Cable-Based Actuation for Small-Scale Model Testing of a Floating Offshore Structure

Anisha Sharma[1,2]

Coauthored by Matthew Hall[2], Hannah Ross[2], Kathryn Johnson[1,2], Will Wiley[2], Senu Sirnivas[2]

[1]Colorado School of Mines, [2]National Renewable Energy Lab (NREL)

Floating Offshore Structure Design

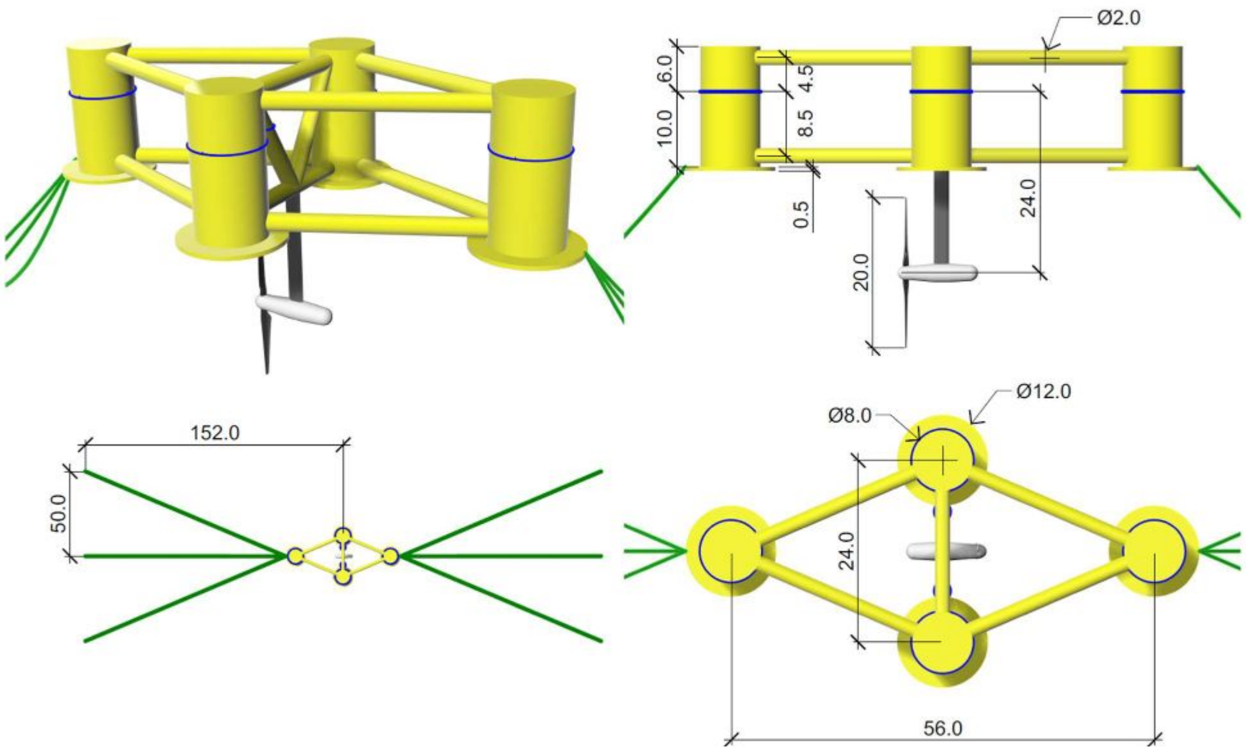


Fig 1. Reference Model 1 (RM1), a floating marine energy turbine[1]

