Probabilistic Modeling of Aboveground Storage Tanks Under Surge and Wave Loads

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Outline

1. Introduction
2. Wave loads
3. Fragility assessment methodology
4. Flotation fragility
5. Buckling under surge and wave loads
6. System fragility
7. Conclusions

Performance of aboveground storage tanks (ASTs) during past hurricane events

Introduction

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Methodology

Flotation

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Motivation and objectives

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- Few fragility assessment studies are currently available:
  - Landucci et al. (2012): Flood/surge and very simplistic model
  - Kameshwar and Padgett (2017a,b): Wind or storm surge
- No studies have considered the hydrodynamic effects (i.e., current and waves) of the surge

Objective of this study:

Develop fragility models for a typical AST subjected to both the hydrostatic and hydrodynamic effects of storm surge

Two failure modes: Flotation and buckling

Numerical modeling of wave loads

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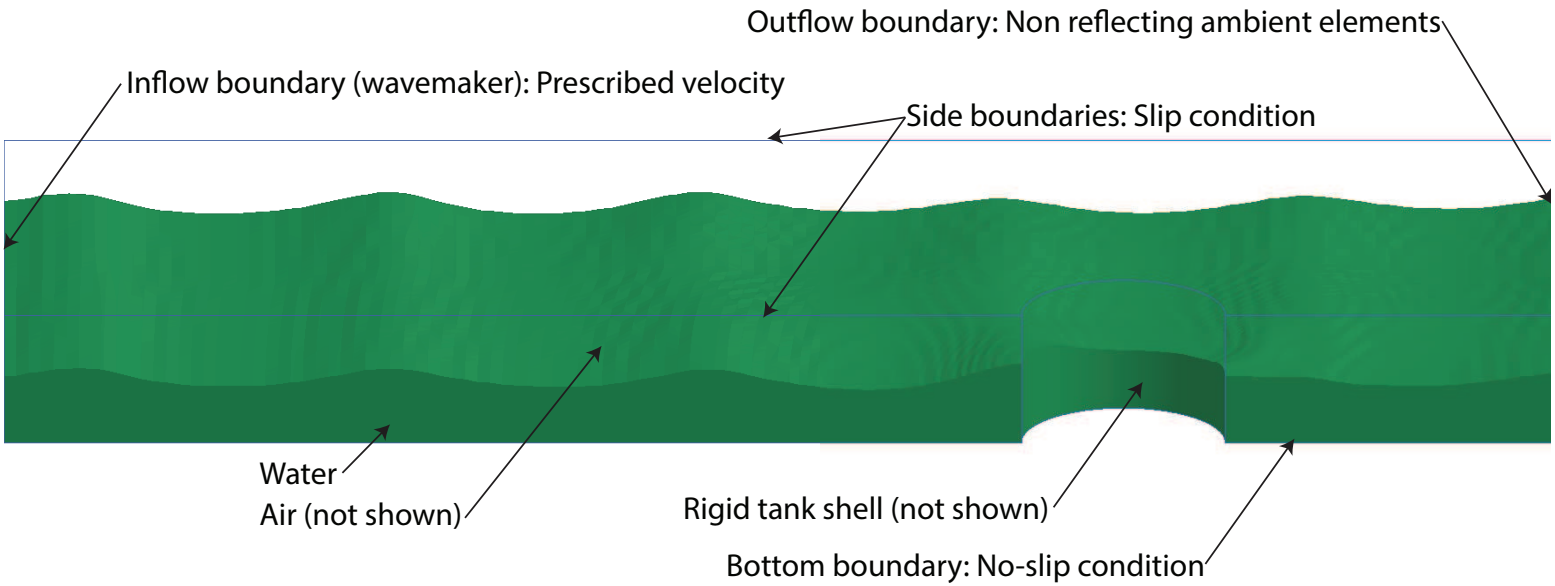
- Case study AST: $D = 15\ \mathrm{m}$ and $H = 10\ \mathrm{m}$
- Overview of the numerical model:
  - Finite element (FE) model developed using the Arbitrary Lagrangian-Eulerian (ALE) method in *LS-Dyna*
  - Waves generated from Fenton's wave theory (Fenton 1988)



Validation of the numerical model for wave loads

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- Modeling assumptions validated against wave experiments performed at Oregon State University (Bernier et al. 2018)

