Using Concrete Wind Turbine Towers in Caribbean

Zaffar Khan, Ph.D.
Atiyyah A. Khan, CEM,
Avinash Omadath, CEM

ABSTRACT

Trinidad and Tobago has been adversely impacted by an economic downturn resulting from depressed oil and gas prices. The country, once a net exporter of oil, must now import oil to provide fuel for its vehicles and industries. This contributes to the country's acute foreign exchange problem. The country is also experiencing a natural gas shortage causing curtailments for liquefied natural gas (LNG). A notable amount of natural gas is used for power generation. Moreover, the petroleum industry which includes multinational corporations, state-owned oil and gas companies plus foreign and local service companies, has reduced their total employment.

One solution is to use renewable energy, particularly wind and solar power, to generate electricity. This has promising benefits as the country's gas reserves can instead be used for exportable petrochemical products to generate foreign exchange.

An issue with developing wind power is the greater cost of steel towers and their shorter lifecycle. This article proposes the use of locally manufactured precast concrete towers for wind turbine generators (WTGs) rather than using imported steel towers. This article explores the benefits and disadvantages of this option from the following perspectives:

- Using local resources, labour and raw materials
- Engineering design considerations
- Transportation considerations
- Costs and economic considerations

INTRODUCTION

Caribbean island nations have for many years been at the mercy of fluctuating oil prices, cost for power generation, the pollution using oil creates and oil's inherent inefficiencies. In countries such as Jamaica, electricity prices have risen above US$0.30/kWh. These high prices have stifled growth, created inflation and reduced the attractiveness of such countries for tourism and investment. The costs of hospitality sector services have increased and many tourist destinations have become less attractive. People in these oil importing countries are economically disadvantaged compared to non-oil importing countries due to the higher costs of fuel and electricity.

One solution being considered by many of the oil importing countries is to use renewable energy which includes developing wind farms. One of the major concerns of technocrats and economists with regard to wind farm development is that most of the components must be imported. Typically, only the site development and foundations use local materials.

This article explores the feasibility of the production of wind turbine towers in Trinidad using greater than 90% local engineering and components. WTG assemblies are usually supplied by companies selected by the wind farm developers. Towers are manufactured in sections of rolled and welded steel plates of varying thicknesses. These are usually sand blasted, primed and painted with epoxy- based paints to reduce maintenance costs. One drawback of steel towers is that they typically have a shorter life cycle than those made of concrete and often require greater maintenance. Not only are steel towers more costly than those made with concrete, but more disruptions in operation are required for periodic maintenance. For these reasons, this article proposes the use of locally manufactured precast concrete towers for wind turbines.

CONCRETE WIND TURBINE TOWERS

Figure 1 shows a typical design of a concrete tower for a horizontal axis 2.0 MW wind turbine. The foundation uses a concrete pad footing with or without piles depending on loads and soil conditions. The tower is constructed of precast sections which are appropriately sized for the logistics of shipping, handling and site installation. This tower design is tapered, wider at the base than the top. Sections are connected using single or multiple strand elements which are laced through ducts in the precast sections, anchored from tip to base using special locks, coupled, post tensioned and grouted. This creates a post-tensioned concrete WTG tower.

At the top of the tower there is a connection plate (steel stub) or mounting pad to which the turbine and gear assembly are mounted. The hub and blades which rotate to drive the turbine are subsequently mounted onto the structure. The precast, post-tensioned concrete tower

