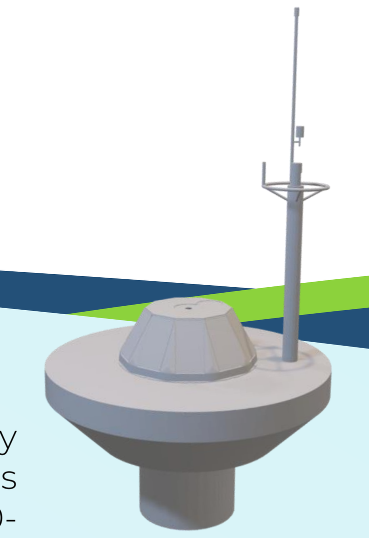
Behaviour of The WatchMate Buoy: 100-Year Storm Event Survivability and Typical Watch Circle Radius

Lane Braun, Colm Molder, Michael Schnablegger
MECH 446: Introduction to Ocean Engineering



Abstract

The case study assigned to undergraduate teams included two objectives. The first was to determine the expected service radius of the WatchMate buoy if it was initially charted off the west coast of Vancouver Island. The second was to determine the forces in the cable assembly during a 100-year storm event. All ocean analysis was conducted in ProteusDS. The maximum watch radius of the WatchMate buoy was determined to be 38.54 meters in the winter, and 23.33 meters in the summer. The 100-year storm event caused a maximum tension of 1603.35 newtons in the bridle and 2060.78 N in the studless chain.

Introduction

The WatchMate buoy is a data acquisition buoy designed by Axys Technologies in Sidney, BC [1]. The buoy is used to collect data on wind-wave conditions for research groups within the Institute for Integrated Energy Systems (IESVic) [2]. The buoy is moored using a free-floating cable assembly that is not connected to the ocean floor. The assigned case study included two objectives:

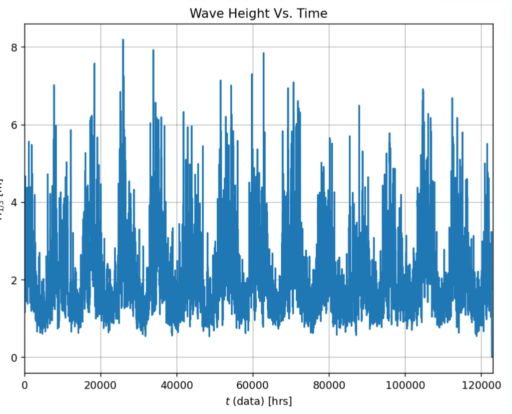
- **Determine the buoy's watch radius during typical summer and winter environmental conditions.**
- **Determine the survivability of the mooring assembly during a 100-year storm event.**

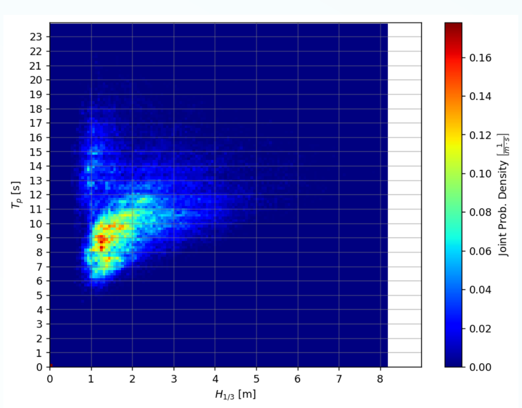
ProteusDS was used to simulate the ocean conditions the buoy could be expected to encounter over its service lifetime [3]. Using the tools developed over the past three months, a five-minute simulation of a 100-year storm event was conducted to estimate the forces in each segment of the mooring assembly.

The coordinates selected for this case study were [49°12'57.6" N, 126°17'49.2"W], near Hot Springs Cove. This location was selected since the residents of Hot Springs Cove, the Hesquiaht First Nation, are only able to access the village through boat [4].

Data Collection

This location was selected with the use of an online fishing map [5]. The tool confirmed the depth at these coordinates was the buoy design depth of 50 meters. Significant wave height and peak period data was found from the Marine Energy Resources Atlas [6]. The data gathered was sampled at a frequency of 1 recording per hour from January 1st, 2004, to January 11th, 2018. A plot of the wave heights over time is seen below on the left and a plot of peak period and significant wave height pairing probabilities is seen on the right.