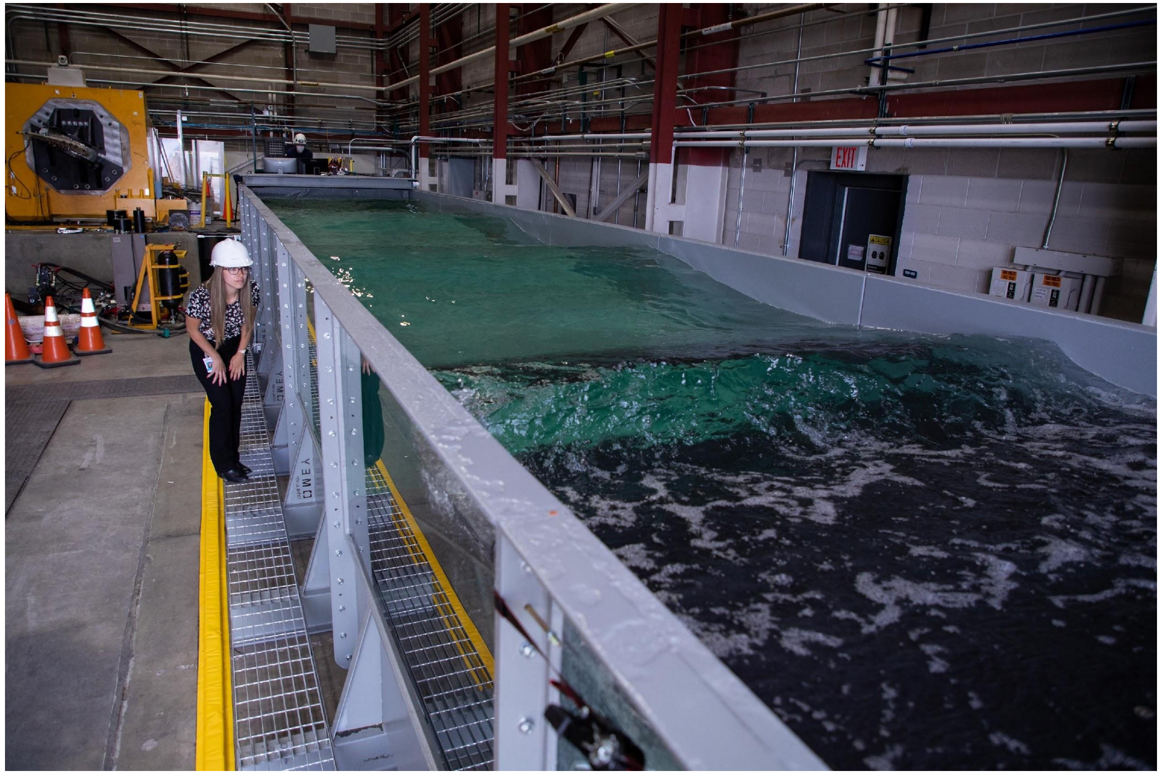


Fig 2. NREL Flatirons wave basin

[1]Wiley et al. (2023), [2]NREL Wave Tank Team

Small-Scale Testing Challenges

Reynolds-Froude Scaling Incompatibilities

Physical Limitations in Test Facilities

Emulation of Aerodynamic Forces Using a Fan Based Actuation System

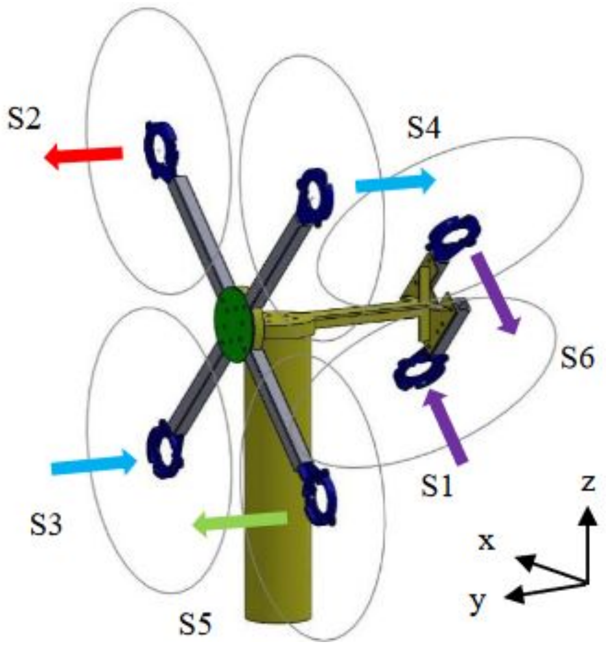


Fig 3. Multi-Propellor Device (MPD) developed to simulate aerodynamic loads using fans[3]

MPD used in this study to emulates the aerodynamic loads of the NREL 5 MW reference turbine at 1:37 scale

[3]Otter et al. (2020)

Emulation of Forces Using Cable Based Actuation

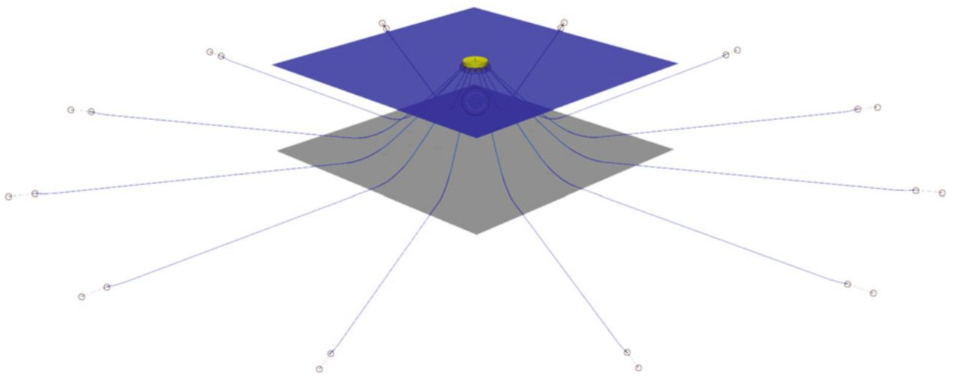


Fig 4. Representation of the emulated system[4]