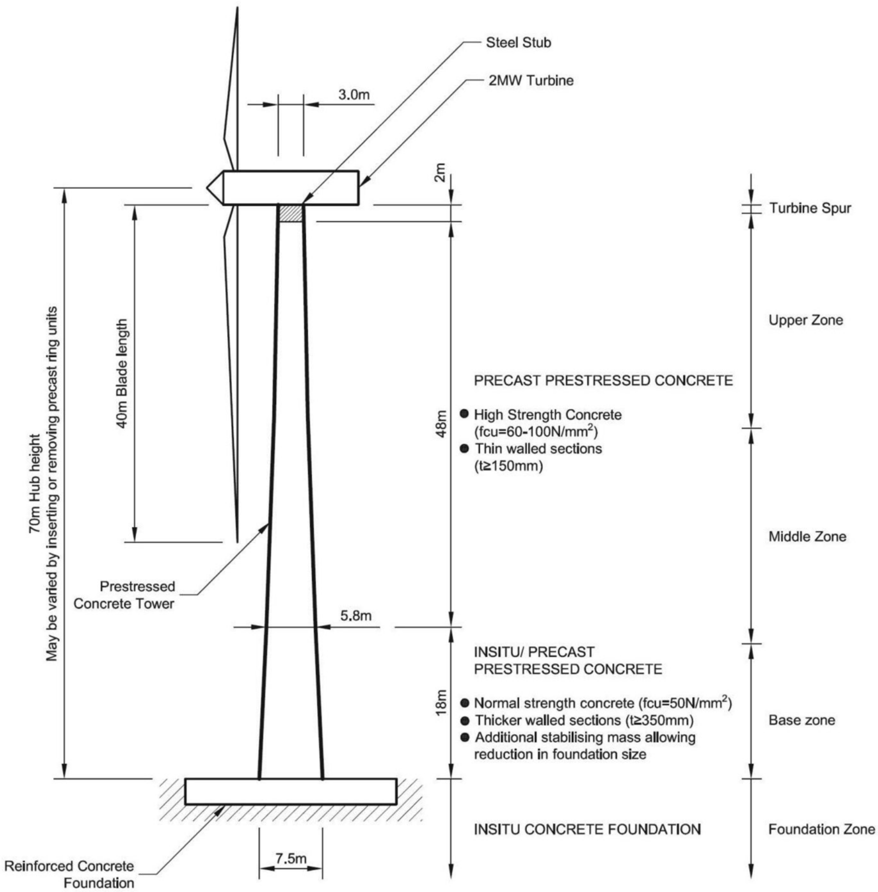

Figure 1. Typical design of a concrete tower for a horizontal axis 2.0 MW wind turbine.

is hollow on the inside to allow for the lift shaft to fit on the inside of the tower section for worker access to the nacelle for inspections and maintenance.

There are two ways to manufacture concrete tower sections depending on the quantity needed and level of repeatability required. One method involves the construction of vertical forms set to specific heights. After the concrete hardens, the forms are stripped from the inside and outside leaving a hollow concrete section. The other more costly approach involves constructing sections of horizontal cylinders which are filled with the required amount of concrete and spun at a predetermined speed to push the concrete towards the circumference of the form, leaving a void in the middle. This void becomes the service shaft to access the tower.

The concrete sections for a 7.5m diameter tower base (see Figure 1) cannot be rotated on a spinning mold because there are inland transportation restrictions on clearance height for highway transport. This can be mitigated by producing these sections at an industrial site near an existing port (e.g., Point Lisas of Labidco) where there are no height restrictions. The wider base section of the tower would be cast in half sections which would then be joined on site by post-tensioning steel reinforcement bars along the circumference.

Concrete has high compressive strength while steel has high tensile strength. Steel reinforced concrete structures take advantage of these characteristics. Figure 2 shows how the steel strands are held in place at the end block of the form for each section. The stressing of the strand (pulling on each strand with a predetermined force) occurs prior to placing concrete in the form. As the concrete hardens, it achieves strength sufficient to withstand the compressive forces induced by the strand and to tightly grip the strands, holding them in place. The strands are cut at the ends of the forms therefore transferring the force from the form work to the concrete section. These forces are transferred along the vertical axis, providing greater flexural strengths than would be possible if conventional reinforced concrete was used.

Constructing the tower in pre-stressed sections using cements other than conventional Portland cements reduces process carbon emissions by 25% to 50%. This is accomplished by using Pozzolanic cements or cements which contain ground granulated blast furnace slag and fly ash, both being recovered waste materials from steel plant blast furnaces or coal process energy plants. While Pozzolanic cements produce concrete with a life expectancy of over 50 years, concrete in structures with ground granulated blast furnace slag and fly ash can produce concrete with life expectancies of 75 to 100 years.

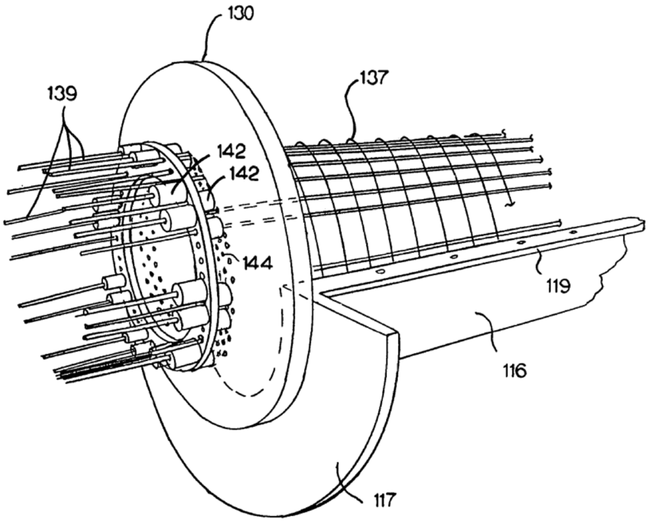

Figure 2. Design of the pre-stress strands at the end block [2].

The cost effectiveness of concrete towers far surpasses that of steel towers since concrete towers have a longer life cycle and are less expensive to maintain. While the lifecycle of WTGs is about 25 years, concrete towers can remain in place for longer periods with newer generators and blades installed as the older ones are replaced. This greatly reduces the life-cycle cost of the towers and increases the feasibility of replacing the WTGs. In the maritime and salty air of the Caribbean, maintenance for periodic onsite repainting of steel towers is costly and disrupts generation potential. Concrete towers also transmit less noise and vibration, are less prone to swaying in heavy winds, and have a greater load bearing capacity. Table 1 shows the parameters for the proposed tower.