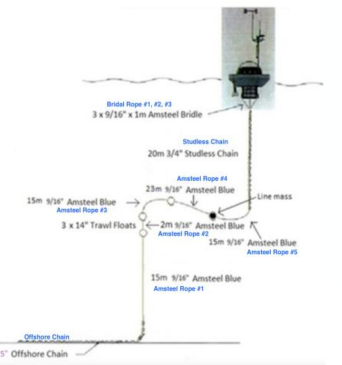


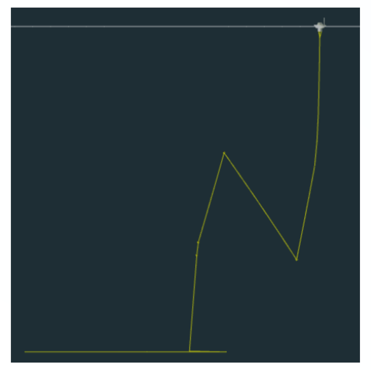
Initial Simulation Setup

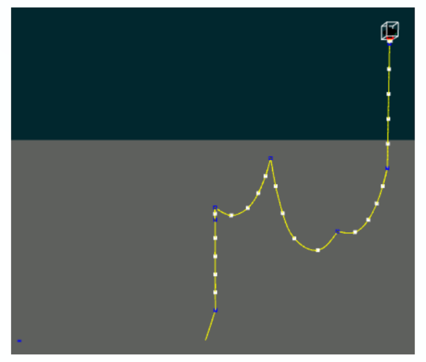
A bridal, studless chain, five segments of Amsteel rope, and an offshore chain comprise the mooring assembly. Along the mooring there are also three trawl floats and one line mass. The layout and numbering scheme for these cables is seen in the left below.

The steps to model the mooring the Proteus were:

- Resting draft of the buoy was found
- Cable start and end points were selected and calculated
- Point masses were used to represent trawl floats and line mass
- Point masses were used for shackles and swivels at connections
- An initial one-minute sim was run to allowing the mooring to settle (see middle image)
- Each of the bridles and the 2m line all contain 2 nodes as not to act as stiff cables
- All other cables besides the offshore chain contained 5 nodes each as to have enough points for data collection. The offshore chain contained 6 nodes as it only acts as a weight





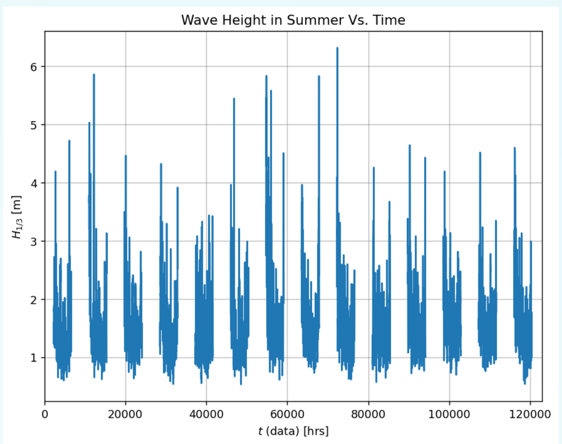


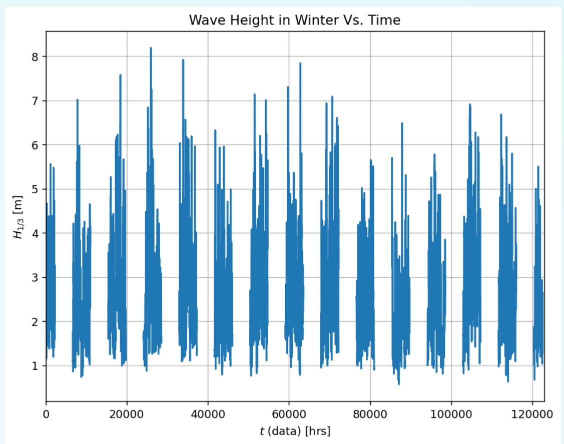
Methodology

Typical Summer and Winter Sea State Determination

To determine the typical sea state during the seasons the following approach was used:

- Consider the year as 6 months summer and 6 months winter
- Since the collected data had 14 years of points starting Jan 2004:
- Split a year into 4 3-month periods the first period is winter, second and third are summer, and the last one is winter
- Repeat that in a loop for each year, adding the data point of the loop to the summer or winter array, depending what section of the loop it is in.
- Obtain the mode from each graph for typical sea states, then use the Beaufort scale to determine wind speed.
- To obtain the peak period use the joint probability plot seen in the right photo in the data collection section





