Telescopic On-Shore Tower

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1. Introduction

In 2011 ESTEYCO started research activities on a disruptive solution for the substructure of offshore wind turbines and in 2013 a self-lifting telescopic tower came as a solution. Such technology was developed focusing on the capability of commissioning off-shore wind turbines and its substructures with full independence of the costly and scarce heavy-lift vessels. This technology was initially proven in 2015 with an on-shore prototype in Daganzo (east of Madrid) and again in Q2 2018 in Gran Canaria Island -first off shore WTG in Southern Europe and first in the world that does not need any significant and expensive marine means- with the construction of the self-installing bottom-fixed offshore wind turbine designed, built and certified by ESTEYCO.

Its design and construction are based on pioneering experience when it comes to conventional precast concrete towers. Since ESTEYCO's first precast concrete tower realization in 2004, more than 1600 towers for several turbine manufacturers have been built, with hub heights ranging from 80m to 120m.

Figure 1: Telescopic On-Shore Tower

The increasing hub-height demands -considering already heights from 140 to 190m- at certain wind farms, driven by challenging non-conventional renewable energy policies and a market where reduction of the CoE is the main driver, the self-lifting telescopic tower has become a key solution not only on the off-shore market but also on on-shore wind farms where large, costly and scarce cranes are no longer required when this solution is implemented.

That's the case of India, where higher and more powerful turbines are expected to appear as a way of putting down the LCoE. Dealing with such heights from 140m up, requires solutions beyond conventionalism and the self-lifting precast concrete tower by ESTEYCO is ready to face this challenge, as it is doing right now somewhere else with the design and upcoming construction of the tallest tower in the world, with a HH of 175m.

The solution, in general terms, is formed by several prismatic concrete sections which at the same time are formed by several prefabricated concrete panels V-shaped, C-shaped or just flat, depending on the case. These sections are preassembled one inside the other prior to the selferecting phase. Additionally, the most upper steel tubular section from conventional steel towers can be used combined with the previous configuration (becoming a hybrid solution) as a variable to reduce the CoE, if applicable.

The solution, patented by ESTEYCO, uses heavy-lift strand jacks always acting at a 40-50m height which are reused to lift one tower section after the other. The recoverable jacks that lift each section are supported by the one below, which also guides the hoisted section as it rises, in a self-installing procedure in which the tower itself is the only supported structure required, as stated, always working from a single access platform at 40-50m height.

2. Description of the Solution

The combination of prefabricated concrete sections with heights around 25m and steel tubular sections from conventional steel towers to shape the tower (full concrete or hybrid) depends on the overall cost analysis once the turbine is defined as a known variable.

Such analysis is based on the study of the wind farm location and the precast concrete panel's factory location (within or outside the wind farm), the lifting means to be used to manipulate the precast panels, the transport availability and restrictions between the two locations, geometrical aspects such as the blade tip and the steel sections geometry to be used, the expected production, the type of cranes available and the local costs variation (labor and materials).

On this section, and as an example, a hybrid tower for a 3.X MW turbine and 165m HH composed by 3 standard steel sections at the upper level and 4 concrete sections at the lower levels is explained.

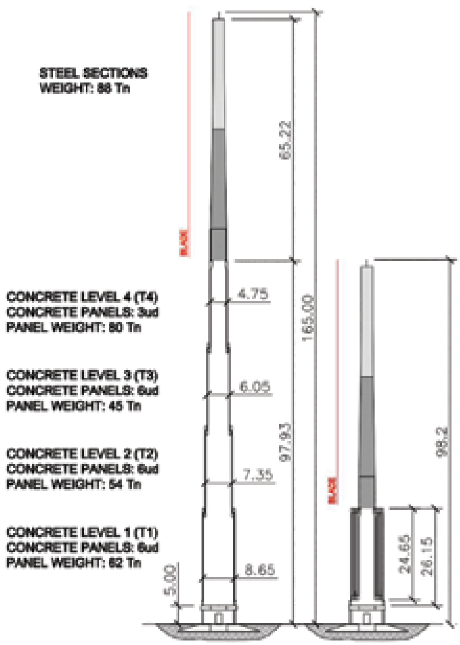

Figure 2: General view and main dimensions and weights of the tower

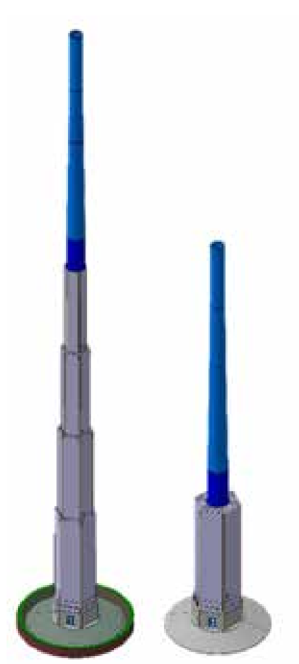

Figure 3: General views of the tower in folded position (before lifting) and unfolded position

The steel upper part contains 3 sections totaling 65m long with a bottom diameter of 4.3m.

