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Effects of wave loading conditions on the fragility of pile-supported wharves/piers

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Outline

1. Introduction
2. Problem description
3. Suggested approach
4. Case study
5. Results and conclusions

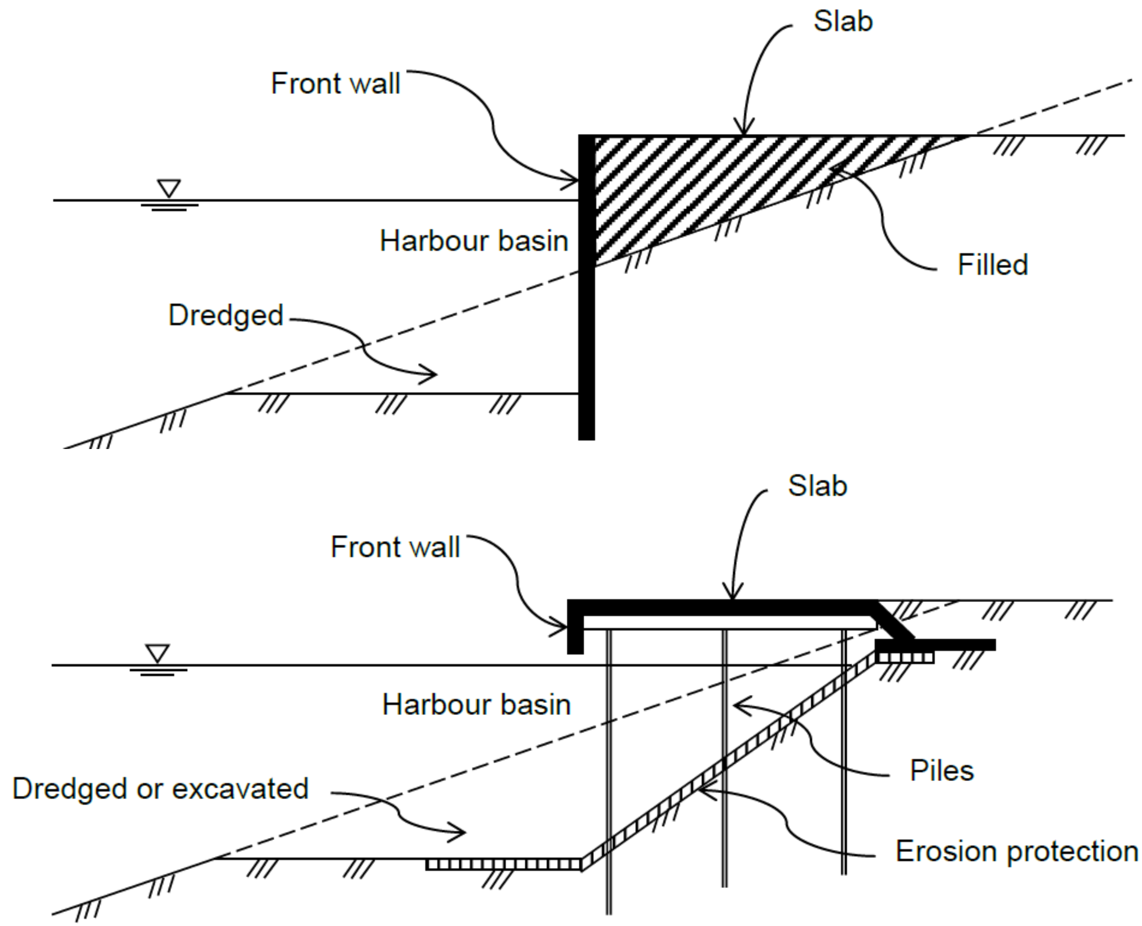
Wharves/Piers

Closed type

(earth fill extended to front wall)

Open type

(wood, steel, concrete piles)



(Cong et al. 2013)

Structural Vulnerability

- West pier collapse

- East pier uplift

Port of Gulfport (Mississippi) after Hurricane Katrina (2005) (Gutierrez et al. 2006)

Structural Vulnerability

Pier deck damage due to uplift wave forces at Cozumel Cruise terminal (photos provided by: Dr. Carlos Ospina, BergerABAM)

Fragility Analysis

1. Estimates failure probability conditioned on selected parameters (e.g., storm surge, wave)
2. Allows uncertainty propagation to input parameters affecting demand (e.g., wave period) and capacity (e.g., material properties)
3. Requires the definition of a limit state function

$$g(C,D) = \begin{cases} Capacity \leq Demand \Longrightarrow Failure \\ Capacity > Demand \Longrightarrow Safety \end{cases}$$

Fragility Analysis

$$g(C_i, D_i) = \begin{cases} C_i - D_i \leq 0 \Longrightarrow Failure \\ C_i - D_i > 0 \Longrightarrow Safety \end{cases}$$

$i =$ examined failure mode (e.g., uplift, shear, flexural, etc.)

