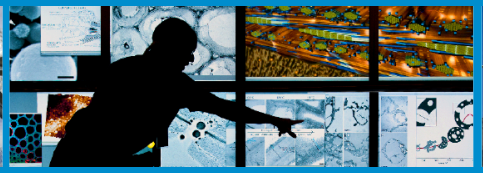
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL's Wave Energy Converter Modeling Efforts

Marine and Hydrokinetic Instrumentation, Measurement & Computer Modeling Workshop

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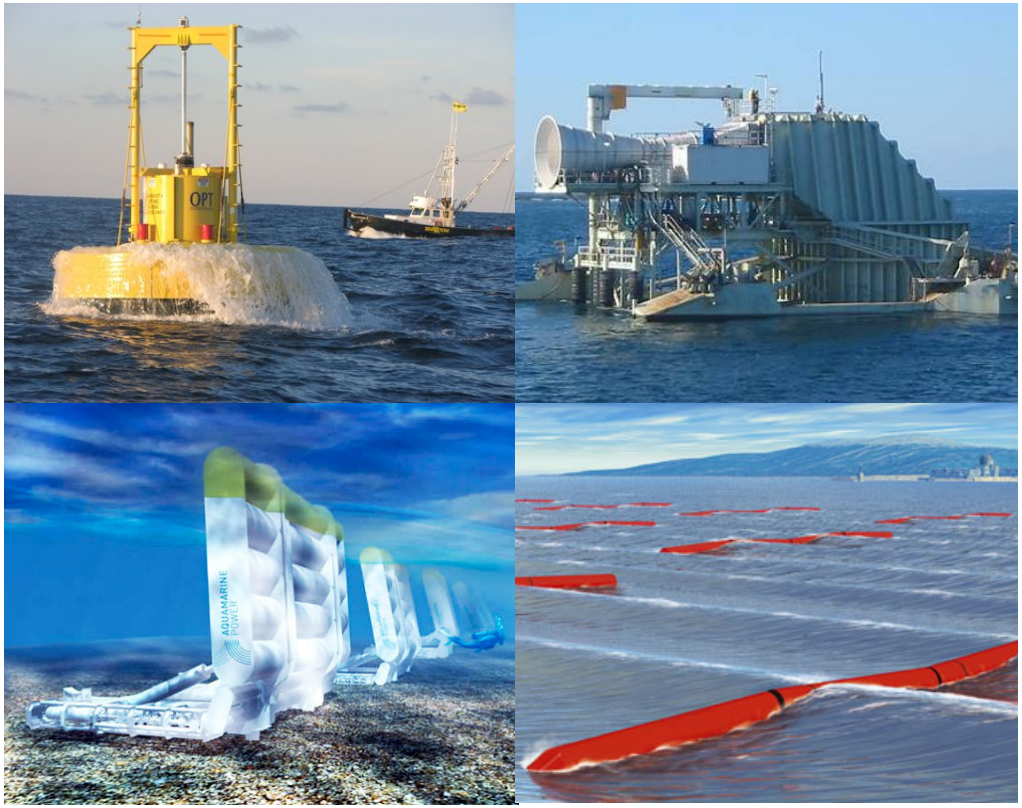
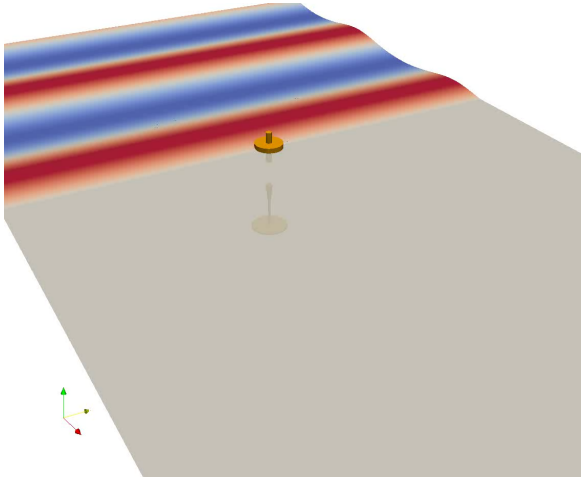
Objectives

