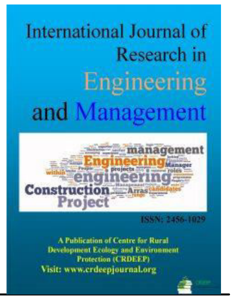
Vol. 4. No. 2. 2020

Contents available at:

www.crdeepjournal.org

International Journal of Research in Engineering & Management (ISSN: 2456-1029)(SJIF: 2.228)



<u>Full Length Research Paper</u>

Behavior of Tension Leg Platform Wind Turbine Subjected to Environmental loads

Oliver Sadek Helmy Sadek[1], M. NourEldin S. Fayed[2],H. A. M. Elarabaty[3],S. Y. Aboul Haggag[4]

[1]*Post-graduated student, Structural Engineering Department, Faculty of Engineering, Ain Shams University,Egypt.*
[2]*Professor, Structural Engineering Department, Faculty of Engineering, Ain Shams University,Egypt.*
[3]*Professor, Structural Engineering Department, Faculty of Engineering, Ain Shams University,Egypt.*
[4]*Associate Professor, Structural Engineering Department, Faculty of Engineering, Ain Shams University,Egypt.*

ARTICLE INFORMATION

Corresponding Author:
Oliver Sadek Helmy Sadek

Article history:
Received: 30-11-2020
Accepted:05-12-2020
Published: 11-12-2020

Key words:
TLP:Tension Leg Platform; WT:Wind Turbine; LAT:Lowest Water Level ;HAT:Heighest Water Level; MSL:Mean Sea Level; AM:Added Mass; RD:Radiation Damping

ABSTRACT

Wind turbine structures are projected to many types of environmental loads. These environmental loads are implemented in this paper and A literature review is done for successive papers, and theses to be able to have a line of research concerning the TLPWT structures and TLP structures for any other purposes. Books are been implemented to the literature review to be able to understand offshore structures' concepts, structural dynamics effect on a structure, different effects of environmental loads on offshore structures, and the main concept of TLP structures. The effect of these environmental loads and other loads is calculated by many references and collected by the author. Also, some of these loads are not effective, these loads and the reason for in-efficiency is implemented by the author. A model held by the ANSYS AQWA program is done by the author to apply these loads on the model, a parametric study is done to know the effect of changing the pontoon's length on the hull's structural properties.

Introduction

In Egypt, there are many environmental challenges nowadays, one of these challenges is generating electricity, as the El-Nahda dam will reduce the amount of electricity generated through the high dam at Aswan, which means that the clean electricity generated by the renewable energy sources will decrease, increasing the required quantity to be generated by the non-renewable resources. The other way to generate electricity safely and economically is by using wind turbines like the ones existing at El-Zaafarana. But constructing wind turbines on land does not make the maximum usage of this land, especially that the place of these turbines should be near the seashore where hotels and resorts may be built to encourage tourism. So, the other alternative is to construct these turbines in the sea, not on land. These wind turbines need a structure of an offshore tension leg platform, which will be discussed in this paper, to be able to generate electricity using a renewable energy source without using a great land space.

Loads acting on the hull

The loads acting on the hull which generates internal forces, resisted by the hull.

Permanent loads

The loads acting with the same quantity and almost constant.

Own weight

The own weight of the TLPWT consists of the structure's dead load which includes hull and tendons, weight, and facility dead load which includes a wind turbine and electrical cables' weight.

Buoyancy force

Due to the difference in the pressure between one point to another, there is a buoyant force exerted on the body. This force exists in any fluid, even air (but with very small negligible value). The pressure at the bottom of the body will be more than that at the top of the same body by the value this value will affect the cross-sectional area of the body by an upward force. This force is exerted on anybody discarding its position on the fluid, floating or submerging, or even sinking. This force would be equal to the weight of the replaced liquid by the body.

Live loads

Simply live loads acting on the hull are the technicians' weights. Which is comparable to other loads, significantly small. Also, this load will act only during construction and maintenance, but it must be taken into consideration.

Environmental loads

The environmental loads consist of all phenomenon which may act upon the structure affecting the design concept. Including loads from above and below water level. The criteria for calculating the applied environmental loads differ from the ordinary criteria by calculating loads for 1 or 2 years. While designing an offshore structure, environmental loads applied are the maximum or critical loads among 100 years period.

This criterion helps to get the design to be more conservative to be stable and safe among future unknown (predictable) environmental loads and decrease the risk of failure due to unpredictable environmental loads.Figure 1Environmental loads acting on TLPWT structure introduces the types of environmental loads acting on the structure.

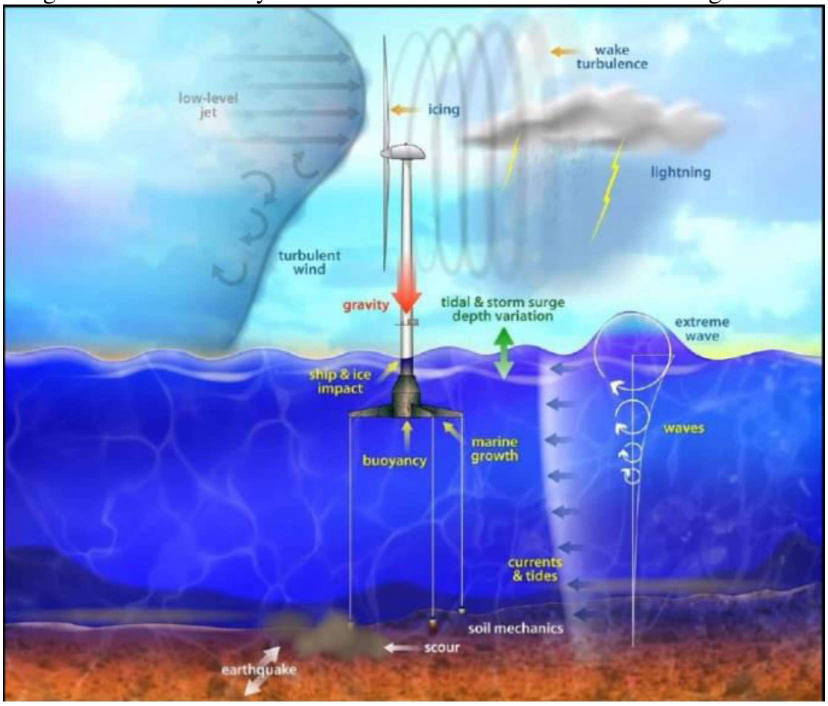


Fig 1 Environmental loads acting on TLPWT structure (Dykes et al. 2011)