Validation of the numerical model for wave loads

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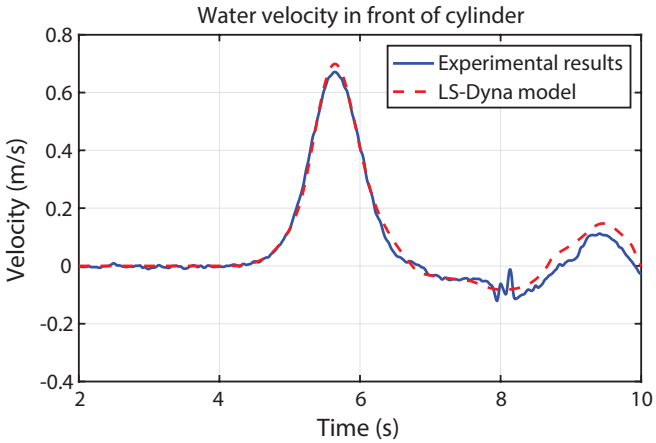
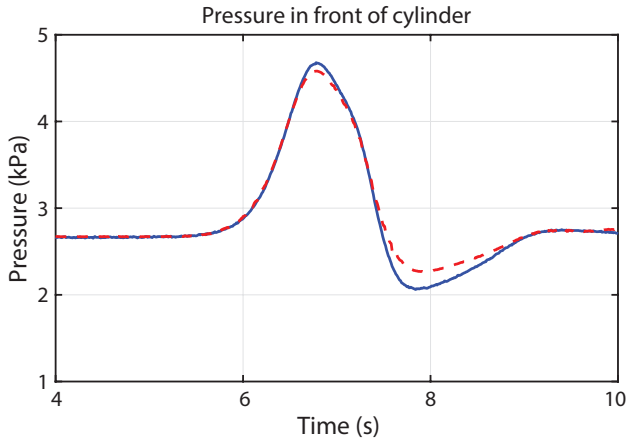
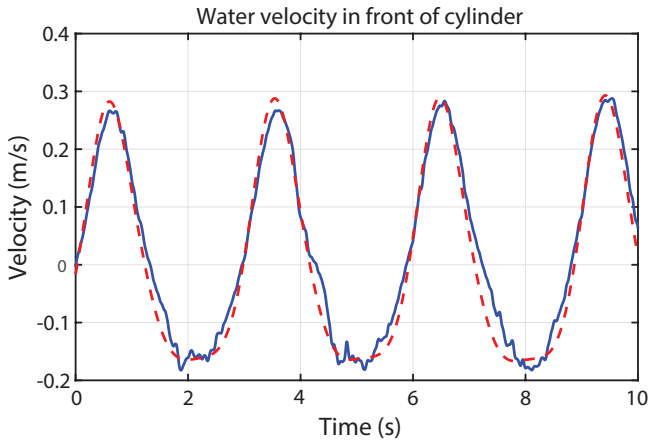
- Validation for solitary wave and regular wave cases:

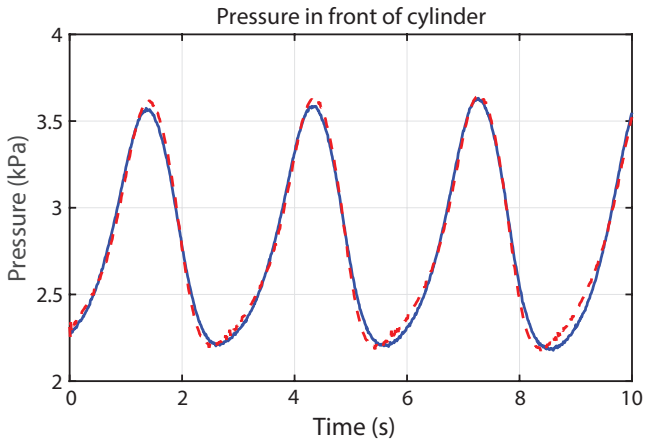
Solitary wave - H = 0.2 m:





Regular wave - H = 0.1 m; T = 2.95 s:





Regression model for pressure distribution

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- Regression model to reduce the computational cost of estimating wave loads for fragility analysis
- Space filling experimental design using Latin Hypercube Sampling (LHS) with 220 FE analyses
- Ranges of surge and wave parameters obtained from simulations of historic and synthetic storms in the Houston region (*ADCIRC*):

Parameter	Parameter name	Range
S (m)	Surge depth	1.0 – 7.5
H_w (m)	Wave height	0.0 – 2.0
T_w (s)	Wave period	3.0 – 6.0
U (m/s)	Current velocity	0.0 – 1.5

Regression model for pressure distribution

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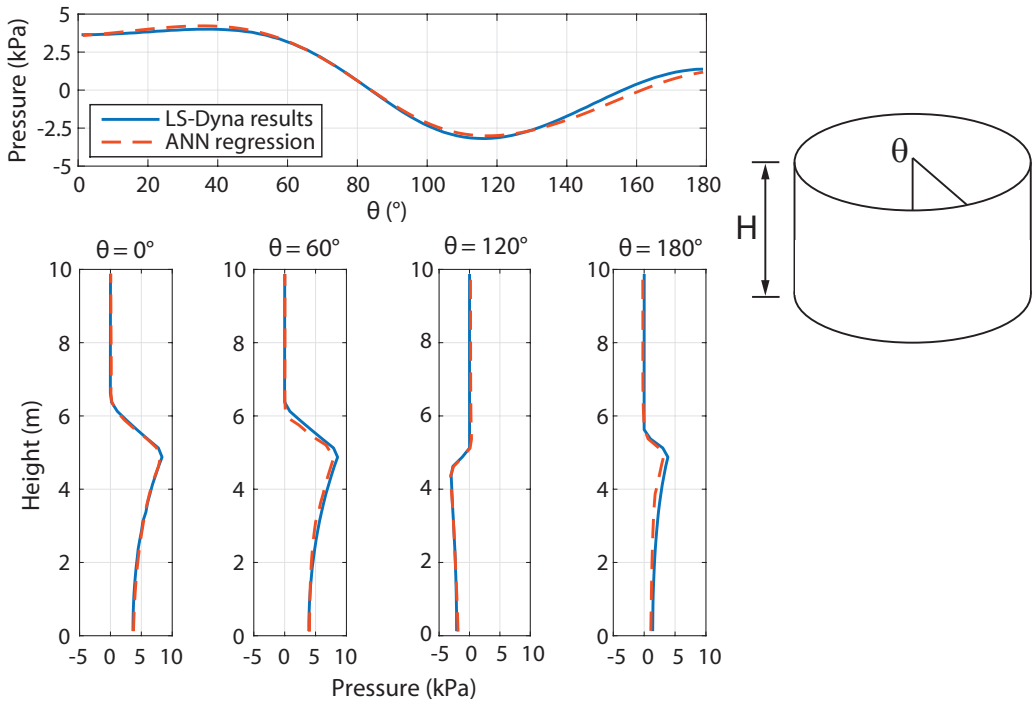
- Pressure distribution regression model using Artificial Neural Network (error less than 10%)

$$\text{Input} : \{S, H_w, T_w, U, \theta, h\} \mapsto \text{Output} : \{P_{hd}\}$$



Fragility assessment under surge and wave loads

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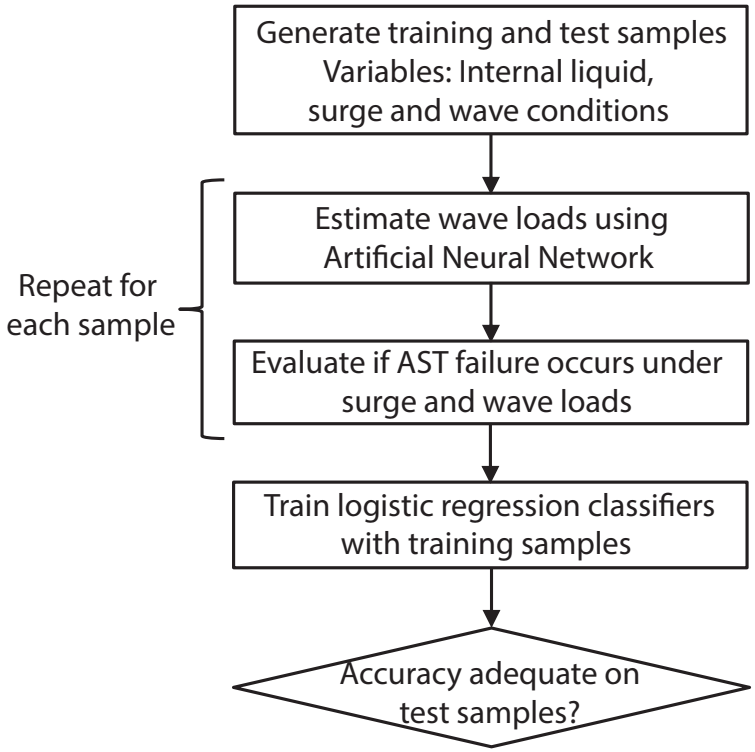
- Overview of methodology:



$$P(\text{Failure} \mid \mathbf{IM}; \mathbf{X}) = \frac{1}{1 + \exp(-l(\mathbf{IM}; \mathbf{X}))}$$

Unanchored flotation fragility model

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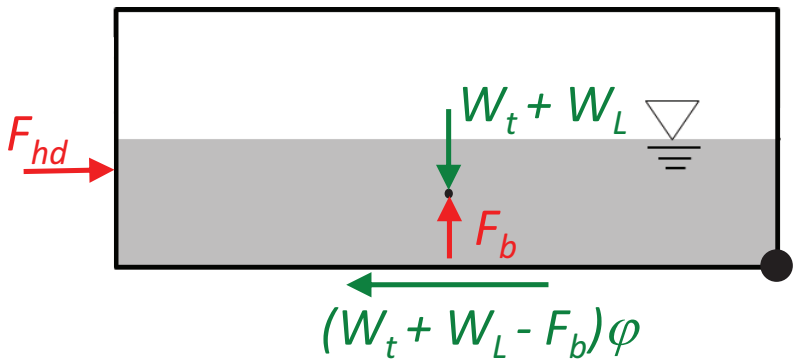
- Three possible mechanisms:

$$W_t + W_l < F_b$$

$$(W_t + W_l - F_b)\,\frac{D}{2} < M_{hd}$$

$$(W_t + W_l - F_b)\,\varphi < F_{hd}$$



- M_{hd} and F_{hd} obtained from ANN model
- Fragility model derived from 10,000 training samples
- Accuracy of 99.5% on 1,000 test samples

Unanchored flotation fragility model

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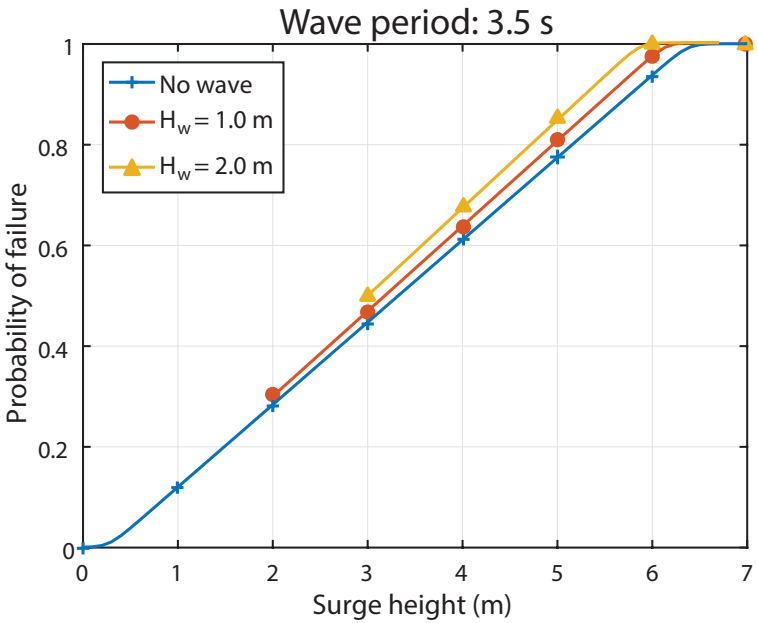
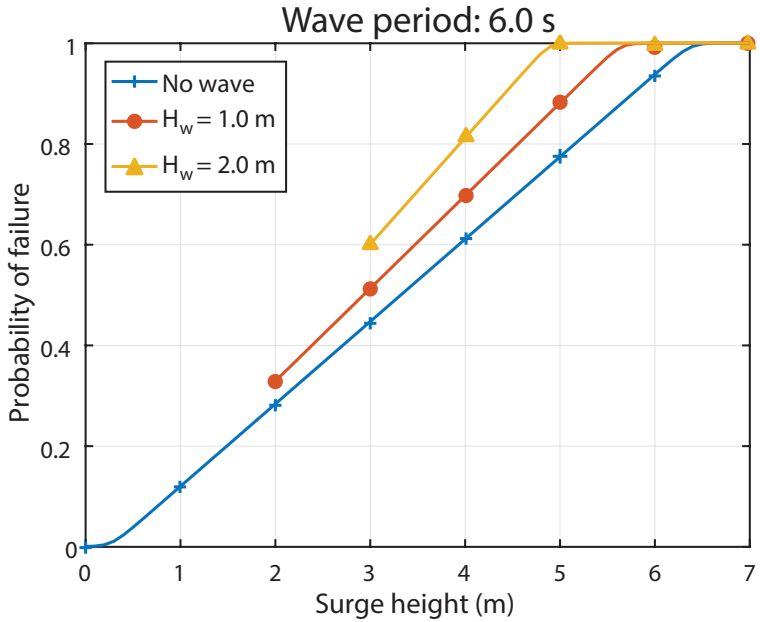
- Fragility model parameterized on:
  - Internal liquid: ρ, L
  - Surge: S, U
  - Wave: H_w, T_w
  - Friction: φ





