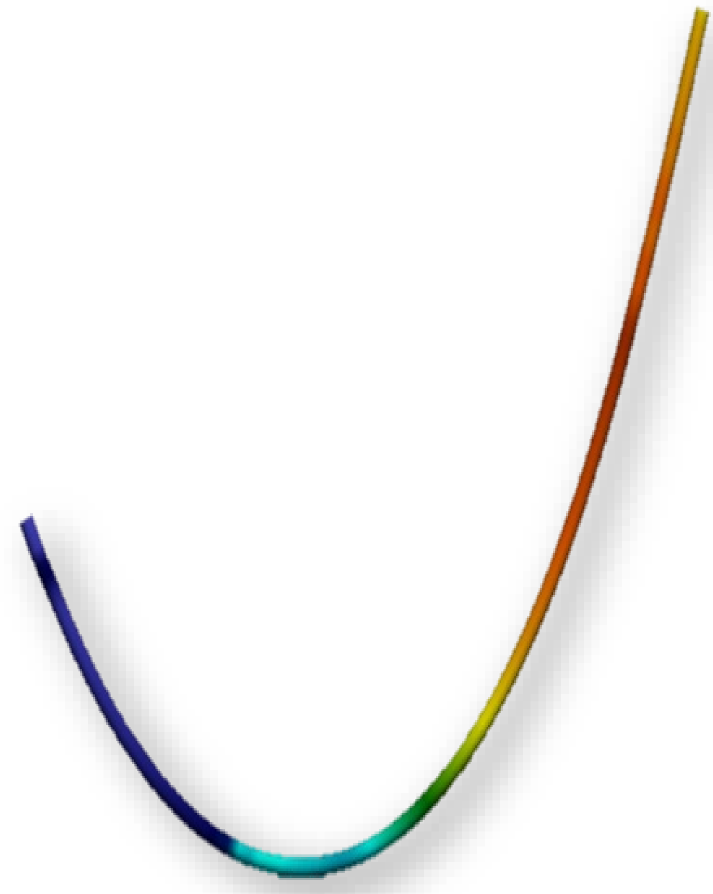
The Development and Application of a Mooring Line Model Framework for CFD Analysis

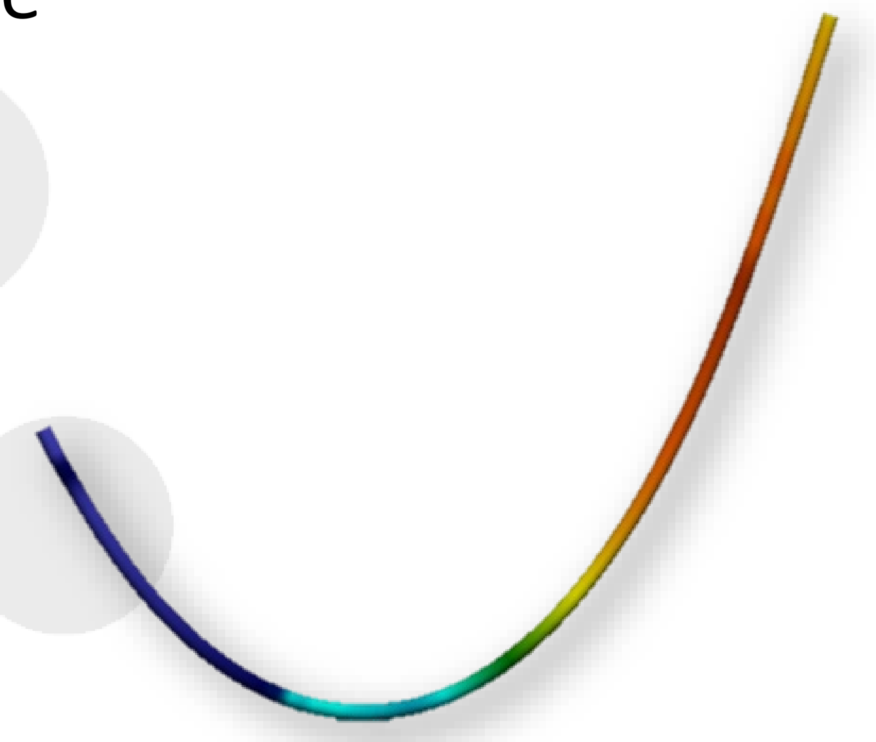
Daniel P. Combest, ENGYS

11th OpenFOAM Workshop June 2016



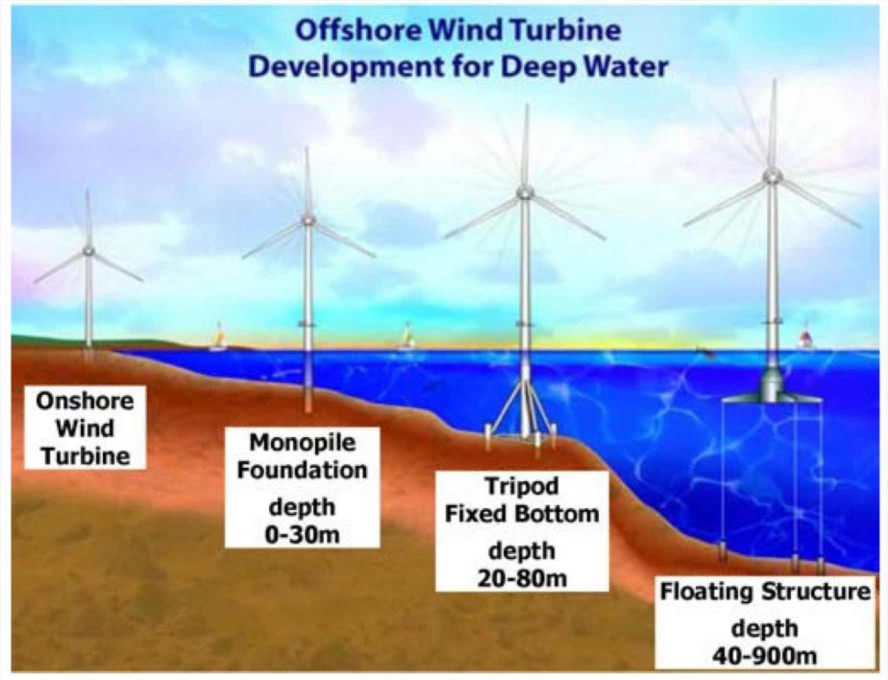
info@engys.com | Tel: +1-317-614-0070 | Fax: +1-317-536-3169| www.engys.com

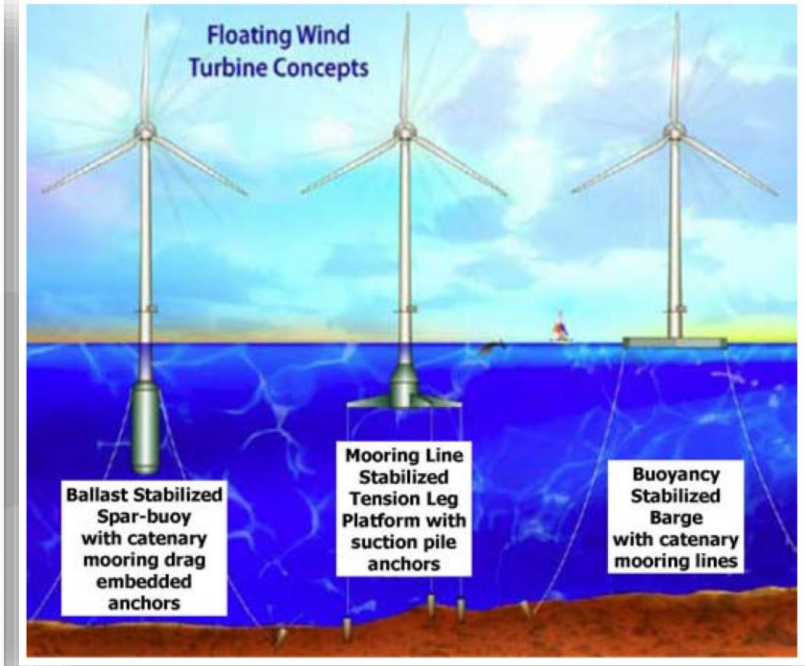
Contents



Mooring Background | Basic Overview

Used to prevent the free movement of a vessel or movable structure when fluid physics may influence the motion of an object.





Pao, Lucy Y., and Kathryn E. Johnson. "A tutorial on the dynamics and control of wind turbines and wind farms." *American Control Conference, 2009. ACC'09.*. IEEE, 2009.