Typical Summer Conditions	
Wave Height	1.61 m
Peak Period	9.62 s
Wind Speed	6.44 m/s

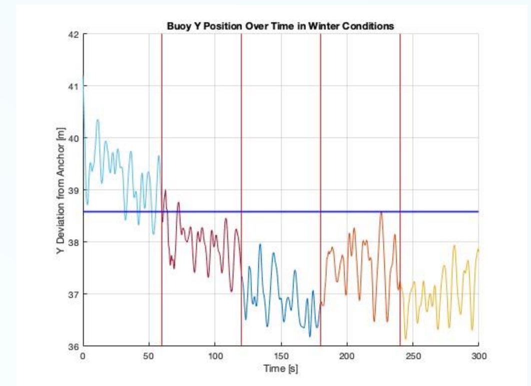
Typical Winter Conditions	
Wave Height	2.94 m
Peak Period	10.6 s
Wind Speed	10.54 m/s

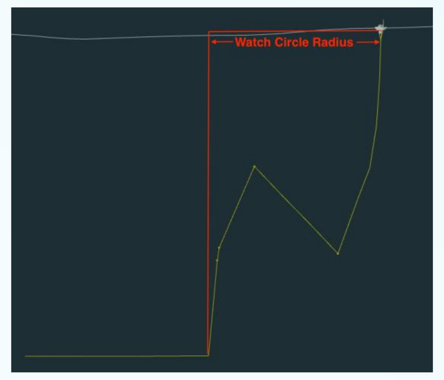
Typical Summer and Winter Simulation

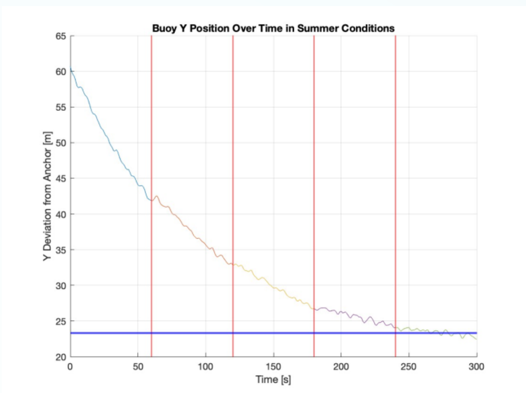
From the initial set-up the previously obtained wave heights were added with a Pierson-Moskowitz spectrum, the wind was added with an Ochi-Shin spectrum and a logarithmic wind driven current was added (everything had a heading of 90° for a "worst case scenario". For both the summer and winter conditions the simulations were run in one-minute steps, changing the wave and wind seed each time. The winter simulation was run for a total of 5 min and the summer simulation was run for a total of 5 minutes.

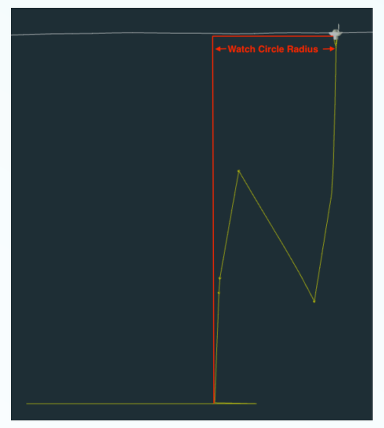
Watch Circle Radius Determination

To determine the watch circle radius the y-position of the buoy was plotted over time for both summer and winter conditions. The watch radii were determined as the point where the offshore chain sits on the ground to the max point away the buoy reached as illustrated below:









During both sims, the buoy moved in a negative direction. This is because the initial set-up had the buoy starting at roughly 40 meters away from the grounded point. The winter simulation took about 2 minutes to settle out and the summer simulation settled out around the end of the fifth minute. From the point the buoy settled, it's maximum peak (horizontal blue line) was chosen to be the watch circle radius as this is the maximum point the buoy will reach from the point it is grounded at the seabed. Another interesting observation from the graphs is that summer curve is much smoother, this is because the waves and wind are much smaller and therefore allow the buoy to settle much smoother. The overall watch radius for the different seasons are as follows:

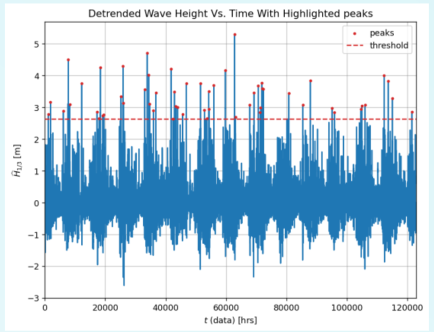
Typical Watch Radii	
Summer	23.33 m
Winter	38.54 m

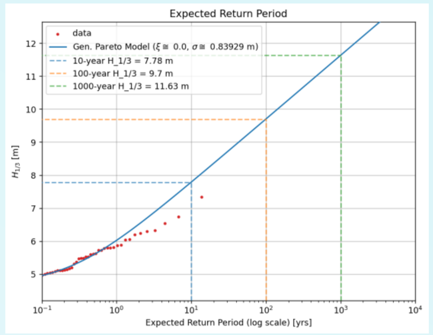
100-Year Storm Sea State Determination

A Peaks-over-Threshold approach was used to model the 100-year Storm sea state. This approach is summarized as follows:

- Removing the 15-day moving average
- Determining peaks per a three-day synoptic heuristic period
- The top four peaks every year were kept to establish the threshold
- Exceedance probabilities were calculated for the ordered peaks
- The Generalized Pareto Model was used to extrapolate exceedance

The identifies peaks over threshold are seen below on the left, and the 10, 100, and 1000 year storm events found using the Generalized Pareto Model are seen below on the right.





100-Year Storm Conditions	
Wave Height	9.7 m
Peak Period	16 s
Wind Speed	24 m/s

The 100-year significant wave height was used to extrapolate a wind speed based off the Beaufort Sea State scale. The peak period was determined from the peak period joint probability density. The resulting sea state is shown in the table to the left:

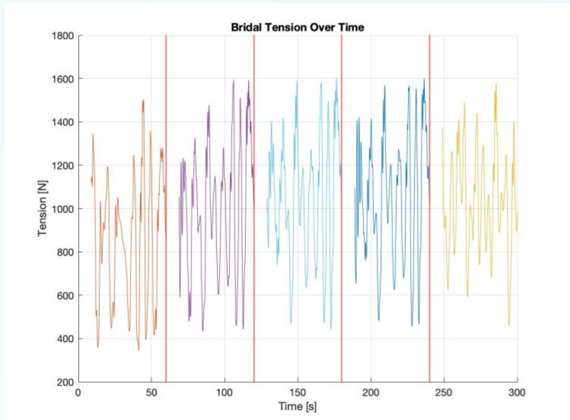
100-Year Storm Simulation

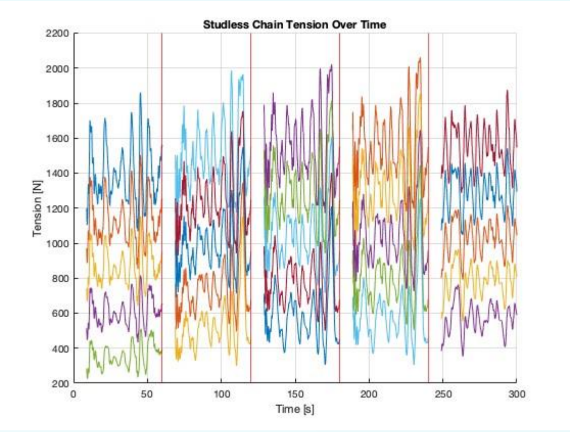
The significant wave height and peak period were used with a Pierson-Moskowitz wave type. The wind selected was a uniform Ochi-Shin spectrum. A logarithmic wind driven current was used. Five 1-minute simulations were run where the end of the previous simulation was exported to begin the next. For each simulation, the wind and wave seeds were altered.

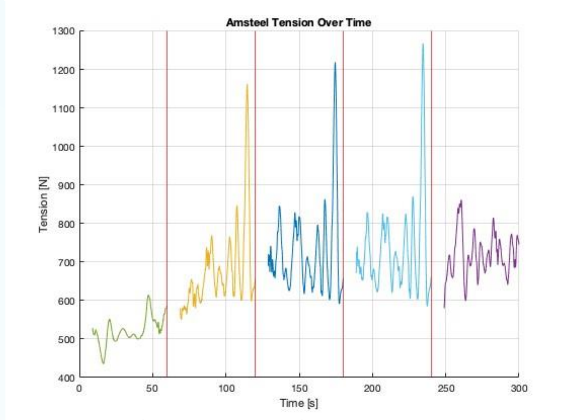
100-Year Storm Mooring Assembly Survivability Analysis

After simulation, plots of tension on mooring elements over time were created. The method of exporting one simulation into another, had the un-intended effect of on occasion starting the Buoy underwater. This led to spikes in tension at the start of each minute. Analysis revealed that removing the first 10 s of each simulation gave enough time for the buoy to settle.

