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# Ruukki Wind towers
## High truss towers for wind turbine generators

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- **General**
  This paper describes freestanding truss-type towers for use in the construction of wind turbines. In particular, the description includes comparisons to tubular steel towers.

- **History of truss towers**
  The truss structure is a long-established technique for building very large, tall towers and has also been used for constructing wind turbines for some time.

  It is generally accepted that large transportable structures are only realisable as a truss structure. Truss towers have been around for centuries and are used in many different construction areas. Examples include observation towers, power lines or antenna support structures. A world-famous example is the Eiffel Tower in Paris. Built in 1889, it is over 300 m high and weighs 7000 tonnes.

  In the 19th century, truss towers were used widely in the USA to construct so-called western windmills for pumping water and producing electricity. Around 6.5 million of these structures were erected before 1930, most of them on a truss tower base. They were on sale through mail order catalogues and marketed as a kit for self-assembly. The truss tower was the easiest way to deliver the equipment.

Figure 1. Deutsches Museum: model of an American wind turbine

In the 1930s, Hermann Honnef designed probably the largest ever planned wind power plants, with a rotor diameter of 160 m, 20 MW energy output and up to five of these rotors mounted on a truss tower. The tower as outlined by Honnef consisted of a truss without posts and even on today's terms was of gigantic dimensions.

Truss towers were used from the very beginning in the modern wind energy industry. Notable examples include the very first prototype wind turbines in the USA such as the Smith Putnam plant with a capacity of 1250 kW, built in 1941.

In 2006, in Laasow, Germany, the highest truss tower for supporting a wind turbine with a hub height of 160 m was erected. The structure has a rotor diameter of 90 m and can generate 2.5 MW of electric power and feed this into the public network. The German company SeeBA developed the tower for a Fuhrländer wind power plant, developed and licensed by Wind to Energy (Figure 2).

As relatively small wind turbines began to be mass produced in the 1980s, truss towers became the default

Figure 2. W2E/Fuhrländer FL 2500 SeeBA tower with 160 m hub height

and tubular towers the exception. That changed quickly in favour of tubular towers as larger plants and structures began to be built.

There are several reasons for this change, but it was largely due to a desire to cut on-site installation times. The manufacture of the tubular tower had to be rationalised as a result. Experts believe that truss towers are about to undergo a renaissance, based on the assumption that plants are becoming increasingly bigger.

Ever-increasing plant capacities means larger rotors and hub heights that exceed 100 m. When meeting these specifications, the truss tower is clearly superior to the tubular tower and other designs.

Today, the root diameter of a tubular tower with 100 m hub height for a wind turbine with 100 m rotor diameter is about 4.3 m. Larger diameters, however, cannot be easily transported on public roads due to height limits under bridges.

Tubular towers much higher than 100 m require a far greater root diameter, which is a limiting factor on this method of construction. An uninstalled truss tower is not affected by this limitation.

With hub heights exceeding 100 m, the truss tower offers a clear advantage in terms of weight, negating the economic benefits of tubular towers.

- **Loads on towers**
  The loads which act on a wind turbine tower are fundamentally different from loads acting on predominantly static towers designed for other applications. The loads on a wind turbine are essentially dynamic in nature. Therefore, it is often the so-called fatigue loads that determine tower dimensions.

  The main loads come from the turbine itself and are transferred to the tower via the yaw bearing. The loads from the turbine are highly complex. For the most part, they are caused by turbulent wind acting on the rotor, but also by inertial and gravitational loads (vibrations, unbalance, gravity) and working loads (e.g. braking, activation of the generator).

  The dynamic behaviour of structural components - such as the rotor blades - plays a major role. Highly developed simulation programs are used to calculate the loads. Today, fatigue strength calculations often determine the dimensions of the individual components, including that of the truss tower.

  The truss tower has a smaller surface area exposed to the wind, but this is compensated for in the tubular tower design due to its smaller flow coefficient.

- **Dynamic behaviour**
  Wind turbine towers are usually slim built, with the result that they are sensitive to vibrations. In the designing stage, it is important to ensure the natural frequencies of the tower do not coincide with the stimulating frequencies of the machinery.

  The most important natural frequency is the first bending frequency. However, the torsional frequency and second bending frequency must also be taken into account. Distinctions are made between rigid, semi-rigid and soft tower designs. Rigid means that the first bending frequency is higher than the maximum transition frequency of the blades. Semi-rigid towers have a first bending frequency between rotation frequency and transition frequency of the blades. Soft towers have a first bending frequency of lower than rotation frequency.