Mooring Background | Simulation Needs

Design Evaluation/Assistance

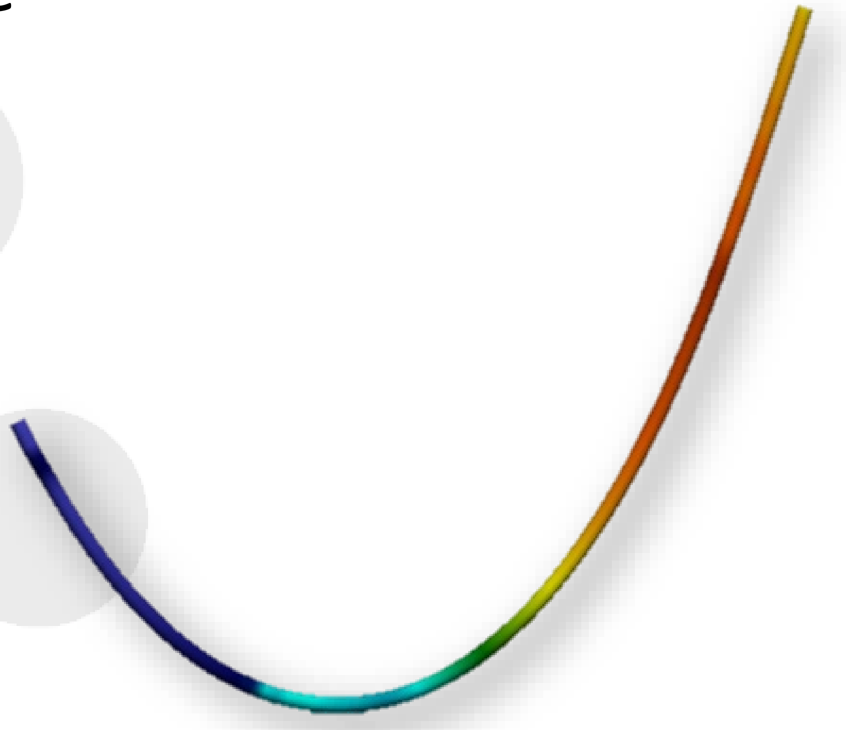
- What sort of mooring line system/configuration is needed to prevent a specific motion of a movable structure?
- How do mooring line dynamic influence the movable structure?

Risk Assessment

- When will mooring lines fail ?
  - Abrasion, excessive load, corrosion, snap loads, etc.
- How will the floating structure respond to failure?

Contents

- Mooring Background
- Simulating Mooring Line Physics
- State of OF Technology
- Dynamic Model
- Dynamic Example
- Test Cases
- Closing Remarks
- Questions



Simulating Mooring Line Physics

Current Area of Interest

time dependent mooring line motion and how this influences a floating structure.

Complex Mooring Dynamics Software

- Commercial
  - Star CCM+ (CD-Adapco)
  - OrcaFlex
  - AQWA (ANSYS)
- Open Source
  - MoorDyn
  - FEAM (FEAMooring)

→ Coupled to NREL FAST

engys

State of OpenFOAM® Technology

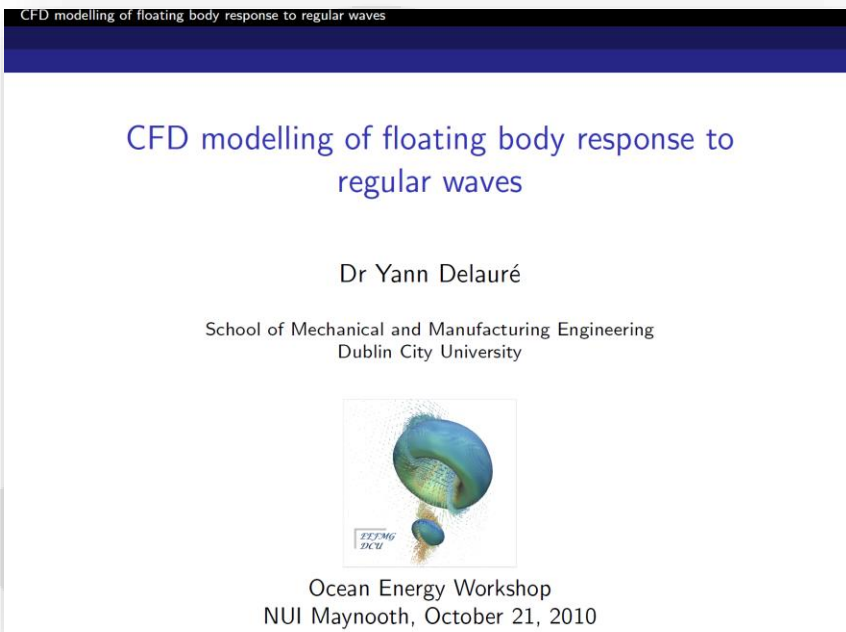
Current “Mooring” Capabilities

- spring damper system
- Weightless
- Applied via the 6DoF restraints

displacement

$$\vec{F}_{spring} = -k\left(||\vec{r}|| - L\right)\frac{\vec{r}}{||\vec{r}||} - C_D\left(\frac{\vec{r}}{||\vec{r}||}\cdot\vec{U}\right)\vec{U}$$

Resting length

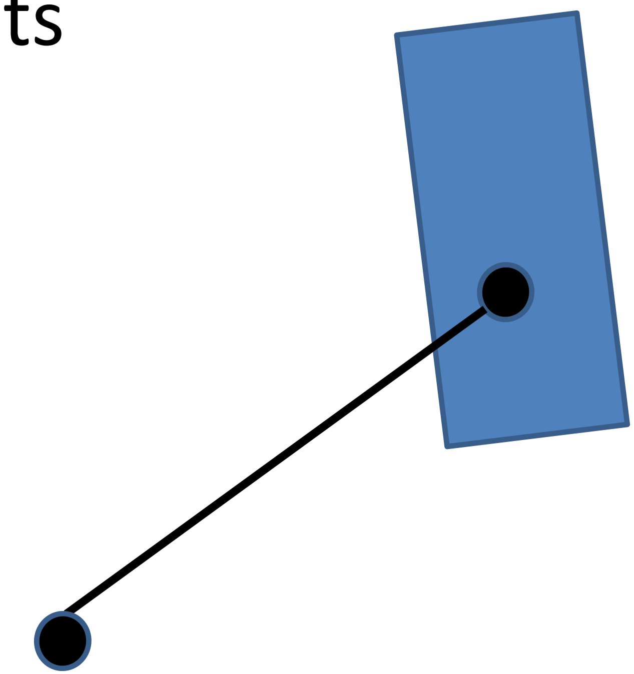

CFD modelling of floating body response to regular waves

CFD modelling of floating body response to regular waves

Dr Yann Delauré

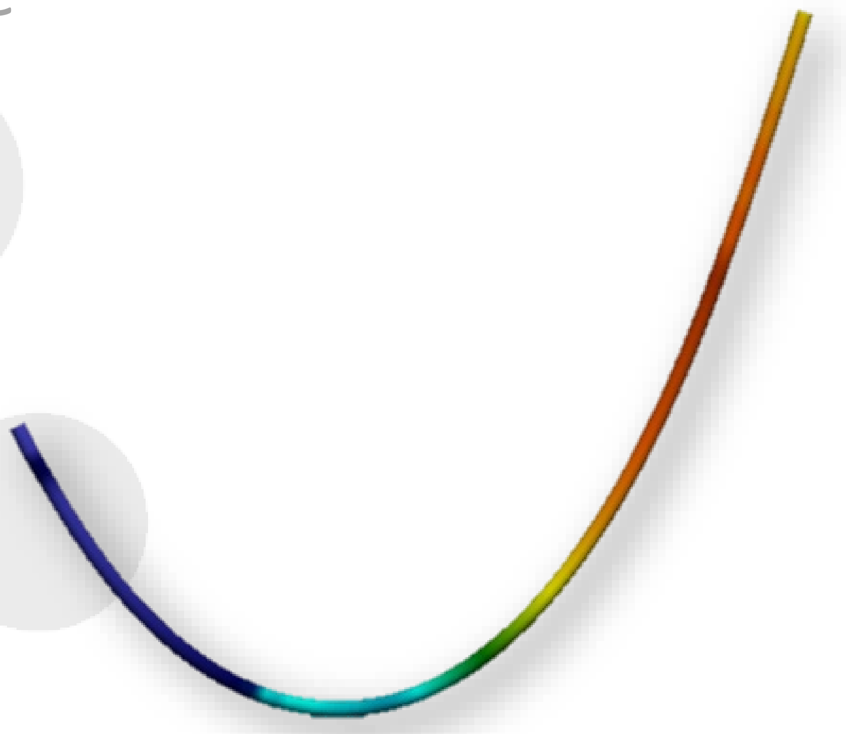
School of Mechanical and Manufacturing Engineering
Dublin City University