Wind load

Wind load must be discussed twice. Once acting on the wind turbine, the other acting on the TLP structure. To calculate the effect of wind load on the structure, the designer must know first the wind velocity at different heights of the structure and the wind turbine blades. As the wind pressure is directly proportional to the square of the velocity at any level. The wind load direction is mainly in the x-axis, surge direction to maintain the maximum usage for the wind turbine. But due to wind direction difference from time to another, wind force may act on the structure by an angle not equal to zero from the surge direction.For the application of the wind effect on the structure, there are two methods to apply the wind. First is applying it as constant speed and direction by taking the 1-minute average values, this method is less accurate, but may be used if it is set to be more conservative. Second is applying a steady component using a 1-hour average speed adding to it a component of time which is a variable calculated from an empirical wind spectrum. The wind spectrum method is more accurate, so it is preferable in this paper such that the wind is the master key of the TLPWT structure. Two wind spectra are introduced, Norwegian Petroleum Directorate and American Petroleum Institute. Such that they are the most popular petroleum companies generating equations and validating them experimentally.(Perdana 2018) These wind spectra are then applied as energy exerted on the whole structure which is more accurate than applying a uniform or linear distributed wind.

Wave load

Simply, after recognizing wavelength and period. Wave equation may be applied to know the height of water every second. This might be not so useful as we must deal with the peak values. But the need is not for the value given from the wave equation as it is the derivative of the wave equation itself concerning time to get the wave velocity and getting its derivative concerning time again to get the wave acceleration at any time and position to get through it finally the wave force acting on the hull. The elevation of any point at any time is not due to one wave motion, but maybe several wave amplitudes and directions form this elevation. There is a big difference between swell and wave loads; swell is defined as waves originating from a distant area and being no longer under the influence of wind forcing.(Rosenthal n.d.) While waves occur due to wind motion; this is the known wave load. While there is a big difference between swell and wave loads, designers study wave loads and neglect swell loads as it is small compared to wave loads and it can be taken within wave loads during calculations or testing. Wave is simply a movement of the water particles in a vertical direction because of wind, volcanos, earthquakes, or any other environmental causes. Wave theories must apply the wave continuity equation, which means that the water is in a steady-state process, such that the total mass introduced and extruded from the system are equal. The general wave continuity equation is as follows:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho V) = 0$$

Such that;

ρ is the water mass density,

V is the water velocity,

$\nabla$is the divergence operator defined as follows:

$$\nabla = \frac{\partial}{\partial x} i + \frac{\partial}{\partial y} j + \frac{\partial}{\partial z} k$$

The wave theory aims to identify wavelength, velocity, acceleration, and dynamic pressure. There are different types of wave theories, the main difference between theory and another is the degree given by the theory. Such that, the simplest theory given is the linear wave theory called Airy's theory, then the higher degree theories are Stoke's wave theory, Solitary wave theory, Cnoidal wave theory, Dean's stream function theory, and Numerical theory by Chappelear. Figure 2Different types of waves(Pham 2005) shows the different main types of wave theories.

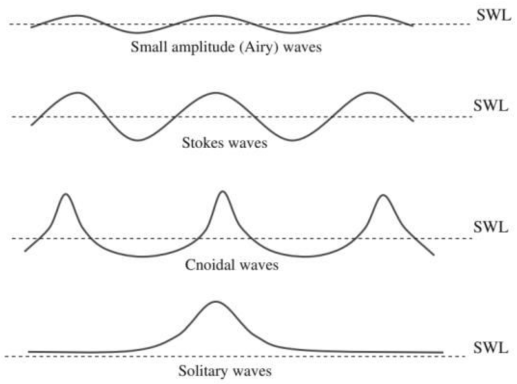


Fig 2. Different types of waves

Current Load

Current is a load exerted from moving water particles horizontally, it is a rare uniformly loading. The load is due to the velocity of the particles which is directly proportional to the height of the point from the seabed, such that the current load decreases while moving downwards to the seabed and is maximum at the water sea level. This load may cause scour if the current doesn't reach zero at the seabed. Many types of current loads can occur at the same place and time, so the superposition of all these loads can get finally a current profile which is may be represented by a function of depth giving velocity and direction of the total current profile.The two main types of current load are differentiated by shallow and deep water, such that the shallow current is caused due to the wind, tides, and the earth rotating motions, while the deep current is caused due to temperature difference, density, and salinity of seawater. The current load is rare uniform among the depth, there is a variance between elevation and another, this variance can be described in shallow water current load by a simple equation, which may be used also in deep water but for elevations near to the seabed.(Ertekin and Rodenbusch 2016) The simple equation is as follows:

$$U_c(z) = U_{c0}\left(\frac{z+h}{h}\right)^{\frac{1}{7}}$$

Such that;

$U_c(z)$ is the current velocity at elevation z , U_{c0} is the current velocity at the seawater level, z is the elevation measured from the seawater level downwards,
h is the total water depth.

In deep water, due to the large water depth, the current load can't be calculated by this simple formula at the upper parts of the depth, it can be measured experimentally and then formulating it by a special equation. Where the lower part is calculated from the equation by measuring the velocity at the top of the estimated part to be shallow water. There are two types of current profiles. Current driven from wind is directly proportional to the height from the seabed, while the tidal current has a different profile due to the given equation. The two profiles are given in Figure 3Current profiles(Posey and Silvester 1975).

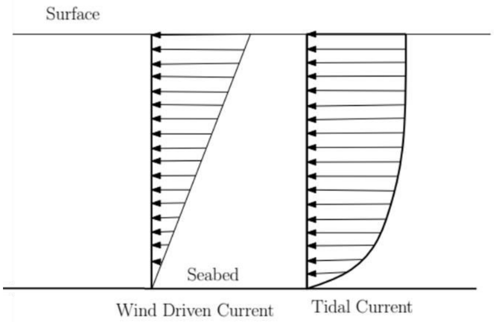


Fig 3*Current profiles*

Seismic load

Seismic load does not act on the TLP hull as it is not fixed to the (ground) seabed. It is tied with tendons, but the effect of earthquake won't be significant due to the flexibility of the tendons for slight motion in horizontal directions and due to the continuous self-equilibrium between dead loads and buoyancy force in the vertical direction. In other words, seismic loads for TLP structures are converted to wave and current loads. Scour may be occurred due to seismic loads. The summary is that the seismic load has no direct effect on the TLPWT structure, but the effect is indirectly through the other environmental loads such as the current load if the earthquake is in the horizontal direction which also may be accomplished by scour effect, and wave loads if the earthquake is in the vertical direction.