Anchored flotation fragility model

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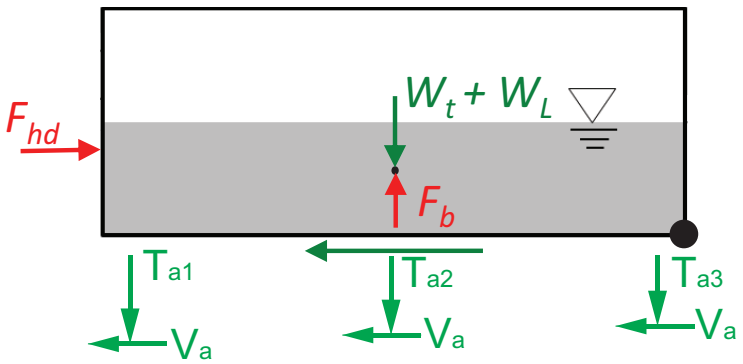
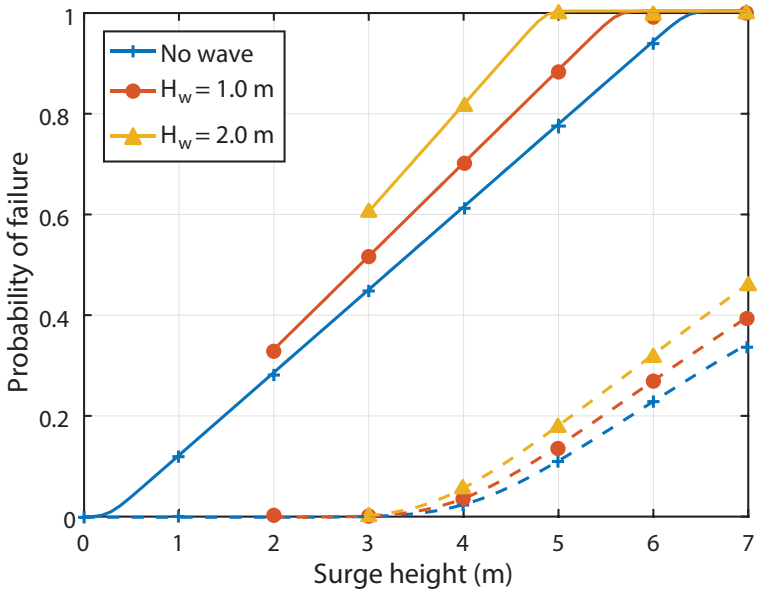
- Add anchors tensile and shear strength to previous inequalities
- Additional parameters:
  - Anchors: d, s, f_y, f'_c, h_{ef}
- Accuracy of 97.2%