Ocean Energy Workshop
NUI Maynooth, October 21, 2010



Contents

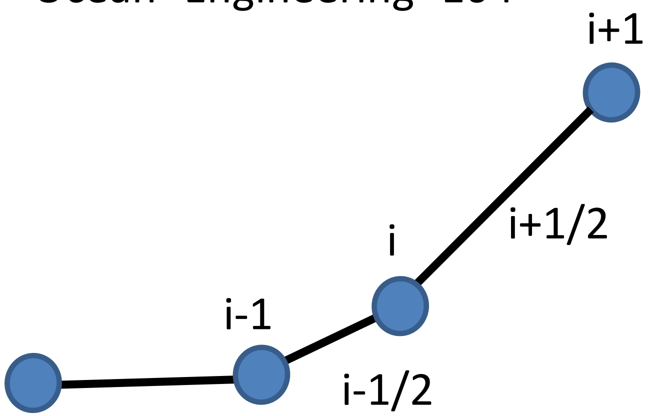
- Mooring Background
- Simulating Mooring Line Physics
- State of OF Technology
- Dynamic Model
- Dynamic Example
- Test Cases
- Closing Remarks
- Questions



Dynamic Mooring Line Model

Lumped-Mass Mooring Model

M. Hall and A. Goupee. Validation of a lumped-mass mooring model with DeepCwind semisubmersible model test data. Ocean Engineering 104 (2015) 590-603.



Internal Forces

- ✓ Buoyancy

$$W_{i+\frac{1}{2}} = \frac{\pi}{4} d^2 \left(\rho_f - \rho_{ml}\right)$$

- ✓ Linear Tension

$$T_{i+\frac{1}{2}} = E \frac{\pi}{4} d^2 \left(\frac{1}{l} - \frac{1}{||\vec{r}_{i+1} - \vec{r}_i||} \right) \left(\vec{r}_{i+1} - \vec{r}_i\right))$$

- ✓ Damping

$$C_{i+\frac{1}{2}} = C_{int} \frac{\pi}{4} d^2 \left(\frac{\vec{r}_{i+1} - \vec{r}_i}{||\vec{r}_{i+1} - \vec{r}_i||} \right) \frac{\partial}{\partial t} \left(\frac{||\vec{r}_{i+1} - \vec{r}_i||}{l} \right)$$

engys

Dynamic Mooring Line Model

- External Forces
  - ✓ Transverse Drag

$$\vec{D}_{i,trans} = \frac{1}{2}\rho_{fl} C_{trans} A_{trans} ||\vec{U}_{i,trans}|| \vec{U}_{i,trans}$$

  - ✓ Tangential Drag

$$\vec{D}_{i,tang} = \frac{1}{2}\rho_{fl} C_{tang} A_{tang} ||\vec{U}_{i,tang}|| \vec{U}_{i,tang}$$

$$m_i \frac{\partial^2 \vec{r}_i}{\partial t^2} = \frac{1}{2}\vec{W}_{i+\frac{1}{2}} + \frac{1}{2}\vec{W}_{i-\frac{1}{2}} + \vec{T}_{i+\frac{1}{2}} - \vec{T}_{i-\frac{1}{2}} + \vec{C}_{i+\frac{1}{2}} - \vec{C}_{i-\frac{1}{2}} + \vec{D}_{i,trans} + \vec{D}_{i,tang}$$

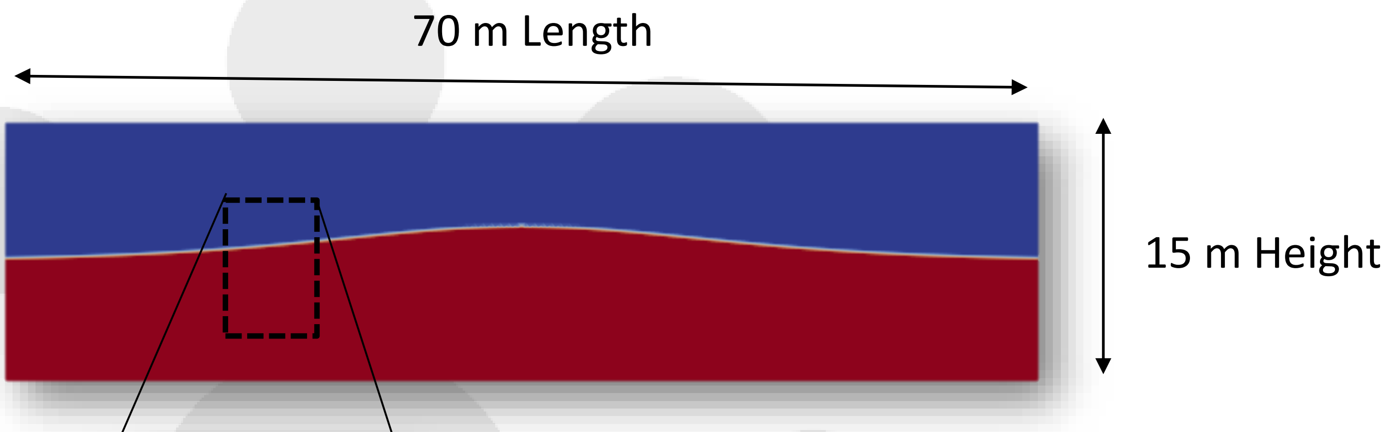
- Model provides information on mooring line position, velocity, forces
- Force feeds back into 6DoF as a restraint

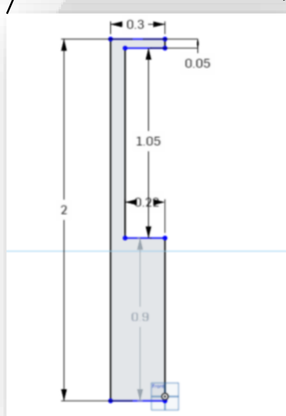
Dynamic Mooring Line Model

- User defined parameters and time stepping specification
- Composite and many line systems
- Line and Catenary Initialization
- Analysis (VTK writer) and Setup Tools

6DoF Example

Solitary Wave In Cyclic Domain





Mass = 446 kg

Buoy
- Mass = 446 kg
- CoM = (17,0, 6.309)

