stiff", according to the first tower eigenfrequency. To avoid an increase of the ultimate and fatigue loads out of the stiffness, the towers should be designed with an eigenfrequency more than 10 % above the 1P- excitation. This means, the excitation of three times the rotation number will be crossed during start-up. If the eigenfrequency is at least 10% below the 3P-excitation, it is called a "soft-stiff" tower design. A stiffer structure with an eigenfrequency more than 10 % above the 3P- excitation (“stiff-stiff”) is not commercially designable for large tower heights. Thus, an optimum design of the hybrid-towers for wind turbines is in the range “soft-stiff”.

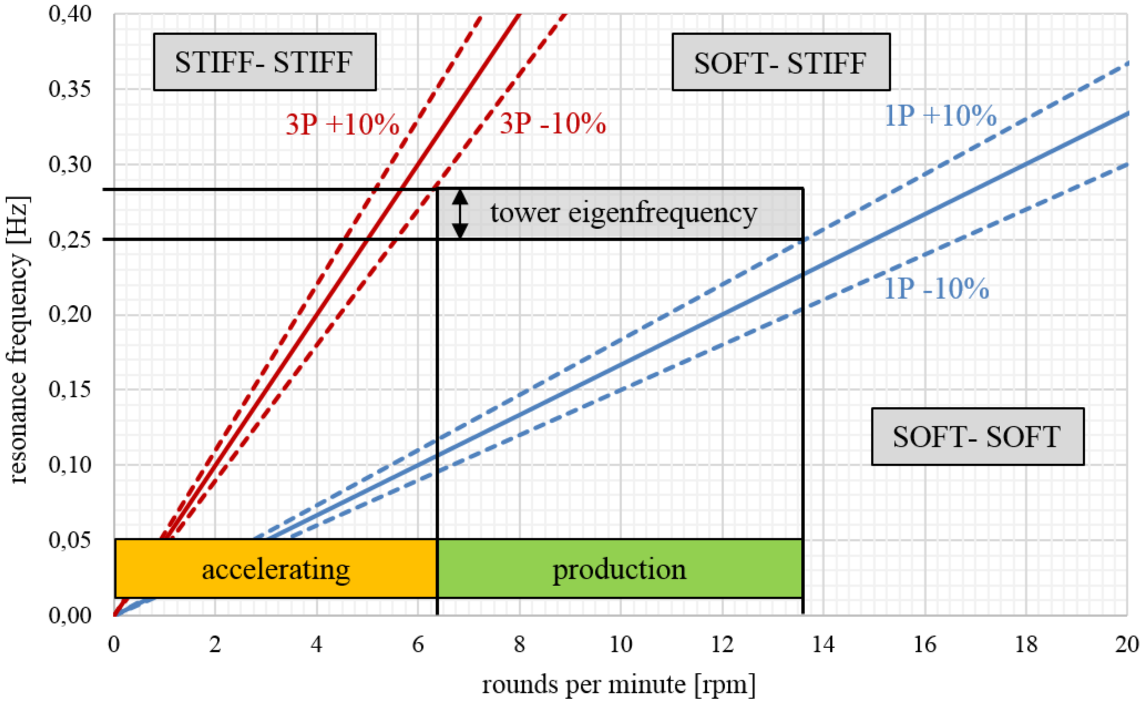


Fig. 6 Campbell- diagram

Decisive parameters for determining the tower’s eigenfrequency of hybrid-towers are the height of the concrete tower and the height of the steel tube tower. Due to the higher stiffness of concrete towers, e.g. the first tower eigenfrequency can significantly increase with a larger concrete tower and a smaller steel tube tower. If this adjustment does not lead to the required stiffness, an increase of the cross-section of the concrete tower will be the easiest way to increase the eigenfrequency. In addition, the fluctuating elastic modulus of the concrete, as well as the elastic springs of the foundation has an influence to the eigenfrequency. A simple spreadsheet analysis to determine the first eigenfrequency is recommended for the pre-dimensioning. The calculation is according to the basics of the law of energy conservation. Therefore, the dead loads of each level are placed horizontally on a respective node in a simplified truss model. The bending line and the displacements of the nodes can be calculated depending on the different inertia moments of area for each height and the ground rotation spring. With the summation of the results for each node, the period of oscillation and the eigenfrequency can be determined with formulas. Own calculations demonstrated, that the simplified spreadsheet analysis has only deviations in the third decimal against an elaborate finite element model with plane elements.