Below the steel sections there are 4 concrete levels made up of precast concrete V-shaped panels prestressed with pretensioned bonded strands totaling around 100m with panels from 40 Tn to 70 Tn weight aprox.

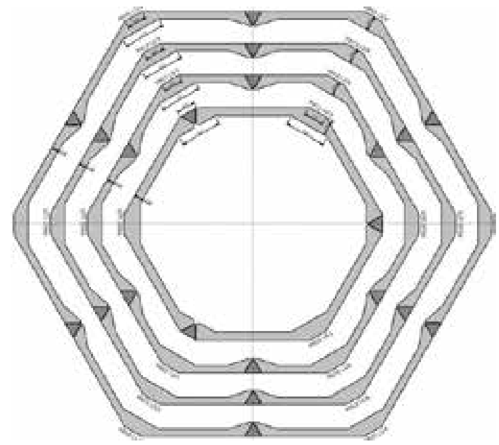

Figure 4: Plan view of different levels cross-sections

Every concrete panel has concrete flanges at both ends to enable the connection between the different sections by means of the horizontal joints.

Panels of the same section are connected by means of concrete-filled vertical joints while the connection between each section is achieved by means of a grout-filled horizontal joints with posttensioned bolts.

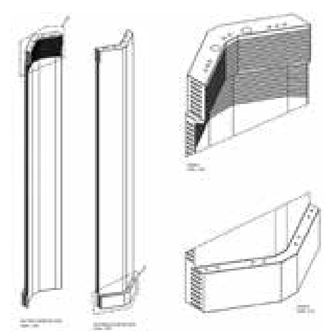

Figure 5: General view of V-shape concrete panels

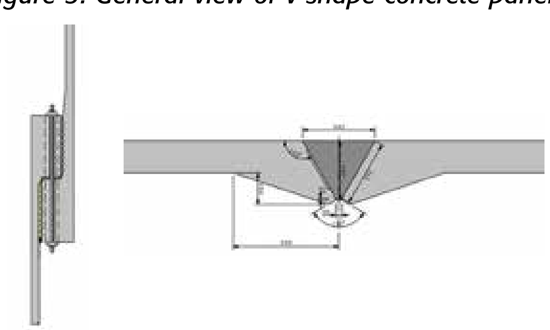

Figure 6: Joints between panels (vertical joint) and sections (horizontal joint)

As a matter of example, the next table summarizes some likely figures for a 165mHH hybrid precast telescopic tower prototype:

	Num. panels per section	Panel weight	Panel thickness	Panel length	Panel width	Panel width*	Panel volume	Section weight
T4	3	79	0.18	24.65	4.84	5.44	31.5	248
T3	6	45	0.15	24.65	2.73	3.33	18.0	295
T2	6	54	0.15	24.65	3.38	3.98	21.5	348
T1	6	64	0.15	26.15	4.03	4.63	25.5	407

* Including reinforcement bars at both sides / Weight in metric ton (T) and dimensions in meters (m)

Table with main dimensions and weights of concrete panels

3. Construction Process

The construction process of the precast concrete telescopic tower involves the following stages:

- Manufacturing of precast concrete panels.
- Transport of the panels.
- Pre-assembly of the panels, conforming levels.
- Upper steel tower, rotor and nacelles assembly.
- Self-erection system (3 lifts)

Following, all these stages are briefly outlined.

3.1. Manufacturing of the precast concrete panels

As mentioned before, the tower is composed by levels, which in turn are composed by precast concrete panels. The manufacturing of these panels is carried out on a factory either within or outside the wind farm.

Figure 7 and 8: General view of the precast panels

The manufacturing process consist of the following sub-processes:

- Reinforcing steel arrangement of the panel
- Prestressing panel system
- Panel concreting
- Painting of the outer surface (optional, as per client demand)
- Installation of temporary and permanent internal elements

The following pictures show the reinforcing steel arrangement of the panels and the concreting phase in a conventional concrete tower factory.