Water level Load

The average level of water is called the Mean Water Level. Which indicates the average level of water at the top of sea level. It is mainly used in design to set the zero amplitude of the current wave.Highest Astronomical Tide is the maximum positive amplitude above the mean water level, which indicates the zero amplitude of water level adding to it all possible harmonic components at the same point and time. It is used as the maximum possible point of water level. Lowest Astronomical Tide is the maximum negative amplitude below the mean water level, which indicates the zero amplitude of water level subtracting from it all possible harmonic components at the same point and time. It is used as the minimum possible point of water level. Increasing and decreasing water level leads to raising and lowering of the structure, which also leads to a slight difference in buoyancy force exerted on the floating structure. Finally, it affects the tension force in the tendons. So, the design is done according to the worst-case scenario, which is for the HAT.(Norske and As 2013)

Tides

Tide is the change in water level up and down due to the change in the effect of gravitational forces of the sun and moon. The position of sun and moon concerning the earth is the main effecting point about the tide. The distance between the two bodies is effective in the gravitational force, so the position of the sun and the moon concerning the earth is affecting the gravitational force twice; first is by radius, and the second is by the direction of the force. This direction is the key point of the tide. Such that the ocean water is moving toward the shore and away from the other by this gravitational force direction. Tide differs from one place to another and differs at the same place due to the difference in the positions of sun and moon each day as there are many special cases as solar or lunar eclipse and other cases. Finally, the tide effect at the deepwater is illustrated to be the difference in water level, which is then compromised to be LAT and HAT. Which has the same effect of water level load, which is finally designed upon HAT.(Talley et al. 2011)

Modeling of the hull

The shape of the model

The model constructed, using the ANSYS® AQWA finite element program, would include many elements. This section would deal with the system of the orientation of these elements and select the elements under analysis and the other elements which are only imported for loading systems requirements.There are many shapes and types of TLP structures. The last and best shape proved to be having the column in the middle and the pontoons are surrounding it in their directions dividing the 360° to equal portions between them. This model is implemented, and 5 alternatives are made. Different parameters are taken into consideration for water depth 150m(Bachynski and Moan 2012). The 5 alternatives are been to comparison in structural and economically wise. Each alternative was examined to obtain the advantage of each alternative. The model implemented for 150m depth would be reliable in this paper for 900m depth, as the main change between the two depths is the increase in environmental loads, this increase would be the key point concerned during the parametric study. Also, by searching different models for different water depths, the dimensions of the models are not so far from each other, the main difference for increasing water depth would be the methods of construction and the cost-wise for increased lengths of the mooring system.

Number of pontoons

The difference between using 3 or 4 pontoons arises in three effects. First, a slight increase in the surge and sway displacements can be recognized as an extra of 5.7%, such that the mean surge displacement for 4 pontoons has a maximum value, due to 6 different loading cases, of 3.5m. While that for 3 pontoons is of 3.7m. Second, an increase in pitch rotation can be recognized as an extra of 15%, such that the mean pitch rotation for 4 pontoons has a maximum value, due to 6 different loading cases, of 0.013°. While that for 3 pontoons is 0.015°. The change in pitch is not negligible, but the pitch value as all is so small. Third, a great increase in the tension force in the tendons which is about 33.33% as the tension force would be carried by 3 tendons instead of 4, so this would affect the cross-section of the tendons. So, the difference between using 3 or 4 pontoons is not based on structural wise at all, it would be mainly based on cost-wise. Using an extra pontoon would cost an extra tendon for the length to the seabed, an extra concrete bulk to restrain the tendon, also an extra pontoon's weight. All these extra elements would be equivalent to extra cost.

The last main point isthe accidental load of tendon's failure. For the 3 pontoons structure, a tendon's failure means the whole structure failure. This is a rare accidental load but must be taken into consideration. The choice finally is money wise, not structural wise. So, the used system for this paper model is 3 pontoons TLPWT structure. As the author's vision is that the tendon's failure is a very rare accidental load that is already resisted by using the FRP tendons instead of steel tendonsalso the effect of the wind farm would reduce the event of this accidental load.

Pontoon's shape

The two alternatives for the pontoon's cross-section are circular and rectangular cross-sections. There are two models examined having the same properties but different types of cross-sections. It is recognized that the circular pontoon is better as it is of lower total weight so lower total cost, but it has less total volume so the buoyant force would be reduced by reducing the volume. Also, there is a significant increase in the surge displacement measured reaching 146% than for the rectangular pontoon, the increase in the pitch rotation reaches 120% increase but it could be neglected as the pitch rotation is very small. So, the used cross-section in this paper's model is the rectangular pontoon as the displacements of the structure would be minimized.

Column's diameter

The column's diameter is depending on the tower's diameter. Such that the column must have a diameter equals to or bigger than that of the tower to be able to set the turbine's tower over the column. The best approach is to let the column's diameter be equals to the tower's base diameter D_T which would be mentioned later in this paper, if this diameter is less than the examined diameters, then the column's diameter D_C would be equals to the examined diameter. Such that the column's diameter would be applying the following formula.

$$D_C = \begin{cases} D_T & D_T \geq 14m \\ 14m & D_T < 14m \end{cases}$$

Column's height

Changing the column's height doesn't affect the loading of the structure, as the hub height is for a constant elevation above mean sea level, such that the outer shape of the model is the same even if the column is short or long. So, increasing the column's height gives more stiffness to the structure. This concept is being ensured by the analysis of 2 models having the same characters but different column's height.

The change between them is that one is having a total column height of 40m above the pontoon, the other is 26m. This change is a 54% increase in height which would lead to a decrease in surge and pitch values. The analysis proved that the change in the surge displacement values is for only a 15% reduction. This would be depressive for the first while. But for deeper thinking, this 15% reduction is for zero extra cost, just reducing the weight from the tower and adding it to the column which increases stiffness. So, the column height used in this paper's model is 40m.