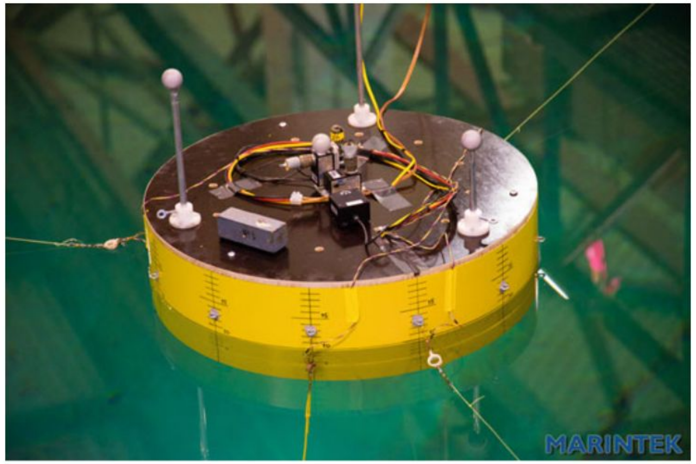
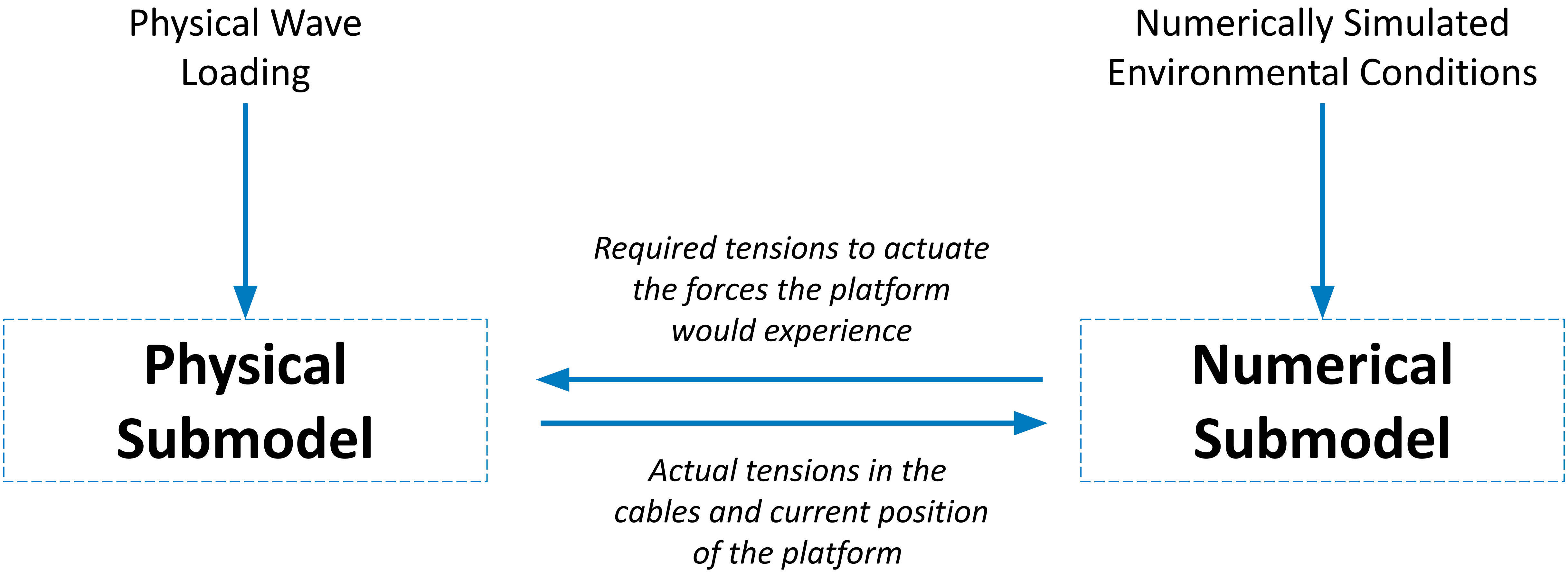


Fig 5. Model of floater in basin[4]

Three actuation lines (visible in Fig 5) connected to the floater applied the calculated load from a numerical simulation

[4]Vilsen et al. (2017)

Hybrid Submodeling Strategy



Hybrid Submodeling Strategy

Physical Submodel ⇄ **Numerical Submodel**

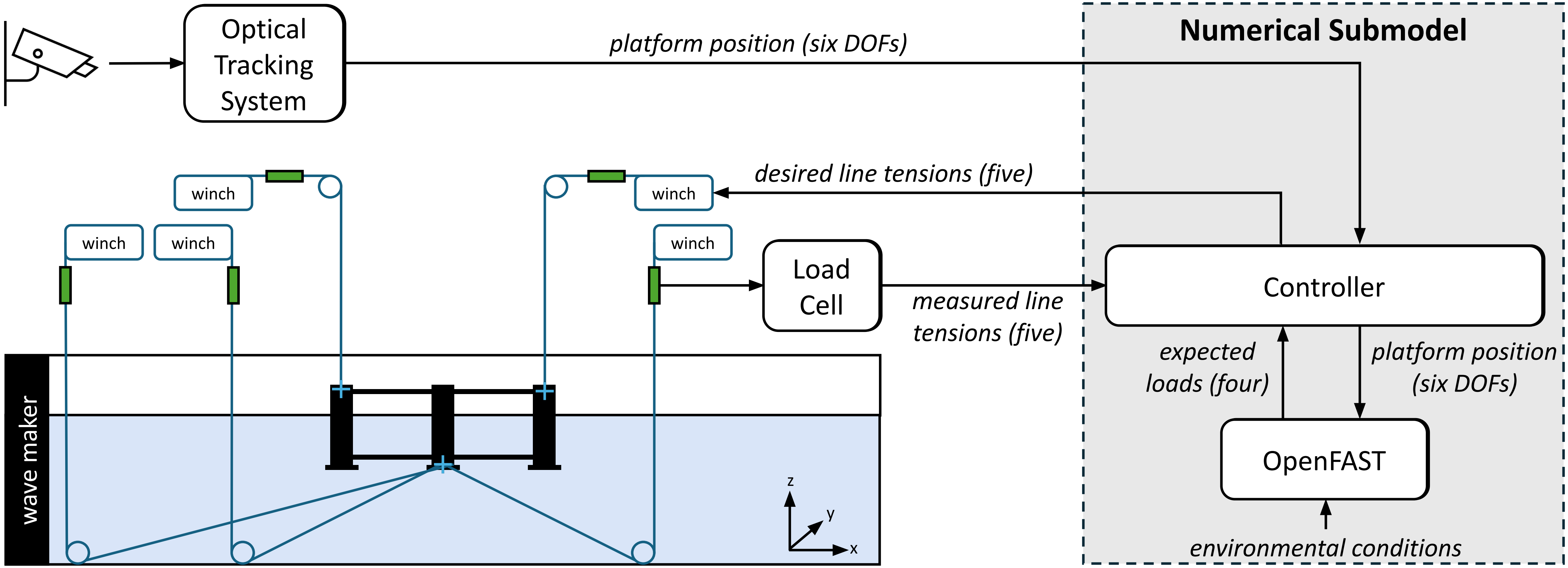


Fig 6. Overview of substructuring strategy

Cable Tension Allocation

$$\boldsymbol{w} = -\boldsymbol{A}^T\boldsymbol{\tau}$$

Wrench Matrix of Expected Forces = Structure Matrix from Cable Geometry x Cable Tensions

