U.S. Advances in Digital Twinning for Offshore Wind Assets

RAVE Workshop 2024

Eric Hines, Azin Mehrjoo, Nasim Partovi-Mehr

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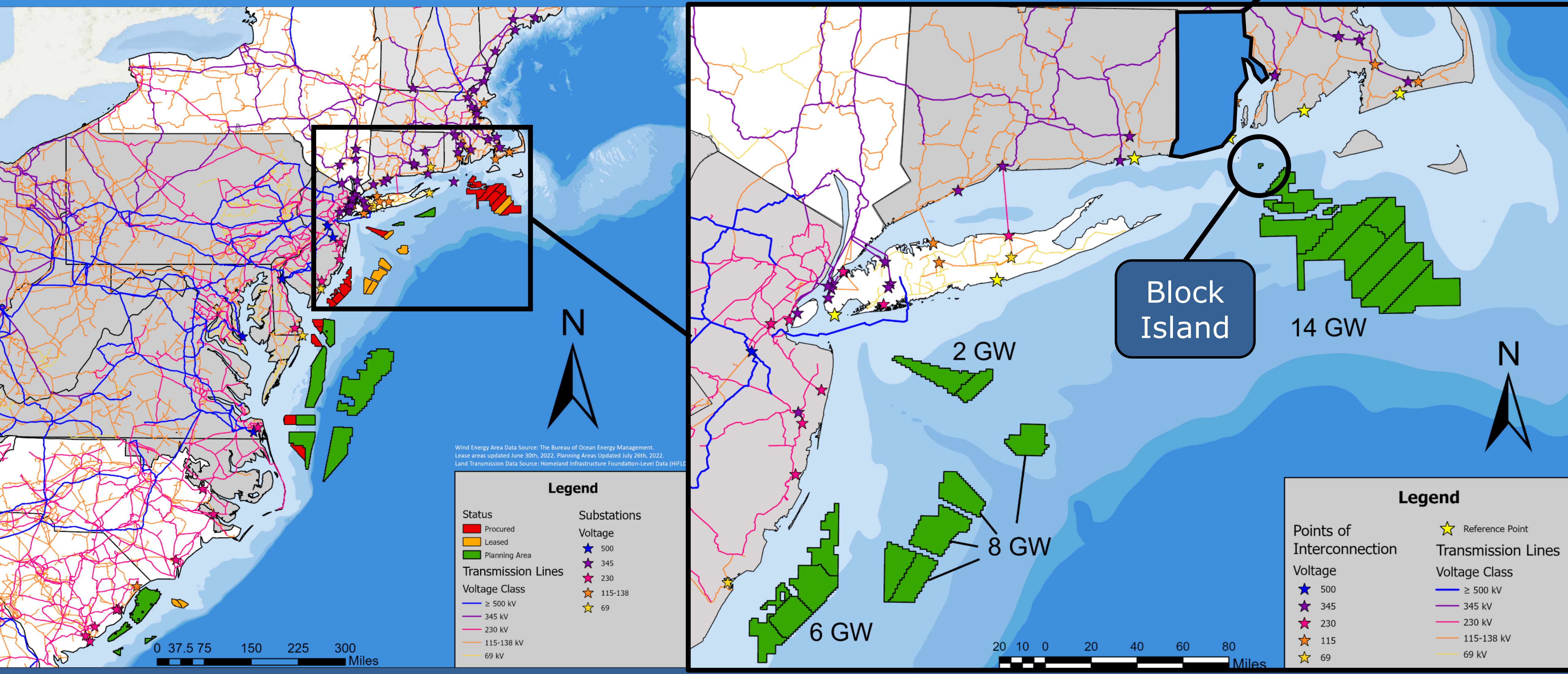
Fatigue Performance

Ph.D. work by Nasim Partovi-Mehr

U.S. East Coast Offshore Wind



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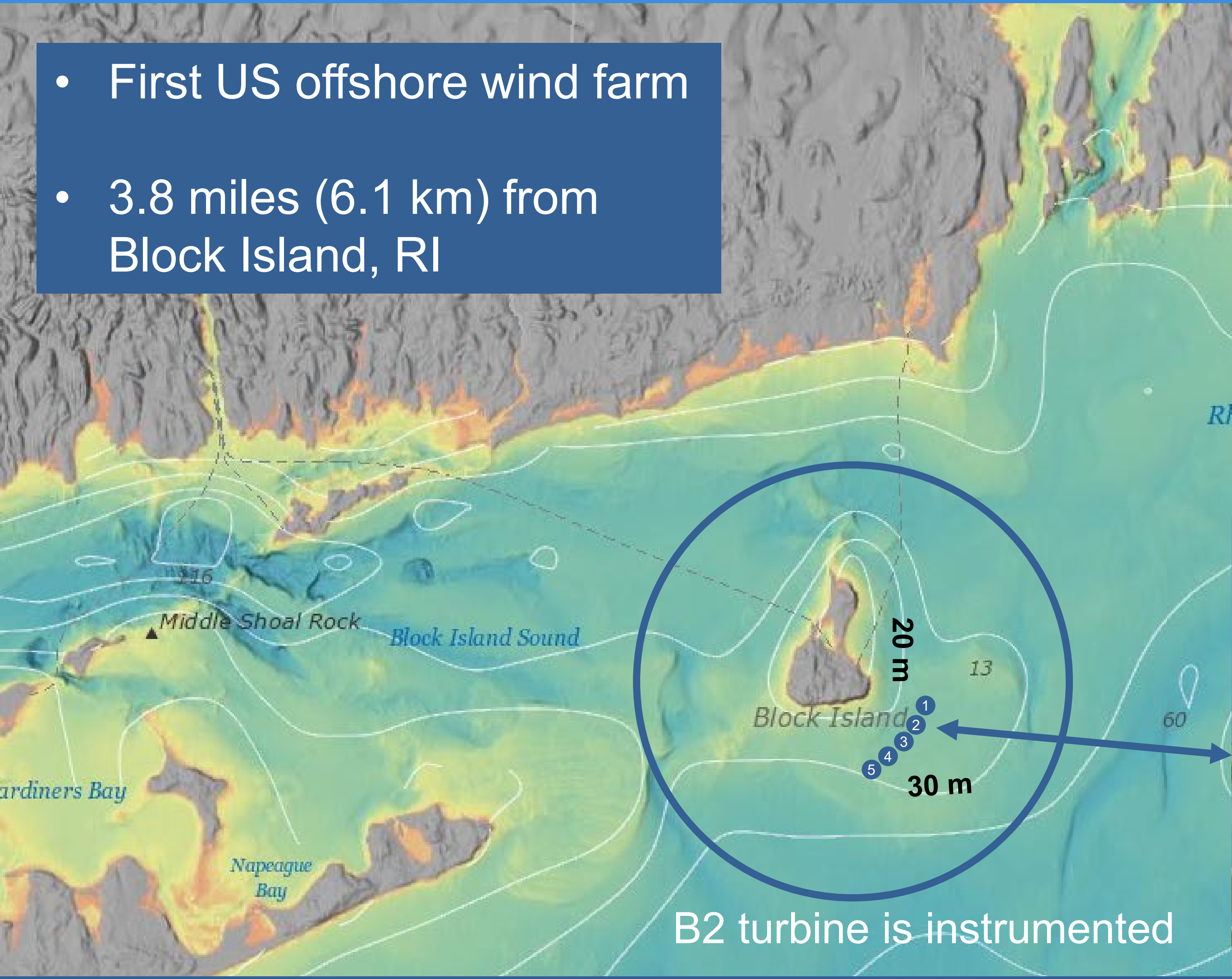
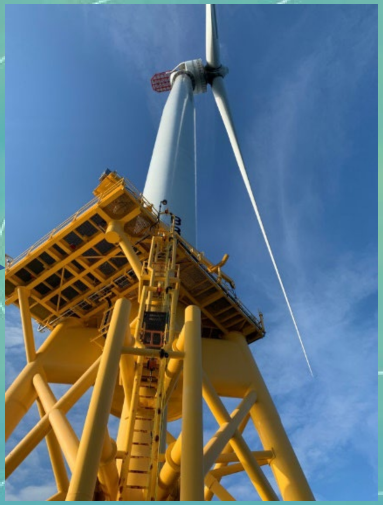
Block Island Wind Farm