- Develop feasible numerical tools to assist modeling of wave energy conversion (WEC) systems
- Provide a baseline system design and a power generation performance analysis
- Collaborate with industry, academia and other national laboratories to accelerate WEC technologies development

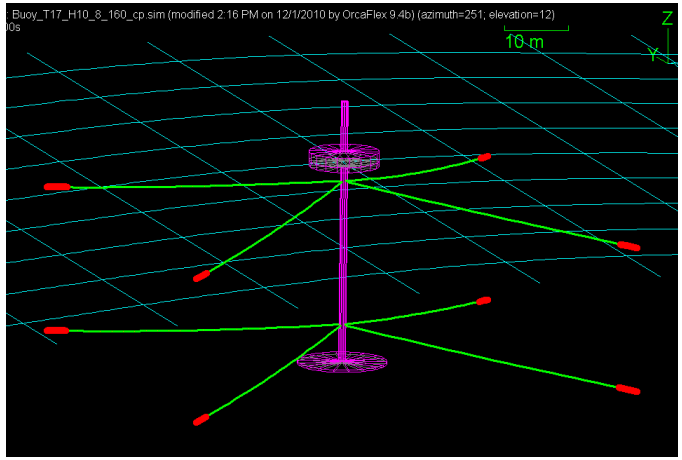


NREL's Modeling Efforts

- **Computational fluid dynamic (CFD) simulations**



- **Mooring dynamics analysis (using OrcaFlex)**

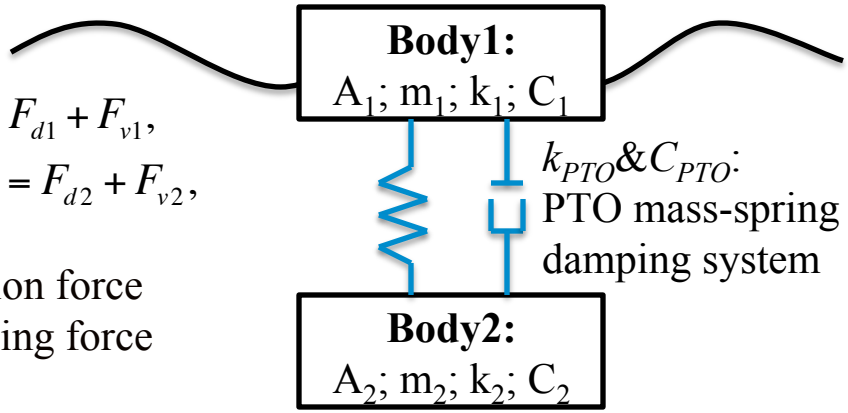


- **Numerical/empirical model: Frequency domain closed form solution**

$$\text{Float: } (m_1 + A_1)\ddot{z}_1 + k_1 z_1 + C_1 \dot{z}_1 + C_{PTO}(\dot{z}_1 - \dot{z}_2) = F_{d1} + F_{v1},$$

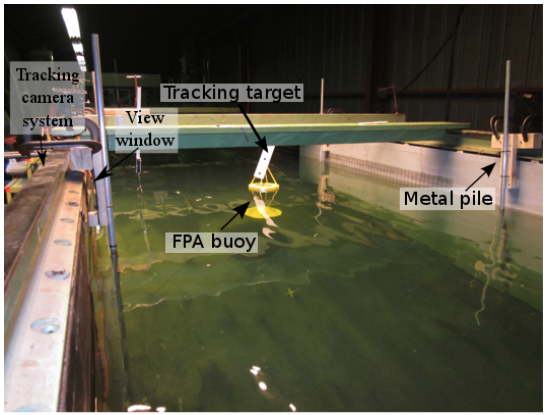
$$\text{Reaction Section: } (m_2 + A_2)\ddot{z}_2 + k_2 z_2 + C_2 \dot{z}_2 + C_{PTO}(\dot{z}_2 - \dot{z}_1) = F_{d2} + F_{v2},$$

