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Title	The dynamic effects of marine growth on a tension moored floating wind turbine
Authors(s)	Wright, C.S., Murphy, Jerry, Pakrashi, Vikram
Publication date	2016-01-01
Publication information	Wright, C.S., Jerry Murphy, and Vikram Pakrashi. "The Dynamic Effects of Marine Growth on a Tension Moored Floating Wind Turbine." Taylor & Francis, 2016.
Conference details	Renew 2016: 2nd International Conference on Renewable Energies Offshore, Lisbon, Portugal, 24-26 October 2016
Publisher	Taylor & Francis
Item record/more information	http://hdl.handle.net/10197/10821
Publisher's statement	This is an Accepted Manuscript of a book chapter published by CRC Press in Progress in Renewable Energies Offshore: Proceedings of the 2nd International Conference on Renewable Energies Offshore (RENEW2016), Lisbon, Portugal, 24-26 October 2016 on 13 October 2016, available online: http://www.crcpress.com/9781138626270

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The dynamic effects of marine growth on a tension moored floating wind turbine

C. Wright¹ & J. Murphy¹

¹*Marine and Renewable Energy Ireland (MaREI), Beaufort Building, Environmental Research Institute, University College Cork, Haulbowline Road, Ringaskiddy, Co. Cork, Ireland*

V. Pakrashi^{1,2}

²*Dynamical Systems and Risk Laboratory, Civil and Environmental Engineering, School of Engineering, University College Cork, Ireland*

ABSTRACT: As the offshore wind industry moves to water depths greater than 50m floating platforms will become the only cost effective solution for mounting turbines. Such platforms will be susceptible to bio fouling over their design life with marine growth capable of altering the hydrodynamic loading. Marine growth causes member effective diameter, mass, drag coefficients, force and hydrodynamic added mass to increase.

In this paper, marine growth of various thickness and surface roughness is numerically modelled on a tension moored floating wind turbine under survival conditions using combined potential flow boundary element method and Morison equation viscous drag. The influence of time variant Reynolds number dependant drag coefficients is compared against time invariant drag coefficients.

Marine growth thickness and surface roughness have a notable effect on the platform hydrodynamic forces. Surge, pitch motions, and nacelle accelerations decrease as surface roughness increases. Maximum tendon forces increase and minimum tendon forces decrease. This increases the probability of a catastrophic tendon snap or slack event. The authors calculate the increase in displacement required to avoid this loss in tension. Detailed limits on the quantity of marine growth are suggested by the authors, above which the platform must be cleaned. The time invariant drag coefficient method has been found to give sufficiently consistent results to the time variant Reynolds number drag coefficient method.

1 INTRODUCTION

1.1 Marine Growth

Marine growth (MG) on vessels and offshore structures has been of great interest to offshore industries. MG is described as the accumulation of biological deposits on the device, also commonly termed bio-fouling. Biofouling is divided into microfouling, the formation of a biofilm with bacterial adhesion and macrofouling, attachment of larger organisms. Examples of macrofouling organisms include the “hard” encrusting animals such as barnacles, molluscs, tube worms, bryozoans and the “soft” non-calcareous biofoulants include hydroids and seaweed.

MG is capable of altering the hydrostatic and hydrodynamic characteristics of offshore platforms. These characteristics are modified by the increased mass of the platform, and increased member effective diameter and surface roughness, which leads to increased drag coefficients, force and hydrodynamic added mass. MG can also increase fatigue loading and accelerate corrosion of the platform. The surface roughness influences the viscous drag force that the member experiences. This drag force increases as surface roughness increases, due to increasing boundary layer turbulence and shear forces, which decreases the momentum of the fluid.

Increased fuel costs due to increased drag from MG on vessels is a well-known problem. In the area of marine renewable energy converters there has been much debate over what the effect of MG will be on device performance and in reality the answer to this question will be device and site specific. Langhamer et al. (2009) measured MG deposits on a demonstration point absorbing (PA) wave energy converter (WEC) and modelled the effects of MG additional mass in the frequency domain. Noting a 5% increase in draft and 5% decrease in power. Wright et al. (2016) used time domain modified Morrison’s equation and BEM to model the effects of various MG roughness and thickness’s on a heaving PA WEC and found a 15% decrease in power for the worst case scenario. Tiron et al. (2013) noted significant effects of MG on an experimental model of a bottom-hinged flap type WEC. Figure 1 shows a photograph of MG on the OE Buoy WEC after 5 months of deployment in Galway bay as part of the fp7 CORES project.