Cable Tension Allocation

$$\boldsymbol{w} = -\boldsymbol{A}^T\boldsymbol{\tau}$$

Wrench Vector of Forces and Moment to be applied

(from numerical model)

$$w = \begin{Bmatrix} Fx \\ Fy \\ Fz \\ My \end{Bmatrix}$$

where

Fx is force along x-axis

Fy is force along y-axis

Fz is force along z-axis

My is moment around y-axis

Structure Matrix

(from geometry of cables)

$$A^T = \begin{Bmatrix} \boldsymbol{u}_1 & \dots & \boldsymbol{u}_5 \\ \boldsymbol{b}_1 \times \boldsymbol{u}_1 & \dots & \boldsymbol{b}_5 \times \boldsymbol{u}_5 \end{Bmatrix}$$

where

$\boldsymbol{u}_m$ is the unitary cable direction vector

$\boldsymbol{b}_m$ is the cable point of attachment vector

Tension Vector of Cables

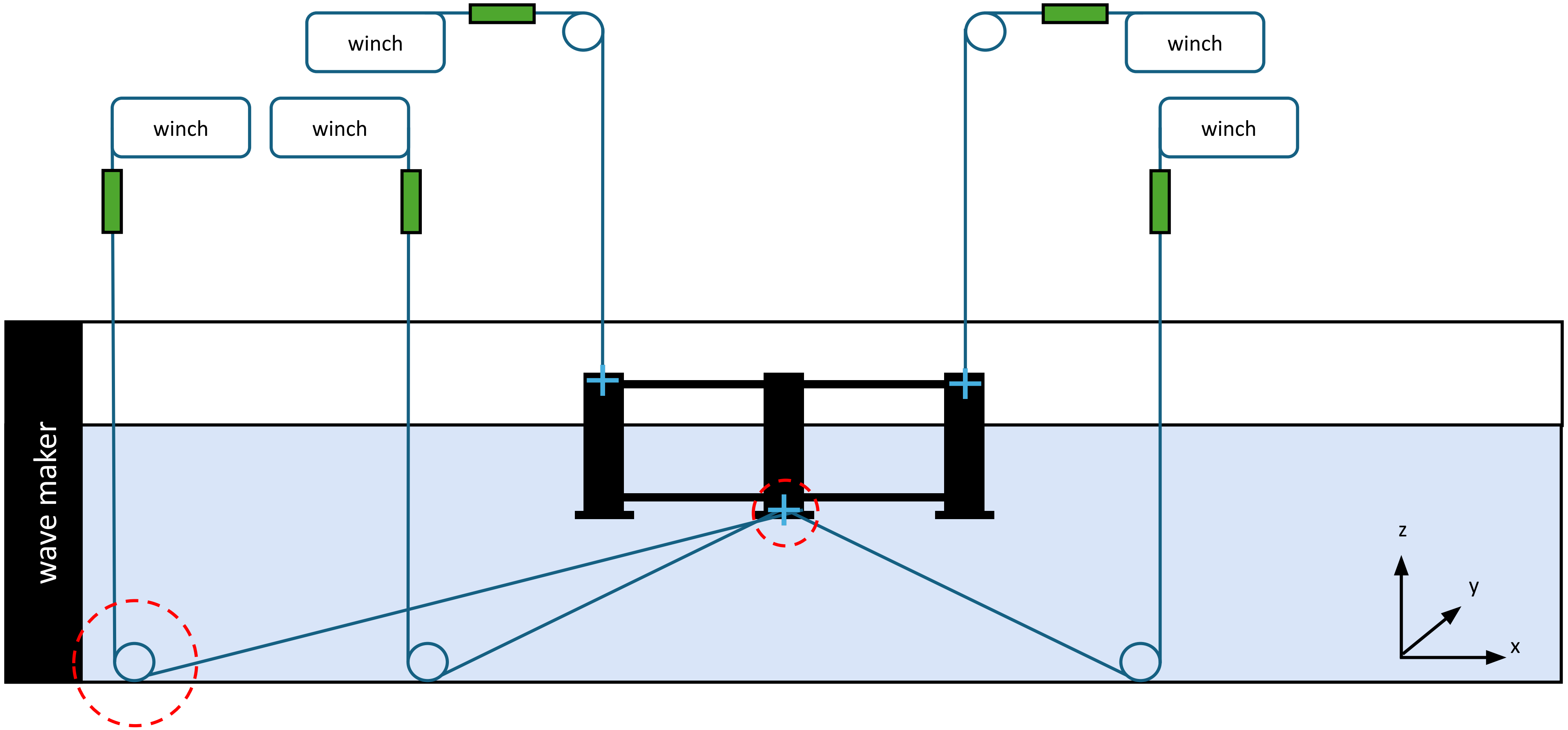
$$\tau = \begin{Bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \end{Bmatrix}$$