- First US offshore wind farm
- 3.8 miles (6.1 km) from Block Island, RI



B2 turbine is instrumented



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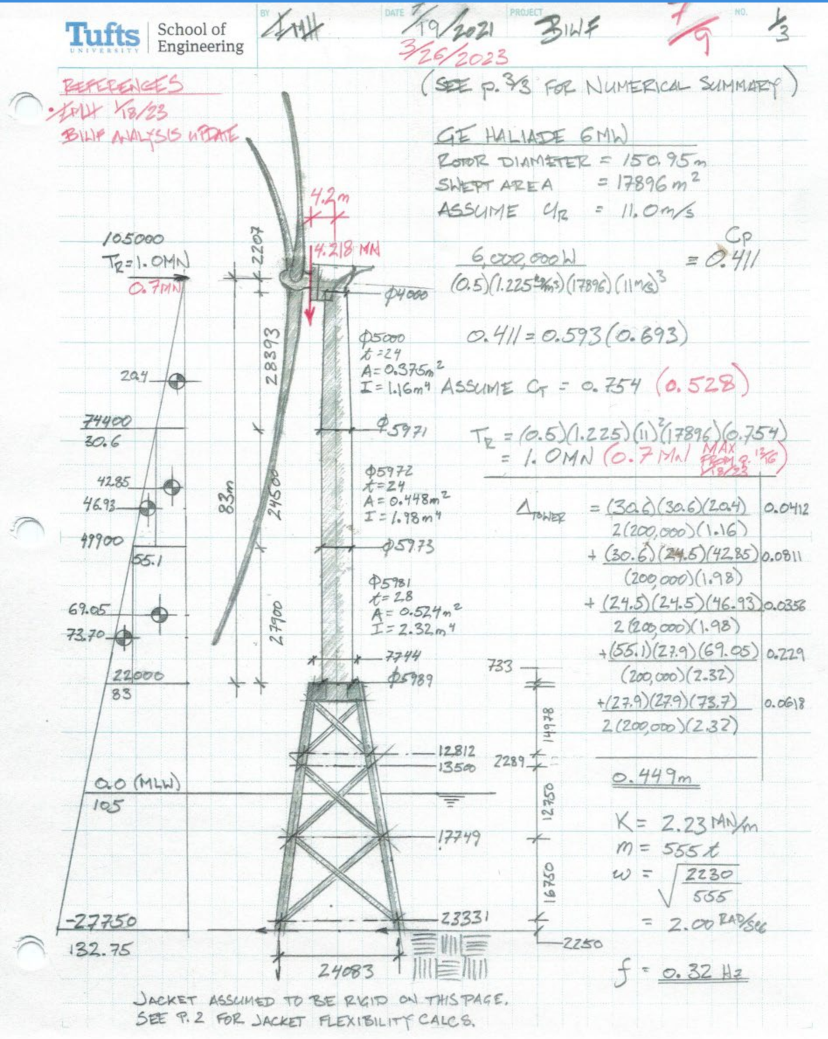
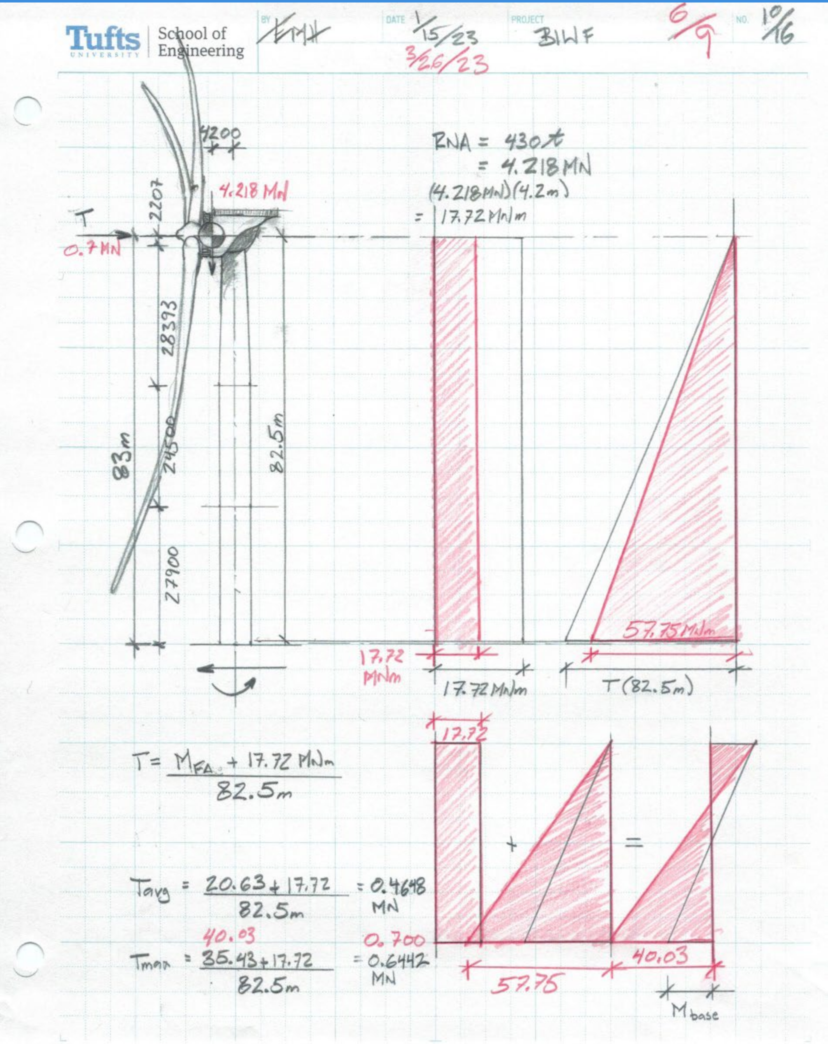
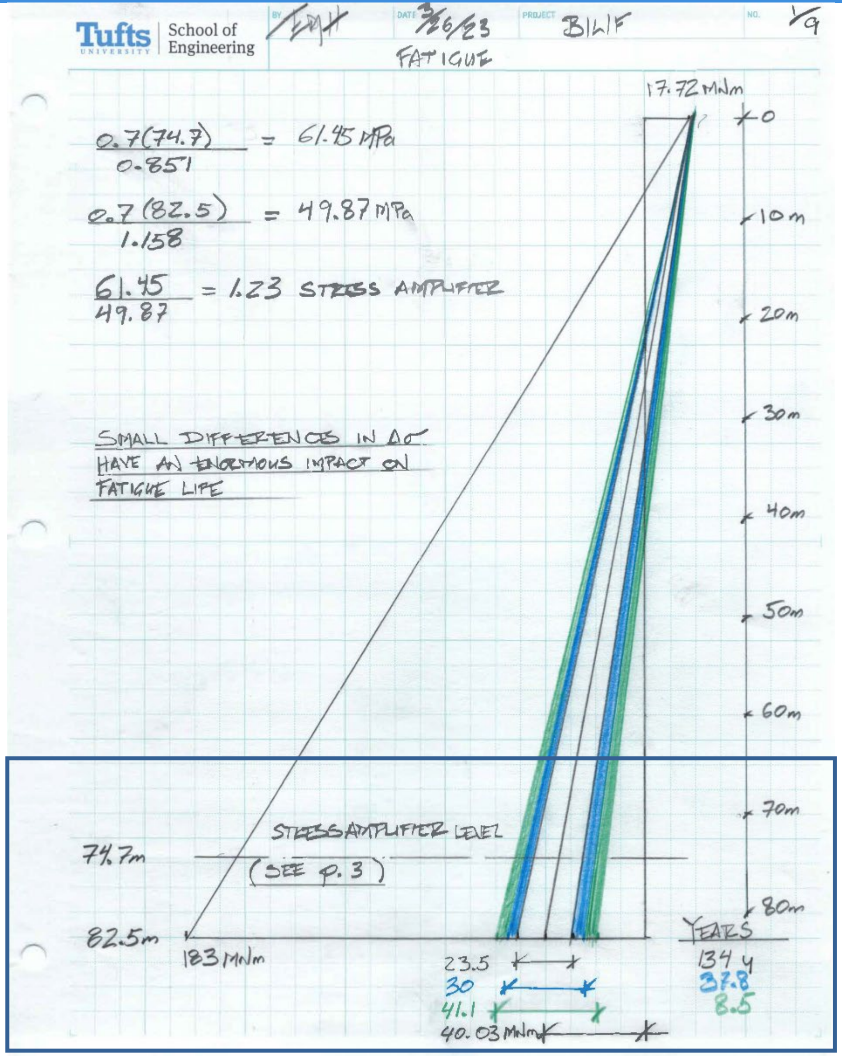
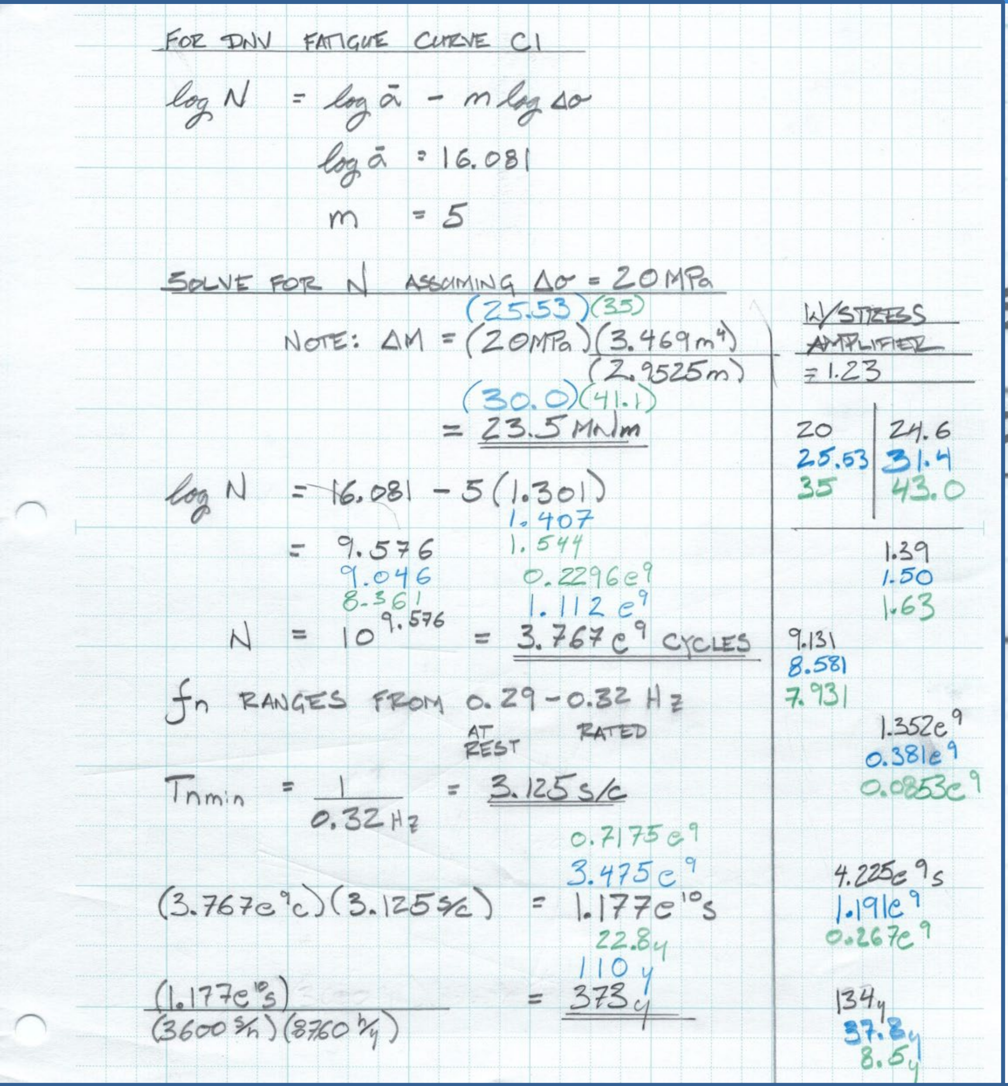
Structural Fatigue Analysis Framework