Modeling of the wind turbine

The wind turbine is not a designed part of this paper. So, it can be modeled as a volume shape having an own weight and is a volume where the wind spectrum acts. To apply this, there is a must to know some parameters used in expressing the dimensions of the wind turbine.Figure 4On-land WT dimensions illustrates the main parameters of the wind turbine.(Rao 2019)

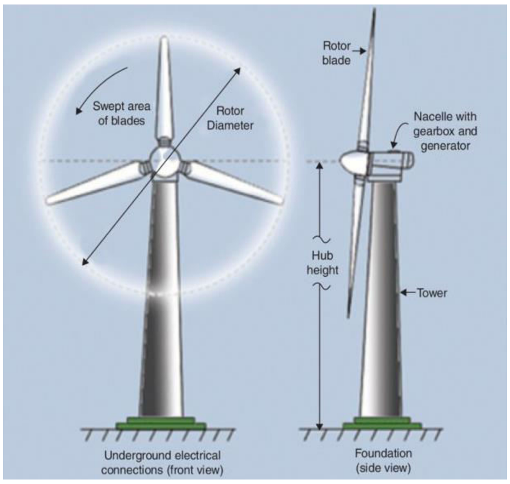


Fig 4 On-land WT dimensions (Guarnaccia, Mastorakis, and Quartieri 2011)

The design WT used for simulation and loading is V90-2.0 MWTM IEC IIA/IEC S designed and manufactured by Vestas®. The following data are given in the 2MW products brochure, Feb. 2020. The given data includes rated power, cut-in wind speed, cut-out wind speed, re cut-out wind speed, wind class, standard operating temperature range, maximum sound power, rotor's diameter, swept area, air brake, electrical frequency, generator type, gearbox type, hub height, and other dimensions about blades, hub, and nacelle.(Vestas® 2020)The important data for the modeling are collected in Table 1 below

Table 1 Turbine's modeling data

Rotor diameter	90m
Swept area	6362m^2
Hub height	80m
Hub's weight	40t
Blade's weight	9t
Rotor's weight	67t
Nacelle's weight	70t
Tower's diameter	3m / 4.5m
Tower's weight	159.25t

Shape model

According to the collected data given in sections4.1, and 4.2 from this paper. Figure 5Modeling shapeshows the isometric of the shape of the model.

Fig 5 Modeling shape

Loads on the model

To set the actual loads acting on the model, the accurate place of the model must be known, to be able to collect accurate environmental data. According to this paper overview, the location of the TLPWT structure would be 20km apart from the El-Zaafarana shore. Using google maps, the location is 29°02'04.8"N 32°49'59.3"E. this location is then be used to collect the accurate environmental data. Figure 6 Location of TLPWT structureis captured from Google maps(Google 2020).

Fig 6 Location of TLPWT structure

Own weights

The weight of each element of the model would be calculated automatically by ANSYS. The main issue is assigning the weights of the other parts to the hull. The tendons' weight can be also calculated automatically by ANSYS by assigning the type. The cables' weight must be assigned to the hull as a point load after the calculation of its weight according to its material choice. The final own weights are collected at Table 2Own weights assigned to model

Table 2. Own weights assigned to model

Tendons' weight	57.36 kg/m
Cables' weight	18650 kg/m

Wind load

The required data about wind includes wind speed at 10m above mean water level to be introduced as the wind load on the structure, the wind speed at 80m above the mean sea level to ensure that the used wind turbine is compatible with the wind speed range, and the wind direction to settle the orientation of the wind turbine.The wind speed 10m above the mean sea level and the wind gust for the same level over a year, 2019 as a sample, is downloaded from the Meteoblue website as shown in Figure 7Wind speed and gust at 10m above MSL. It is noted that the maximum wind speed at 10m above the mean sea level is 10.032m/sec, while the maximum wind gust speed is 22.5m/sec. These values are significant to be applied to the model.(Meteoblue 2020)

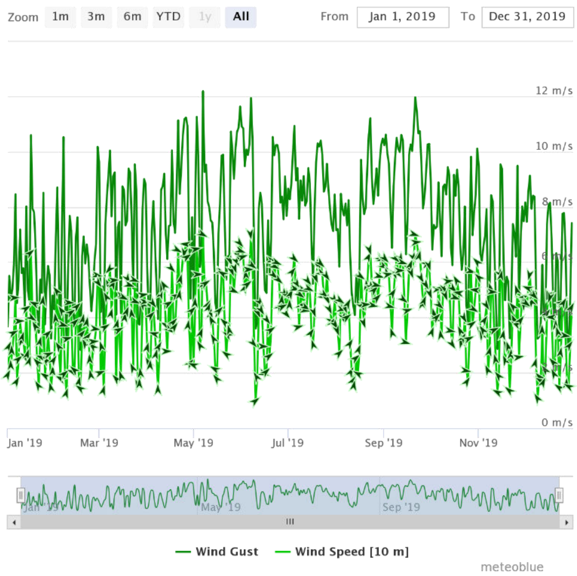


Fig 7. Wind speed and gust at 10m above MSL

Thus the orientation of the wind turbine would be perpendicular to the direction between NW and NNW, such that the swept area collects the maximum percentage of the wind load acting on it and does not miss any portion due to the angle of inclination between the acting load and the swept area. The data given is been revised according to the data given by the Egyptian Meteorological Authority. The EMA gives the occurrence of the different wind speeds and directions. The data is been collected among 10 years. The prevailing wind direction is North West. The prevailing wind speed is 10Knots, 5.1m/sec. the maximum wind speed is 33Knots, 17m/sec.(Egyptian Meteorological Authority 2020)

Wave load

The wave load is implemented in the modeling as the wave height. Such that the wave height is set from the readings of the red sea wave heights from 2008 to 2018. This data was collected in 10-years monthly data, each year was given in an individual report. A sample from the zoomed view is given inFigure 8Wave height for red sea(Research 2020). Where the data is collected and listed to know that the wave height in the required area is maximum 10.87ft, 3.31m. This maximum height would be implemented to the model.(NOAA Center for Satellite Applications and Research 2018)

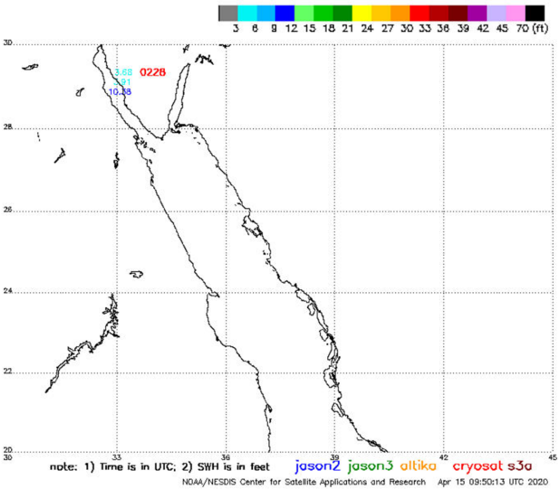


Fig 8. Wave height for red sea

The wave natural period is important, not only for the modeling, for the design to be considered to prevent resonance occurrence. The natural periods and frequencies are given in Figure 9Natural periods of waves(Toffoli and Bitner-Gregersen 2017). The book implements that the natural periods of capillary waves, ultra-gravity waves, and gravity waves ranges to 20sec. These are the most important wave periods to be considered, as they have high energy on the arbitrary energy scale. So, the maximum wave period is implemented to the design as 20sec.