where

T_n is line tension in cables 1-5

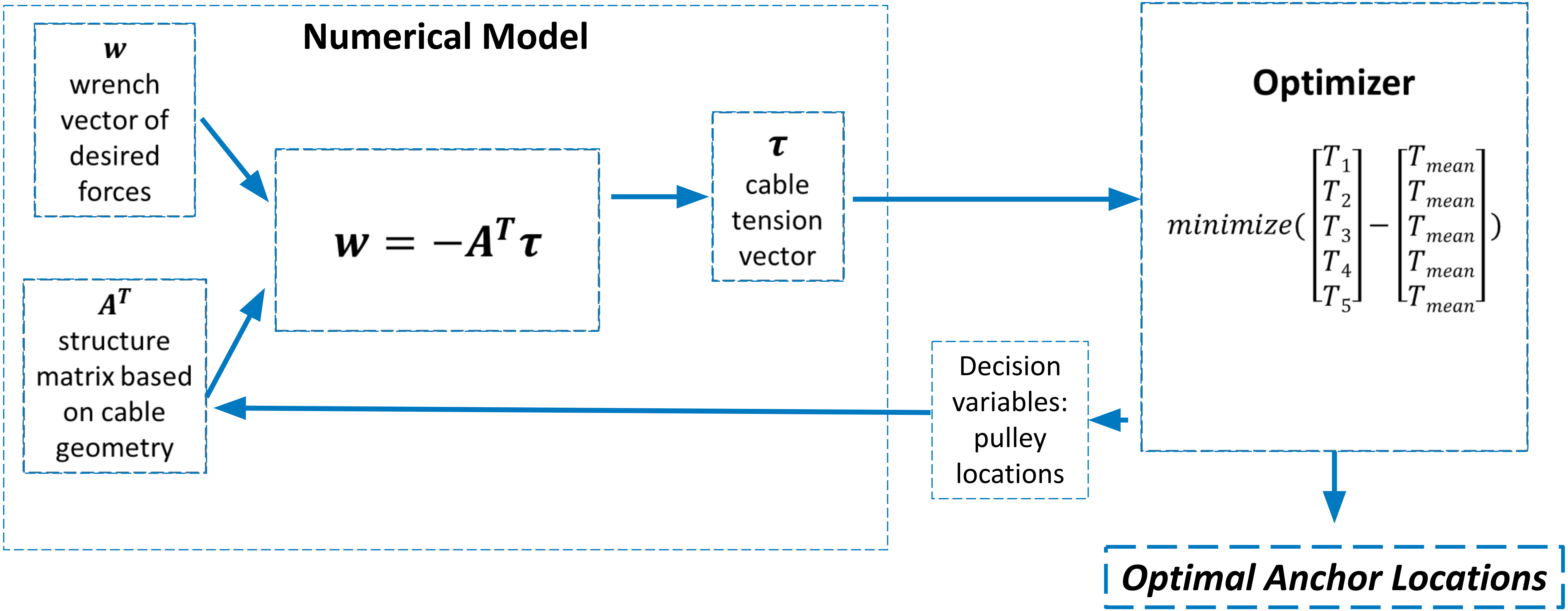
Cable Geometry Optimization

Objective: Find the optimal cable anchor points such that the cable tensions are as close to a mean reference tension value as possible



Cable Geometry Optimization

Objective: Find the optimal cable anchor points such that the cable tensions are as close to a mean reference tension value as possible

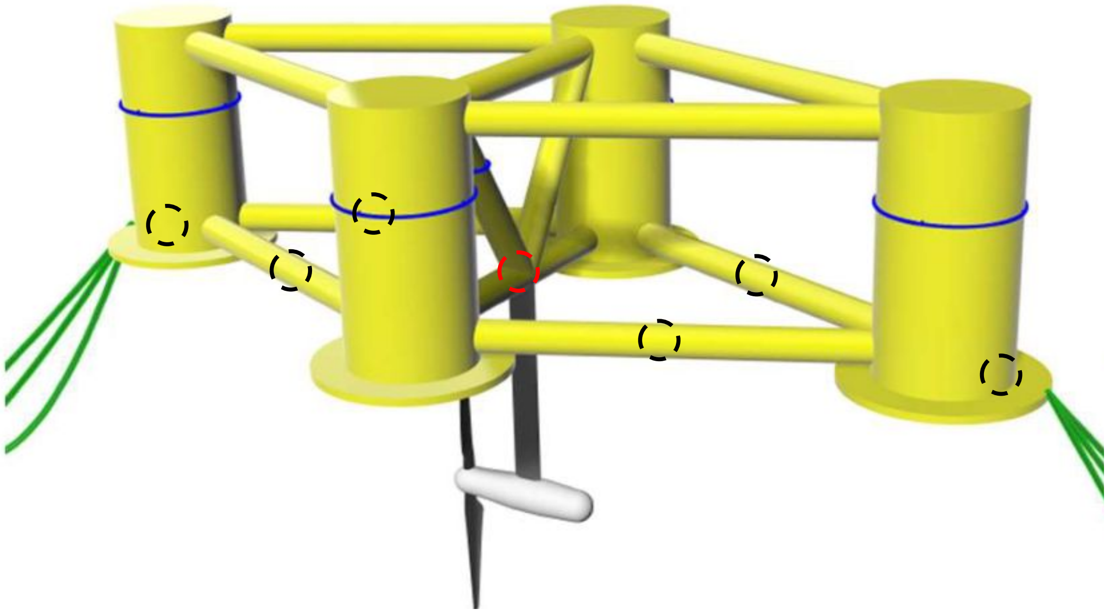


Cable Attachment Points on Platform

Considerations

- Structural integrity of chosen attachment points
- Ease of access to limit crossing of cables and platform structure
- Efficient force actuation in the desired DOFs