The plots below show tension in each element of bridal three, the studless chain, and Amsteel rope 1. Amsteel rope 1 and bridal 3 were chosen because they experienced the highest tension of their subset. The bridal and Amsteel elements all experienced similar tensions, while the studless chain elements had a wide variation as seen in the figure.







Static Safety Factor Determination

The safety factors for each mooring material are:

9/16" Amsteel Rope max tension: 1,603.35N

9/16" Amsteel Rope min strength [8]: 161,700N

Safety Factor: 100.85

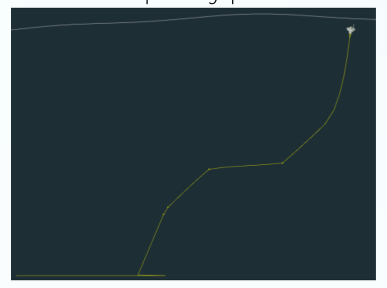
3/4" Studless Chain max tension: 2,060.78N

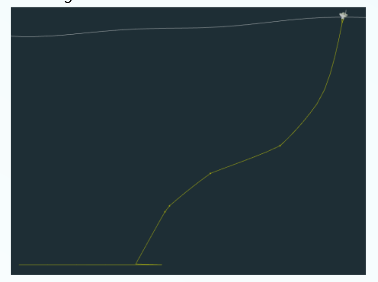
3/4" Studless Chain proof load [8]: 160,818N

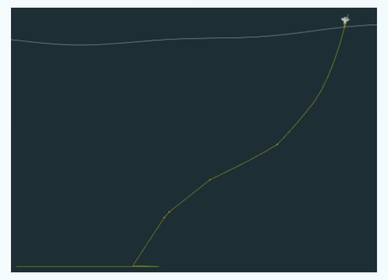
Safety Factor: 78.04

Max Tension Dynamics

Investigating the simulation at the period of max tension (234.4s) the following dynamics are seen at 232.6s, 234.4s and 235.6s left to right. In the first image a large wave fully submerges the buoy, in the second image the buoys buoyancy rapidly brings it to the surface and tensions the line. Finally, the wave quickly passes tossing the buoy into the air.







Fatigue Failure Analysis

A study by the Amsteel manufacturer, Samson, has found Amsteel Blue has negligible strength losses due to fatigue [10]. As such, only fatigue on the studless chain will be analyzed.

From [7] , a fatigue safety factor for a situation with varying mean and alternating stress's that have a constant ratio, as is the case with the WatchMate mooring, can be found by:

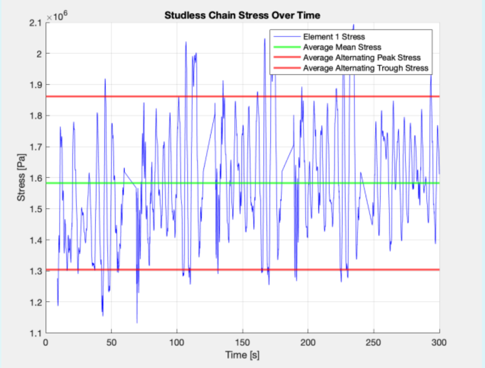
$$N_f = \frac{S_e S_{ut}}{\sigma_a S_{ut} + \sigma_m S_e}$$

where S_e is the corrected material endurance limit, S_{ut} is the ultimate strength, σ_a is the alternating stress (deviation above and below mean) and σ_m is the mean stress. The corrected endurance strength is given by: $S_e = C_{load} C_{size} C_{surf} C_{temp} C_{reliab} S'_e$ where S'_e is the uncorrected endurance limit.

The ultimate breaking stress (S_{ut}) of 3/4" studless chain is 1018.1 MPa [8]. For steels, from [7]: $S'_e \cong 0.5 S_{ut} = 509.04\ MPa$. For axial loading at temperatures below 450C: $C_{load} = 0.7$, $C_{size} = 1$, $C_{temp} = 1$. For hot rolled material with an ultimate strength of 1018.1 MPa [9]: $C_{surf} = 0.3996$. Choosing a reliability factor of 99.9%: $C_{reliab} = 0.753$.