$$p_{f,uplift} = P\left[g_{uplift}\left(C_{uplift}, D_{uplift}\right) \leq 0 \mid IMs\right]$$

$IMs =$ intensity measures (e.g., surge elevation, wave height, wave period)

$C_{uplift} =$ uplift capacity (connection strength, deck weight)

$D_{uplift} =$ uplift demand (vertical wave forces)

Adopted Wave Model

McConnell et al. (2004)

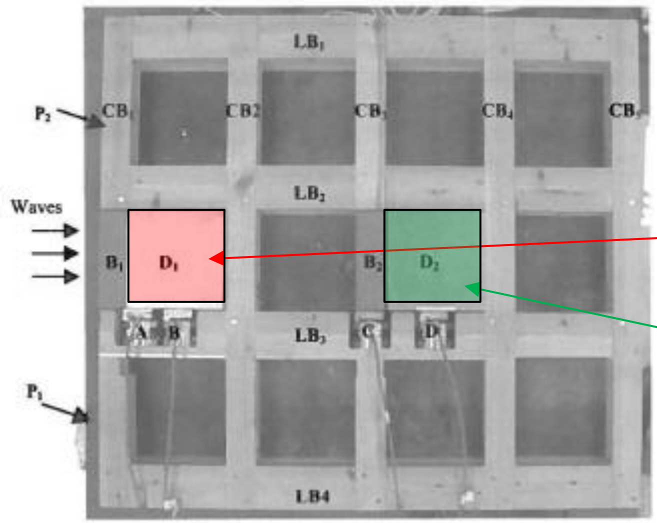
$$F_{v,imp} = F_{v,qs} \frac{a_{v,imp}}{(t_r/T_m)^{b_{v,imp}}}$$

$$F_{v,qs} = \left(F_v^* \frac{a_{v,qs}}{\left[\frac{(\eta_{max} - Z_c)}{H_s}\right]^{b_{v,qs}}} \right) \times \varepsilon_1$$

$a, b =$ empirical coefficients from regression analysis of the test data (McConnell et al. 2004)

$\varepsilon_1 =$ model error to envelope data with a wide degree of scatter (Balomenos and Padgett 2018)

Empirical Coefficients (quasi-static)