Figure 9 and 10: Reinforcement of the panels. Concreting of the panels

The following pictures were taken during the Off-shore Gran Canaria Island telescopic concrete tower prototype construction yard.

Figure 11: Panel handling

It is important to highlight the concepts of scalability and modularity of the factory, allowing to adapt the weights and dimensions of the panels to many different constraints and particularities (stockage capacity, transport limitations, etc…). Thus, the initial investment may be well adapted to the size of the specific project.

3.2. Stockage and Transport

After the manufacturing process, the panels are stocked inside the facilities of the factory, waiting to be transported to their final locations.

Figure 12: General view of the factory stock area

Handling of the panels within the factory is made by pairs or individual gantry cranes - depending on the available capacity- and transported to the final location thanks to conventional extensible trucks. The supporting tools for the panels are made of steel and adequately positioned for each panel dimension in the truck.

Figure 13 and 14: Transport of concrete panels with truck and dolly

3.3. Pre-assembly of the panels

As a general description, the tower pre-assembly consists of positioning the concrete panels from inside out (starting with T4 and finishing with T1) on top of the foundation pedestal slab by using a 500 Tn mobile crane or similar and specifically designed reusable tools. Once the panels pre-assembly is finished, the assembly of the steel tubular sections, nacelle and rotor takes place by using a 600 Tn crawler crane or similar, regardless of the final height of the tower, as all these installation works take place at a limited height (40-50m).

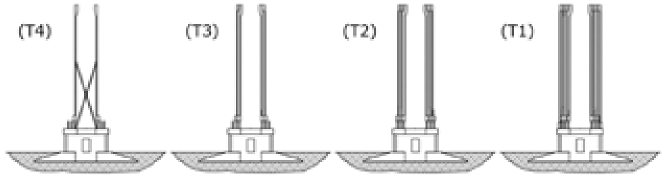

Figure 15: Concrete panels pre-assembly stages on top of the pedestal slab.(T4 stability by mans of internal tempoarary props)

The main activities included in the pre-assembly stages are as follows:

- Previous works on top of the pedestal.
- Concrete panels lifting from trucks and rotation to vertical position (T4).
- Positioning and levelling of concrete panels (T4).
- Execution of vertical joints (T4).

- Panel lifting, positioning and leveling and execution of vertical joints (T3, T2, T1).
- Filling with grout of T1 horizontal joint with the pedestal.
- Pre-assembly tools removal.

The previous works on site consist of setting up the central axis and installing the temporary supports both on the pedestal top slab.

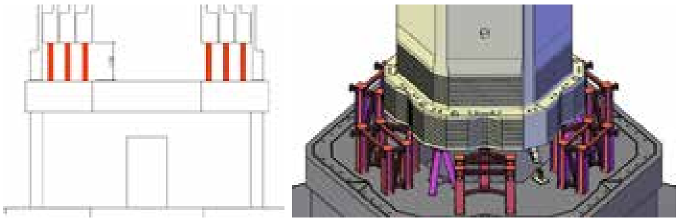

Figure 16: Temporary concrete panels support

The panels need some prior installation of internal elements such a working platform, internal props on T4 to provide stability once its panels are erected or vertical joints external jacks to keep contiguous panels vertically aligned, among others.

Figure 17 and 18: Internal elements installation (working platform and prop on T4)

The following step consists of tilting the panels to its vertical position to assemble the first tubular concrete section T4. They will be placed on top of the installed temporary supports. External vertical jacks will keep the panels vertically aligned when concreting the vertical joints.

Figure 19: Tilting of the panels

Figure 20: External jacks on vertical joints

Once the T4 section is installed, the same procedure is applied on T3, T2 and T1. The stability of the panels on sections T3, T2 and T1 is achieved by means of positioning plates attached on the upper flange of the panels connected to T4.

Once all panels are pre-assembled and vertical joints are filled, the horizontal joint of level T1 with the pedestal can be filled with grout. The bolts will be placed after T1 preassembly.