This determines a corrected fatigue endurance strength of $S_e = 107.22\ MPa$

To determine mean and alternating stress, the stresses of element one of the studless chain (Highest stress was found here) were plotted. Again, the first 10 seconds of each simulation were removed. Mean stress σ_m was found from the average of this data set. Alternating stress σ_a was found by determining the average peak height (based off the max values within a 6 second heuristic) and subtracting the mean from this height



Fatigue Safety Factor Determination

Ultimate breaking stress: $S_{ut} = 1018.1\ MPa$

Corrected endurance strength: $S_e = 107.22\ MPa$

Average mean stress: $\sigma_m = 1.58\ MPa$

Average alternating stress: $\sigma_a = 0.28 MPa$

Safety Factor: $N_f = 240.2$

Results

The simulations completed in ProteusDS produced reasonable results to the objectives outlined for this case study. The maximum radius the buoy could be expected to travel was found to be 38.54 meters . A displacement of this magnitude was found to occur in winter conditions. During the summer months the watch radius is only 23.33 meters.

During a 100-year storm event, the maximum tension was found to be 1603.35 Newtons in bridle 3 and 2060.78 N in the studless chain. The table below shows the maximum force in each component of the mooring assembly. The simulated forces were well below the maximum rating for each component in the mooring assembly.

Component	Max Tension [N]	% of Proof Load
1. 3 x 1 m x 9/16" Bridle Rope	1,603.35	0.888566296
2. 20 m x 3/4" Studless Chain	2,060.78	1.280567198
3. 15 m x 9/16" Amsteel Blue #1	1,267.38	0.702373875
4. 2 m x 9/16" Amsteel Blue #2	1,161.94	0.643939703
5. 15 m x 9/16" Amsteel Blue #3	1,087.99	0.602957087
6. 23 m x 9/16" Amsteel Blue #4	1,061.97	0.588536969
7. 15 m x 9/16" Amsteel Blue #5	1,163.41	0.644754367
8. 54 m x 3.5" Offshore Chain	657.5	0.014907469

Conclusion

A location off the coast of Hot Springs Cove was selected to analyze the watch radius in typical operating conditions and the 100-year storm event survivability of the WatchMate buoy. It was determined that the buoy would operate within a 23-to-39-meter radius during typical environmental conditions and depending on the season. The studless chain experienced the highest percentage of maximum rated force. The mooring assembly was found to be properly designed for a 100-year storm event.

References

[1] "Welcome to AXYS," https://axys.com/. (accessed Aug. 1, 2023).

[2] "Institute for Integrated Energy Systems - University of Victoria," UVic.ca, https://www.uvic.ca/research/centres/iesvic/index.php. (accessed Aug. 1, 2023).

[3] R. Nicoll, "ProteusDS Homepage," ProteusDS, https://proteusds.com/. (accessed Jul. 29, 2023).

[4] "Hesquiaht First Nation," HesquiahtFirstNation, https://www.hesquiaht.ca/. (accessed Jul. 29, 2023).

[5] "Boating : Free marine navigation charts & fishing maps," i, https://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Hot%2BSprings%2BCove%2Bboating%2Bapp#11.72/49.2145/-126.2965. (accessed Jul. 29, 2023).

[6] Marine Energy Resources Atlas Canada, https://meracan.ca/ (accessed Jul. 29, 2023).

[7] R. L. Norton, *Machine Design: An Integrated Approach*. 6th Edition, Chapter 6, Pearson, 2019.

[8] Anthony Truelove, *"Mooring Line Parameters"*, MECH 446: Introduction to Ocean Engineering, August 2023.

[9] "Studless chain - offshore mooring chain," Boomarine, https://www.boomarine.com/products/studless-chain#:~:text=Studless%20Chain%20is%20the%20one,galvanizing%20or%20black%20spray%20paint. (accessed Aug. 1, 2023).

[10] "Tension fatigue testing," Samson Rope, https://www.samsonrope.com/resources/mooring/tension-fatigue-testing#:~:text=at%2080%25%20method)-,Test%20Results,ropes%20due%20to%20tension%20fatigue. (accessed Aug. 2, 2023).