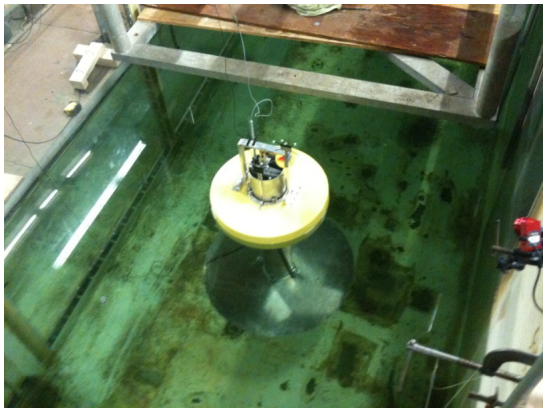
A: added mass coefficient; F_d: wave excitation force
C: radiation damping coefficient; F_v: viscous damping force
m: mass of the body;
k: restoring force

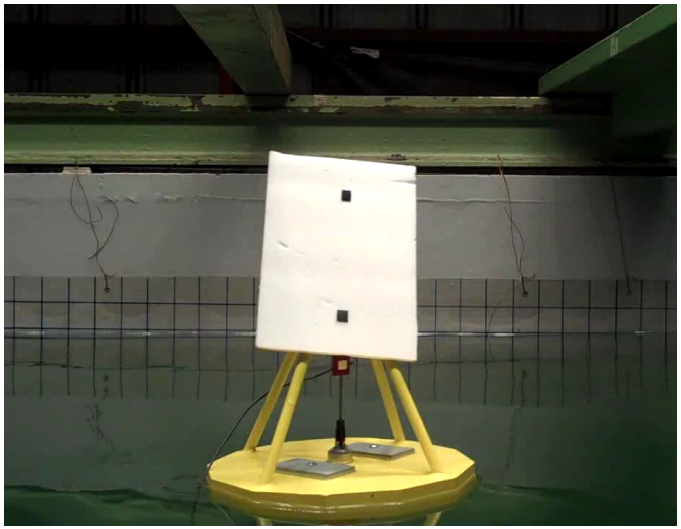


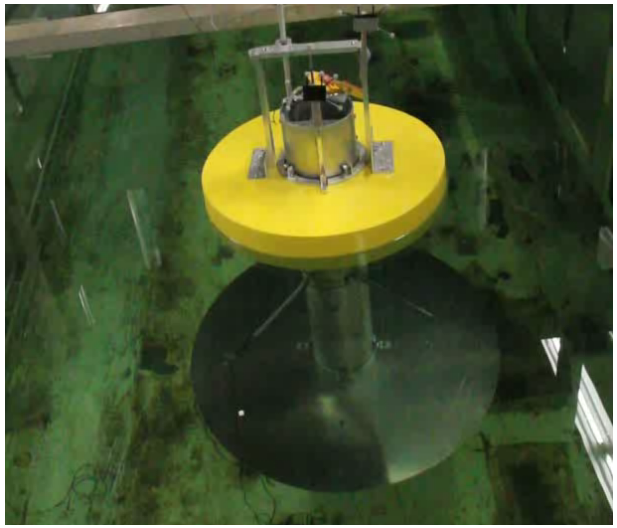
NREL's Modeling Efforts

- **Experimental wave tank tests**
  - Survivability (extreme waves) analysis (1/46 & 1/100): UC Berkeley, Dec 2010
  - Power performance analysis (1/33): UC San Diego Scripps, Aug - Nov 2011