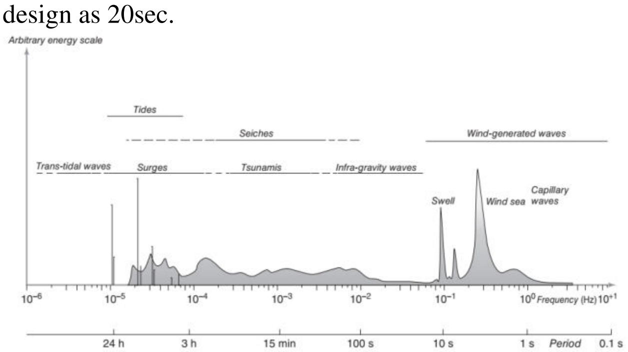


Figure 9Natural periods of waves

Current load

The current load for the red sea is given by a current speed at the surface of the mean sea level. The data is given inFigure 10Current speed of red sea(Naval Postgraduate School 2002). Such that the selected speed is given as 0.4knots. This speed is 0.21m/sec. this would be the significant value implemented to the model. The current speed at lower levels is validated by verbal data given by the Egyptian Meteorological Authority to be between 0.54knots and 0.75knots, oriented to southeast direction. Such that the relative orientation between wind load and current load is around 0°.

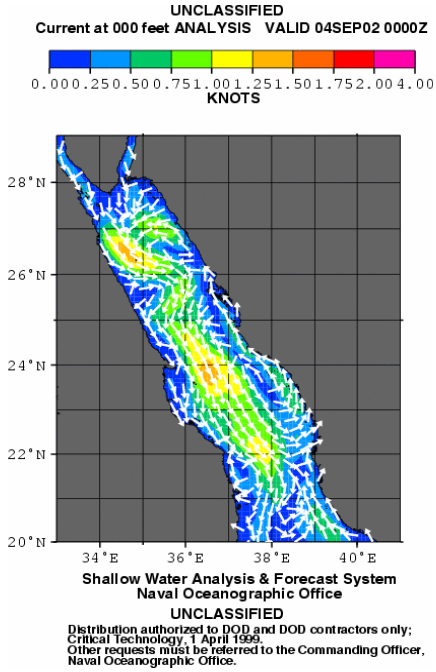


Fig 10. Current speed of red sea

Validating model

Based on the model held by Kristian FrengSvendsen in his paper and master's thesis. The following data given inTable 3Validating model's data(Svendsen 2016), are applied to an equivalent ANSYS AQWA model to validate the results.

Table 3. Validating model's data

Number of pontoons	3
Cross-section of pontoon	6m×6m
Pontoon's thickness	0.0337m
Column's thickness	0.0551m
Pontoon's length	28m
Column's height	32m
Level of pontoons' base	-25m
Seabed	-150m

The source model was held in 2016 by Kristian FrengSvendsen using SIMO RIFLEX analysis program(Svendsen 2016), to form a beam model for the TLPWT structure to calculate the frequencies and model properties, to ensure that the natural frequencies' values are far away from the external loads' values to prevent resonance occurs. Another equivalent model was held by this paper's author using the ANSYS AQWA analysis program to ensure that the outputs of the two programs are having slight differences to be able to form a new model having the environmental loads discussed in this paper by the ANSYS AQWA analysis program.

The following figures illustrate the output graphs from both SIMO RIFLEX model(Svendsen 2016)and ANSYS AQWA model. Such that A_{11}, and A_{22} are added masses in surge, and sway directions respectively; B_{11}, and B_{22} are radiation damping values in surge, and sway directions, respectively.