2 MODEL

2.1 Tension Moored Floating Wind Turbine

The Pelastar “Baseline” platform, a tension moored floating wind turbine is modelled for this study (Hurley & Nordstrom 2014). Figure 2 shows a 3D

Figure 1. Marine Growth on OE Buoy after 4 months deployment.

The use of antifouling paints, such as those used on vessels has been proposed for the marine renewable industry. Issues with reapplying the paints every 1-5 years and their non eco-friendly nature have led to their use in WECs being cited as an impractical response (Tiron et al. 2015).

As the offshore wind industry moves to water depths greater than 50m floating platforms will become the only cost effective solution for mounting turbines. At the date of writing the authors are unaware of any publications into biofouling of floating wind turbines.

Marine growth is modelled on PelaStar, a tension moored floating wind turbine platform, which has been studied in much detail. These types of platforms are stabilized through tension in the tendons provided by excess buoyancy. Thus they are especially susceptible to changes in platform mass, that may be caused by marine growth, which reduces the pre-tension of the tendons.

Numerical Modelling is carried out in the time domain using FASTlink. Survival sea and wind conditions are modelled. Viscous damping was modelled using additional modified drag only Morrison's equation elements. MG is analysed as a change in surface roughness and member diameter of the platform members. Drag coefficients are Reynolds number dependant, but in numerical models are generally assumed constant. The influence of time variant Reynolds number dependant drag coefficients compared against time invariant drag coefficients is investigated.

Figure 2. Pelastar Baseline platform

model of the platform. This is a platform designed for the UK offshore wind round three waters. It should be noted some platform parameter data was unavailable and had to be estimated and that this study is not an analysis of the performance capabilities of this particular platform. The turbine is modified from the 6MW in the report to the 5MW NREL reference turbine (Jonkman 2009). Hub Height is set at 90m above still water level and the OC3-Hywind tower is used (Jonkman 2010). Platform steel mass

Figure 3. Tendon numbering and drag elements

is 1174 Mg and displaced volume is 4033m³. Tendon length is taken as 49.86m and stiffness is taken as 1.5E6kN. Water Depth is taken as 75m.

2.2 Numerical Model

Hydrodynamic parameters are computed from Ansys Aqwa for 8 wave directions and 50 frequency's from 0.008Hz - 0.4Hz. Time domain modelling is carried out using the coupled Orcaflex and Fast package FASTlink v8 (Masciola 2011). Survival state is modelled using a Jonswap spectrum with Hs of 8.2m, Tp of 12s and above-rated wind speed of 46m/s. Simulations time is 11000s, discounting 200s for start-up transients gives a useable time of 10800s (3 Hours). Fifteen random wave phase seeds are run for each test and kept constant across cases. Figure 3 shows the tendon numbering.

2.3 Marine Growth Modelling

Variations in both the MG surface roughness (k) and member effective diameters (D_E) are modelled. The surface roughness length is set as smooth 0.0007m, rusty 0.003m, mild MG 0.005m, Moderate MG 0.02m, Severe MG 0.035m and Extreme MG 0.05m. Drag coefficients are determined from the surface roughness length according to DNV (2007). Figure 3 shows the influence of surface roughness length on drag coefficients. MG thickness is set as 0 and 100mm, in order to isolate the roughness effects. D_E is calculated as $D_E = D_C + 2t$, where D_C is the clean diameter and t the MG thickness. MG density is set as 1325 kg/m³. Drag forces are applied to the plat-

form using modified drag only Morrison equation elements. Discretization of platform elements is varied depending on the variability of the member section or member submergence. Thus members near the still water line are divided into 0.5m sections, while deeper members are divided into 3m sections. Element width is set at the average of each section. Table 1 illustrates the MG simulations. Simulation 1a is termed the baseline.