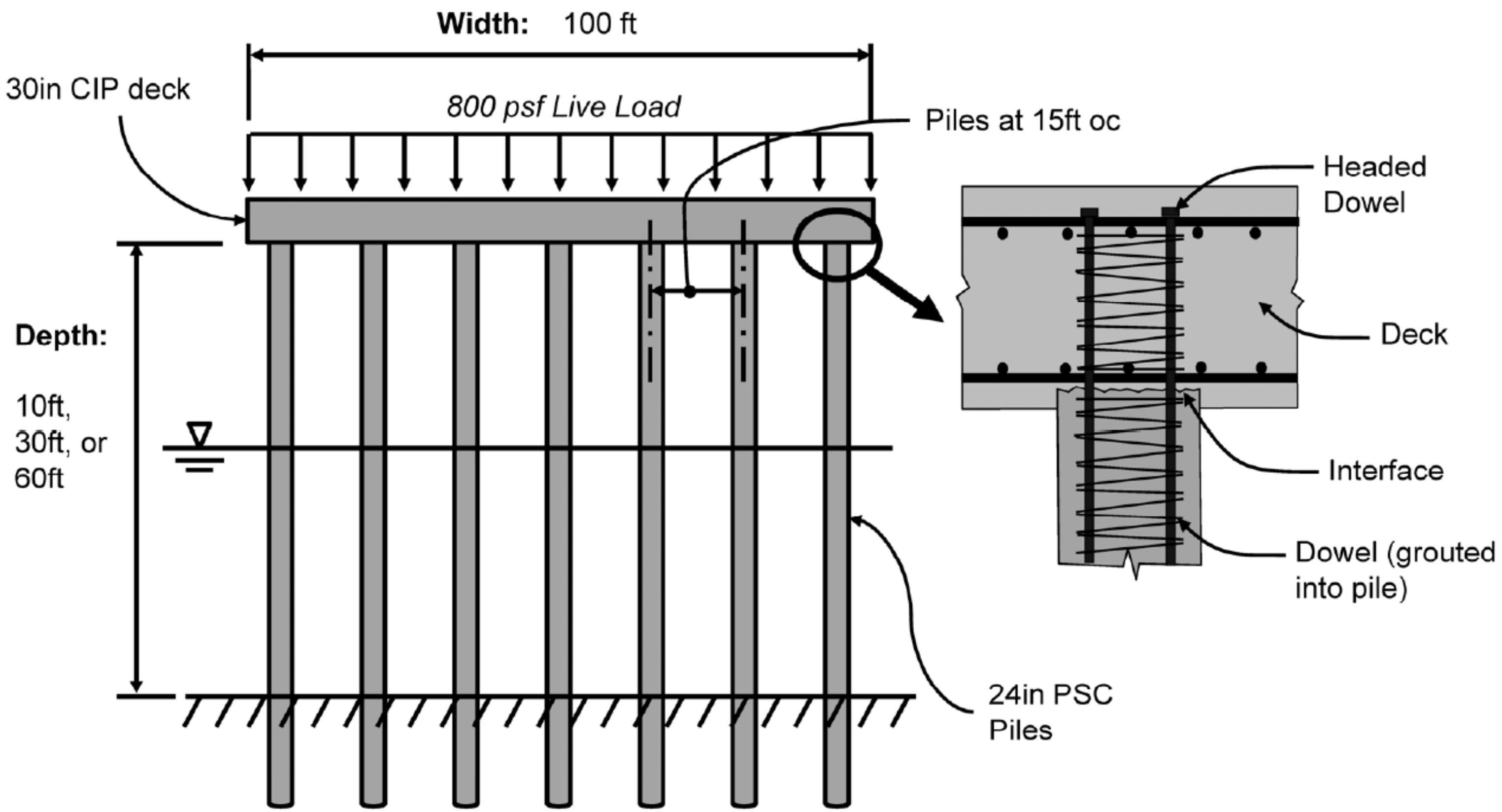


Tested model
(McConnell et al. 2004)

Configuration	$a_{v,qs}$	$b_{v,qs}$	ε_1		
			Distribution	Mean	Stdev
Seaward deck	0.82	0.61	Normal	1.0	0.167
Internal deck	0.71	0.71	Normal	1.1	0.333

$$F_{v,qs} = \left(F_v^* \frac{a_{v,qs}}{\left[\frac{(\eta_{max} - Z_c)}{H_s}\right]^{b_{v,qs}}} \right) \times \varepsilon_1$$

Dowelled Deck-Pile Connection



Typical pile-supported port and connection details (Stringer and Harn 2013)

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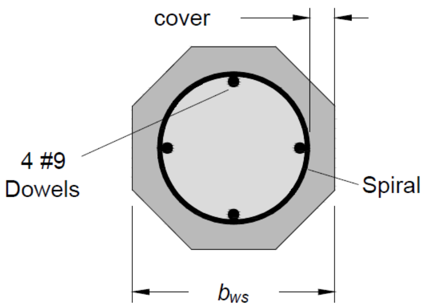
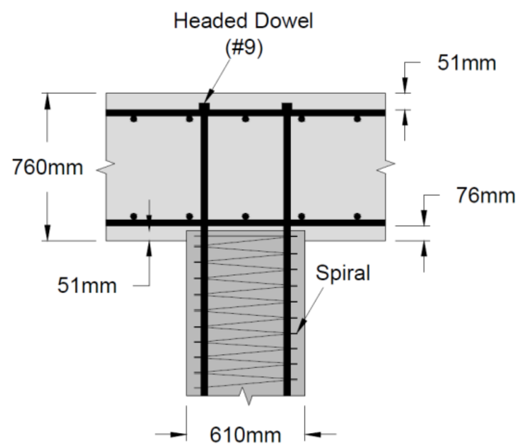
Examined Connections

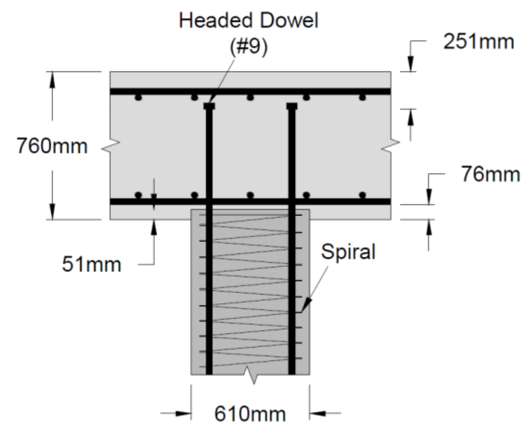
2 Connections



Dowels above deck's top mat reinforcement



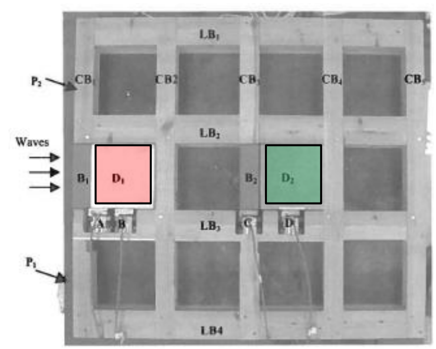
Dowels below deck's top mat reinforcement