Lower Attachment Point Candidates



Upper Attachment Point Candidates

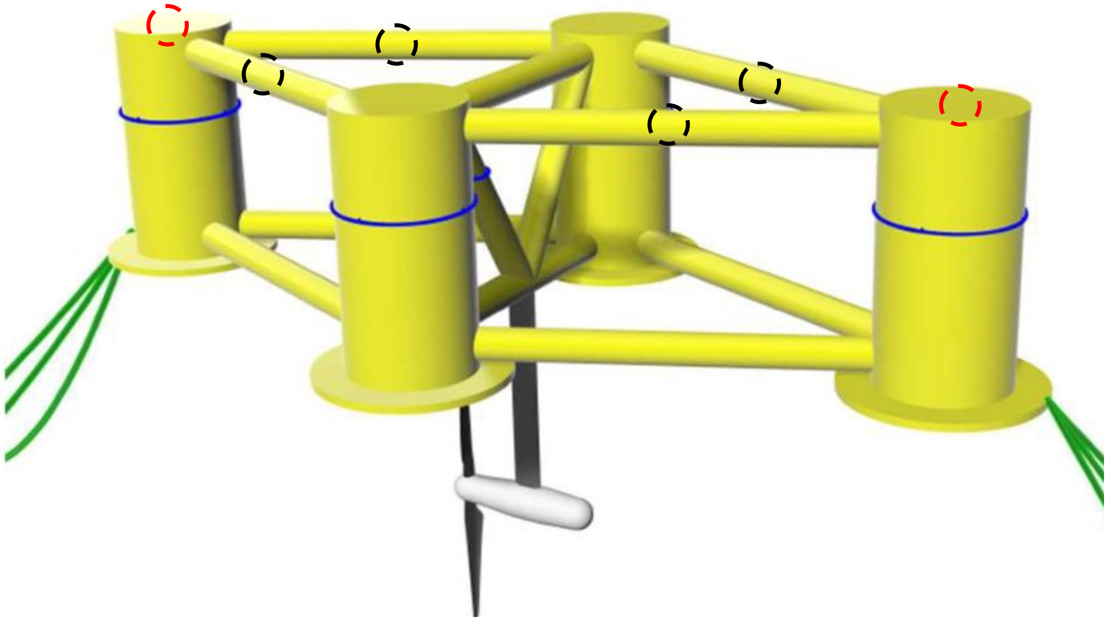


Fig 7. Possible cable attachment points on floating tidal energy convertor RM1

Optimization Results

Tension Ranges

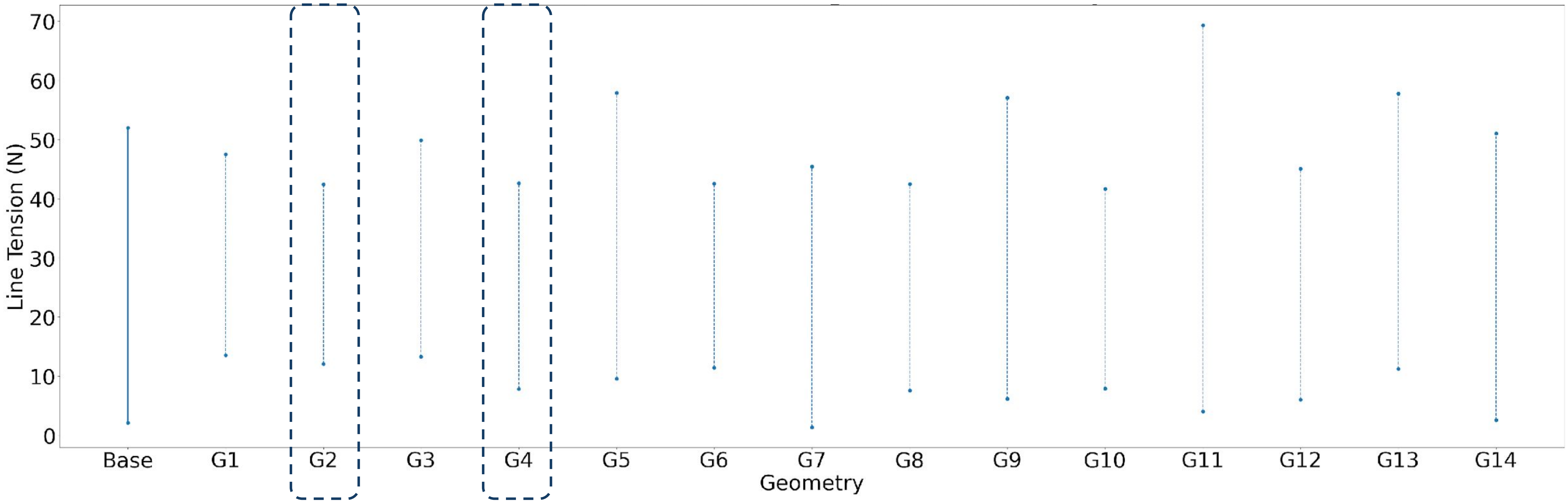


Fig 8. Overall tension range for base geometry and each optimized geometry