Table 2 provides a cost estimate for the concrete components and freight to transfer the products to most Caribbean destinations (US$75 per Mt).This assumes that the cost of pre-stressed concrete to the manufacturer is US$ 0.10/kg. Using a 100% mark up for the initial cost of the concrete forms, the sales cost would be US$0.20/kg or US$200.00/Mt.

Including insurance and freight (CIF), the concrete towers cost US$742,511 each. With the extra cost of cranes and assembly estimated

Table 1. Precast concrete wind turbine tower design.

Description	Quantity (meters)
Height of tower	70.0
Wall thickness of base section	0.35
Wall thickness of top section	0.25
Diameter at base	7.5
Diameter at top of base section	5.8
Outside diameter at base of top section	5.8
Outside diameter at head of top section	3.0
Height of top section	48.0
Height of base section	18.0

Table 2. Estimated cost of the concrete components.

Description	Quantity	Units
Volume of concrete per tower	1,125	CuM
Total weight of components	2,700	Mt
Cost per Mt of precast concrete	$200	US$
Total cost of components	$540,008	US$
Cost of freight (each)	$75	US$
Total cost of freight	$202,503	US$
Total cost with insurance and freight	$742,511	US$

to be 50% more, the total cost for each concrete tower is estimated to be about US$1,114,000. One manufacturer, Spancast Caribbean Limited in Arima, Trinidad, was contacted and confirmed that their plant and operations can be configured to produce these concrete towers.

Table 3 shows the costs of steel towers assuming that the fabricated tower would cost US$2,500 per tonne using 50mm thick epoxy coated steel plate.

Table 3. Estimated cost of a steel tower.

Description	Quantity	Units
Total weight of steel towers	561	Mt
Cost per Mt of fabricated steel tower	$2,500	US$
Total cost of components	$1,402,500	US$
Cost of freight	$75	US$
Total cost of freight	$42,075	US$
Total cost with insurance and freight	$1,444,575	US$

Based on these initial calculations the cost of concrete towers is US$1,113,800 while the steel towers are US$1,444,575. Concrete towers are therefore less expensive.

CONCLUSIONS

Depressed oil and gas prices coupled with a natural gas shortage have adversely affected Trinidad and Tobago's oil and gas-based economy. A proposed solution is the construction of wind turbines to generate the country's electricity, thereby offsetting the local use of the reserves.

Of the two options for building the wind turbine towers, the advantages of a concrete towers far surpass that of steel towers. Concrete towers are better suited to the weather conditions of the islands and have greater load bearing capacities. Local companies are capable of constructing concrete towers. Compared to steel towers, concrete towers are more efficient, reduce vibration, require less maintenance, and experience less downtime. The initial cost of each 70m high concrete tower is only 77 % of the more expensive steel tower. The lower initial costs plus the concrete tower's longer lifespan, means that concrete towers have a lower life cycle cost than steel towers.

References

[1] Miceli, F. (2016). Wind farms construction. www.windfarmbop. com (accessed 5 March, 2016).
[2] Foust, E. et al. (2008).Method for making multiple part concrete pole. Patent U.S. 7343718 B2.
[3] Precast/Prestressed Concrete Institute (2016). https://www.pci.org (accessed 5 March, 2016).
[4] Portland Cement Association (2016). http://www.cement.org (accessed 12 March 2016).
[5] World Steel Association (2012). Steel solutions in the green economy: Wind turbines.
[6] Casey, T. (2015). Warren Buffett gives a gigantic concrete wind turbine tower to Iowa.

ABOUT THE AUTHORS

Zaffar Khan is director for the MBA program in sustainable energy management at the Arthur Lok Jack Graduate School of Business, University of the West Indies. He completed the executive education program in competition and strategy at Harvard Business School. He has won several international awards including the Individual Achieve-

ment Award 2014 from the Energy Institute of the UK and the Energy Professional Development Award for Latin America from the AEE in 2015. He also won an award for academic and applied research from the Accreditation Council of Trinidad and Tobago in 2014 and 2015. He is a senior member of the AEE, vice president of the Trinidad and Tobago Chapter of the AEE as well as the vice president of the Energy Institute, Caribbean. Email: zaffar.khan@fac.gsb.tt.

Atiyyah Khan is currently a consultant with Econsultants Trinidad Limited. She holds a Bachelor of Science degree in mechanical engineering from the University of the West Indies and a Masters in industrial innovation entrepreneurship and management from the University of Trinidad and Tobago. She is also an AEE Certified Energy Manager. For the past seven years she has been a lecturer with the Ministry of Education in Trinidad, teaching physics and mathematics. Email: Atiyyah@gmail.com.

Avinash Omadath, an engineer by profession, passed the CEM exam in 2015. He holds an MBA in sustainable energy management from the University of the West Indies, Arthur Lok Jack Graduate School of Business. Mr. Omadath is an adjunct faculty member in the department of engineering, University of Trinidad and Tobago.