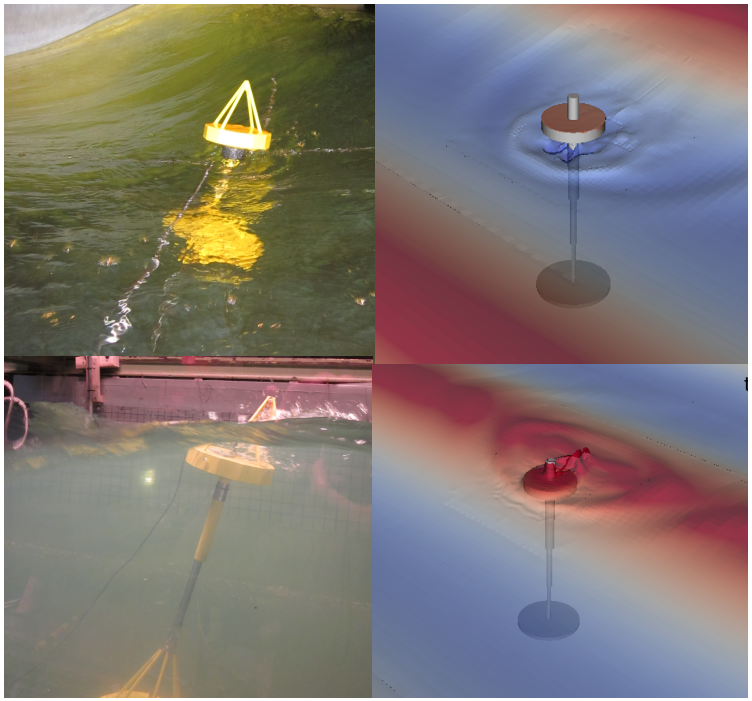




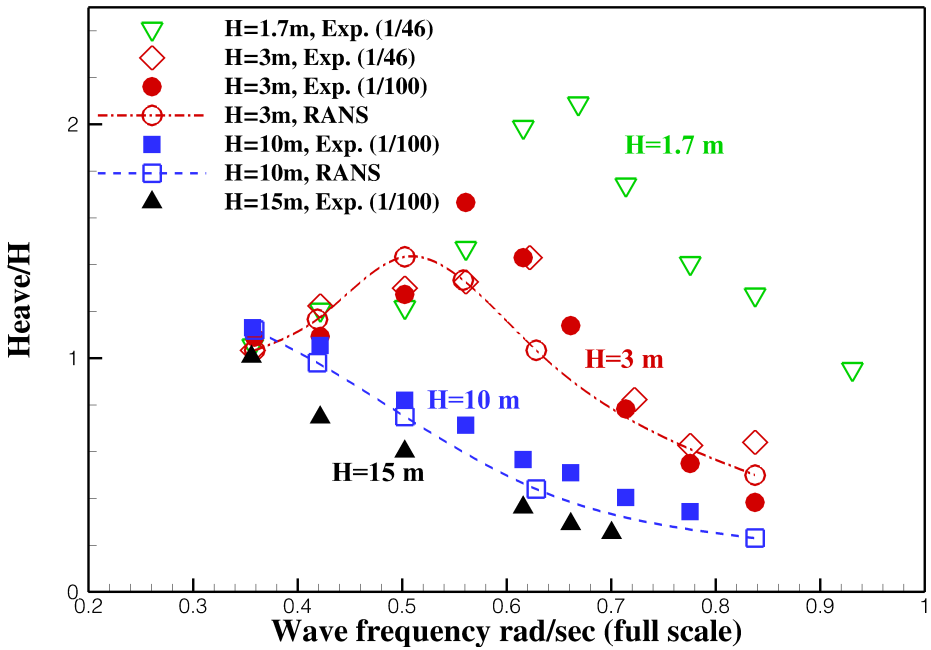
Collaborated with RE Vision

Results: Extreme Waves

Snapshots from CFD simulation and exponential wave tank test