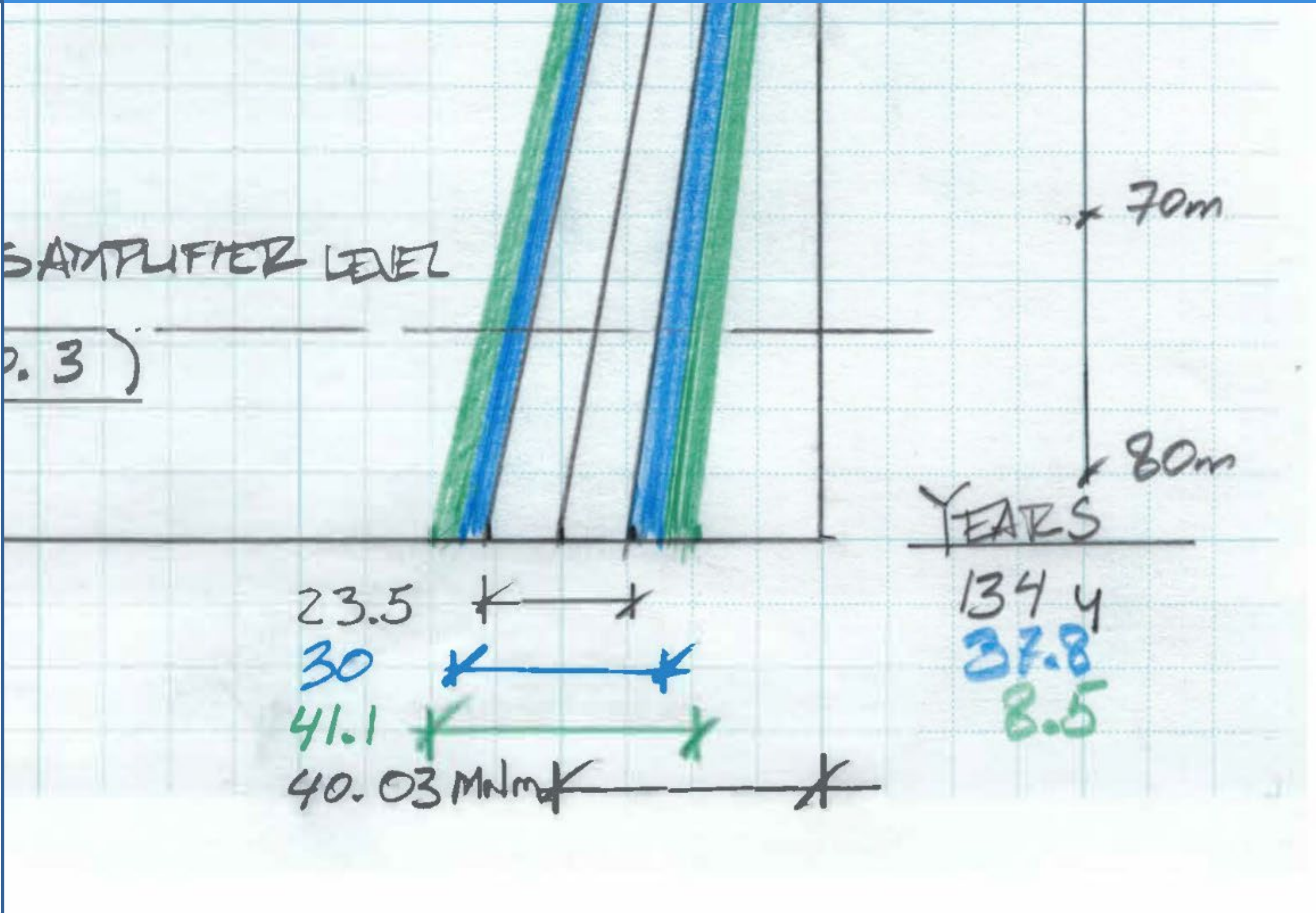






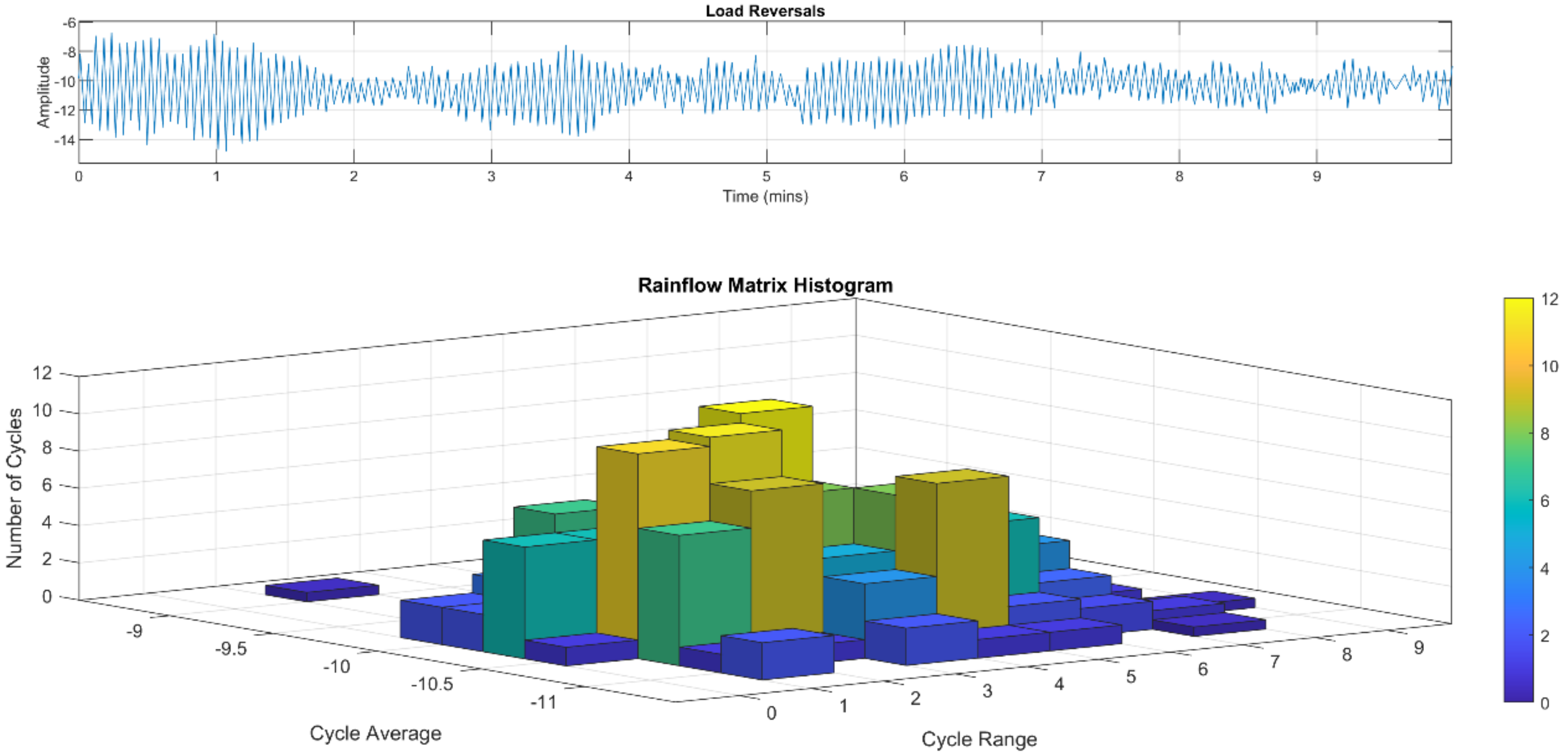
Structural Fatigue Analysis Framework





Rainflow counting of stress cycles

- Rainflow counting for a 10-minute interval on December 17, 2021 starting at 06:52 am