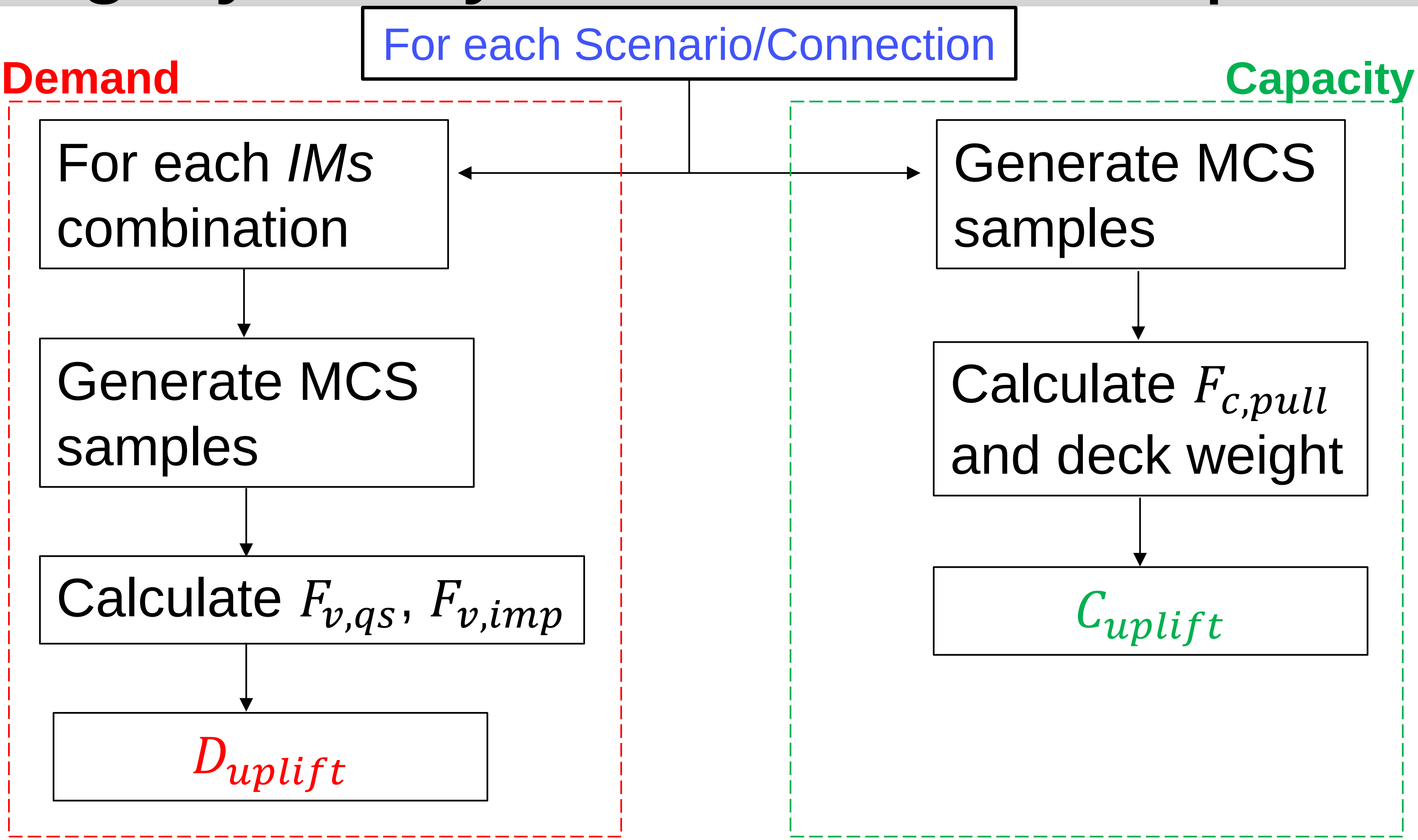
Details of examined connections (Balomenos and Padgett 2018)