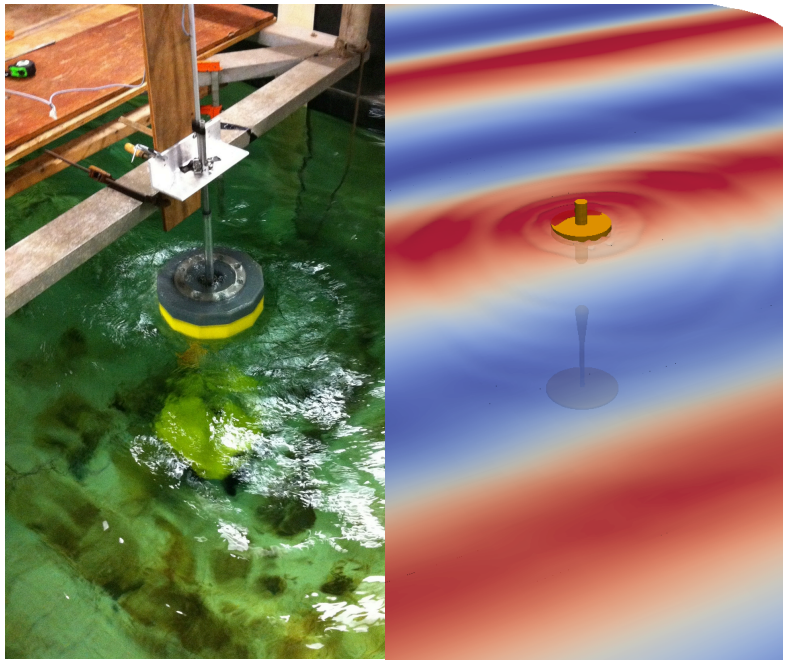


Heave Response

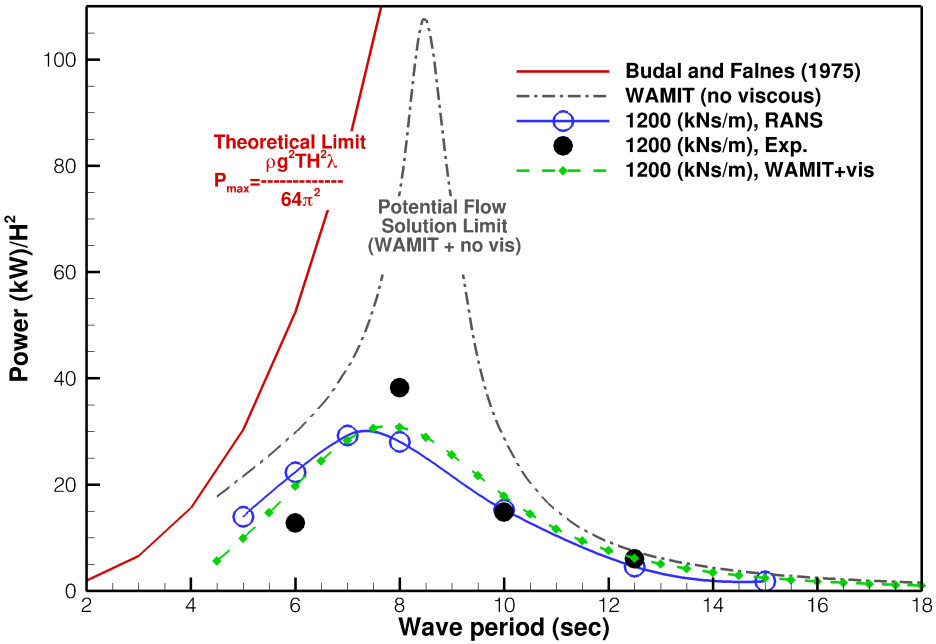


Results: Operational Waves

Snapshots from CFD simulations and exponential wave tank test