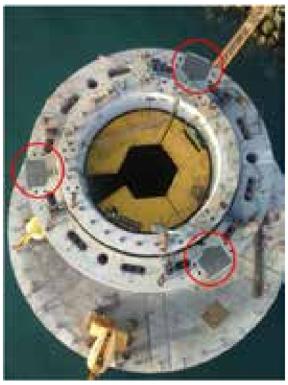

Figure 21: Vertical joints

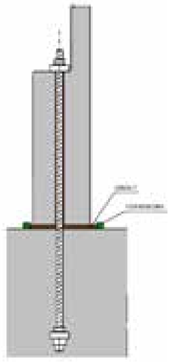

Figure 22: T1 horizontal joint

3.4. Upper steel tower, rotor and nacelle assembly

Once the concrete panels have been pre-assembled, and prior to the lifting phase, the steel segments, if existing, turbine and blades are installed. In case the telescopic tower is a full concrete tower this phase will consist of installing just the connection steel adapter, the turbine and blades.

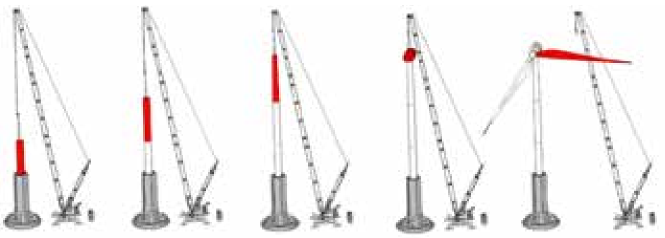

Figure 23: Upper steel tower, rotor and nacelle assembly

3.5. Self-lifting phase

Once the steel tower sections and turbine have been installed, the tower can be lifted. The key of the lifting process is the use of high capacity lifting jacks, and their efficiency for large heights allowing a much lower price than a conventional crane. This system is based on a proven technology in multiple industries, with a track record of over 30 years.

Heavy lifting is made with strand jacks that are attached to the top of the outer section of the concrete tower. All the required works are performed from a single platform, reducing the risk of personnel moving up and down.

Figure 24, 25 and 26: Stand- jack positioning

The main activities included in the lifting phase are as follows:

- Preparations of all auxiliary elements and installing jacks at T3 upper flange.
- Inner section T4 lift with jacks reacting on T3 outer section.
- Performing T4-T3 horizontal joints.
- Jack displacement from T3 upper flange to T2 upper flange (some centimeters outwards).
- Lifting of T2 section.
- Performing T3-T2 horizontal joint.
- Jack displacement from T2 upper flange to T1 upper flange (some centimeters outwards).
- T2 lift with jacks reacting on T1 upper flange.
- Performing T2-T1 horizontal joint.
- Dismantling of auxiliary elements.

On the following image, all elements installed on the preparation phase are shown. Mainly, the elements to be placed on the preparation phase are the platforms on Level 1 and Level 2, the

Figure 27: Tower lifting process

guidance system, the upper lifting kits with the strand jacks, a system to collect the strands and setting up the power system.

Once the preliminary stage is fulfilled, the three (3) lifting phases start. On the next image, the lifting phases of T3 and

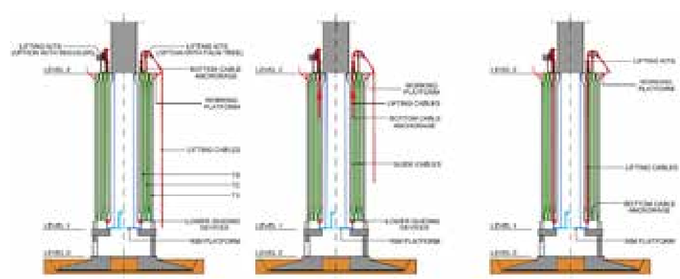

Figure 28: Auxiliary elements arrangement

T2 are shown together with the connection of each horizontal joint by means of a prestressing bars and shear keys filled with grout. The grout is poured in the keyed joint once the bars have been prestressed, adding stiffness and water-tightness to the joint and protecting the elements within the tower.

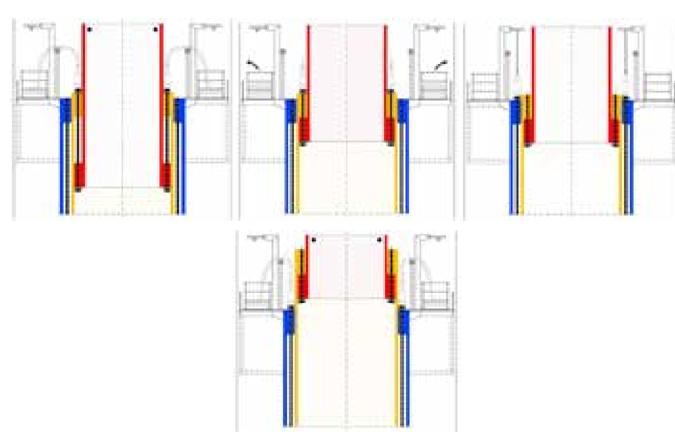

Figure 29: Stages of the lifting process: lifting, prestressing, relocation of jacks and lifting again

Once the lifting phase has finished, all auxiliary elements and lifting equipment is removed and taken to the next tower to start the process again.