2 Scenarios/Connection

1. SM = Seaward deck
2. IM = Internal deck



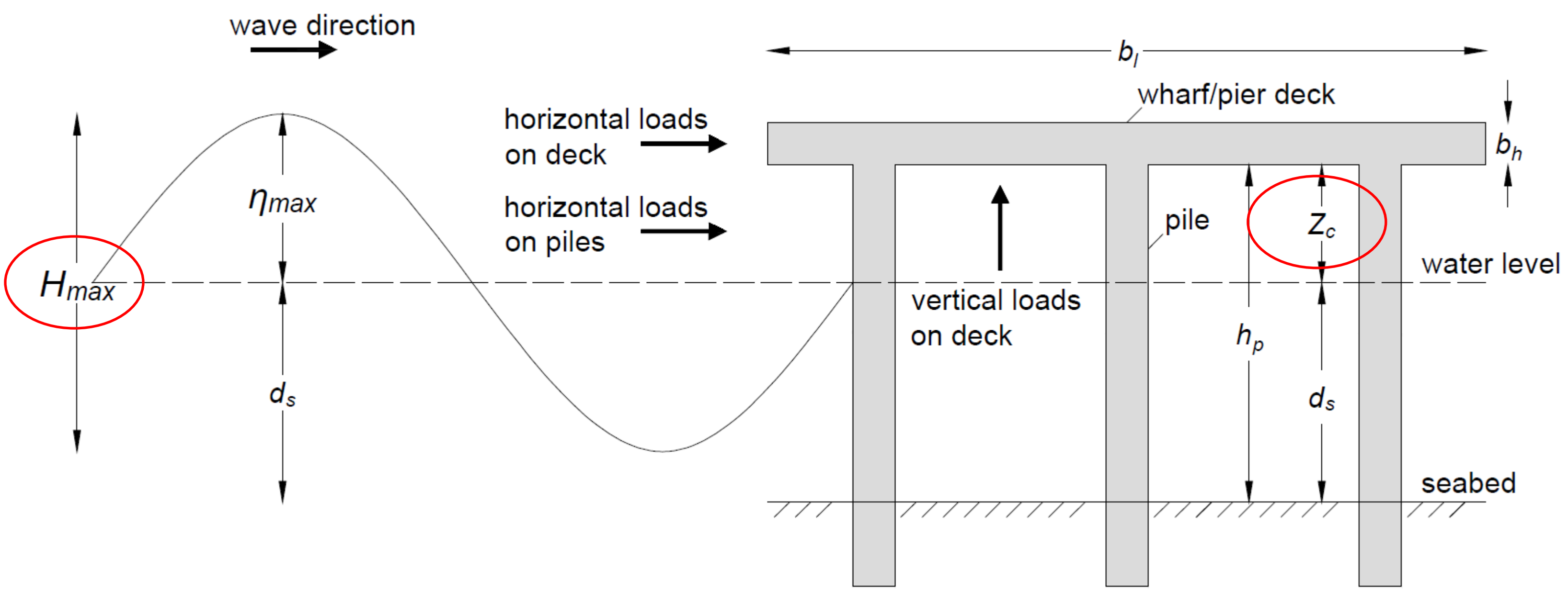
Fragility Analysis Flowchart – Uplift



Uplift fragility flowchart (Balomenos and Padgett 2018)