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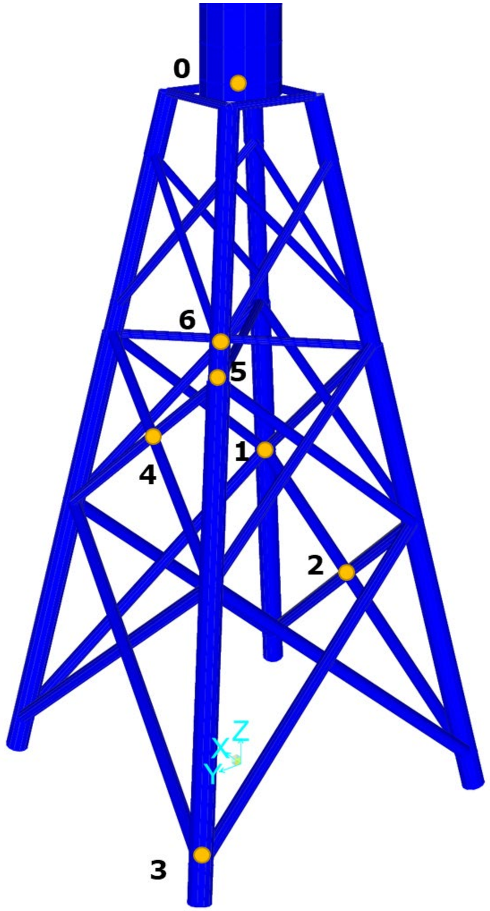
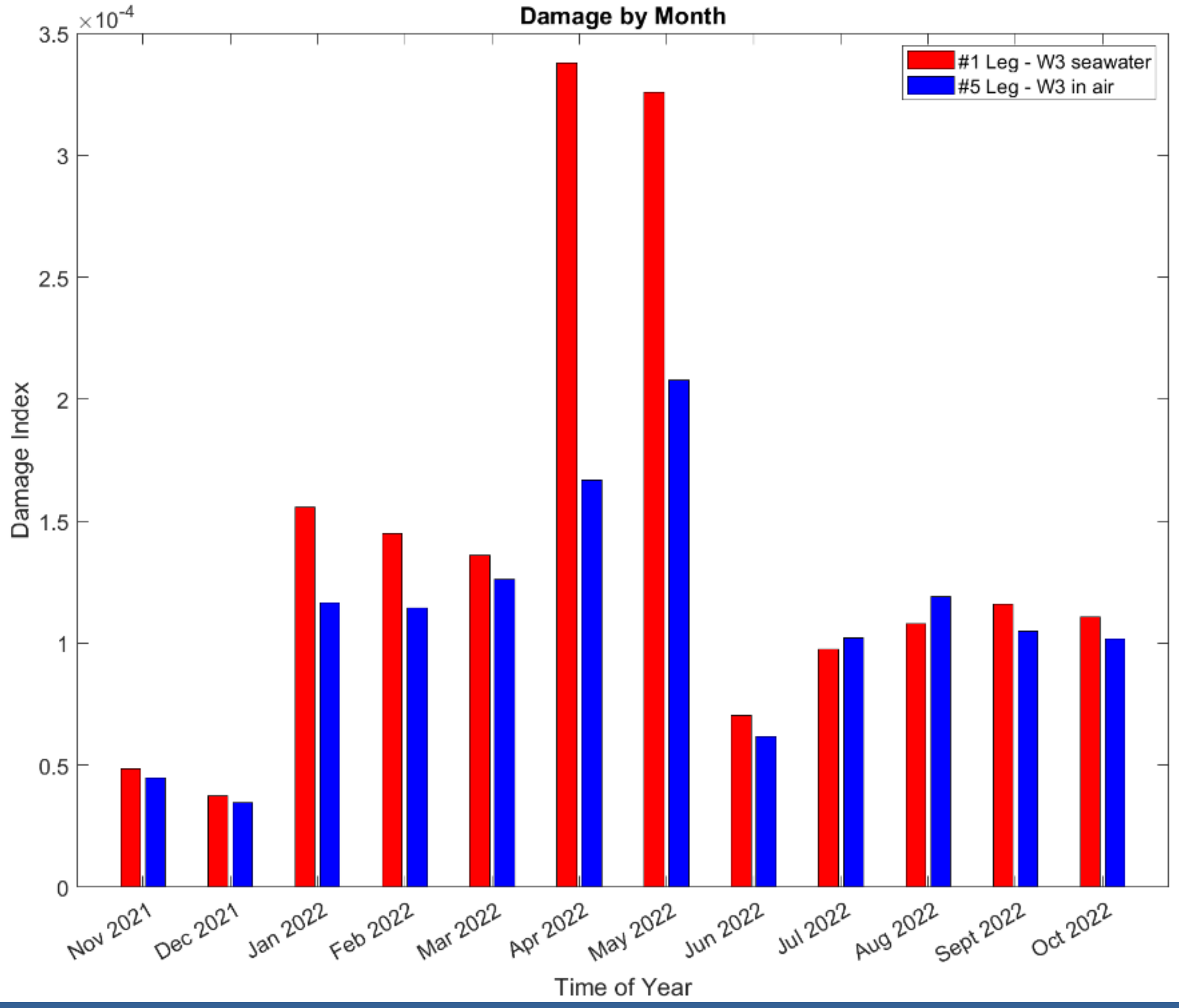
Virtual Sensors via Modal Expansion

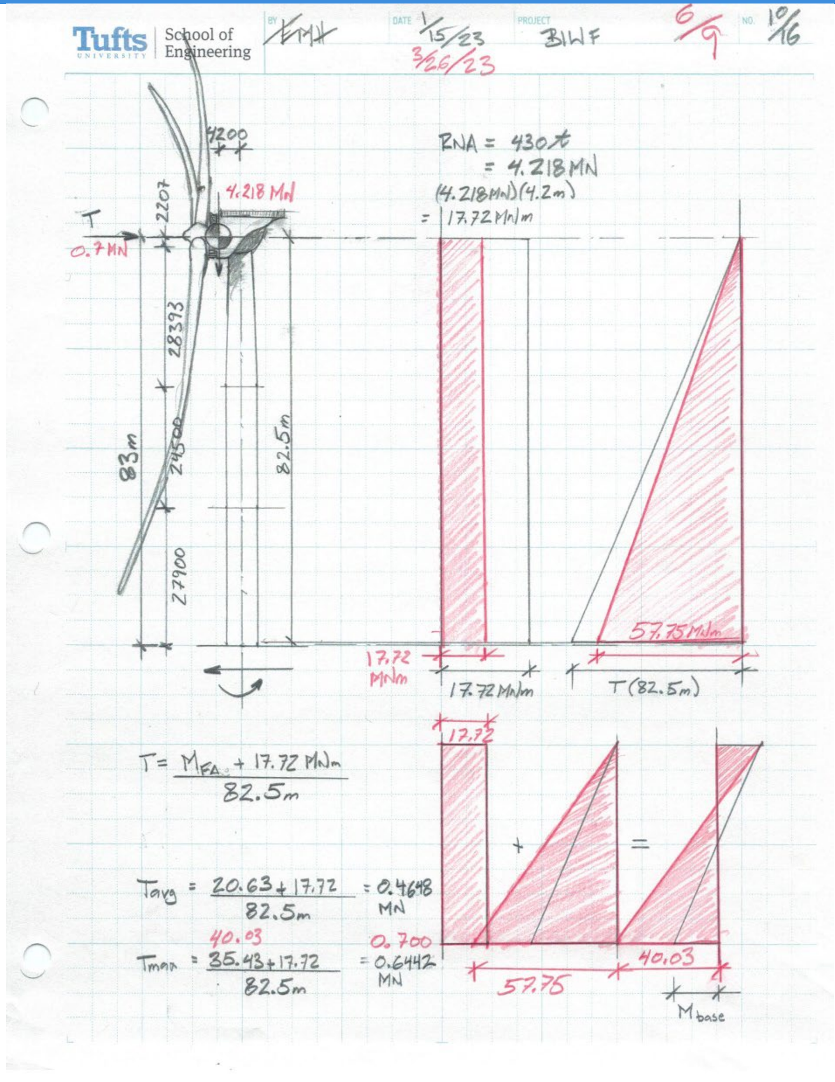
- Damage vs. time ratio to the lifetime of 25 years using extrapolating 1-year monitoring:



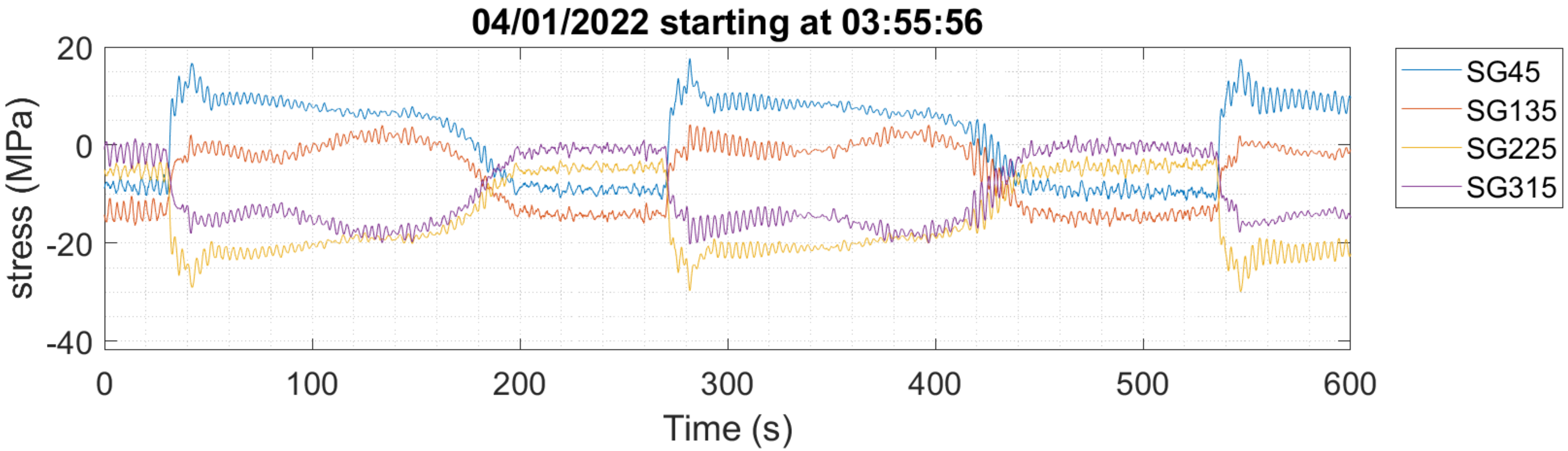
Joint	Environment	Measured	Designed
#1	W3 Cath.Prot. DFF = 3	196 y	26 y
#2	W3 Cath.Prot. DFF = 3	222,000 y	76 y
#5	W3 in air DFF = 2	386 y	50 y