Table 1. Marine Growth Simulations

Thickness (m)	Surface Roughness Length [m]					
	0.0007	0.003	0.005	0.02	0.035	0.05
	Smooth	Rusty	Mild MG	Moderate MG	Severe MG	Extreme MG
0.0	1a	1b	1c	1d	1e	1f

Figure 4. Drag Coefficient depending on Surface Roughness for a 7m Diameter Cylinder.

2.4 Time Dependent Reynolds Number Drag Coefficients

In addition to surface roughness, drag coefficients are dependent on Reynold's number, Keulegan-Carpenter number and Strouhal number. In numerical models drag coefficients are generally taken as constant, this relates to a post-critical flow regime and large Reynolds numbers. In highly unsteady flow regimes with large platform motions, such as those experienced in survival sea-states, which a floating wind turbine must endure, Reynold's number fluctuates greatly. Figure 5 shows the effect of both changing surface roughness and Reynolds

number on drag coefficients. The Reynolds number axis scale is varied in order to clarify the changes at low Reynolds number. The most significant effects

Figure 5. Drag Coefficient depending on Surface Roughness and Reynold's Number for a 7m Diameter Cylinder

of marine growth are predicted to appear at peak relative velocity when the wave and platform velocity are out of phase. Reynold's number is calculated as, $Re = vD/\nu$, where D = Diameter, v = relative flow velocity and ν = fluid kinematic viscosity. The authors compare the effect of time dependent Reynolds numbers drag coefficients against time invariant drag coefficients by calculating the drag coefficient at each time step.

2.5 Slack Tendon and Limits of Marine Growth

The critical issue for marine growth on a tension moored platform is avoiding the slack tendon case, which occurs when a tendon loses all tension and may result in undesirable snap loading. In order to avoid this, the platform buoyancy must be designed to take into account the increased mass due to marine growth. Variations in the buoyancy and thus pretension results in nonlinear changes in the platform dynamics, due to changes in platform natural frequencies and hydrodynamic loading. As a detailed study is required taking into account structural analysis, the authors simplify the platform redesign by only taking the required increase in buoyancy into account, ignoring the increase in loading that this would provide. The buoyancy increase is applied in 50 Mg increments, as a point load. Platform member sizes remain constant. The worst case random wave seeds are then simulated. The minimum acceptable tension is varied from a tight to relaxed limit, set as follows: the tight limit is the same as that of the smooth pre-marine growth case, while the relaxed value is taken as 50% of this. The amount of MG al-

lowable in order to keep within this 50% reduction is also calculated.

3 RESULTS

3.1 Surface Roughness and Thickness

In order to determine the influence of both MG surface roughness and length three analysis cases are chosen as follows: Case 1) The marine growth is assumed to have no thickness value $D_E = D_C$, just a surface roughness effect. Case 2) The marine growth is assumed to have a thickness value of $t = 100\text{mm}$, and a surface roughness effect. The results for each of the first two cases are compared against the corresponding thickness's smooth case ($k = 0.0007\text{m}$), while Case 3) is the same as Case 2 but compared against the smooth Case 1. Case 1 and 2 describe the effects of surface roughness while Case 3 describes the effect of surface roughness and thickness and is a more realistic comparison between a platform under extreme marine growth and an as deployed case. Table 2 shows the three cases and which base case each is compared against. Comparison percentage variations are calculated as $PC_2 = 100 \times (X_2 - X_1)/X_1$, where X_1 is the base case, and X_2 is the case under comparison. Thus a negative and positive result indicate a decrease and increase over the base case

Table 2. Marine Growth Comparison Cases

		Surface Roughness Length [m]					
Case	t(m)	0.0007	0.003	0.005	0.02	0.035	0.05
		Smooth	Rusty	Mild MG	Moderate MG	Severe MG	Extreme MG
1	0.0	1a	1b/1a	1c/1a	1d/1a	1e/1a	1f/1a
2	0.1	2a	2b/2a	2c/2a	2d/2a	2e/2a	2f/2a
3	0.1	2a/1a	2b/1a	2c/1a	2d/1a	2e/1a	2f/1a

Figure 5 shows the RMS and maximum motion and acceleration effects of each case. Figure 6 shows the RMS, maximum and minimum tendon tensions. Percentage changes against the base case are shown. The mean of the 15 random seeds are shown with error bars depicting the seed with extreme positive and negative results for each case. The influence of the seed number can be seen as notable, for example the maximum heave displacement percentage change for Case 1 varies from +5% to -8% with a mean value of -2%.