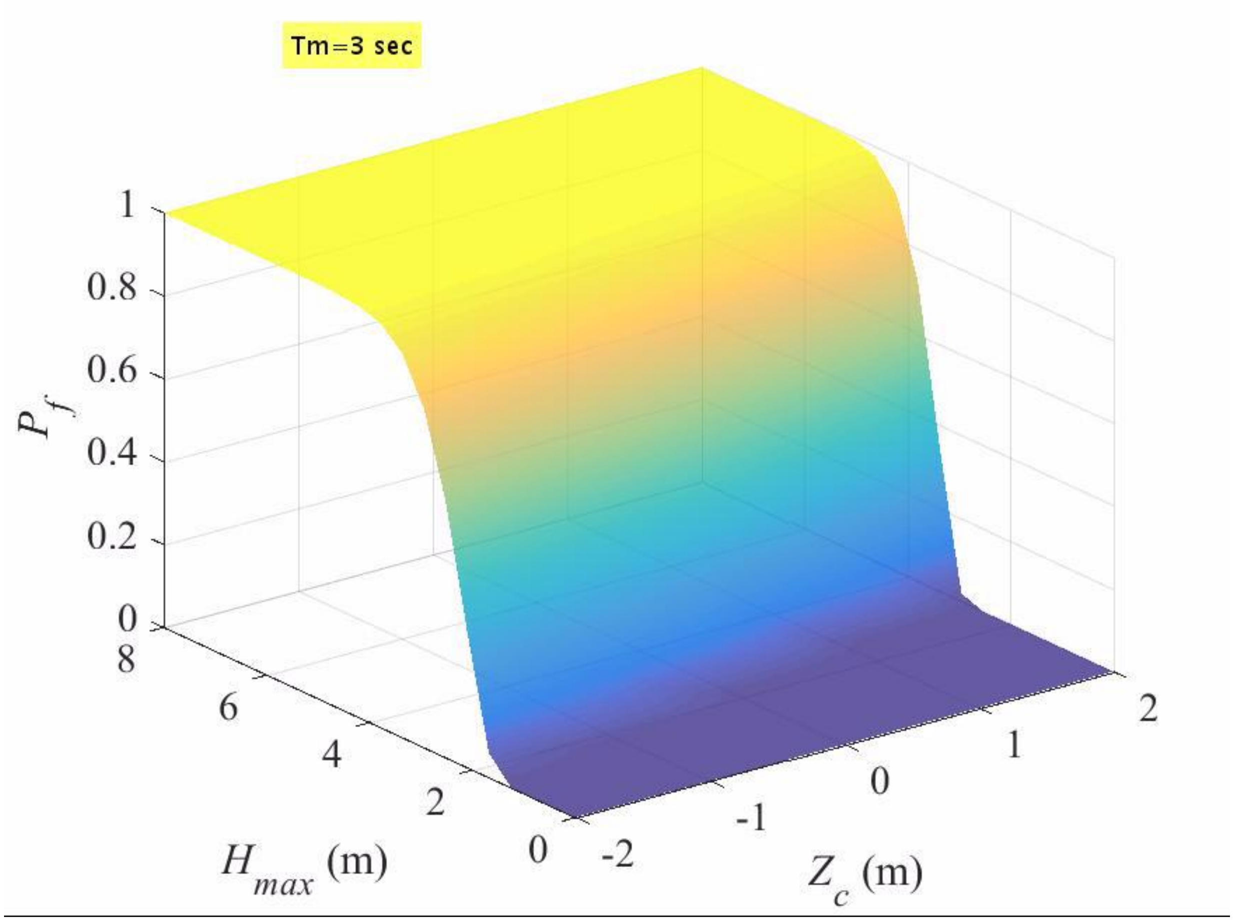
Fragility Analysis

$$p_{f,uplift} = P\left[C_{uplift} \leq D_{uplift} \middle| H_{max}, Z_C, T_m\right]$$

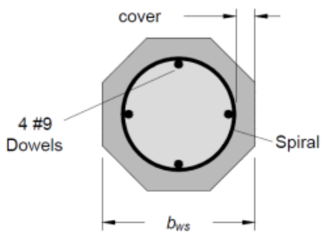


Wave forces on pile-supported deck (Balomenos and Padgett 2018)

Fragility Surface – Seaward (PM-IN)