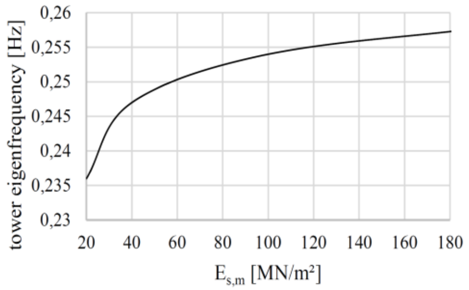
In the following calculation, the influence of the ground with a simplified determination of the rotation spring is shown as an example. The torsion-resistant stiffness for circular ring foundations can be app. determined with Eq. (1):

$$c_{\varphi} = \frac{M_{Gr}}{\varphi_{Gr}} = \frac{E_{s,m} \cdot I_{Gr}}{t_{Gr}} \approx \boxed{\frac{2}{9} \cdot E_{s,m} \cdot \frac{{d_a}^4 - {d_i}^4}{d_a}} \qquad (1)$$

with: $E_{s,m}$ = stiffness coefficient of the ground
d_a = external diameter of the circular ring foundation
d_i = internal diameter of the circular ring foundation

The hybrid²-tower with e.g. a foundation of d_a = 26 m and d_i = 10 m obtains the eigenfrequency shown in Table 1 depending on the different soil type.

Table 1 Calculation of the tower eigenfrequency

<table>
<tr><th>$E_{s,m}$ [MN/m²]</th><th>c_{φ} [MNm/rad]</th><th>tower eigenfrequency [Hz]</th><td rowspan="5">
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<tr><td>100</td><td>383000</td><td>0,254</td></tr>
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The calculations of the eigenfrequency in Table 1 and the Campbell-diagram in Fig. 6 show that the critical value of the eigenfrequency with these dimensions will be reached by a stiffness coefficient on the ground of 40 MN/m². Due to the modular design concept and the possible adjustment to the different grounds, the hybrid²-tower can be conformed to bad ground conditions. If this is not enough, the soil can be improved. Otherwise, a deep foundation out of bored piles is necessary.

FATIGUE

In addition to the proof of the ultimate limit state and the serviceability limit state, the proof of fatigue is very important. The fatigue loads cover all load applications in the planned lifetime of a wind turbine. In the components of the wind turbine material fatigue occurs because of the dynamical loads. Due to the high load cycles up to 10^9 within a lifetime of 20 years, there is still a lack of experience and design concepts for new materials.

Also new findings occur in the design of reinforced concrete. The DIBt-guidelines refer to the old CEB FIP Model Code 1990. The final draft of the *CEB FIP Model Code 2010*[10] was published in March 2012.

A new design concept was developed with experimental tests from *Lohaus et al.*[11], which was introduced in CEB FIP Model Code 2010. The new design model decreases the factor for the reduction of the design value for concrete under fatigue loading. The design value of the CEB FIP Model Code 1990 is shown in Eq. (2). It is proposed that this formula can only be applied for concretes with fck ≤ 120 N/mm². In addition, this equation even declines for cylinder compressive strength higher than 125 N/mm² and leads to an uneconomical design. The advanced design method for concrete under fatigue loading shows Eq. (3) and is shown graphically in Fig. 7.

$$f_{cd,fat} = 0{,}85 \cdot \frac{f_{ck}}{\gamma_c} \cdot \beta_{cc}(t) \cdot \left(1 - \frac{f_{ck}}{250}\right) \quad \text{für } f_{ck} \leq 120 \text{ N/mm}^2 \tag{2}$$

$$f_{cd,fat} = 0{,}85 \cdot \frac{f_{ck}}{\gamma_c} \cdot \beta_{cc}(t) \cdot \left(1 - \frac{f_{ck}}{400}\right) \quad \text{für } f_{ck} \leq 200 \text{ N/mm}^2 \tag{3}$$

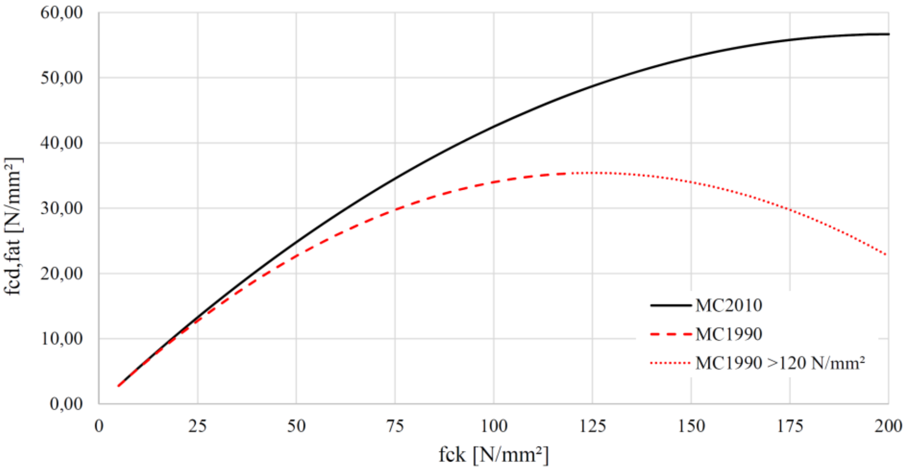

Fig. 7 Comparison to concrete compressive strength in fatigue between Model Code 2010 and Model Code 1990