Optimization Results

Geometries

Base Geometry

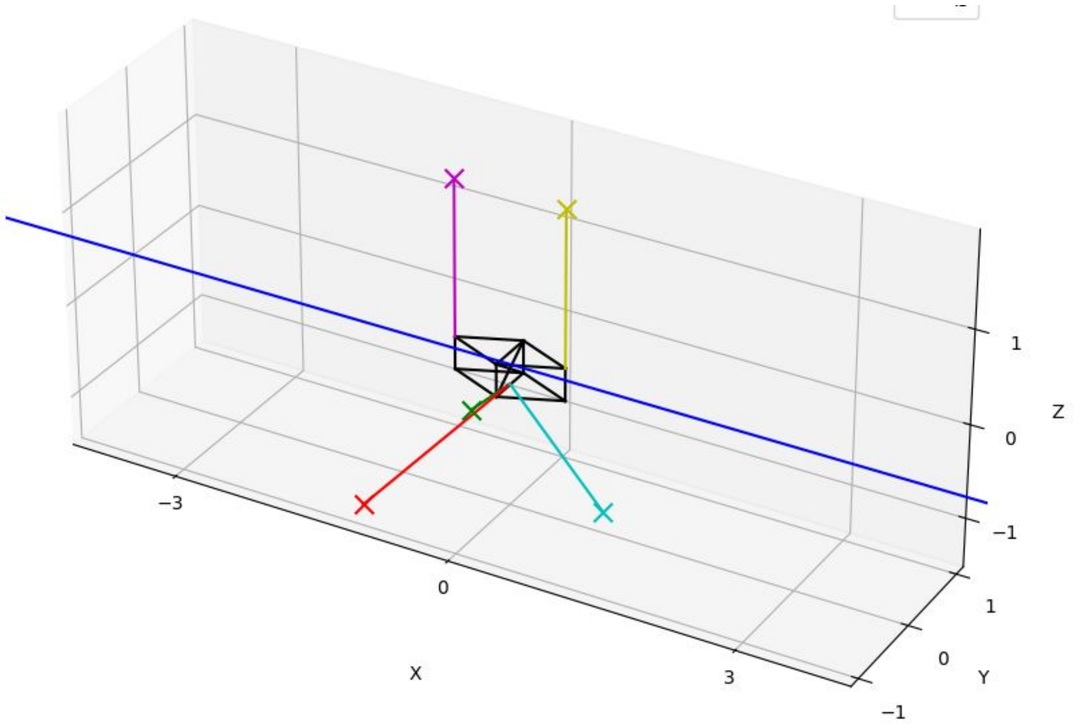


Fig 9. Base Geometry

Optimized Geometries

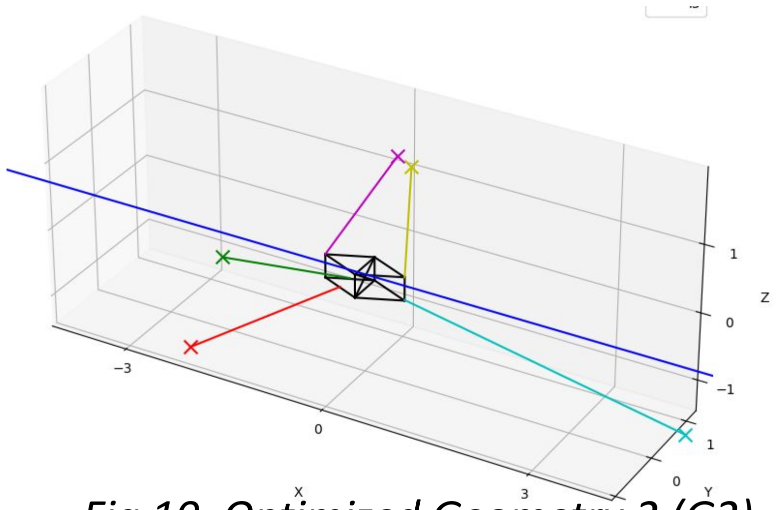


Fig 10. Optimized Geometry 2 (G2)

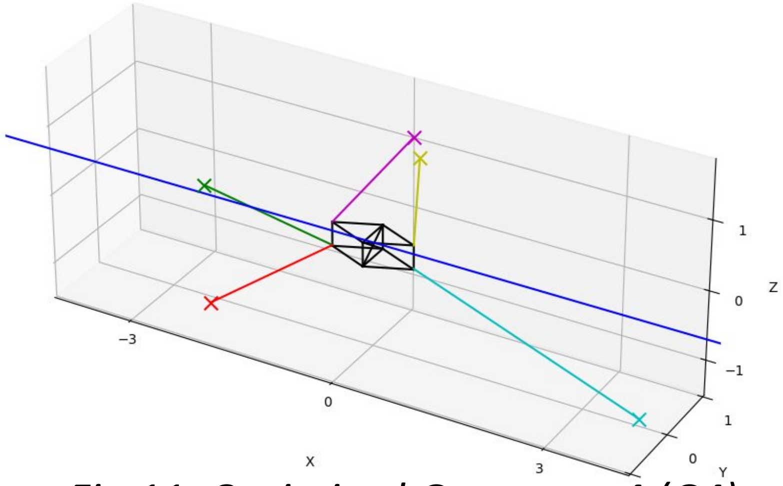


Fig 11. Optimized Geometry 4 (G4)