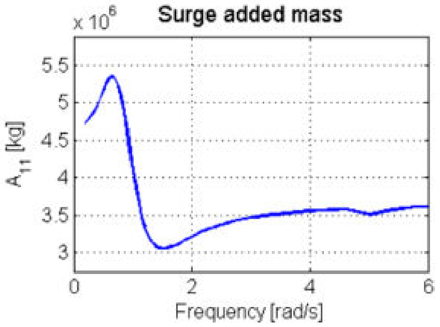


Fig 11 Surge added mass SR

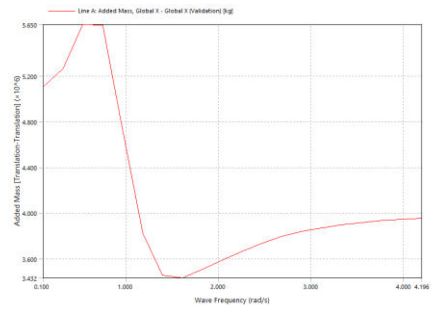


Fig 12 Surge added mass ANSYS

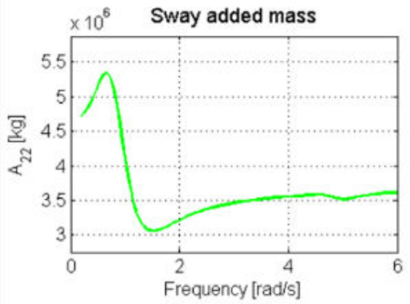


Fig 13 Sway added mass SR

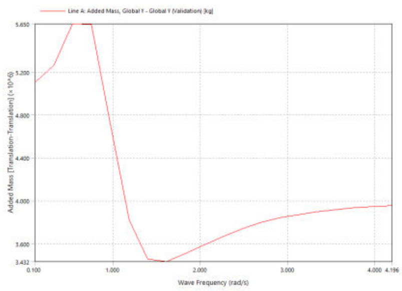


Fig 14 Sway added mass ANSYS

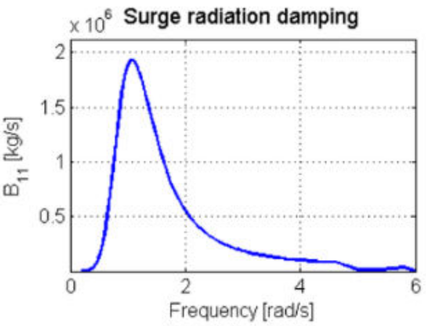


Fig 15 Surge radiation damping SR

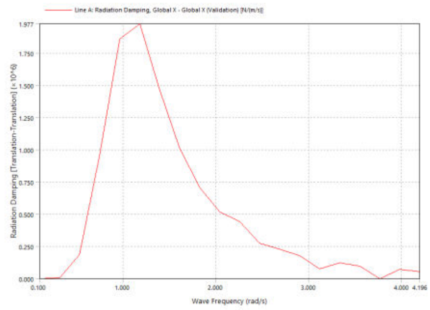


Fig 16 Surge radiation damping ANSYS

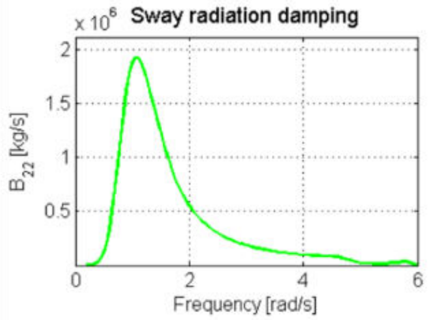


Fig 17 Sway radiation damping SR

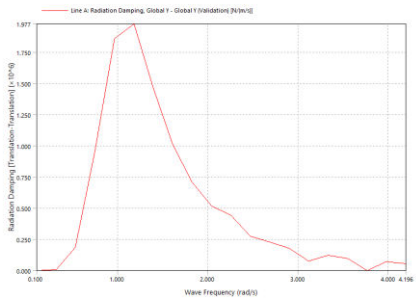


Fig 18 Sway radiation damping ANSYS

By comparing added mass values, the values are different such that the peak value is 5.4×10^6 kg at 0.8rad/sec at the SIMO model, while the peak value is 5.65×10^6 kg at 0.8rad/sec at the SIMO model. The peak point is the same, while the value changes by 4.63% due to changing meshing system.By comparing radiation damping values, the values are equal such that the peak value is 1.977×10^6 kg/sec at 1.2rad/sec. So, the model is validated.

Parametric study

The main point of view of the parametric study is starting from where others end. The start of this paper's model would be the implemented model in "Design considerations for tension leg platform wind turbines" paper(Bachynski and Moan 2012). This model would include some changes in the implemented model. The following data is the implemented data from the external model and by the choice of the author of this paper. The data is collected in Table 4 Dimensions of the model(Bachynski and Moan 2012).

Table 4 Dimensions of the model

Number of pontoons	3
Cross-section of pontoon	6m×6m
Pontoon's length	32m
Pontoon's thickness	0.04m
Column's thickness	0.06m
Column's height	40m
Level of pontoons' base	-30m

The inclination of the tendons is significant for the action of the mooring system, which is not a part of this paper. A review is done to get the best inclination designed or experimented by other researchers. The best inclination was given as vertical tendons are the best as minimum translation is exerted by the structure(Milano et al. 2019). Based on this inclination ϑ, the distance between the tendons' bases could be calculated as follows

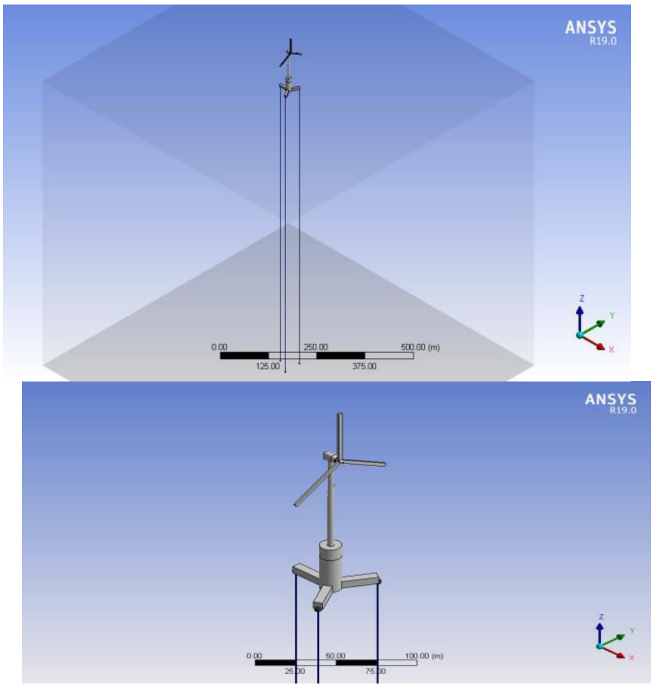
$$Distance\ between\ bases = hull's\ width + water\ depth \times \tan\vartheta$$

By substituting by the model's water depth as 900m, the distance between the bases would be the same as the distance between the top points of the tendons at the hull. There are other dimensions and data implemented by the author along with this paper which is given below in Table 5 Specified model's dimensions

Table 5 Specified model's dimensions

Tendon's cross-section	27314.3cm^2
Column's diameter	14m
Inclination of tendons	0°

The final dimensions of the model are illustrated by the elevation and cross-sectional plan of the hull given byFigure 19 Hull's dimensions. Also 3D shot from ANSYS model is captured to ensure water depth and cabling system.



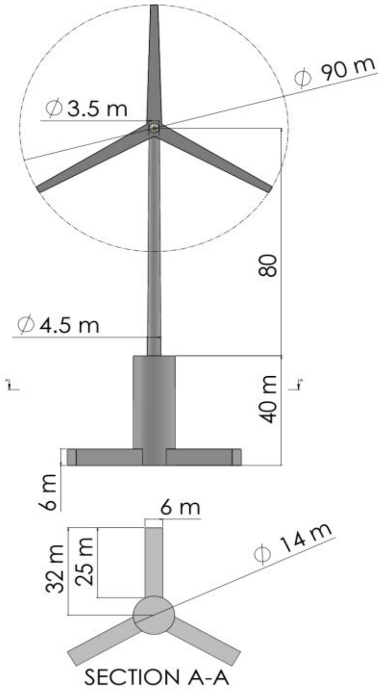


Fig 19 Hull's dimensions

For design-wise, increasing the pontoon's length increases stability and increases also the amplitude of internal loads acting on the pontoon's elements, especially internal moments. So, a parametric study would be held to make different models changing the pontoon's length to reach the best pontoon's length. The start of the modeling would be the implemented pontoon's length as mentioned in Table 4 Dimensions of the model. The parametric study for changing the pontoon's length is given in Table 6 Parametric pontoon's lengths.