  In the early days of modern wind power, rigid towers were built, which were also relatively heavy. Later financial considerations caused a switch over to semi-rigid towers, which are more or less standard today.

  Tubular towers have serious limitations for higher hub heights and larger turbines with larger head masses. It is difficult or at least very costly to produce a rigid tubular tower easily transportable by road that has a hub height exceeding 100 m, since the base diameter of the tower would be too big.

  Truss towers, for which there are essentially no limits on diameter, do not exhibit these problems. Moreover, when the height of the tower is increased, this has little affect on the natural frequency, as the tower is extended downward, where the structure is already necessarily more rigid.

  In terms of torsion, a truss tower is softer than a tubular tower and the torsional frequency often falls in the range of the stimulating frequencies. Load calculations and measurements show, however, that this rarely leads to torsional oscillations. A theoretical explanation for this is that the exciting forces and moments either have no lever arms or very low lever arms to the tower axis.

- **Types of structures**
  The possibilities are endless and varied when designing a truss tower. Numerous variations arise merely by having a different number of corner posts. Wind turbine

towers are mostly known to have 3, 4, 6 or 8 corner posts. The secondary bracing structure of the tower can also vary. There are simple or crossed diagonals, with or without an auxiliary frame. Constructions also come with or without horizontals.

Tower construction is also possible without any corner posts, as Honnef's design mentioned in the history section shows. There is also an almost limitless number of applicable steel profiles.

There are circular, square and rectangular sections, hollow sections, L-profile, angled sections, welded profiles, or combinations thereof. Several profiles are frequently combined into one diagonal or a corner post.

This flexibility in the range of variation allows optimised tower design according to the wind turbine specifications.

The design can also be optimised to meet the requirements of economy, appearance, ease of construction and disassembly, maintenance, availability of materials or profiles, life span, special climatic conditions and not least, logistics.

The suitability of a particular tower design varies depending on turbine size, hub height and other parameters.

The stresses on the corner posts are inversely proportional to the number of posts. For this reason it makes sense for small towers with low capacities to have three corner posts and for the number of posts to increase with the size of the turbine. With higher towers, it makes sense to increase the number of corner posts. High towers have large bases, making the diagonals very long and therefore heavy. Additional corner posts reduce the wall width and defuse this problem.

For turbines in the range 2-6 MW and hub heights exceeding 100 m, the conventional square truss tower made of L sections becomes increasingly complex. The cross-section of commercial L profiles is limited, so the corner posts and diagonals often have to be compiled out of more than two sections. The large wall widths in the lower part of the tower require high buckling stability, which L sections do not offer. This requirement can only be met by installing additional auxiliary trusses, additional horizontal connections or three-dimensional reinforcements.

Figure 3 Tripod tower made of tubes

Figure 4 Octagonal tower made of tubes

Ruukki has developed a new steel section for towers of this size. The result is a truss tower with 6 corner posts. This means the tower wall infill can be achieved with simple diagonals. The spire, the transition piece to the yaw bearing of the turbine consists of a short, conical tube with a nearly closed base and a flange to hold the yaw at the top of the tower. The tower stands on six separate foundations. A particular advantage of this concept is that the new sections have a higher fatigue class of joint (> / = 112 N / mm²), and because of high resistance to buckling, wide walls are permitted without the need for auxiliary trusses.

By varying the diameter and the thickness of the sections, they can be optimised to meet the static and dynamic requirements of the profile. (Figures 5 and 6).

Combining different cross-sections in a tower can prove useful and help to exploit their specific advantages. In the upper area down to just below the bend, the diameter is small and consequently there are many diagonals connected, but the beams are short and hence the buckling stability is high. In the lower area, where the diameter of the tower is larger, the buckling stability of the beams is important, but on the other hand there are fewer connections as the beams are longer.

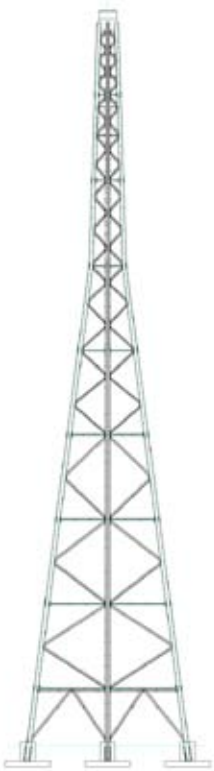

Figure 5. Corner post section as compiled hollow section.