Power Extraction Performance & Model Validation



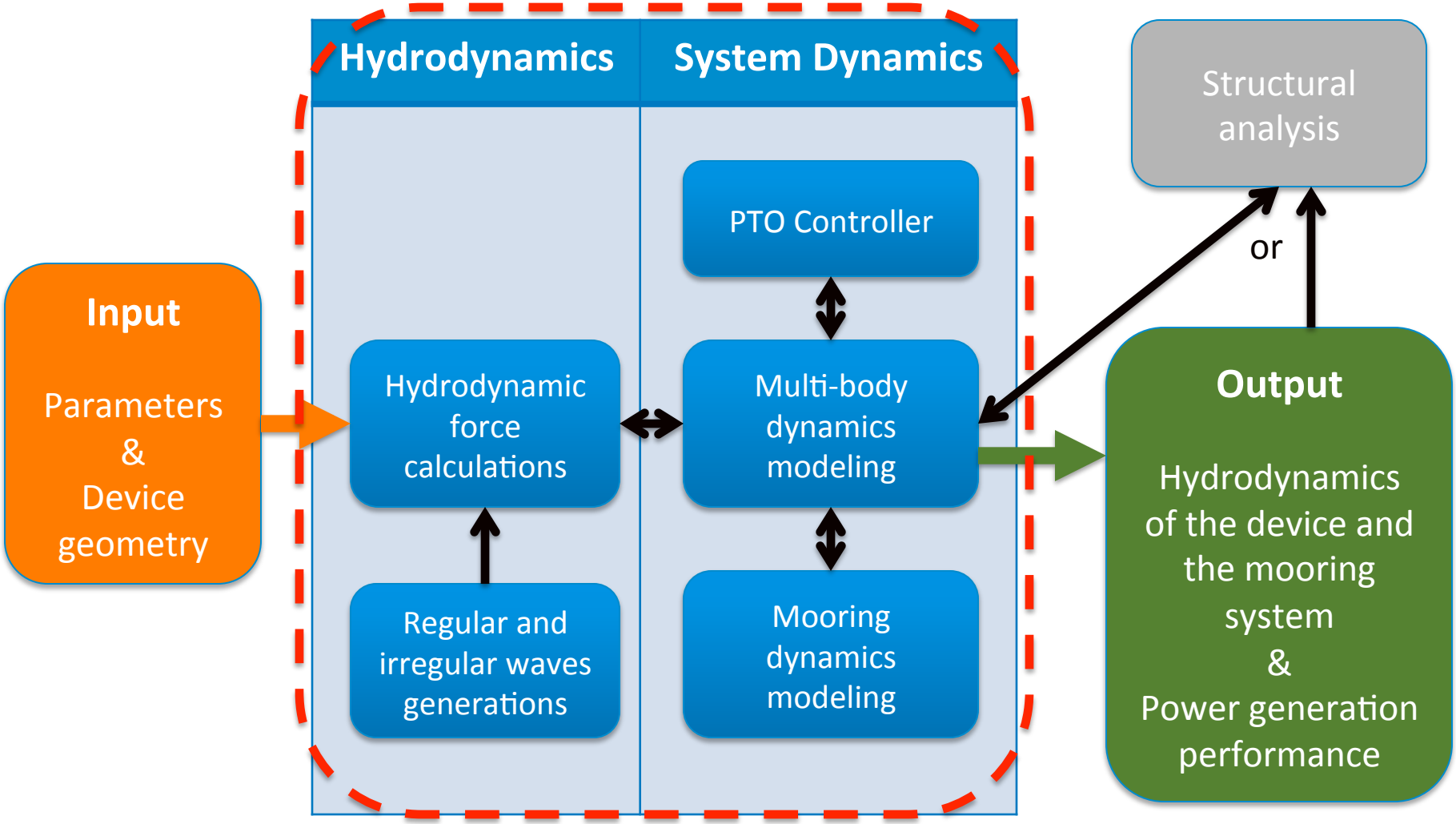
- Note that the float geometry was slightly different from the one used in the numerical simulations.