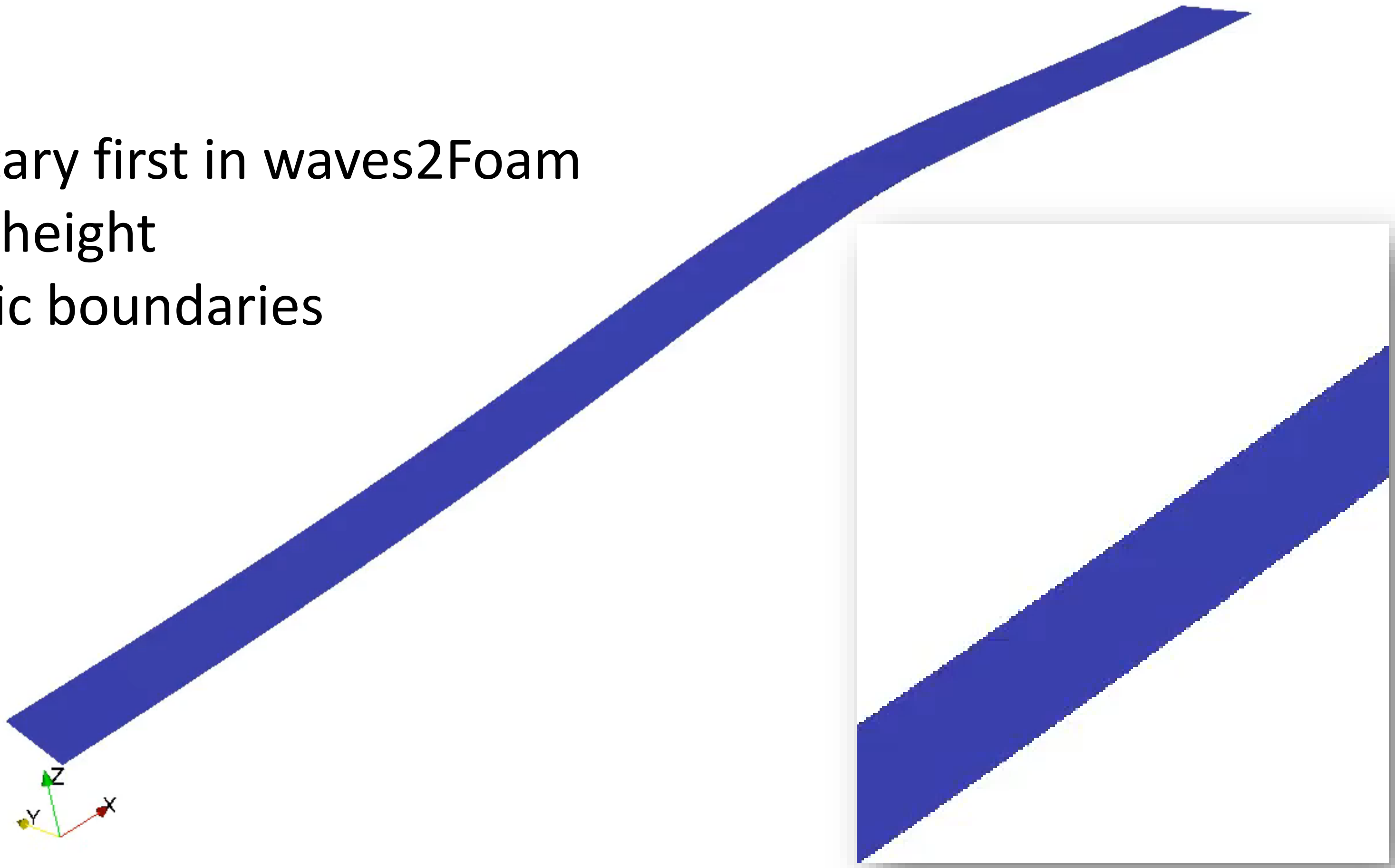
Mooring Line
- Lamba = 10 kg/m
- EA = 3.9e6 N

engys

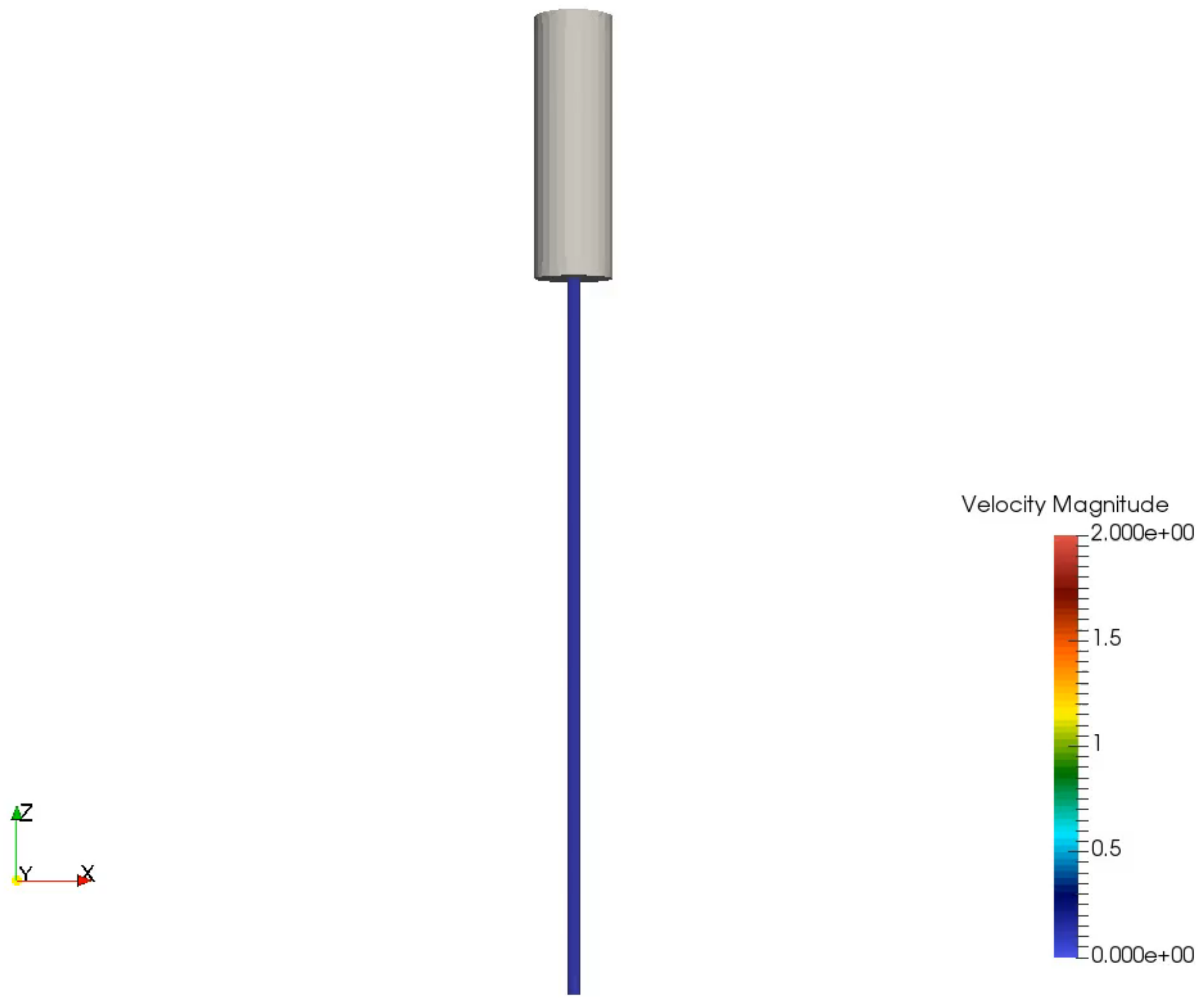
6DoF Example

Wave

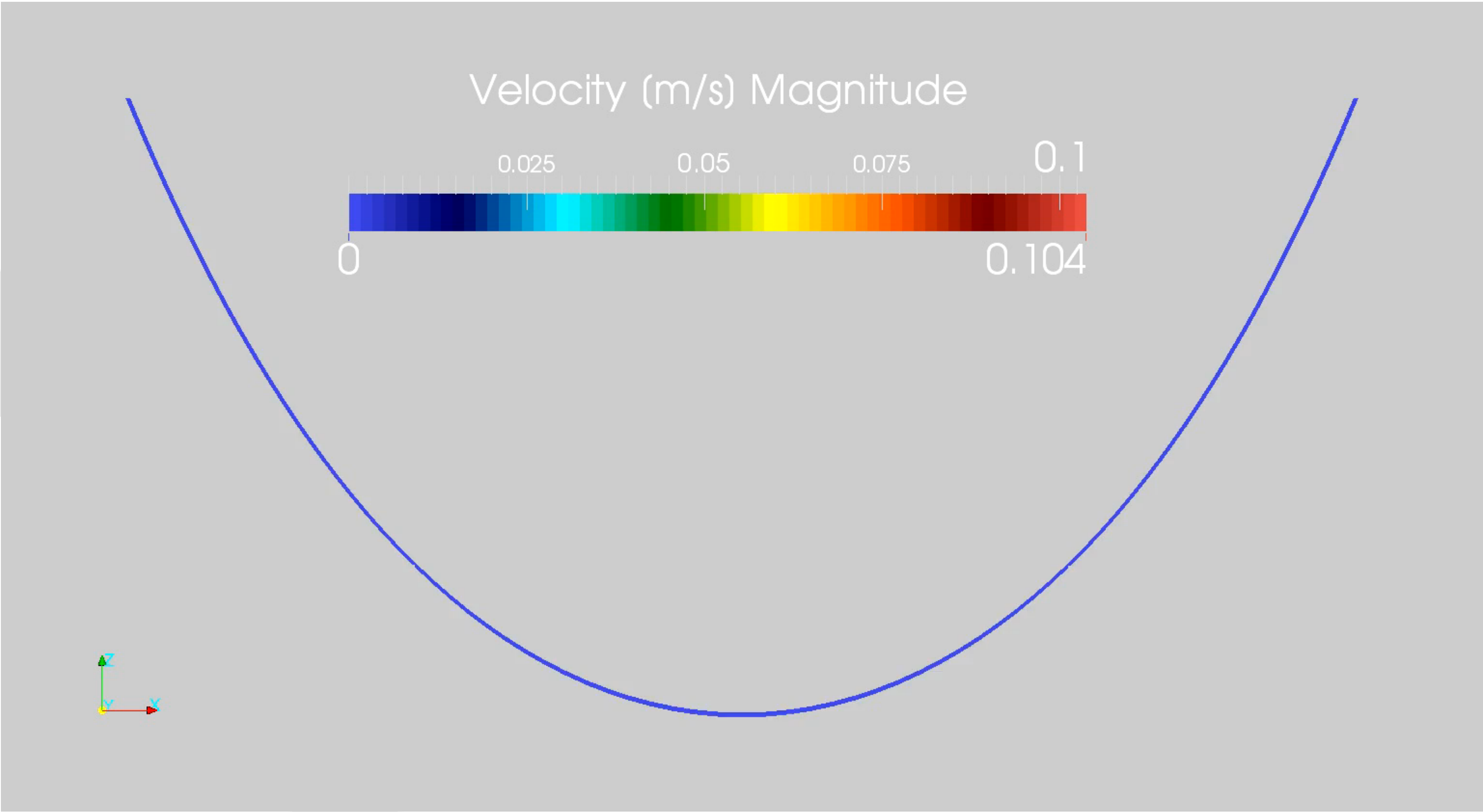
- Solitary first in waves2Foam
- 2 m height
- Cyclic boundaries