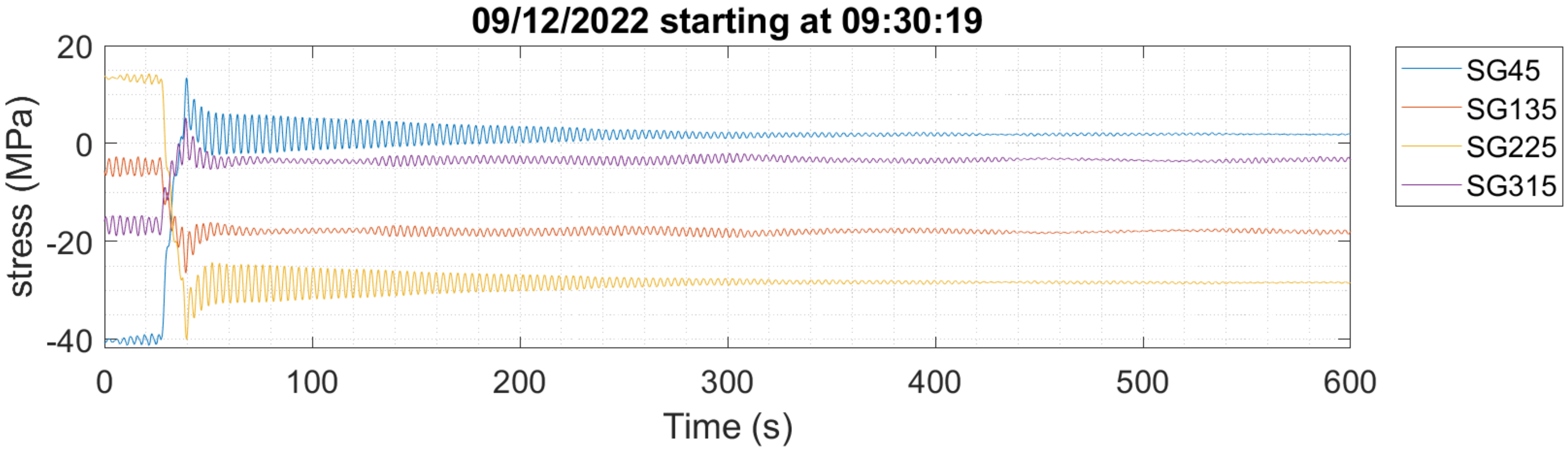
What cycles cause the most damage?





Sample stress time histories with high damage





2021 Wangwen Review of Fatigue Curves

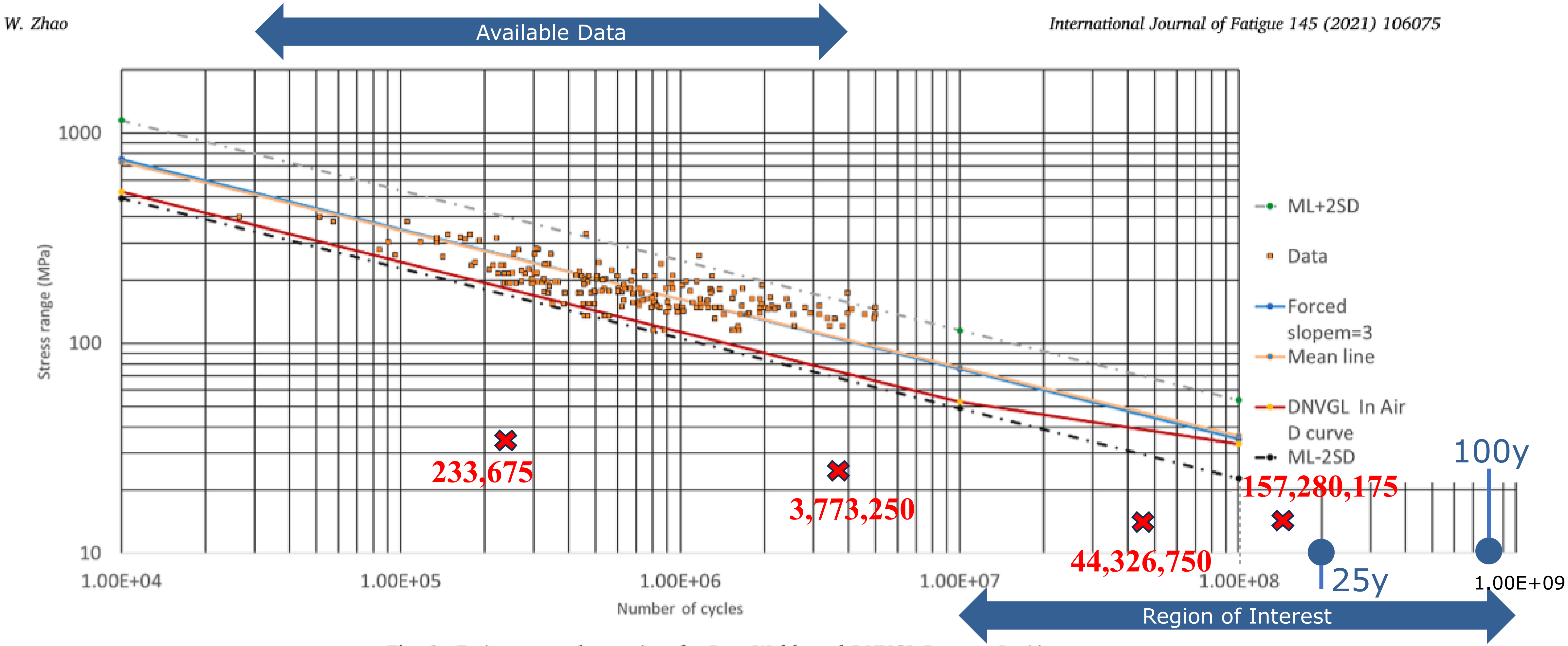


Fig. 9. Fatigue tests data points for Butt Welds and DNVGL D curve In Air.

(3600 s/h)(8760 h/y)(25 y) / (T = 4 s) = 1.97 E+08

Windows-Based
Bayesian Assimilation Framework

Physics-Informed Neural Networks

Ph.D. work by Azin Mehrjoo

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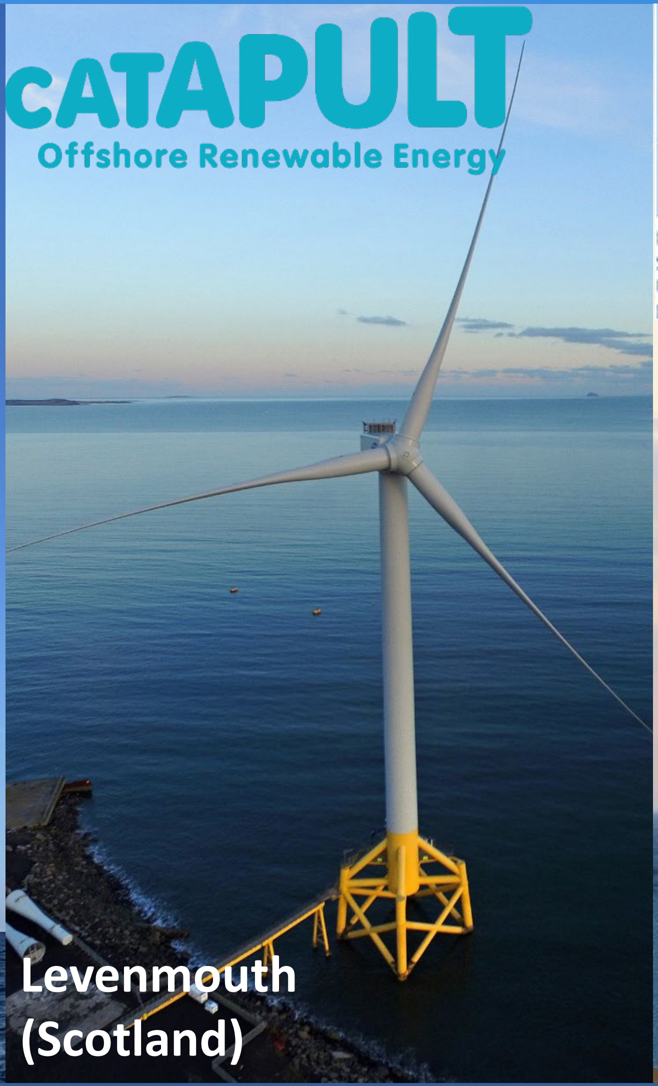
U.S. + North Sea Experience

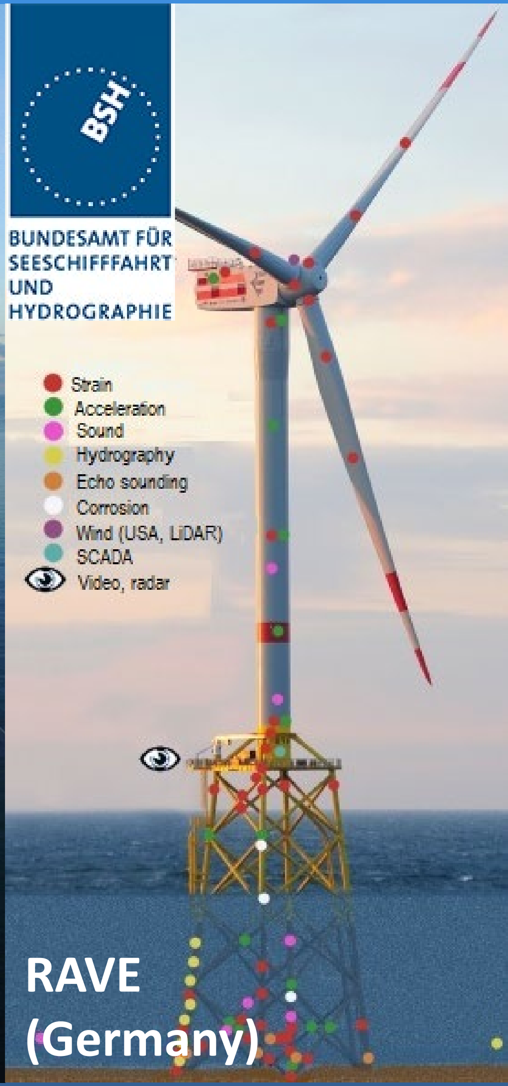
Block Island
(Rhode Island)

