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Feasibility and Advantages of the Space Frame Wind Turbine Tower at 100 and 125 Meters in Deep Water Offshore Wind Farms

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ABSTRACT

The land based space frame tower is considered for use at deep water offshore sites. Two tower heights up to 125m and water depths up to 54m were considered. Linear wave theory was used to calculate the wave loading. A finite element model of the tower with the wind and wave loading superimposed predicts a required member size increase of 35% for 125m to be used in 54m water. The use of at offshore sites presents possible significant reductions in marine segment weight compared to other offshore foundation techniques.

INTRODUCTION

In order to initially determine the feasibility and potential advantages of using the land based tower developed by Wasatch Wind, an analysis of the offshore loading was performed. The load calculation assumes a linear wave, breaking waves are not considered in this analysis. Comparisons were then made between the above mentioned tower at both 100m and 125m in tower height, to currently used and or conceived offshore tower techniques. A description of the at the two heights mentioned above is shown in Table 1.

Table 1: Land based tower details.

Tower Height (m)	Base Diameter (m)	Tower Mass (10^3 kg)
100	9.5	102.6
125	12.1	126.8

An extreme wave [1], extreme wind condition was assumed for the analysis. Table 2 shows the analysis conditions used for both the towers considered. The wind speed shown is at the hub height. Since the intent was to analyze the towers in the deepest water depth possible, the mean sea level (MSL) for each tower height was maximized by assuming the minimum allowable clearance between the rotor blade and the peak wave to be 16m. See Figure 1 for illustration.

Table 2: Wind and wave parameters used for analysis

Tower Height (m)	MSL (m)	Wave Height (m)	Wave Period (s)	Wind Speed (m/s)	Rotor Dia. (m)	Clearance (m)
100	29	9.7	11	64	90	16
125	54	9.7	11	64	90	16

The scope of the analysis is as follows:

- Determine peak wave and wind loading on the tower
- Determine required increase (if any) in member sizes for the land based tower design to handle offshore loading.
- Compare space frame tower to current offshore tower techniques
- Determine feasible corrosion control techniques for offshore use

Figure 1: Illustration of sea and tower parameters

WAVE AND WIND LOADING

The wave and wind loading were determined using the parameters from Table 2 above. The peak wave and peak wind were assumed to occur instantly and in phase. The wave loads on the submerged tower section, the wind loads on the above water tower section, and the tower top loads from the turbine were then statically superimposed on a finite element model of the tower to determine component loading.

Wave Loads

Linear (Airy) wave theory was used along with Morison's equation to calculate the wave force on the submerged tower section. The values used for C_D and C_M, for use in Morison's equation, were 1.0 and 2.0 respectively [2]. Table 3 shows the total calculated wave force on the submerged section for the two water depths considered. Tower dynamics were not considered for wave load calculations. This was done for simplicity and because the wave period of 11s is much greater than the tower natural bending period of 3.33s.

Table 3: Total calculated wave load on submerged tower section

Hub Height (m)	MSL (m)	Total Wave Load (kN)
100	29.3	610
125	54.3	889

Wind Loads

Wind loads were determined from a ten minute, IEC Class 1a EWM time series using a 3MW turbine with a 90m rotor diameter. Turbulent inflow was used, therefore, unlike the wave load calculation, the wind loads take tower dynamics into account. The peak, time coincident tower top loads were extracted from the time series. The loads were extracted at the time when F_{res} was maximized. The wind loading on the above water tower section was calculated at a wind speed of 64 m/s.

Finite Element Results

As mentioned earlier, the wind and wave loads calculated above were superimposed on a finite element model of the tower and the static response was calculated. The loading in the primary tower members (longitudinals and helicals) was compared to the load bearing capacity for these members. From these results, the required increase in member size was determined. Figure 2 shows a finite element plot of the member loads in the tower under the superimposed wave, wind, and turbine loads. Table 5 lists the required member size increase for the loading calculated above.