Table 6 Parametric pontoon's lengths

Model	Length
PL 1	30m
PL 2	28m
PL 3	34m
PL 4	36m

Results

The models are compared by comparing the natural modes, added mass values, and radiation damping values.The following would illustrate the outputs implemented by an ANSYS AQWA model for different parametric dimensions. Different natural modes for different models are listed in seconds, illustrated byTable 7 Natural Modes.

Table 7 Natural Modes

	RX (Roll)		**RY (Pitch)**		**Z (Heave)**	
	Amplitude	**Period**	**Amplitude**	**Period**	**Amplitude**	**Period**
Source	9.61013 °	8.49423 s	9.61152 °	8.48219 s	10.0000 m	5.40936 s
PL 1	9.64794 °	8.98067 s	9.64863 °	8.96674s	10.0000 m	5.40175 s
PL 2	9.61566 °	9.68724 s	9.61532 °	9.67095 s	10.0000m	5.39186 s
PL 3	9.60834 °	8.06612 s	9.60938 °	8.05638 s	10.0000 m	5.41580 s
PL 4	9.70203 °	7.64300 s	9.70257 °	7.63434 s	9.99905 m	5.42139 s

The Added mass and radiation damping values for sway direction for the source model are given in Figure 20 Added Mass chartand Figure 21 Radiation Damping chartillustrating that the maximum added mass occurs is 6954 tons at wave frequency 0.1 Hz which increases stability and decrease tension effect on tendons, also radiation damping value differs such that the maximum damping reached is 2.082×10^6 N/(m/s) at wave frequency about 0.16 Hz. These frequencies are not the most effective through this model. The most effective values are for frequency around 0.05 Hz, as this is the frequency of the wave velocity acting on the hull. The effective added mass is 6493 tons, the effective radiation damping is 1.74×10^4 N/(m/s) which is about 0.85% from the maximum damping but still effective and would be more effective for shorter wave periods.

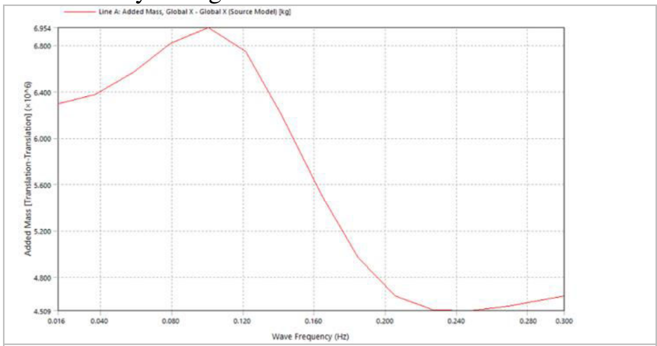


Fig 20 Added Mass chart

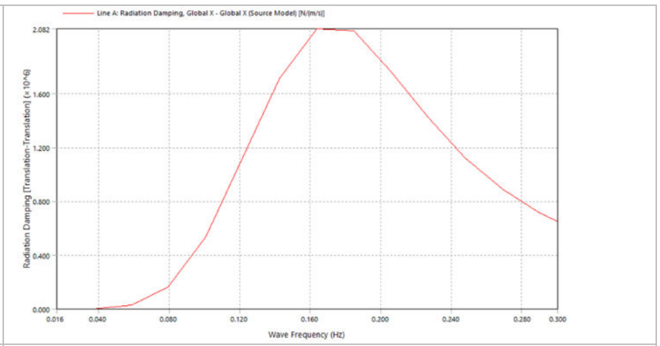


Fig 21 Radiation Damping chart

The difference due to changing the pontoons' length is listed inTable 7Natural Modessuch that the increasing the pontoons' length decreases the maximum amplitude of the roll's rotation but while completing an increase the amplitude return increasing. So, the optimum length for the pontoon according to roll's rotation is the PL3 model with length 34m. The pitch rotation amplitude's relation to pontoons' length is as same as the roll's rotation relation. So, the optimum length for the pontoon according to pitch's rotation is the PL3 model with length 34m. the heave motion is almost the same while changing the pontoons' length. The natural period of the 3 natural modes is far away from the natural period of the applied loads, also there is no relation of constant integer magnification factor between them. The natural period is not effective in choosing the best model.So, the best model is chosen to be PL3 with pontoons' length 34m as listed in Table 6 Parametric pontoon's lengths.The added mass and radiation damping values of the PL3 model – the chosen best model – are illustrated inFigure 22 Added Mass chartandFigure 23 Radiation Damping chart.

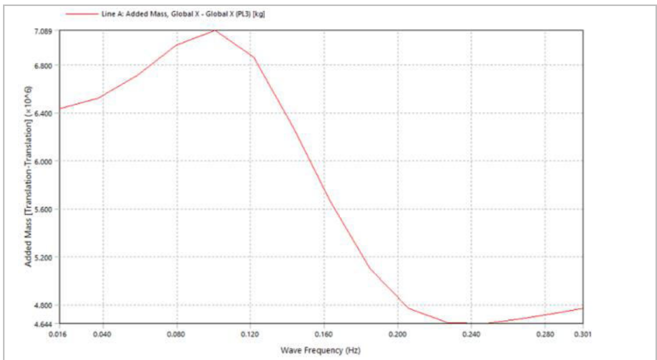


Fig 22 Added Mass chart

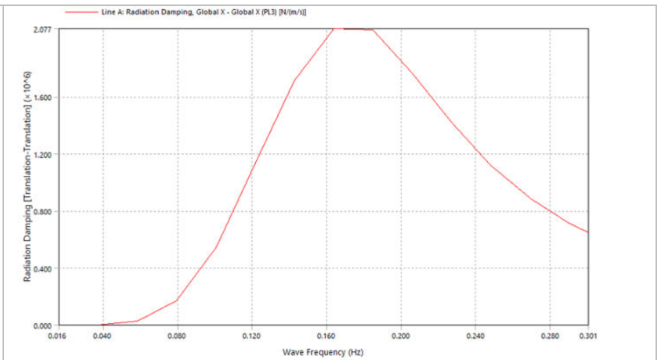


Fig 23 Radiation Damping chart

The maximum added mass value increases to 7089 tons, while the most effective added mass value at 0.05 Hz increases to 6640 tons. The maximum radiation damping value decreases to 2.077×10^6 N/(m/s), while the most effective radiation damping value at 0.05 Hz increases to 1.83×10^4 N/(m/s).