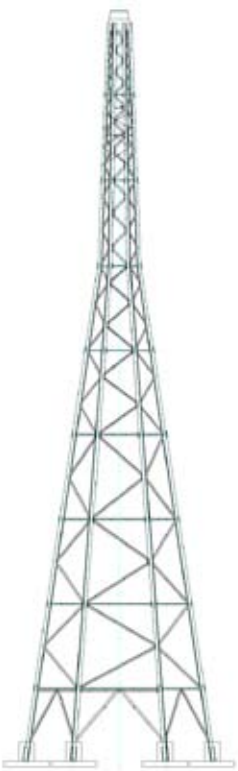

Figure 6. Infill section as compiled hollow section.

- **Connections**

  The extremely high dynamic loads on the truss tower can only be reduced by using so-called non-slip joints. The first this type of joints were carried out with hot rivets. HV screws have been also generally used. These screws are retightened over the first hours of use and then randomly inspected on an annual basis.

  A new development in the construction of wind turbine towers is the BobTail® lockbolt. These are also highly pre-stressed bolts. In simple terms, the nut is pressed onto the bolt grooves. Once done, it is impossible to loosen the nut. The tension is secured and guaranteed to remain. The bolts cannot be retightened and maintenance is not necessary. But even without unscrewing the nut, relaxation is present at every joint from where the steel has been joined together, which can reduce the preload of the locknut.

  Independent, recognised institutions are currently conducting thorough studies into the usability of bobtails. This is necessary in order to ensure a sufficient preload tension is maintained, even under the dynamic forces a wind turbine is subjected to over a life span of 20 years (Figure 7). The results of these studies are currently very promising. It is expected that this type of connection will be used to make Ruukki truss towers in the near future.

- **Protection against corrosion**

  Like any other tower, truss towers need protection from atmospheric impact. The use of disassembled steel sections means that each individual part can be protected before assembly. This process is called hot-dip galvanising. It is a standardised procedure and most of the larger companies that offer this service are certified.

  The coating thickness should be between 80 and 200 microns, but this depends upon the chemical composition of the steel. A proper zinc coating will survive the operational period of a truss tower of 20 years without need for further maintenance.

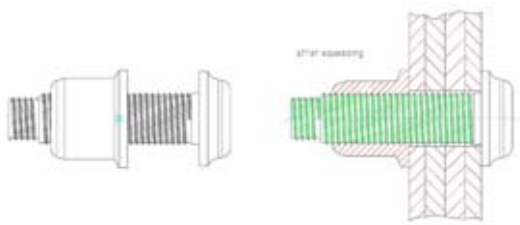

Figure 7 Huck BobTail® lock bolt

High mechanical strength hot-dip galvanising of material of appropriate thickness is the best method protecting against with regard to the issue of relaxation at the bolt joints.

- **Opportunities for the future**
  As already mentioned above, the modern truss tower presents an excellent alternative for the wind energy industry in view of the increasing size of the turbines.

  Recent developments and research have focused on special steel grades and the aim of further reducing weight by using high-strength steels. All these studies have also always had the aim of further reducing costs in order to make the provision of environmentally friendly energy as efficient as possible. Further development of this tower design must result in larger towers and fewer specific investment costs.

  The new generation of truss towers can be built on sites on which the traditional towers could not be erected. In Scandinavia, for example, wind farms are already being planned in major forested regions, where only towers with hub heights of more than 100 m make viable economic sense.

  Although markedly different to current German plans, this does open up the possibility of deploying renewable energy sources outside of populated areas. Because of its logistical advantages, the truss tower certainly has a good chance of being deployed in the near future in these wooded areas.

- **Impacts on the environment**
  There are basically no known notable negative environmental impacts which require special authorisation deriving from the deployment of truss towers.

  Electricity companies have studied sufficiently the potential consequences of leaching from the galvanised surface. No exceptional after affects are to be expected.

  The external appearance of wind turbines mounted on truss towers are still a source of discussion and criticism. Here the topic should be quickly mentioned in a value-free way for the sake of completeness.

  Environmental impacts during the production of the towers are comparable with those of other systems. Here the truss tower is advantageous as far less of the raw material steel is used in its production.

  Preliminary life cycle assessment (LCA) for the Ruukki truss tower has been conducted by an external professional organisation. Due to the lower material usage both in steel structure and concrete in the foundation, the truss tower has less environmental impacts compared to tubular steel or concrete-steel hybrid towers (Eco-Indicator 95 comparison). Hence the energy balance, the period of time when the wind power station produces the energy which is used to produce it, is shorter than in other tower concepts.

  At the end of its useful life, the tower can be demolished by current technologies and the steel components can be scrapped and recycled. Less concrete is used in the foundation than in the foundation of tubular tower concepts and the cost of reconditioning the environment will be lower.

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