Ørsted Turbine
(North Sea)

CVOW
(Virginia)

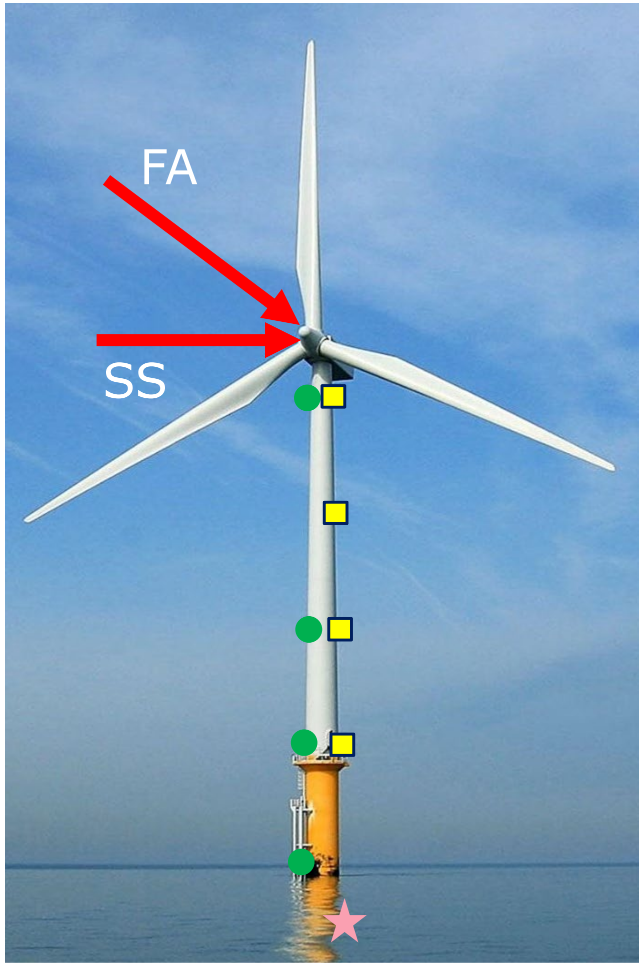


Levenmouth
(Scotland)



RAVE
(Germany)

Find a dynamic input at hub height that reproduces measured results



Input load
FA = fore-aft
SS = side-to-side

Accelerometers

Strain gauges

Virtual Sensor

1- Windowed Based Input Estimation(WBIE)

2- Physics Informed Neural Network(LSTM)

Given:

- A validated model
- Available Measurements
- Position and number of the unknown loads

Find:

- Input load time history
- Estimation of vibration response at unmeasured locations (virtual sensing)

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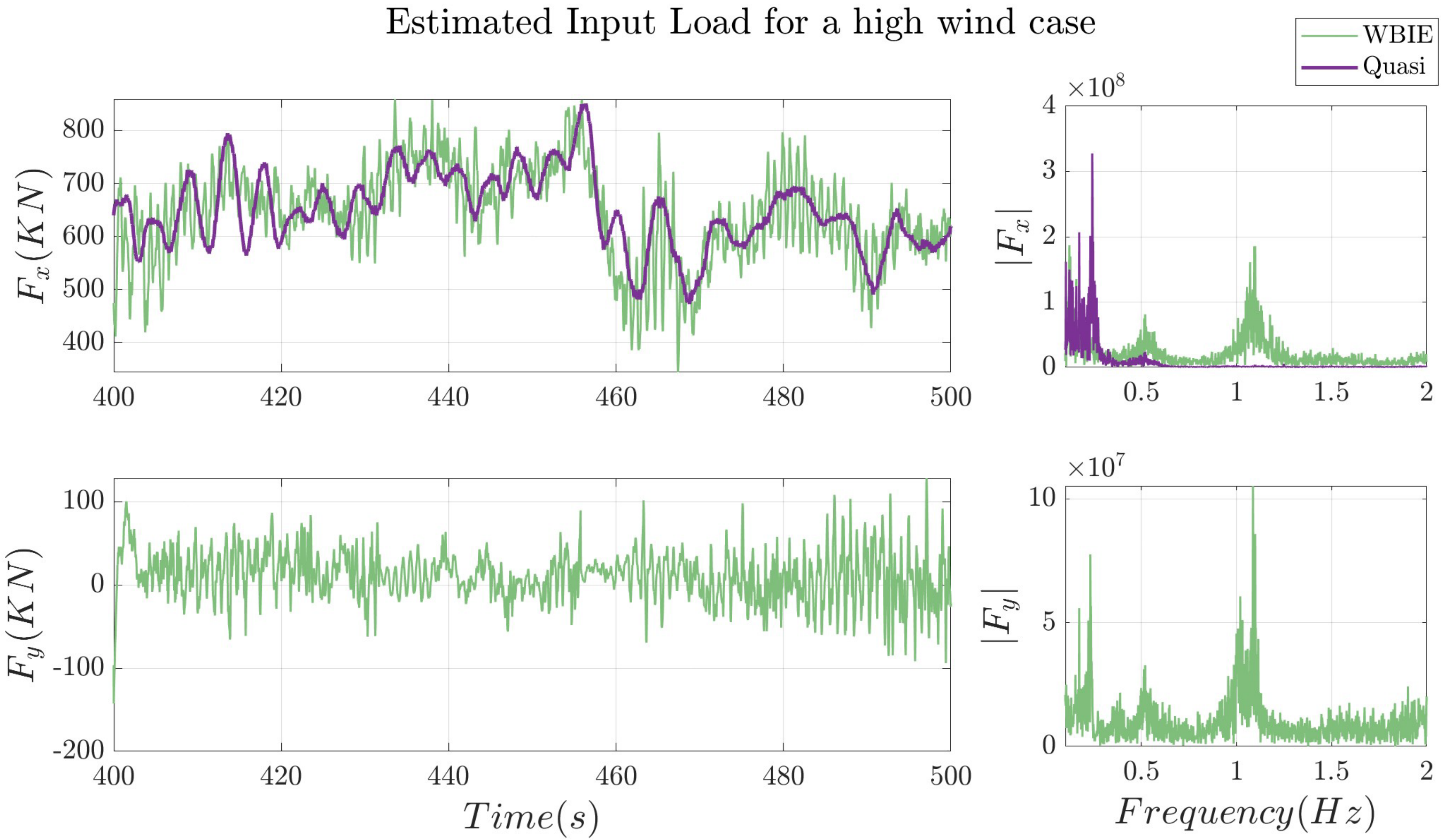
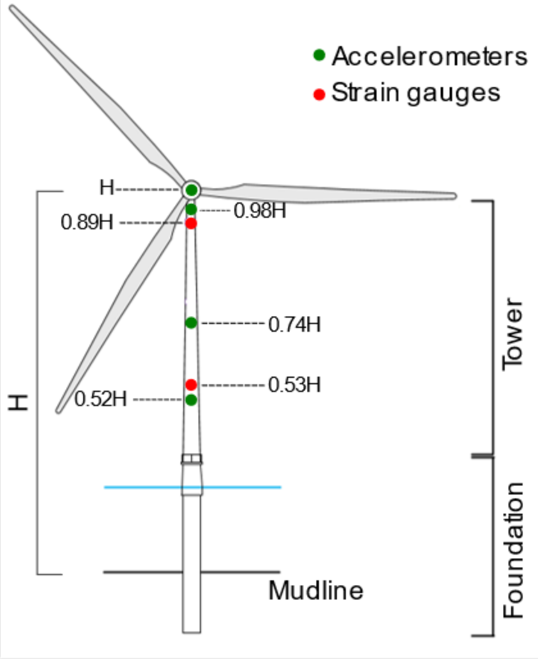
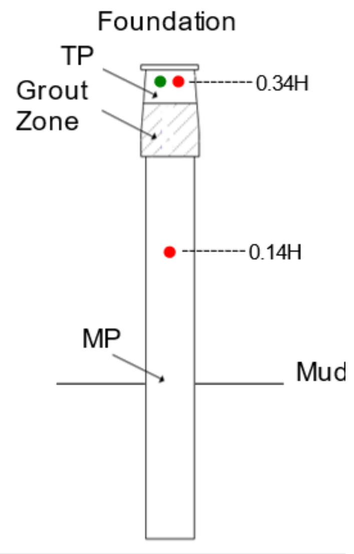
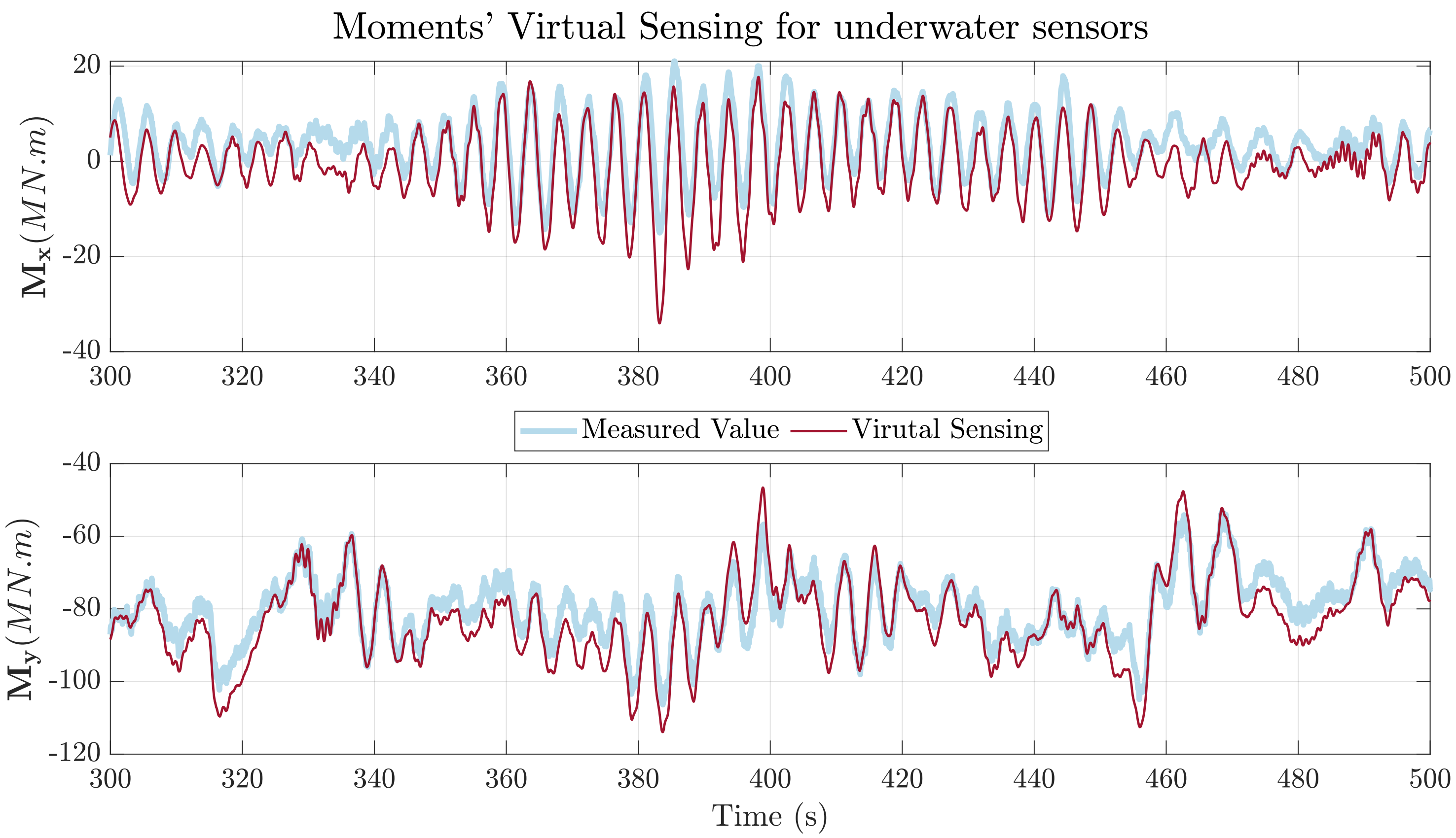
Estimated input load for a high wind case