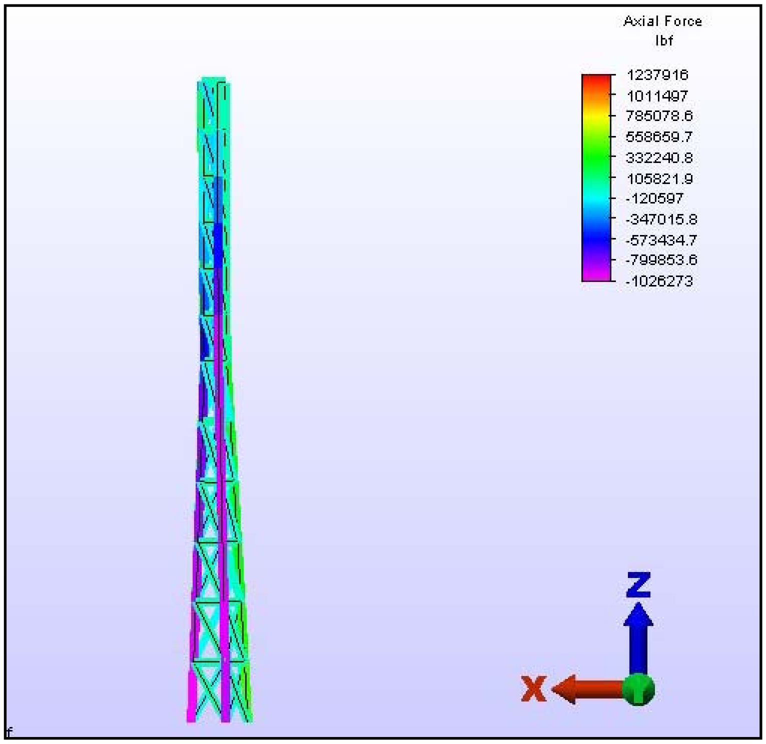

Figure 2: Finite element results showing member loads

Table 5: Percentage increase in member size for offshore loading

Tower Height (m)	Longitudinal Members	Helical Members
100	0%	0%
125	35%	5%

OFFSHORE MARINE SEGMENT COMPARISON

The marine segment of an offshore wind turbine is defined as the portion of the tower structure that lies between the sea bed and the sea surface. The actual foundation is defined as the portion of the structure that contacts the sea floor [3]. The proposed marine segment of the space frame tower is compared to the monopile and tripod marine segment structures from [3].

The author in [3] presented possible required marine segment weights for use with 6 MW turbines in 21m MSL. These weights are compared with the marine segment weight in Figure 3. Note that the marine segment weights cited in [3] have been scaled appropriately to compare with the at 3 MW and the water depths analyzed. Also, the weights shown have been adjusted to reflect the member size increase determined above.

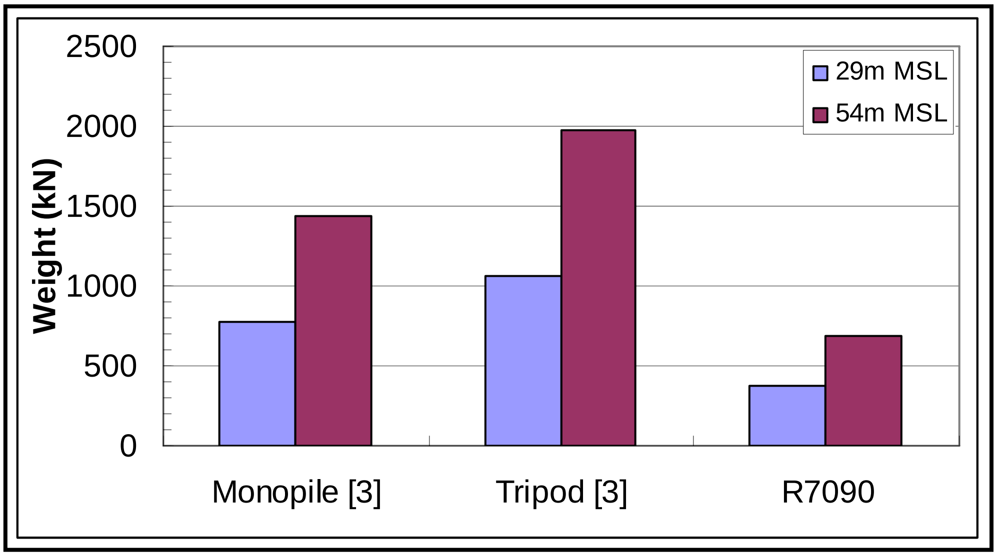

Figure 3: Marine segment weight comparison; monopile and tripod weight have been scaled for proper comparison. R7090 is the Space Frame

Of the various existing foundation types, the would be suitable for use with gravity base, tripod (multipod), and suction buckets. No design or computational analysis has been done on any of these foundations coupled with the , this analysis is solely qualitative.

For use with a gravity base, the could attach directly to the concrete base as shown in Figure 4. Since the is five sided with five primary load bearing chords, a pile could be attached to each of the chords at the base of the as an alternative to a tripod used for tubular towers. This is illustrated in Figure 5. Suction buckets could also be attached to the in a manner similar to that shown in Figure 5 for the piles.