4. Manufacturing And Assembly Rates

The rate at which regular height towers are generally produced in the wind energy sector is 2 tower/week. These rates haven't ever been achieved when heights go over 120-130m. However, ESTEYCO's self-lifting technology is able, after the usual learning curve that drives these kinds of processes, to get very close, providing construction schedules that may fulfill even the most challenging projects.

4.1. Manufacturing rates

Considering the on-shore telescopic tower prototype, the number of panels per tower required would be 21 (3 panels for T4 and 6 panels on T3, T2 and T1). A factory with a serial production of 21x2 panels/week would require two parallel working lines with one mold for each type of panel on each working line.

4.2. Pre-assembly rates

The pre-assembly procedure considers a group of 3 towers where specialized teams perform the same activity on each tower in a "batch working" manner instead of a "one-piece working" manner. This system provides 3 preassembled towers every eighteen working days (3x6-day weeks). A 2 tower/week schedule would just need to double the rate during half of the time, without impacting in the unitary cost.

4.3. Steel upper segments, rotor and nacelle assembly rates

This phase will be performed right after the pre-assembly phase once every tower is fully preassembled. In a same "batch working" manner, a cluster of three towers would be operated together to avoid changing crane configuration to place all steel elements one after another on one single tower.

4.4. Self-erecting phase

Following the same approach as the preassembly procedure, the self-erecting phase consists of a production of three towers every eighteen working days (3x6-day weeks) with 3 lifting sets. As a reference all the previous works prior to the first lift take 2 days, each lifting phase takes 1 day, and activities related to the horizontal joints execution amounts 2 days per horizontal joint.

5. Enhancement. Precast Braced Foundation Posibility of Use

Driven by the reduction of the CoE, Esteyco came up with the braced foundation patented solution where quantities of materials are reduced up to 40% for concrete and up to 25% for steel leading to overall cost reduction up to 10% depending on the case.

Figure 30: Braced foundation 3D

This solution brings not only a CAPEX reduction but also an increase of the AEP since the foundation geometry rises the pedestal up to 6m maximum above the ground level and hence the hub height for a defined tower. With a hub height increase and a favorable shear gradient the AEP can be increased by 1-3%, depending on the wind shear of the specific location.

Based on the assumption that the tower door is placed on the foundation itself, the general geometry of a braced foundation compared to a conventional foundation for a precast telescopic tower is shown next.

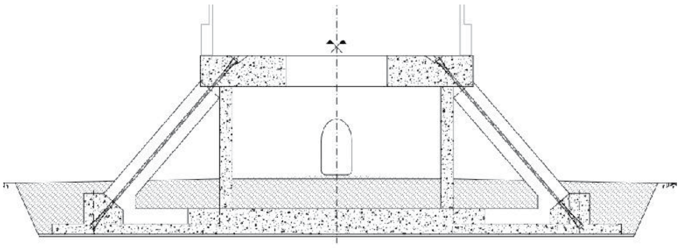

Figure 31: Braced foundation for a telescopic tower

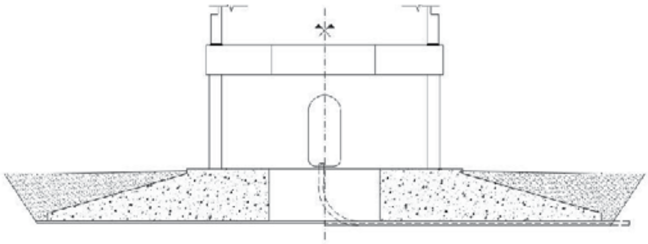

Figure 32: Conventional foundation for a telescopic tower

6. Conclusions

The self-lifting telescopic tower is ready to enter in wind energy markets as India, where a tight competition brought by the auction system is currently taking place. This technology will make possible to reach hub heights not even considered so far, as a result of the avoidance of big and expensive assembly cranes, since not only the tower but also the turbine is installed at a very reasonable height. The technology is available for every turbine manufacturer or developer willing to go beyond the current limits, putting down the LCoE to the greatest extent, thus maximizing the profit of the project.