Buckling under surge and wave loads

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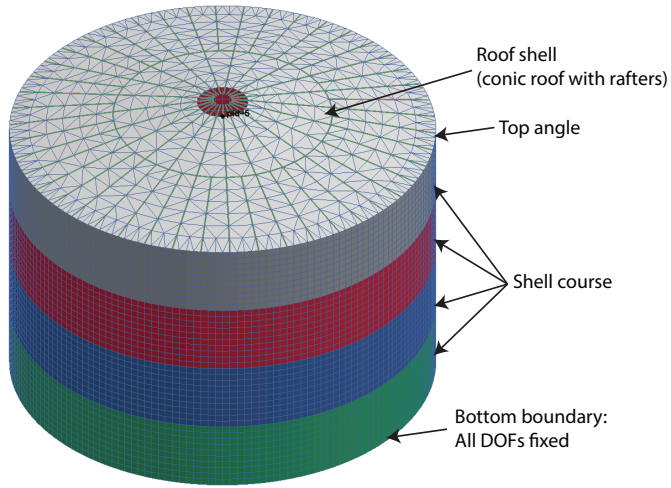
- Buckling strength is assessed via finite element (FE) analysis
- Overview of FE model (*LS-Dyna*):
  - AST designed per API 650 standard



- Loads applied on FE model are obtained from ANN
- Fragility model derived from 2,000 buckling analyses
- Accuracy of 97.5% on 200 test samples

Buckling fragility model

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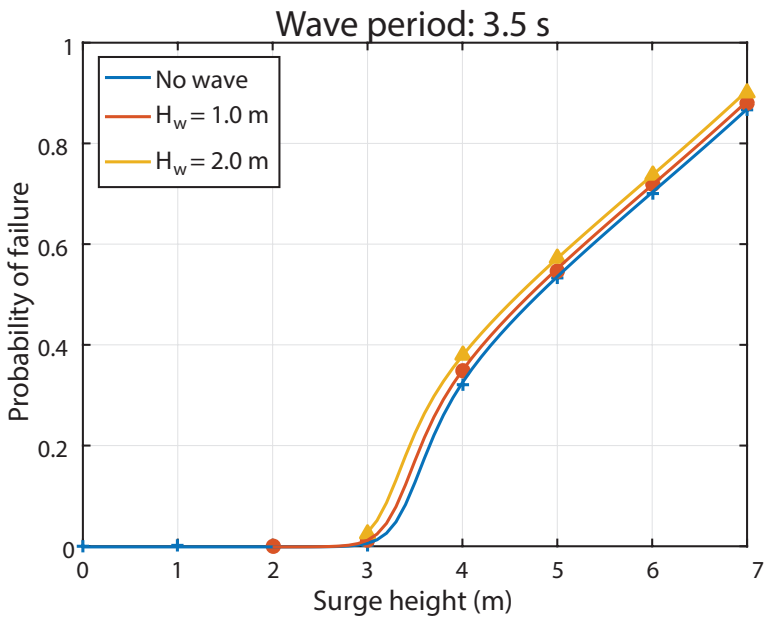
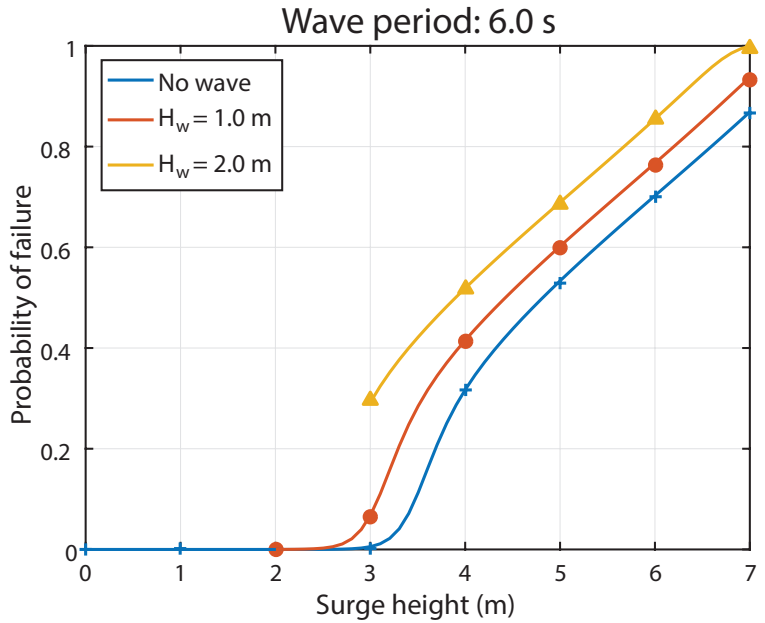
- Fragility model parameterized on:
  - Internal liquid: ρ, L
  - Surge: S, U
  - Wave: H_w, T_w