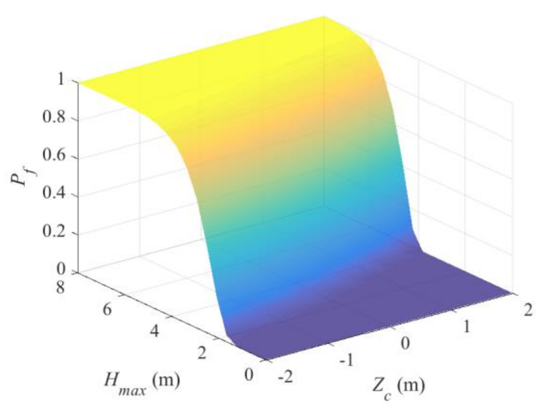
Fragility Surfaces

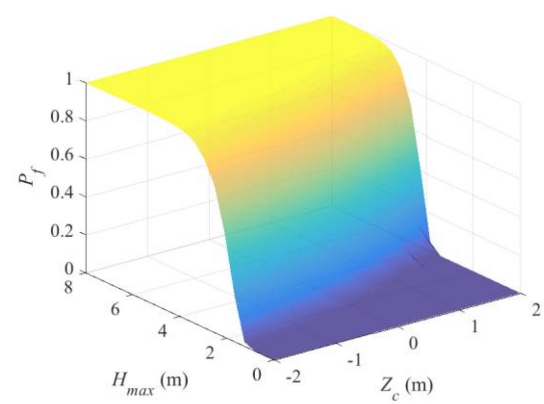


$T_m = 6\ s$

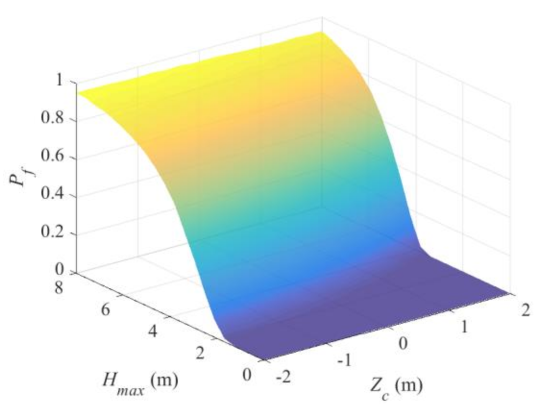
PM-IN | **PM-OUT**

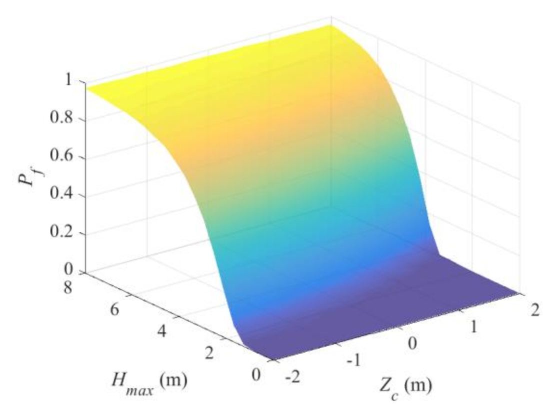
Seaward





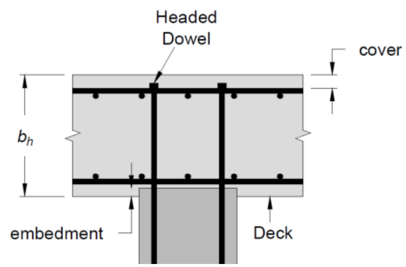
Internal

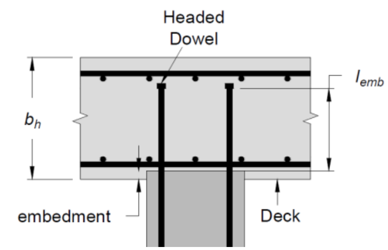


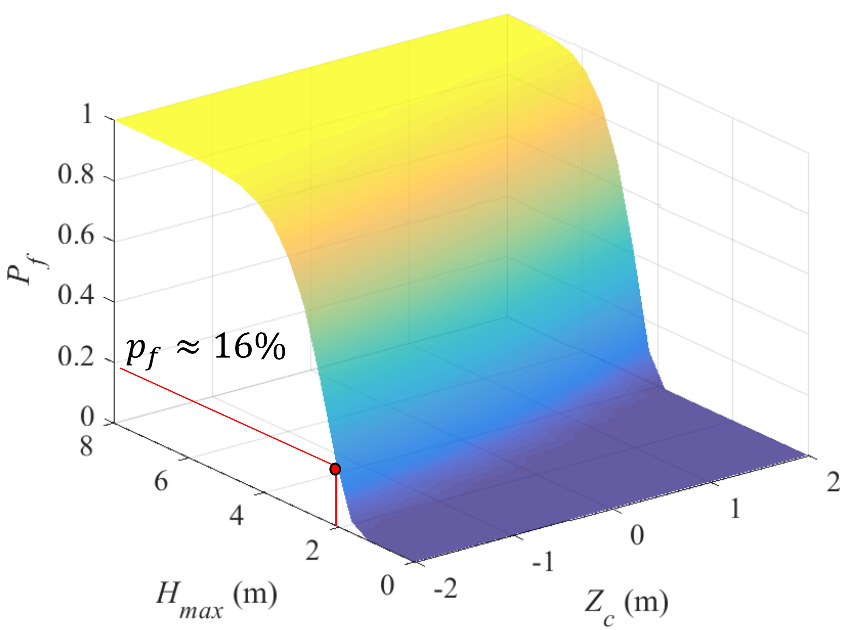


Fragility Surfaces – Seaward