Cases 1 and 2 show marine growth to have a low to mild effect. Extreme marine growth RMS of motions and accelerations vary from -0.4% to -2% with tendon tensions almost constant. Maximum displacement of motions and NRA accelerations varies from -1.5% to -8%, Maximum tendon tensions varies

from +0.8% to - 1.6%, minimum tendon tensions show a more distinct effect, from +18% to -2%. Case 3 shows marine growth to have a moderate to

of a catastrophic slack tendon event, that must be avoided.

Figure 5. Dynamic Effect of Marine Growth on Platform Motions and Accelerations

severe effect. Changes in RMS of motions and NRA accelerations varies from +12% to -12%, with tendon tensions -16%. Maximum motion displacement changes vary from -0.2% to -26%, maximum NRA accelerations are -8%, maximum tendon tensions are -8% to -14%, minimum tendon tensions are -21% to -62% Case 3 demonstrates the severe effect marine growth can have on the dynamics of a platform. It shows that it is the change in effective diameter and increase in weight due to marine growth (meaning a decrease in tendon pre-tension) which governs the worst-case dynamics of the platform. Case 1 and 2 demonstrate the effect of changing surface roughness to be small in comparison. The greatest dynamic effect marine growth can have is the lowering of the minimum tendon tension. This increases the chance

Figure 6. Dynamic Effect of Marine Growth on Platform Tendons

3.2 Time Dependant Reynolds Number Drag Coefficients

Figure 7 shows the time varying Reynolds number and drag coefficients for the Extreme MG surface roughness at 100mm thickness (simulation 2f). The effect of varying the drag coefficients appears to be minimal. This is due to the drag force already depending on the square of the velocity. Figure 8 shows a scatter plot of the time series of acceleration and percentage difference between methods described here. It can be seen that as acceleration reaches peak values the difference in values approaches zero, and opposingly as acceleration reach-

tions about the zero point. This can be explained by the fact that as motion values approach zero, velocity approaches its maximum and the well known phenome of errors “blowing up” as values approach zero. From an extreme load point of view these values around zero are of little interest. Therefore the constant Reynolds number approach is deemed satisfactory.

3.3 Slack Tendon

The minimum tension, in the critical tendon 1, from cases 1 and 2 is 1028 kN and 389 kN respectively. For the tight and relaxed limits of 1028kN and 514kN, an increase in buoyancy of 500 and 100Mg consecutively is required. It must be noted that this increase in buoyancy increases the tendon pretension and thus increases the maximum tendon tensions. Thus an increase in structural steel will also be required. In order to stay within the 50% relaxed limit it is calculated that a maximum of 80mm of marine growth is allowable. It must be noted that these limits to not apply to corrosion or fatigue issues which may be significant.

4 CONCLUSIONS

Marine growth of various surface roughness and thickness values were modelled on the PelaStar floating wind turbine. The effects of surface roughness were found to be minimal in comparison to the effects the MG thickness had on the platform dynamics. Platform motions and accelerations were seen to reduce with increasing thickness. This is a beneficial benefit of increased MG. Tendon maximum tensions also benefited from reduced loading under increased marine growth thickness. Tendon minimum tensions also showed a reduction in loading, although in this case it is an unwanted effect, which increases the probability of a slack tendon event. The worst case scenario showed a reduction in minimum tendon tension from 1028kN in the baseline to 389kN. The increase in platform buoyancy required to reduce the risk of slack events is prescribed as 500Mg. In order to stay within the 50% relaxed minimum tendon limit, a maximum of

Figure 8. Percentage change between Acceleration Calculated by Constant and Reynolds Number Dependent Drag Coefficient Methods.

80mm of marine growth is allowable. The time invariant drag coefficient method has been found to give sufficiently consistent results to the time variant Reynolds number drag coefficient method. The effect of random wave phase seed is deemed to be significant.

Suitable motion and tendon force damping methods may also be utilized in order to reduce the effects of MG. For example platform damping may be applied through the use of single or multiple tuned

liquid column dampers (Jaksic 2015a,b) or tendon spring dampers (Wright 2015).

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