Conclusion

The environmental conditions subjected to the TLPWT structure was implemented in this paper and discussed in details to show that there are effective environmental loads on TLPWT structure as the wind which is the main significant environmental issue as it is the target to be used, as wind kinetic energy is transferred to electrical energy. Also, wave loads generated by wind and other environmental cases are significant for TLP structure, current loads are set to be important as the submerged part of the hull is subjected to these loads. The seismic load is set to be non-significant load as the TLP structure is floating so that movements occur in the seabed does not affect the structure due to the flexibility of tendons. Water level loads affect the TLP structure slightly such that its effect may be neglected or taken into consideration by the worst-case scenario, as the change of water level only affects the tension force exerted on the tendons to compensate for the change. Tides have the same effect as water level loads. Ice loads and marine growth are only affecting the TLP hull by extra weights of either ice or marine growth, so these loads are being estimated and taken into consideration. The scour effect may be neglected such that the huge bases of the tendons are set to initial settlement much higher than done by scouring and earthquake, also current speed is almost zero at the seabed leading to the negligible effect of scour.

A model was constructed using ANSYS AQWA finite element program, the model was including the weights mentioned before, and only the effect of wind energy, wave loads and current loads of seawater. These effects were collected from online websites using the coordinates of the Zaafarana location as set by the author from Google Maps, the collected information was verified by the Egyptian Meteorological Authority results collected for the wind to be applicable for other collected loads. The modeled wind turbine was introduced by Vestas®, the parameters used for the initial model are collected from previous research pieces. A parametric study was done concerning the pontoon's length. The outputs of the model are given in the results.

The increase in the pontoons' length affects the natural modes amplitude by decreasing it in roll's rotation by 0.02% which could be negligible value compared to the added material to add 2m length to each pontoon, same is for pitch rotation. The significant effect is for added mass value which increases by 2.25% which increases stability, the more relevant effect is for radiation damping value which increases by 2.5% which set the hull to damp the vibration due to studied dynamic loads due to environmental loads much faster.

Recommendations

It is implemented by the author to design the hull using FRP material. Further work might be done to make full design considerations and fulfillments to be able to use FRP materials for offshore structures. Also, a value engineering model might be done to calculate the feasibility of the high-cost FRP materials uses.

It is proposed by the author to discuss the wind-current relationship deeper to use the wind and current loads in generating electricity, by adding a current turbine to the TLPWT discussed structure.

In this paper, the supports in waterbed are modelled as fixed supports. Future work might be done by changing the type pf support to hinged supports, also scour effect must be taken into consideration.

References

Bachynski, Erin E., and Torgeir Moan. 2012. "Design Considerations for Tension Leg Platform Wind Turbines." *Marine Structures* 29(1): 89–114. http://dx.doi.org/10.1016/j.marstruc.2012.09.001.

Dykes, Katherine et al. 2011. *Applications of Systems Engineering to the Research, Design, and Development of Wind Energy Systems*.

Egyptian Meteorological Authority. 2020. *Wind Speed and Direction among 10 Years*. Cairo.

Ertekin, R Cengiz, and George Rodenbusch. 2016. "Wave, Current and Wind Loads." In *Springer Handbook of Ocean Engineering*, eds. Manhar R Dhanak and Nikolaos I Xiros. Cham: Springer International Publishing, 787–818. https://doi.org/10.1007/978-3-319-16649-0_35.

Google. 2020. "Https://Www.Google.Com.Eg/Maps."

Guarnaccia, Claudio, Nikos Mastorakis, and J Quartieri. 2011. "A Mathematical Approach for Wind Turbine Noise Propagation."

Meteoblue. 2020. "Https://Www.Meteoblue.Com."

Milano, Daniel et al. 2019. "Impact of High Order Wave Loads on a 10 MW Tension-Leg Platform Floating Wind Turbine at Different Tendon Inclination Angles." In *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, Glasgow, United kingdom, Ocean, Offshore and Arctic Engineering Division-. http://dx.doi.org/10.1115/OMAE2019-96243.

Naval Postgraduate School. 2002. "Https://Www.Oc.Nps.Edu/Nom/Day4/Scenario3/Red_sea_surface.Html."

NOAA Center for Satellite Applications and Research. 2018. "Https://Www.Star.Nesdis.Noaa.Gov/Socd/Lsa/NearRealTime/Reports.Php."

Norske, Det, and Veritas As. 2013. "DNV-OS-J103 Design of Floating Wind Turbine Structures Numerical Numbering in the Finally Published Document ." (June).

Perdana. 2018. "API RP 2SK." *Journal of Chemical Information and Modeling* 53(9): 1689–99.

Pham, Hoang. 2005. *System Software Reliability (Springer Series in Reliability Engineering)*. https://ent.univ-ubs.fr/uPortal/cgi-bin/nph-proxy.cgi/000000A/http/www.springerlink.com/content/978-1-85233-950-0/#AboutSection.

Posey, Chesley J., and Richard Silvester. 1975. "Offshore Structures." *Nature* 258(5532): 192.

Rao, K R. 2019. "Wind Energy: Technical Considerations -- Contents." In *Wind Energy for Power Generation: Meeting the Challenge of Practical Implementation*, Cham: Springer International Publishing, 1–426. https://doi.org/10.1007/978-3-319-75134-4_1.

Research, NOAA Center for Satellite Applications and. 2020. "Https://Manati.Star.Nesdis.Noaa.Gov/Datasets/SGWHData.Php."

Rosenthal, W. "6.2.4 Surface Waves in Deep Water: Datasheet from Landolt-Börnstein - Group V Geophysics · Volume 3C: 'Subvolume C' in SpringerMaterials (Https://Doi.Org/10.1007/10312328_5)" ed. J Sündermann. https://materials.springer.com/lb/docs/sm_lbs_978-3-540-31370-0_5.

Svendsen, Kristian Freng. 2016. "Structural Design and Dynamic Analysis of a Tension Leg Platform Wind Turbine , Considering Elasticity in the Hull." (May).

Talley, Lynne D., George L. Pickard, William J. Emery, and James H. Swift. 2011. "Gravity Waves, Tides, and Coastal Oceanography." *Descriptive Physical Oceanography*: 223–44.

Toffoli, Alessandro, and Elzbieta M Bitner-Gregersen. 2017. "Types of Ocean Surface Waves, Wave Classification." In *Encyclopedia of Maritime and Offshore Engineering*, American Cancer Society, 1–8. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118476406.emoe077.

Vestas®. 2020. "Https://Www.Vestas.Com/." *2 MW Product Brochure*.