Optimization Results

Tension Time Series

Base

Upper Line Tension Range (N): 40.8 N
Lower Line Tension Range (N): 43.3 N

G2

Upper Line Tension Range (N): 17.7 N
Lower Line Tension Range (N): 30.4 N

G4

Upper Line Tension Range (N): 22.6 N
Lower Line Tension Range (N): 32.5 N

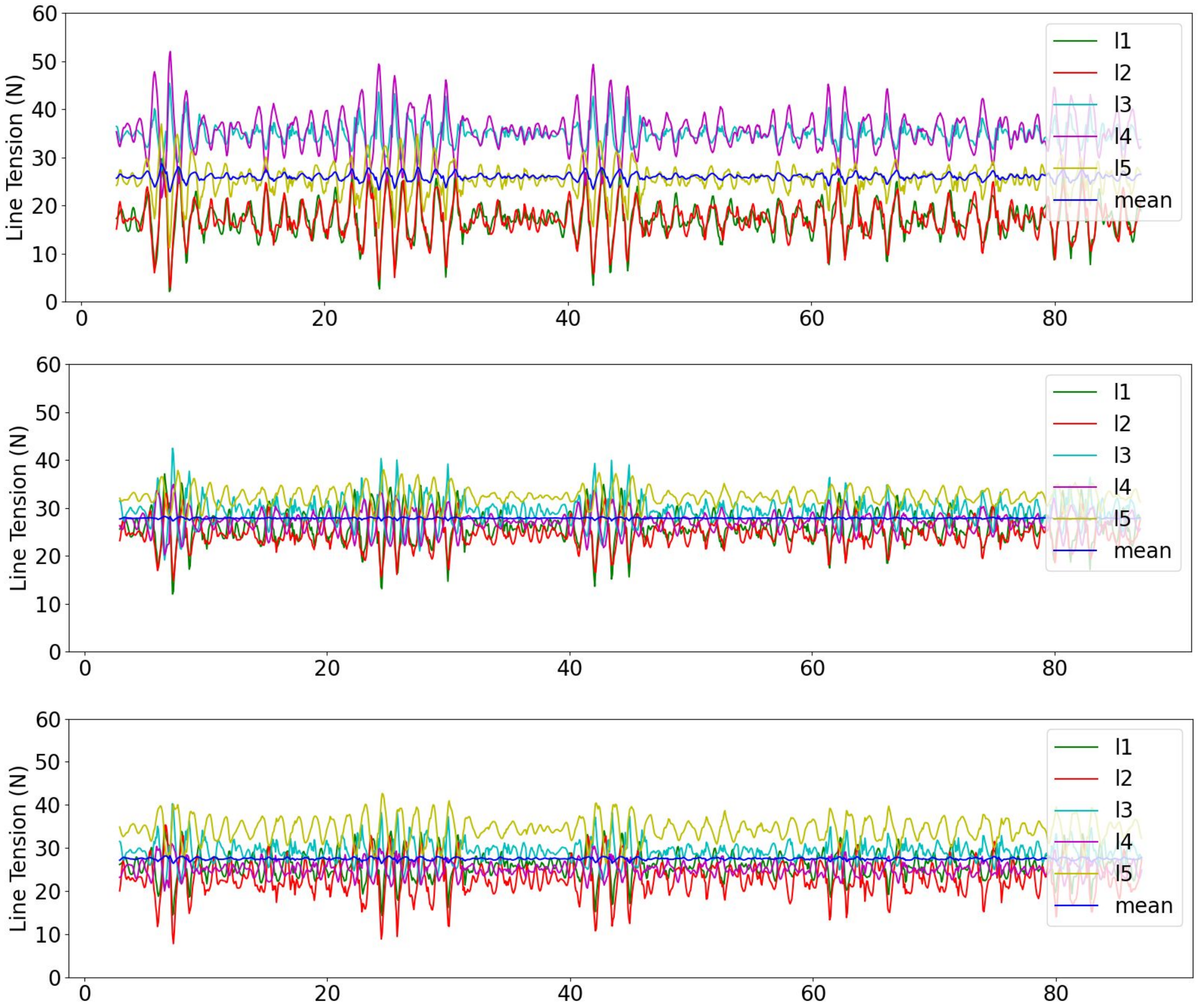


Fig 12. Tension time series for three geometries

Optimization Conclusion

Takeaways

Identifying patterns and key features across multiple optimized geometries

Considering the tradeoff of added complexity vs improvement of tension allocation

Implications

Eliminate the need for wave and wind generation capabilities in order to test floating structures

Testing of other offshore structures (i.e. floating wind turbines and wave energy convertors)

Model more complex flows in both wind and tidal scenarios

Conclusion

Future Work

Build Physical Actuation System and Supporting Structures

Summer 2024

Build Physical RM1 Model

Summer 2024

Deploy and Begin Initial Wave Basin Testing

Fall 2024

References

Hall, M. (2016). *Hybrid Modeling of Floating Wind Turbines* [The University of Maine]. https://digitalcommons.library.umaine.edu/etd/2477

Otter, A., Murphy, J., & Desmond, C. J. (2020). Emulating aerodynamic forces and moments for hybrid testing of floating wind turbine models. *Journal of Physics: Conference Series*, *1618*(3), 032022. https://doi.org/10.1088/1742-6596/1618/3/032022

Vilsen, S. A., Sauder, T., & Sørensen, A. J. (2017). Real-Time Hybrid Model Testing of Moored Floating Structures Using Nonlinear Finite Element Simulations. In M. S. Allen, R. L. Mayes, & D. J. Rixen (Eds.), *Dynamics of Coupled Structures, Volume 4* (pp. 79–92). Springer International Publishing. https://doi.org/10.1007/978-3-319-54930-9_8

Wiley, W., Ross, H., Sundarrajan, A. K., & Tran, T. T. (2023). Design and Modeling of an Open-Source Baseline Floating Marine Turbine. *Renewable Energy*.

Cable-Based Actuation for Small-Scale Model Testing of a Floating Offshore Structure

Anisha Sharma[1,2]

anisha.sharma@nrel.gov

Coauthored by Matthew Hall[2], Hannah Ross[2], Kathryn Johnson[1,2], Will Wiley[2], Senu Sirnivas[2]

[1]Colorado School of Mines, [2]National Renewable Energy Lab (NREL)

Acknowledgements

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office Powering the Blue Economy Fundamental Research and Development program. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes. This work is supported by Colorado School of Mines and National Renewable Energy Laboratory Advanced Energy Systems Graduate Program, Colorado School of Mines, Golden CO 80401, USA.