Summary of NREL's Modeling Efforts

- **CFD simulations and experimental wave tank tests have been conducted:**
  - Survivability analysis - hydrodynamics and extreme wave loads
  - Operational wave analysis – power extraction performance
- **A frequency-domain solution was developed to estimate the power performance:**
  - The results agreed well with both CFD results and experimental data.
  - A time-domain version will be useful for estimating the annual power at deployment locations.
- **Viscous damping effect is essential:**
  - The viscous damping coefficient in the empirical model need to be carefully selected.
  - Scaling effect can be significant when validate the numerical modeling results with experimental measurements (if the model scale is small).

Moving Forward

Conceptual framework

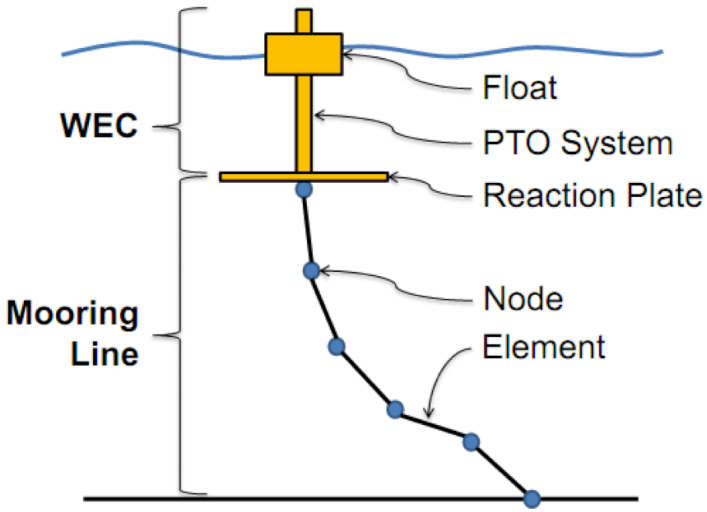


Modeling Strategies

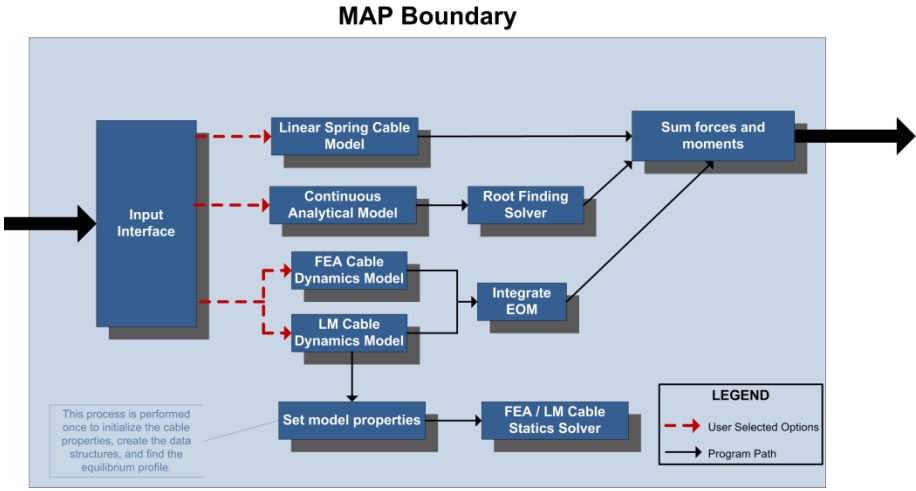
- Tools for design analysis and optimization
- Leverage existing commercial packages, while developing open source numerical tools as needed
- Apply to future WEC studies, in particular, Reference Model Projects
- Validate with experimental data, CFD simulations and other numerical results