6DoF Example



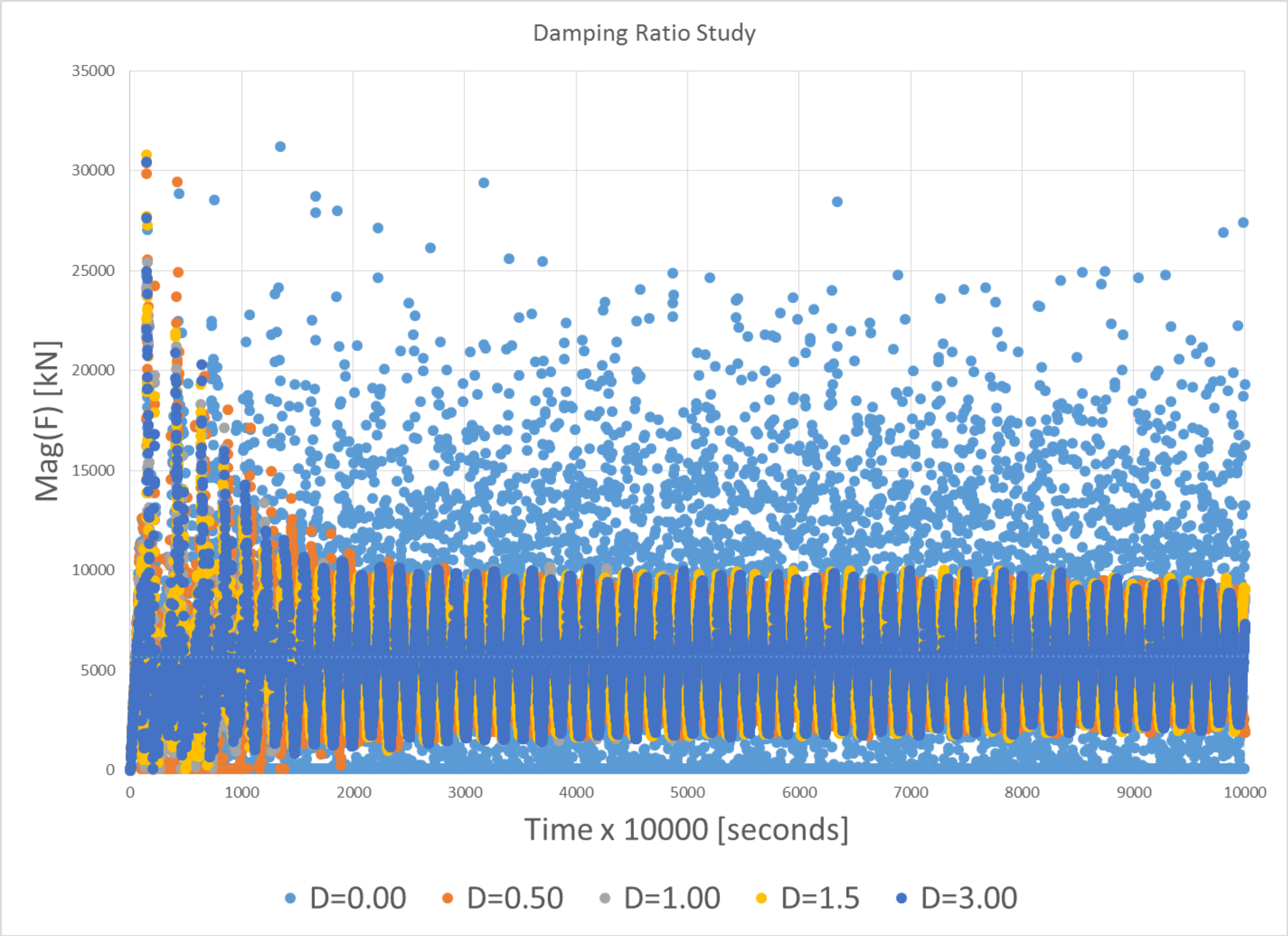
Validation Case | Quasi-Static Cable



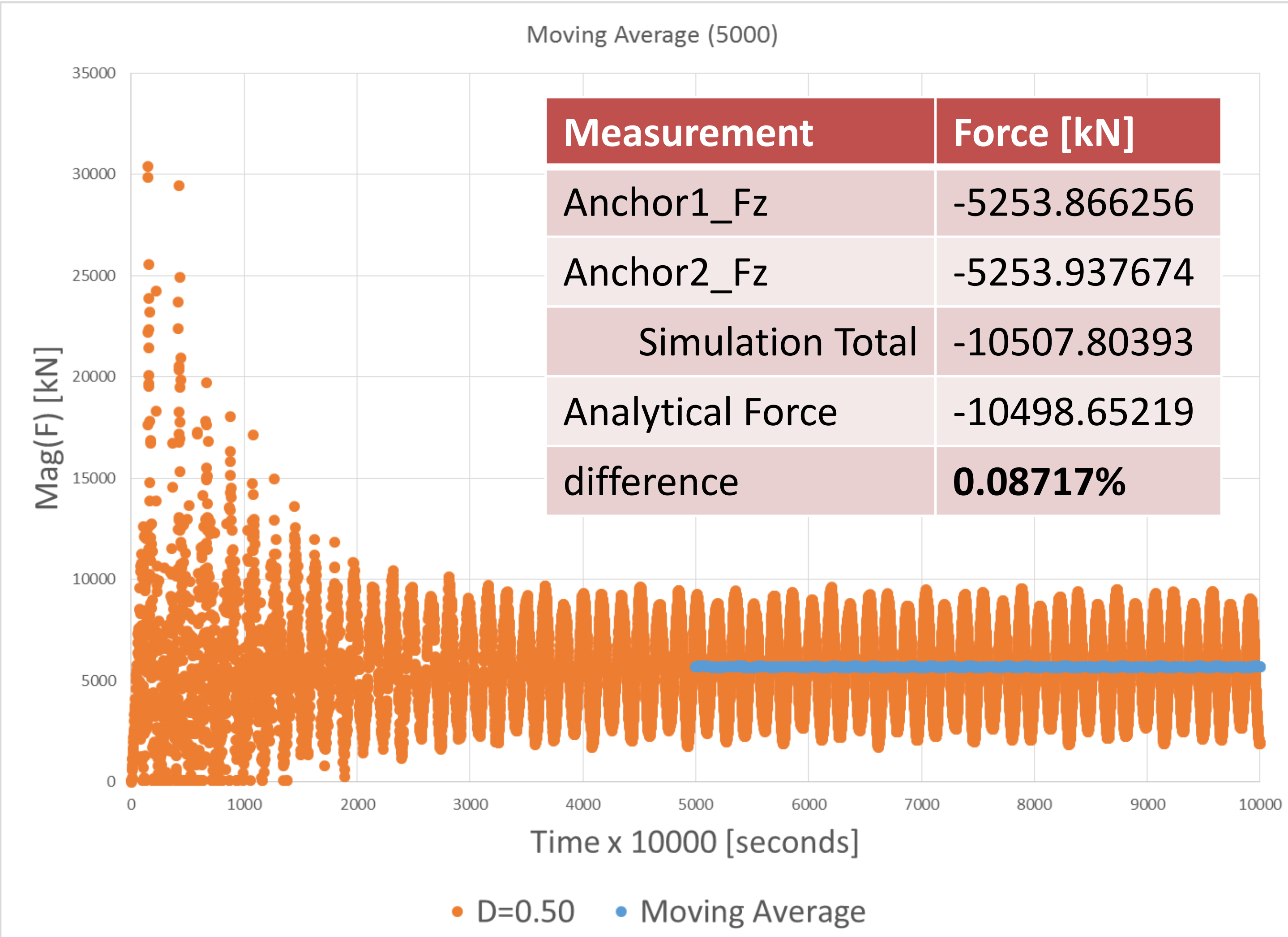
- 80 segment line during 1 second initialization
- Small oscillations in velocity, force, and tension