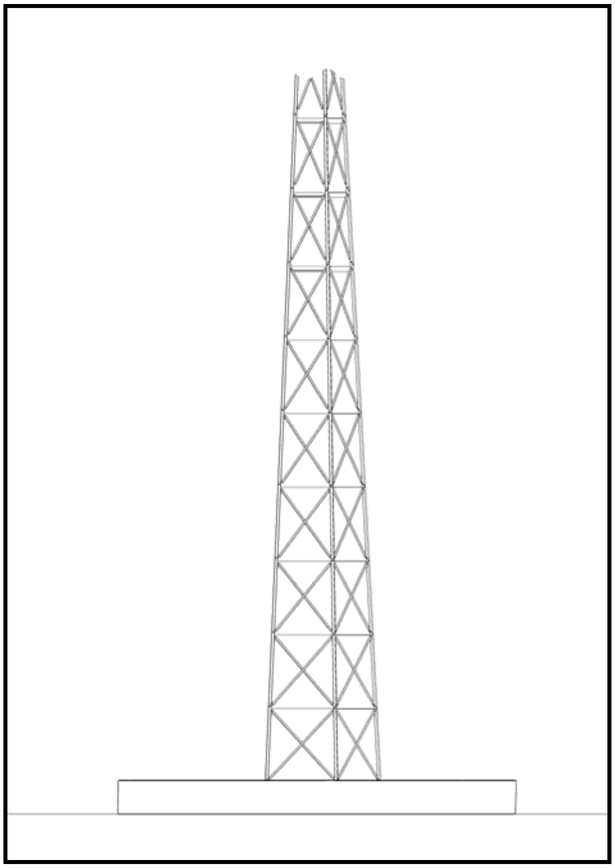

Figure 4: Space frame mounted to gravity base on sea floor.

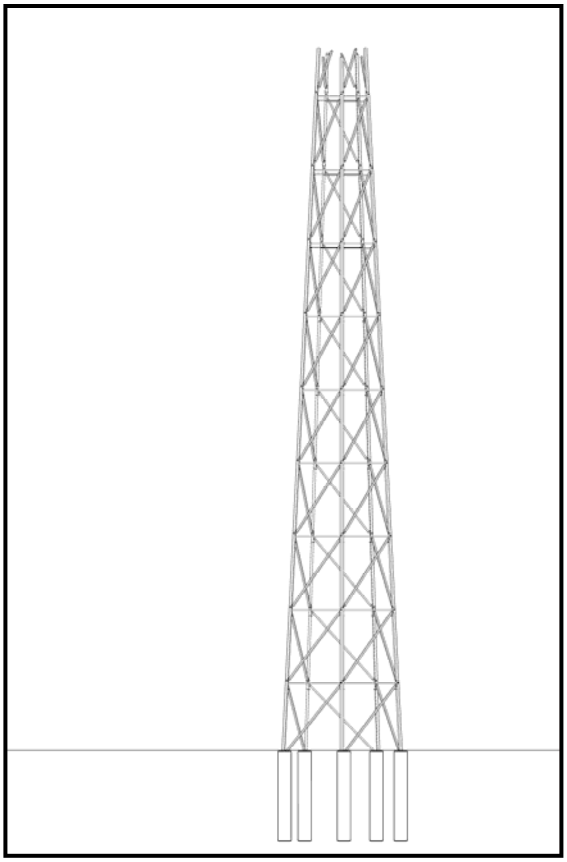

Figure 5: Space frame attached to piles in the sea bed.

CORROSION PROTECTION

A major concern in using the Space Frame for submerged offshore applications is corrosion. It is intended that offshore use of would comply with all applicable corrosion control standards such as [4] and [5].

In general, permanently submerged structures are protected using a cathodic protection system and structures in atmospheric zones are protected with an appropriate metallic coating [6]. The Space Frame would deploy a cathodic protection system based on sacrificial anodes to protect the portion of the tower below MSL. This would require a welded connection to an anode for all load bearing structural members below MSL or verification that the electrical resistance across each structural connection is less than 0.10 Ohm [5]. An appropriate coating system could be designed to protect the portion of the in the splash and atmospheric zones. The combination of both cathodic protection and a coating system could be used where needed [6].

CONCLUSIONS

Considering the simultaneous occurrence of a peak, non-breaking wave of 9.7m and an extreme wind speed of 64 m/s, the wind and wave loading on the space frame in 29m and 54m water depths was calculated. Statically superimposing the loading on a finite element model of the tower shows that a 35% increase in longitudinal member size is necessary for the at 125m height in 54m water depth. With this increase accounted for, the marine segment of the shows as much as a 65% weight reduction verses the monopile and tripod marine segments cited in [4]. Significant cost and fabrication advantages could be realized by using the Space Frame in conjunction with a gravity base, multi-pile, or suction bucket foundation. Corrosion control could be accomplished using standard cathodic protection system and metallic coating techniques.

REFERENCES

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