Future Modeling Tools Developments

- **MAP (Mooring Analysis Program)**
- **Contain a variety of mooring representations to achieve different levels of fidelity**
  - Simple, closed-form analytical mooring models (quasi-static)
  - Finite Element mooring line representations

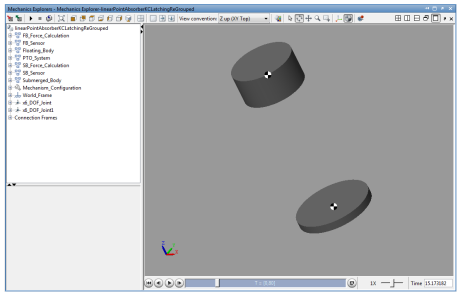


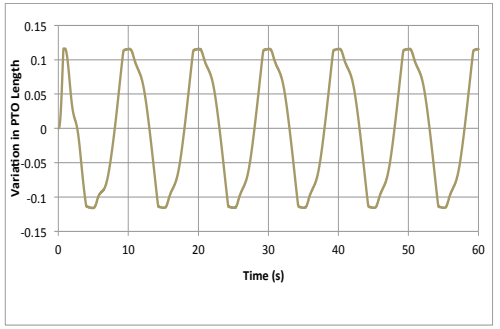
- ***Multi-segmented, quasi-static component of MAP***



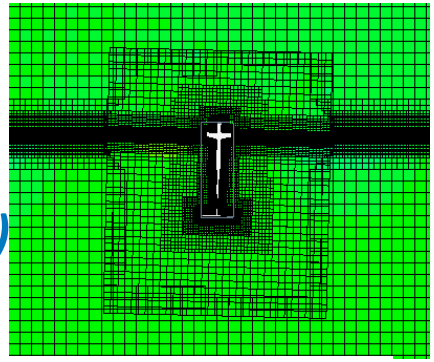
Future Modeling Tools Developments

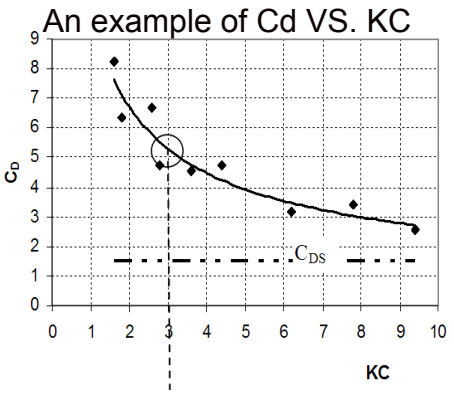
- **Time-domain multi-body system dynamics model**
  - Using ***MATLAB –SimMechanics***



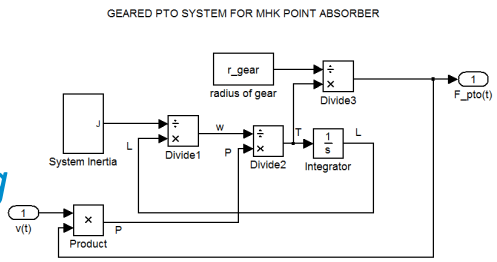


- **Viscous damping coefficients analysis for various WEC devices**
  - Using ***CFD (StarCCM+ & OpenFoam)***

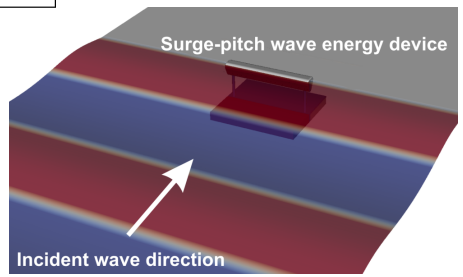




- **PTO design and analysis**
  - Using ***MATLAB-SimuLink***
  - *PTO control and optimal tuning*
  - *Collaborating with SNL*



- ***Next Reference Model FY13: Surge-pitch WEC device***



The End

Questions?