engys

Validation Case | Quasi-Static Cable



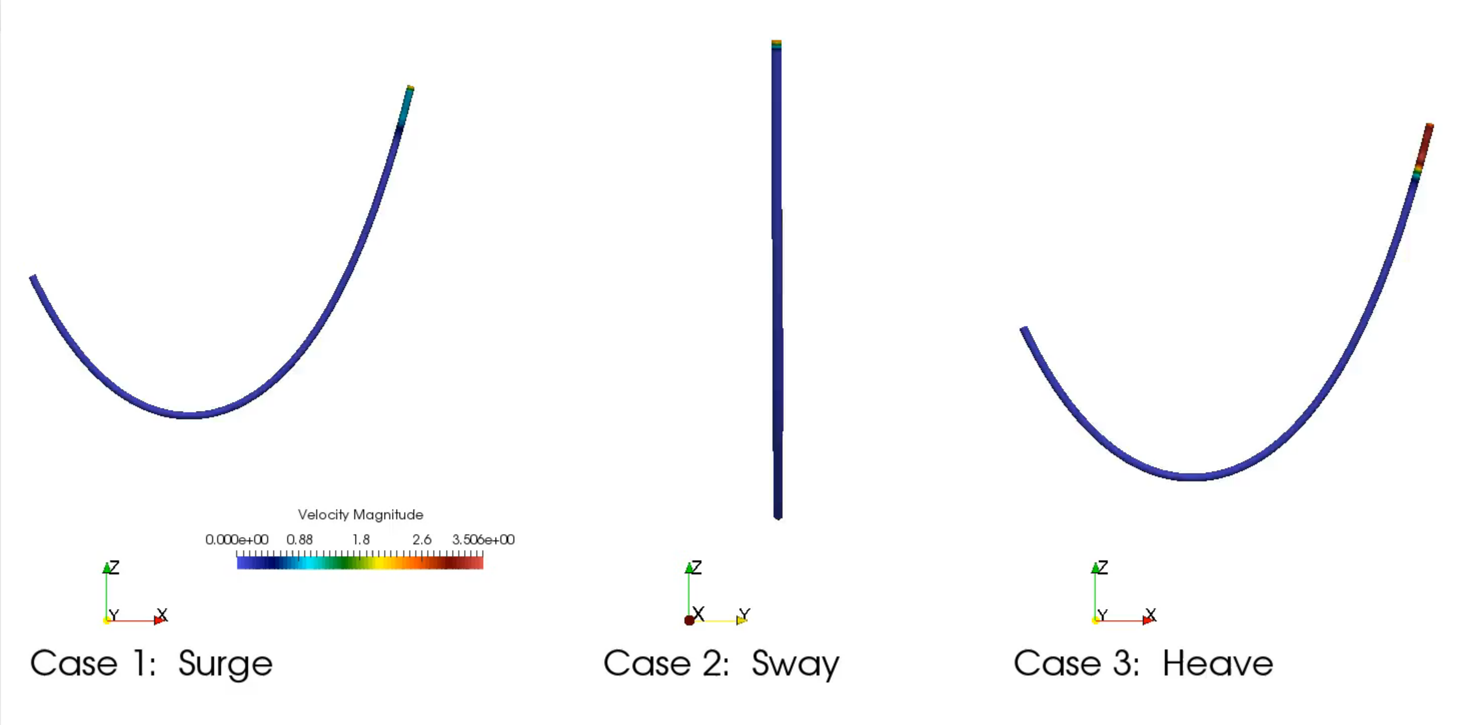
Validation Case | Quasi-Static Cable



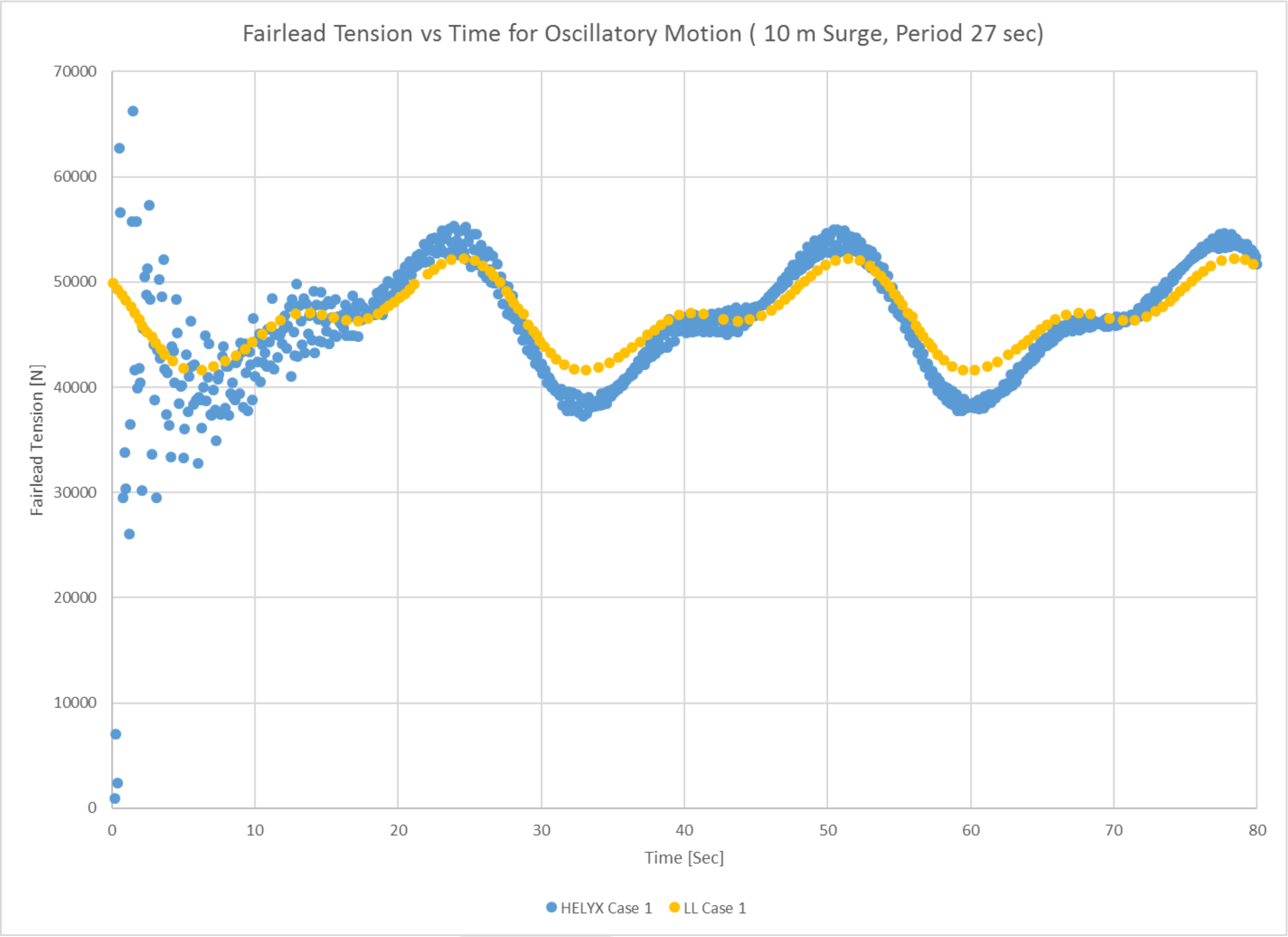
Measurement	Force [kN]
Anchor1_Fz	-5253.866256
Anchor2_Fz	-5253.937674
Simulation Total	-10507.80393
Analytical Force	-10498.65219
difference	**0.08717%**

OrcaFlex Comparison | Dynamic Comparison

- Original case used to verify OrcaFlex against another code
- Test case 99-102 Low and LangleyOMAE 2006, Sept 24, 2007
- OrcaFlex: Exact model and settings unknown, tangential drag turned off, densities scaled, “effective” tension gathered
- 170 m, 26 tonne cable, EA of 5e9 [N], diameter 0.396 m
- Oscillating at 10 meter motion with a period of 26 seconds