Furthermore, new Wöhler curves for concrete were prepared under pressure threshold stress by the experiments of *Lohaus et al.*[11] and are reflected in the Model Code 2010. It could be determined that the Wöhler curves in Model Code 1990 are very conservative for normal-strength and high-strength concretes. The Wöhler curves in Modell Code 2010 result in higher numbers of cycles to failure in the range of high-related upper stresses than the Model Code 1990. In the range of low-related upper stresses or rather high numbers of cycles to failure with more than log N > 8, the curves in Model Code 2010 result in a lower number of cycles to failure. As there are no test results available in the range of high load cycles that lead to failure, an approximation curve with right-side failure was prepared. The regarding figure is shown on page 13. With regard to the load application of wind turbines, the behaviour of concrete and other materials with fatigue load cycles to failure with more than 10^8 still has to be researched in detail.

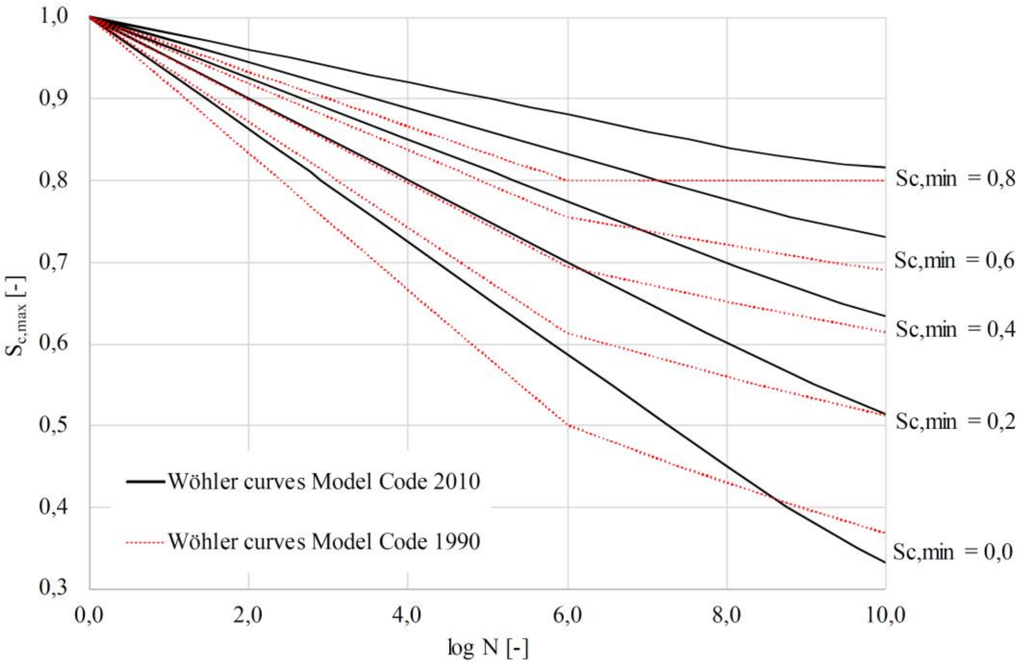

Fig. 8 Comparison of Wöhler curves in Model Code 1990 and Model Code 2010

After the new examinations were included in the Model Code 2010, it is proposed that this should be presented in the standards of Eurocodes DIN EN 1992 and the DIBt-Guidelines, as well.

The proof of fatigue is also relevant for the hybrid²-towers, because of the high load cycles of the framework construction.

CONCLUSIONS

In Germany, a special focus is put on the development of renewable energies, especially in the wind power. For the economic yield of a wind turbine, a sufficient wind speed is necessary, which can be reached in interior lands only at high altitudes. The resulting increase in hub heights of wind turbines steadily requires tower constructions that are more massive and are associated with high transport and assembling costs. This paper describes the design and construction of the hybrid²-tower and its advantages. In addition, the special problems of static calculations for the eigenfrequency and fatigue are explained in detail.

The mission statement driving the development of the new hybrid²-towers for onshore wind turbines is to optimize the performance of the supporting-structure. The new tower concept reduces the use of materials and thus the weight of the tower decreases remarkably. Moreover, the hybrid²-towers are designed to slashz the transport and assembling costs.

The hybrid²-towers are currently being developed as part of a research project at the University of Applied Sciences *Technische Hochschule Mittelhessen* together with *Oberhessisches Spannbetonwerk GmbH.* The project is funded by the state of Hesse, Germany.

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