System fragility

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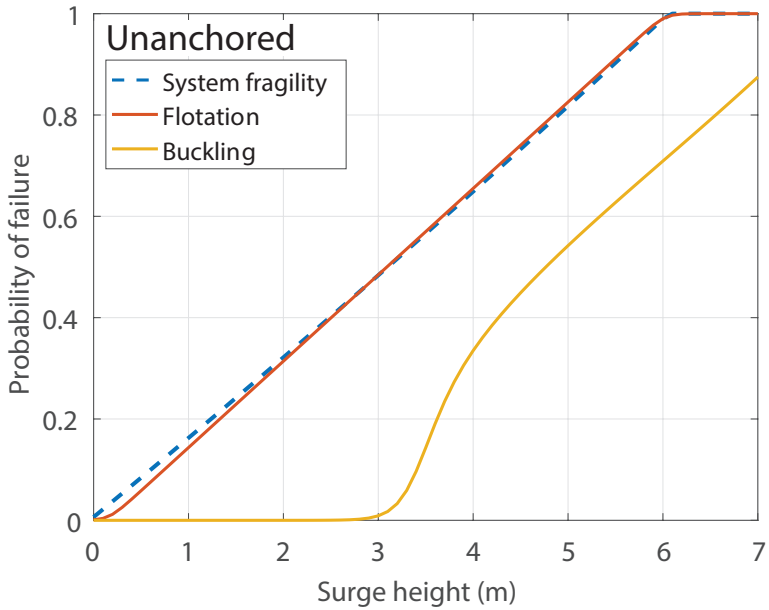
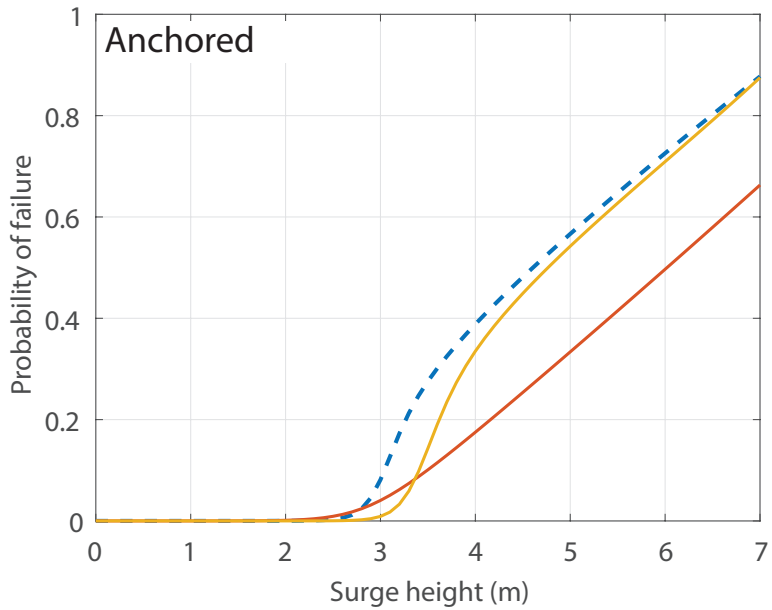
- Both failure modes using series system assumption

$$P(\text{Failure}) = P(\text{Flotation} \bigcup \text{Buckling})$$





Conclusions and future work

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- Developed numerical model and regression model to easily estimate wave loads
- Provided better understanding of failure mechanisms under surge and wave loads
- Developed the first fragility models for an AST subjected to surge and wave loads
  - Importance of waves to adequately estimate probability of failure
  - Flotation is the failure mode of interest for unanchored ASTs
  - Buckling is the failure mode of interest for anchored ASTs
- Future work:
  - Fragility models parameterized on AST geometry
  - Risk assessment framework

Acknowledgements

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Questions

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