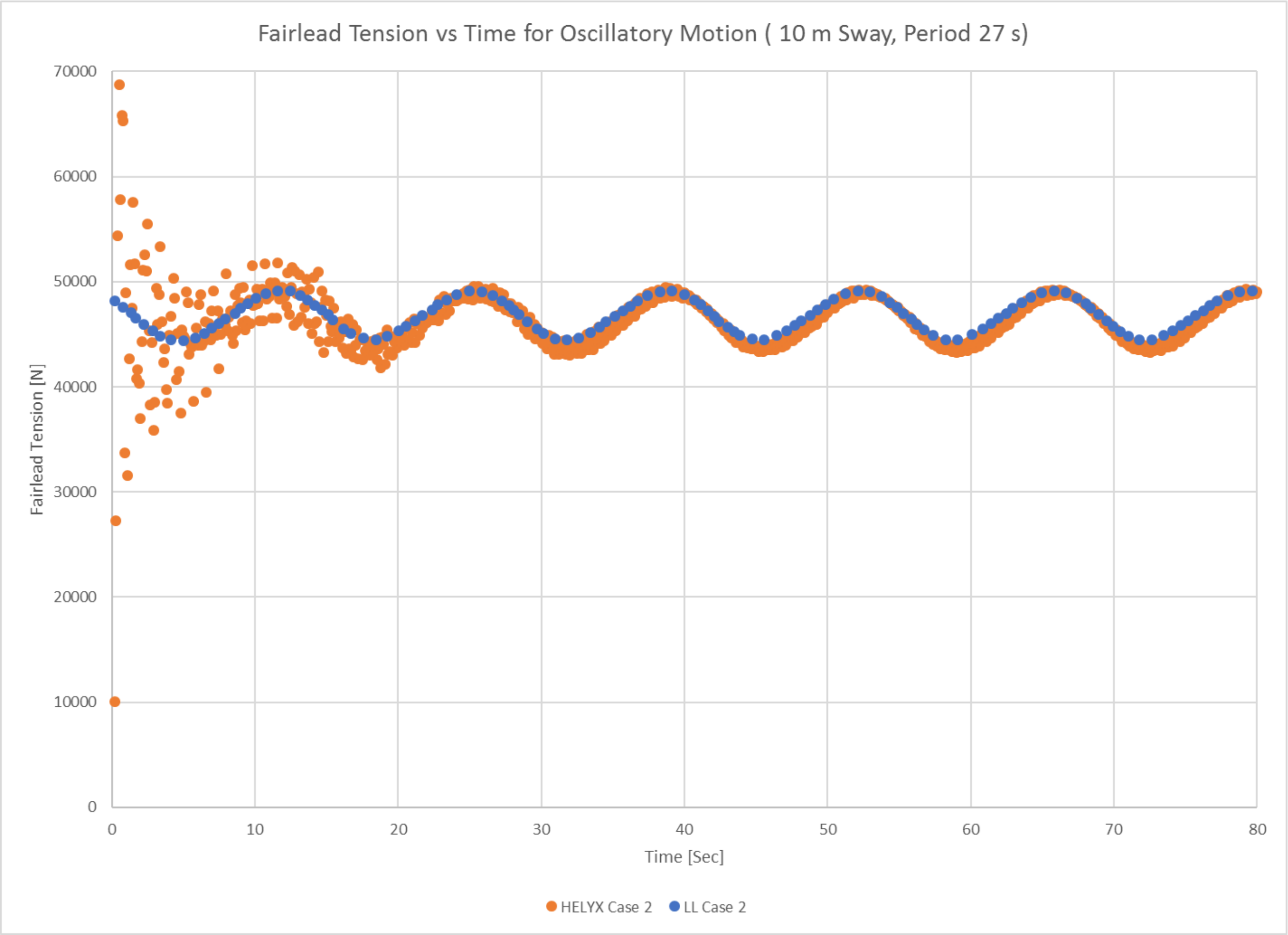


OrcaFlex Comparison | Dynamic Comparison



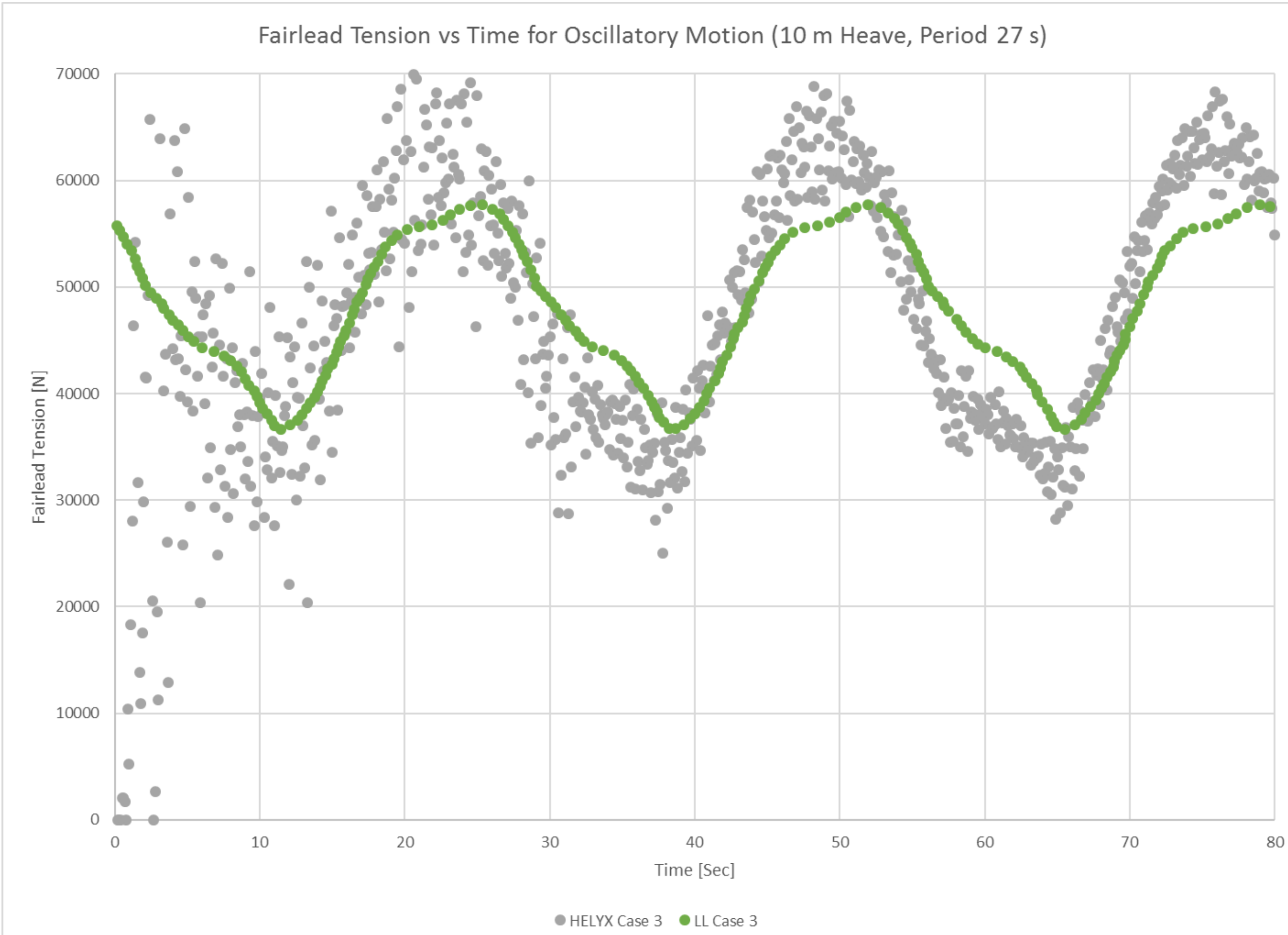
Case 1: Surge

OrcaFlex Comparison | Dynamic Comparison



Case 2: Sway

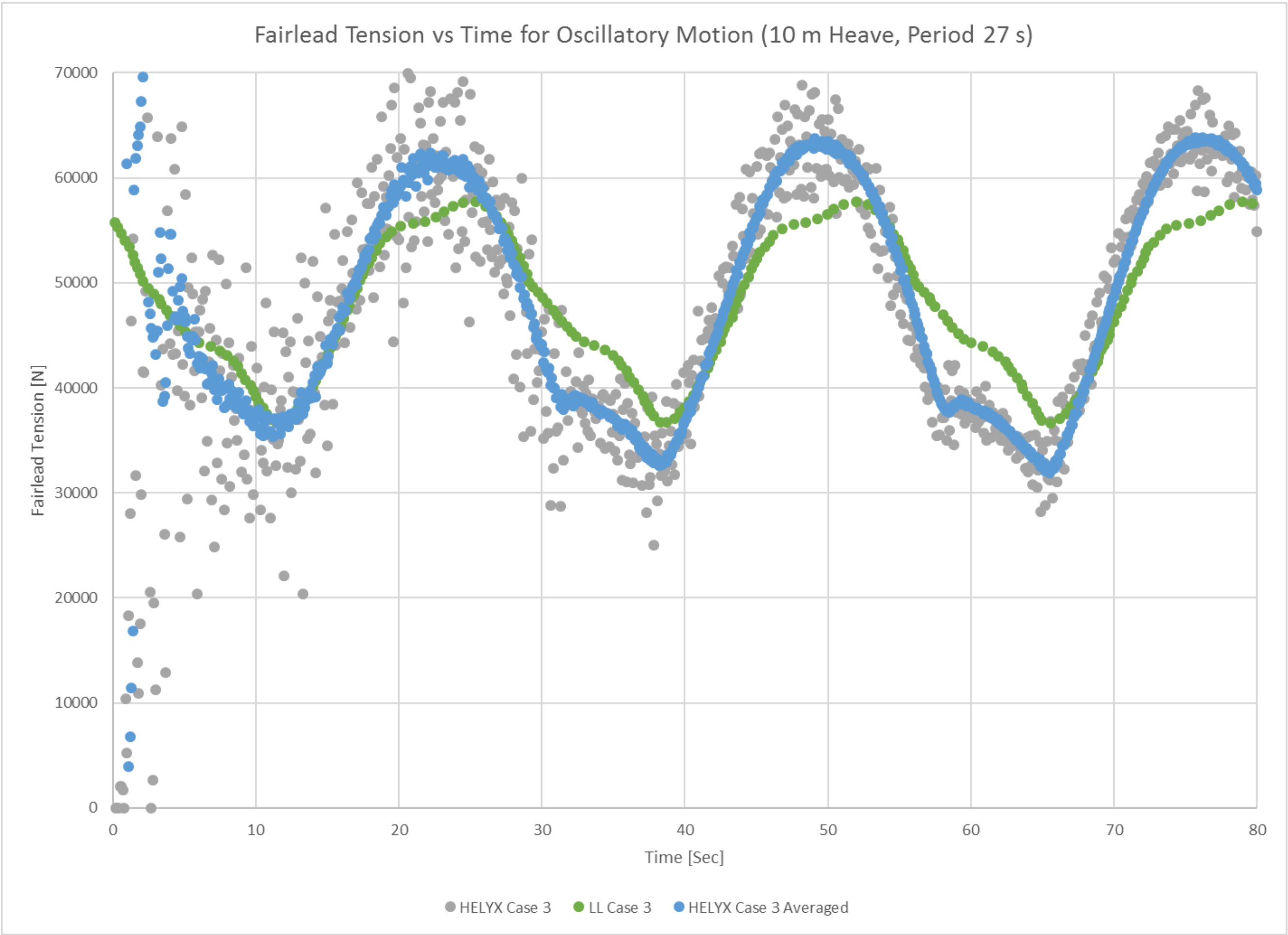
OrcaFlex Comparison | Dynamic Comparison



Case 3: Heave

engys

OrcaFlex Comparison | Dynamic Comparison



Case 3: Heave (averaged fairlead forces)

Closing Remarks

Overall

- Timescales of the cable become important
- Having a separate application to "prototype" and setup mooring line prior to CFD was helpful

V & V

- Static case validated against the analytical solution
- The dynamic case compared to OrcaFlex was globally similar, but added physics may bring it closer to verification.

Closing Remarks

V&V (continued)

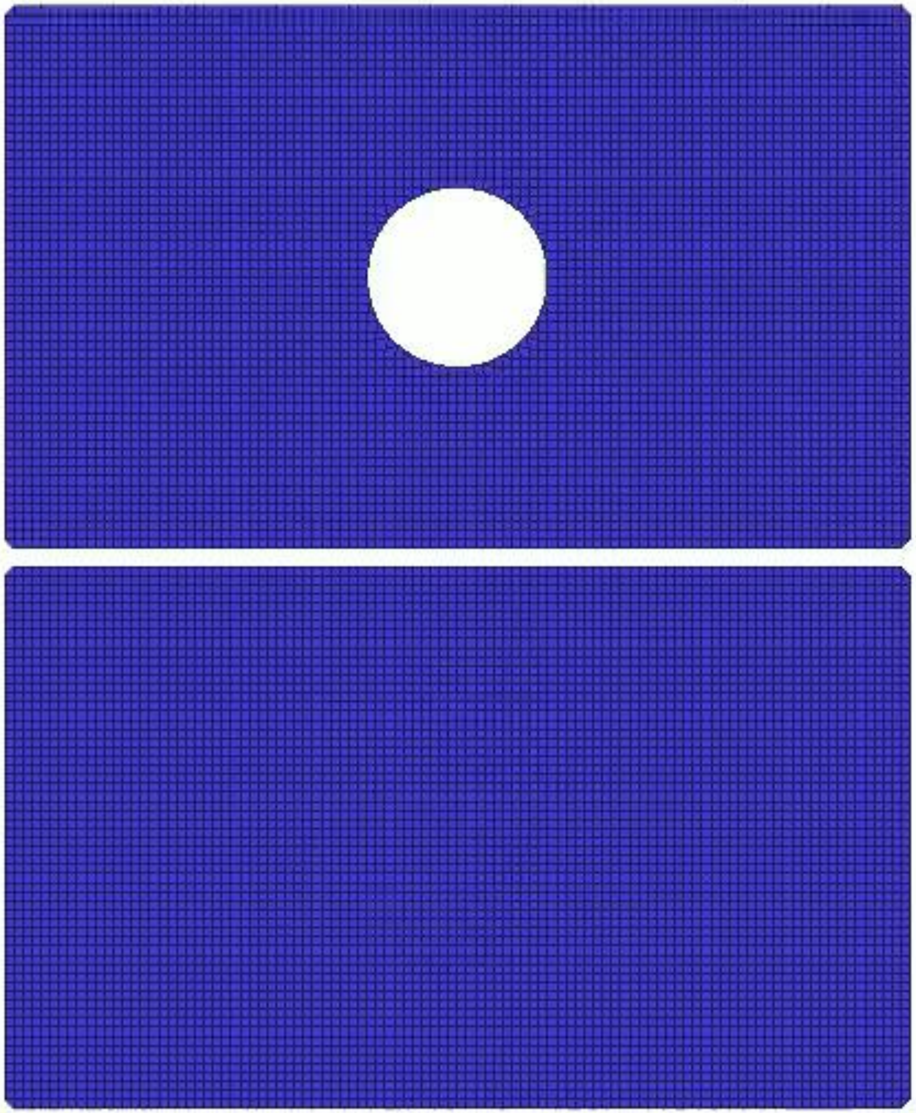
- Seek out more complex validation data for transient fairlead force and position for a given line composition.

Future Work

- Look into frequency domain analysis of the vibrational modes
- Nearly all failures were due to 6DoF divergence from pinching cells. Leveraging Geometric Immerse Boundaries (GIB) will prevent this issue.

engys

Closing Remarks



(G Karpouzas, E de Villiers) . Further Developments on the Geometric Immersed Boundaries. 11th OpenFOAM Workshop, 2016

Acknowledgments

Special thanks to Allan C. McClure Associates for sponsoring this work

Alan C. McClure Associates, Inc.

Naval Architects • Engineers

A Registered Texas Engineering Firm

http://www.acma-inc.com/

engys

Questions?

info@engys.com | Tel: +1-317-614-0070 | Fax: +1-317-536-3169| www.engys.com

engys®

Disclaimer

ENGYS Limited is the proprietor of the copyright subsisting in this work. No part of this work may be translated, reprinted or reproduced or utilised in any material form either in whole or in part or by any electronic, mechanical or other means, now known or invented in the future, including photocopying and recording, or in any information storage and retrieval system, without prior written permission from ENGYS Limited.

Applications for permission to reproduce any part of this work should be addressed to ENGYS Limited at info@engys.com

engys®