Virtual Sensing at unmeasured locations

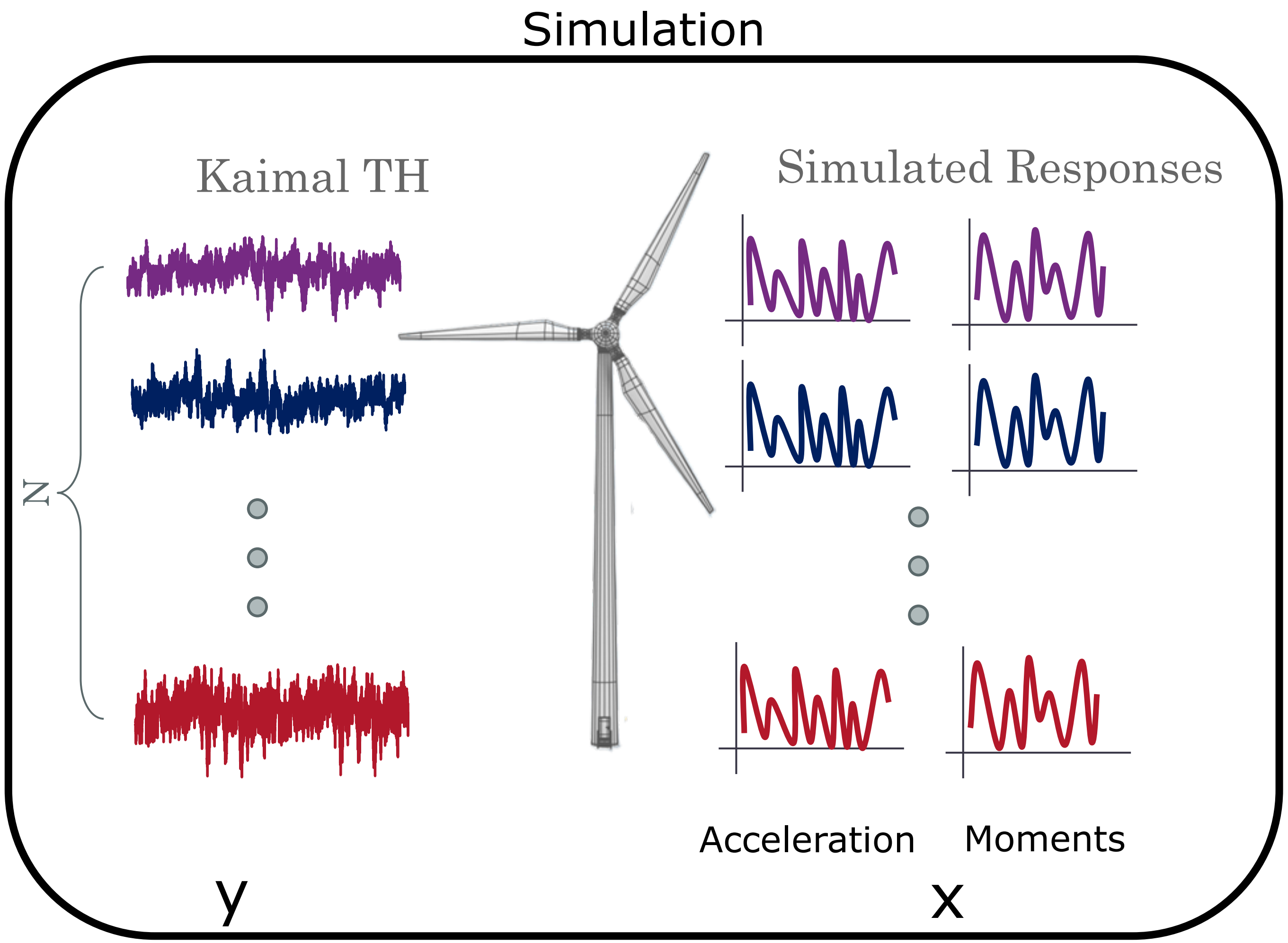


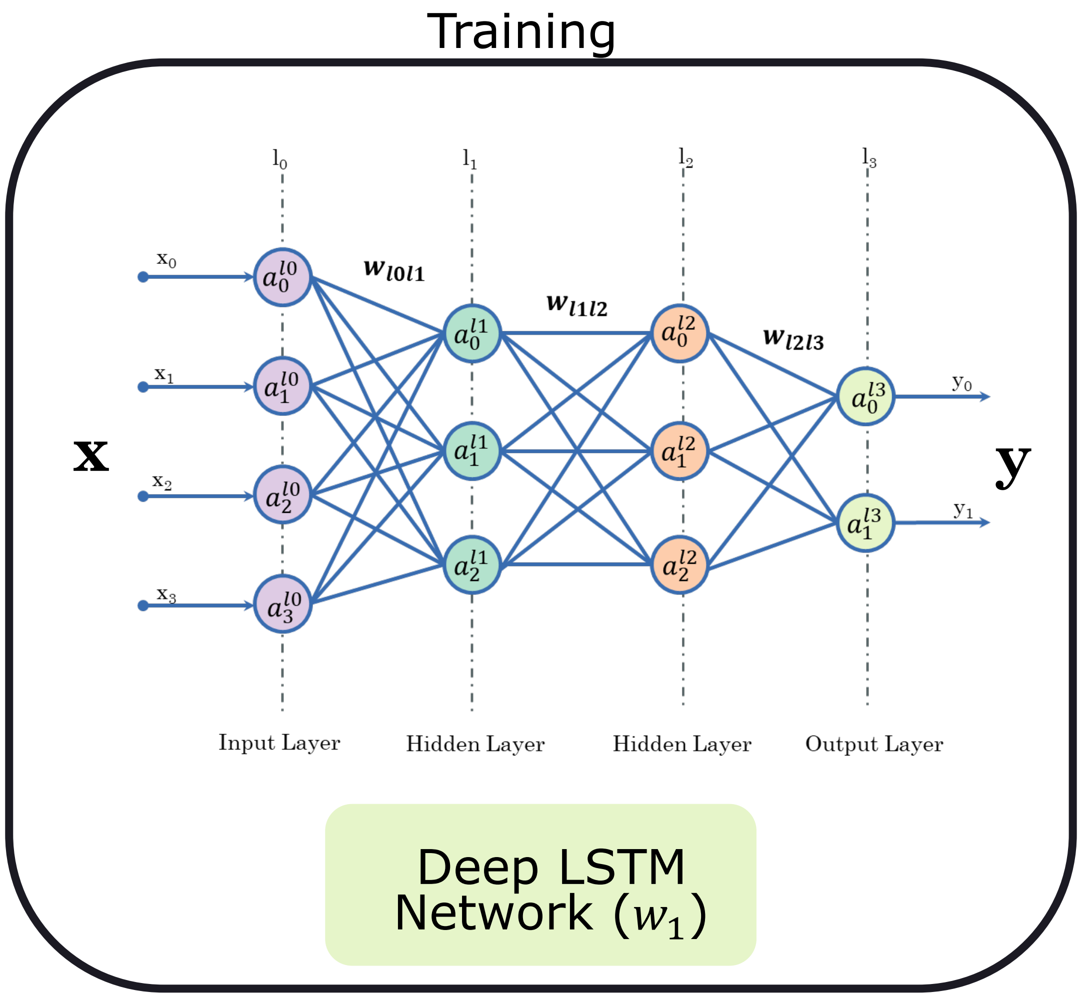




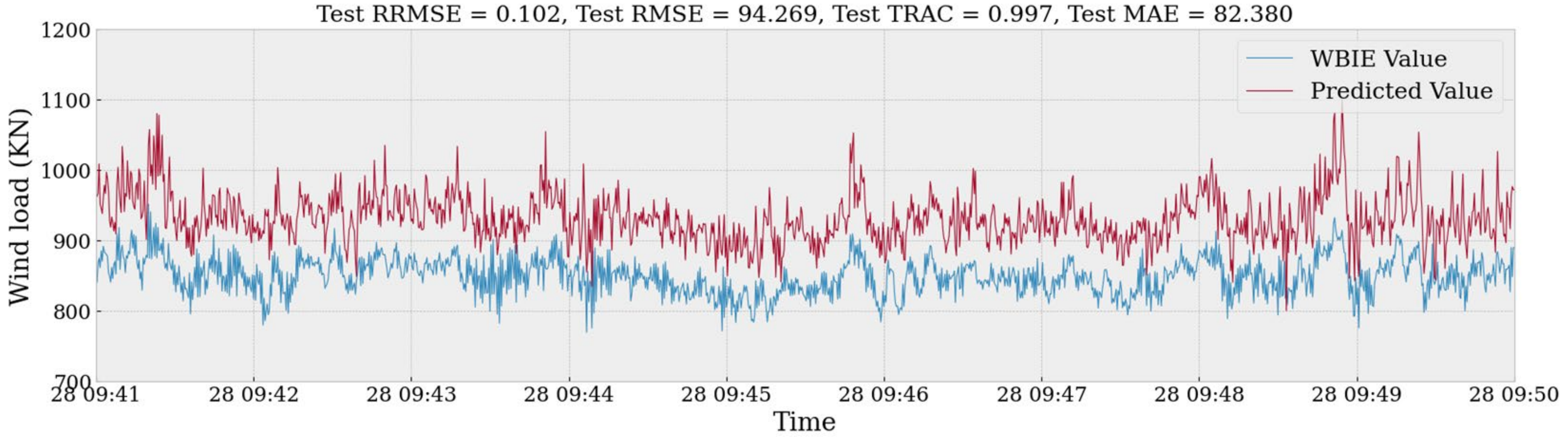
Physics Informed Neural Network

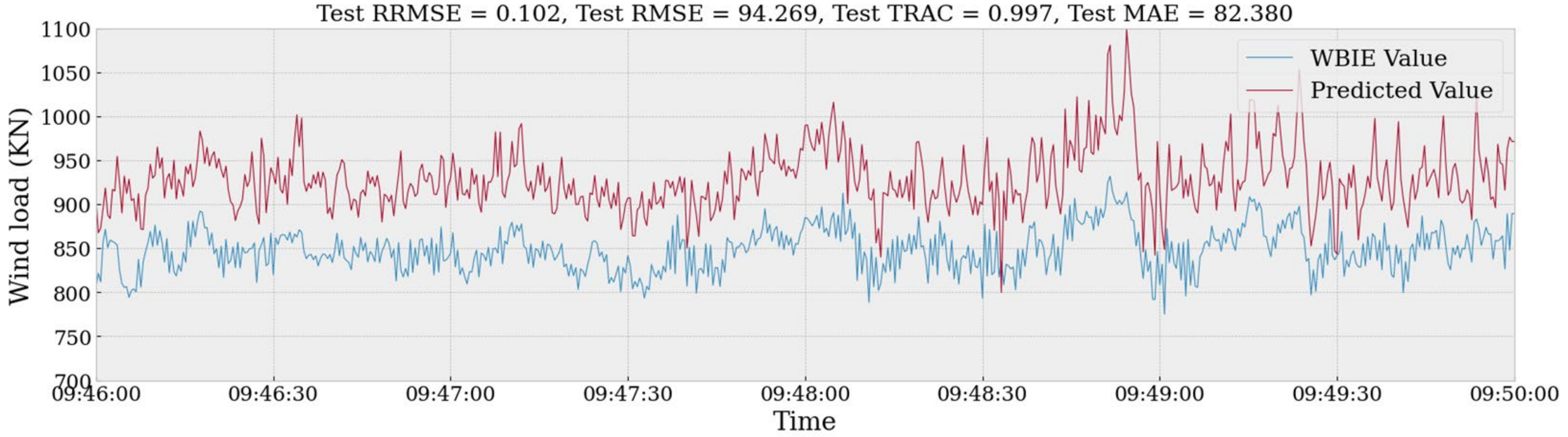
I Train Using Numerical simulated data



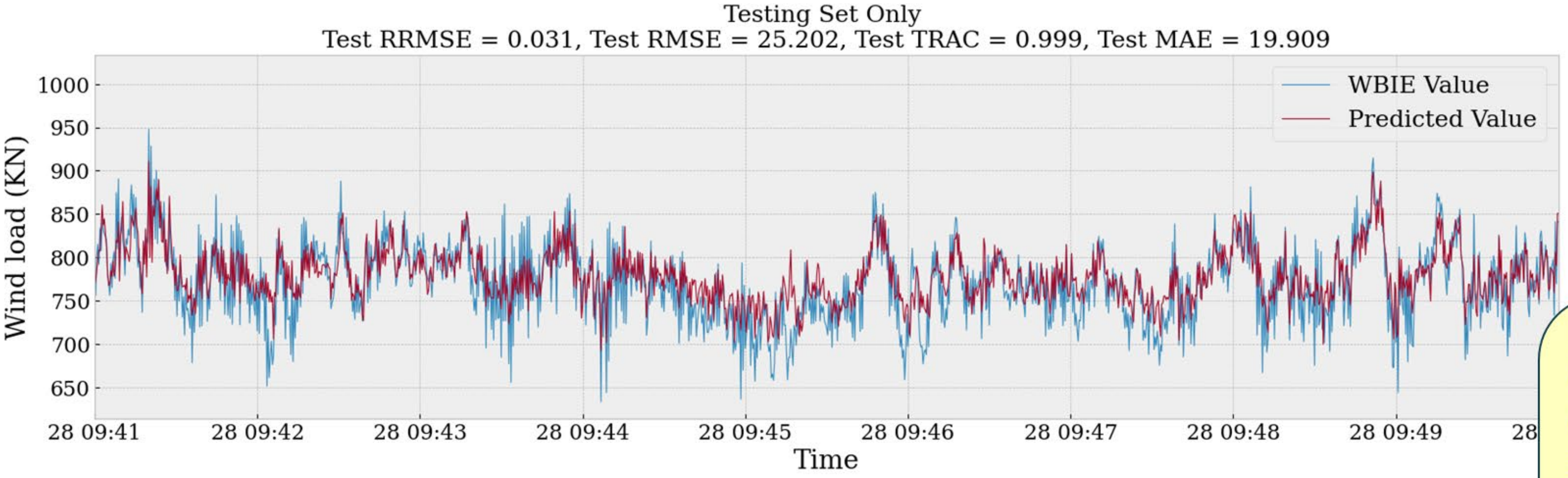


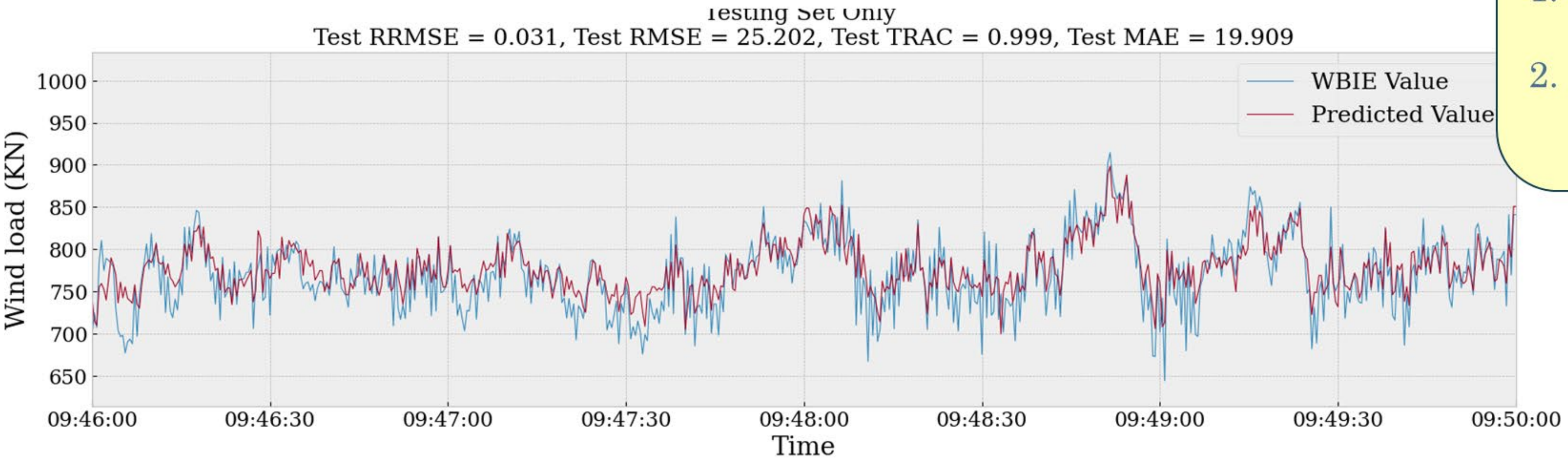
Phase I model: Test on Real Data





Train Phase 2 by Fine-tuning





Fine tuning on 80 minutes of real data:

1. Measured acc and mom (x)
2. Estimated Inputs from WBIE (y)

Comparison

Physics-based estimator	Physics Informed NN estimator
Very Accurate estimation Interpretability	Accurate estimation Fast Scalability
Needs a physical model Takes long to run for 10 minuets of measurements	Black Box Dependency on the quality of training data

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