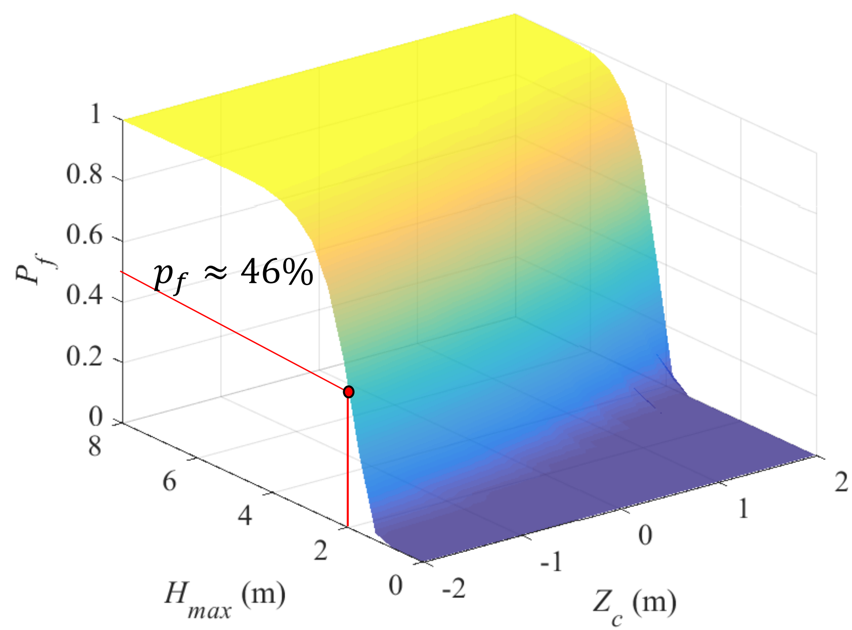
$T_m = 6\ s$





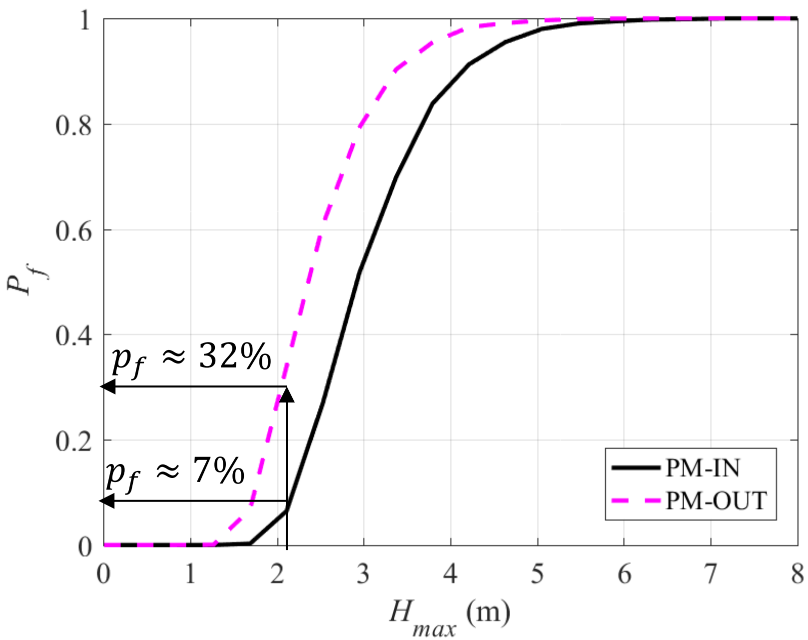


Dowels **above** deck's top mat reinforcement



Dowels **below** deck's top mat reinforcement

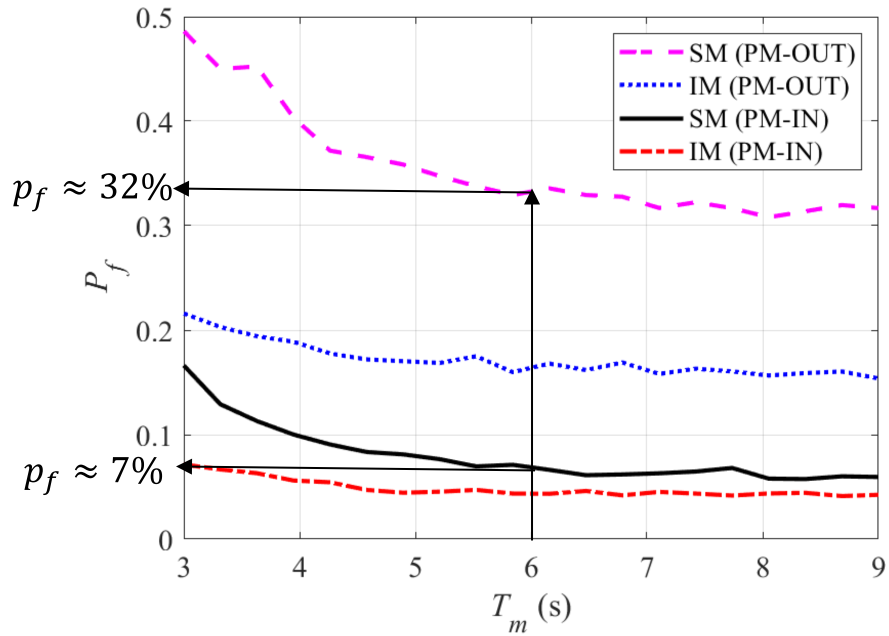
Fragility Curve



Fragility curve

$Z_C = -1.15$ m and $T_m = 6$ s

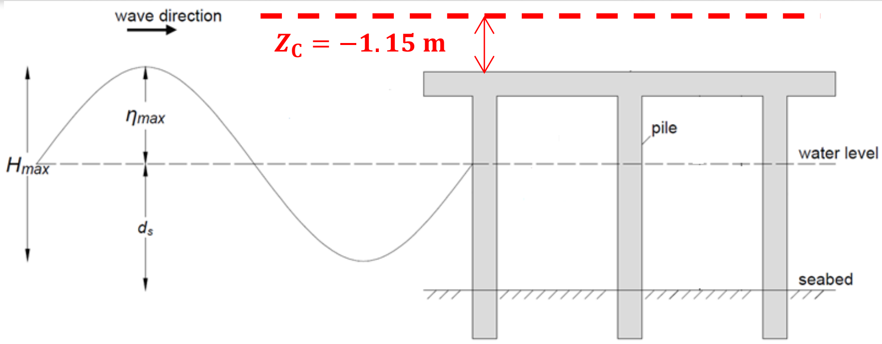
(SM connection)

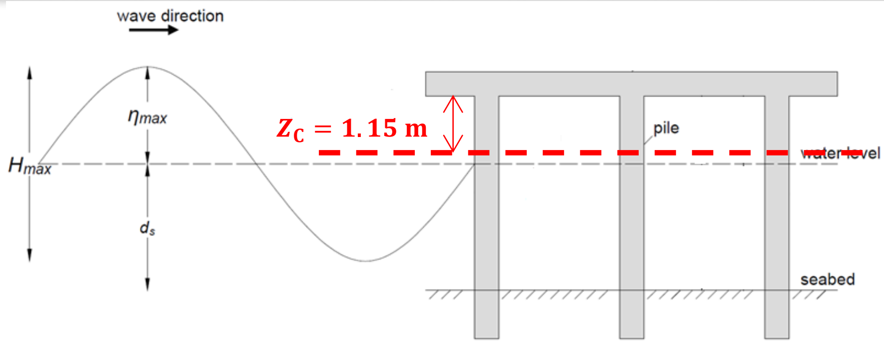


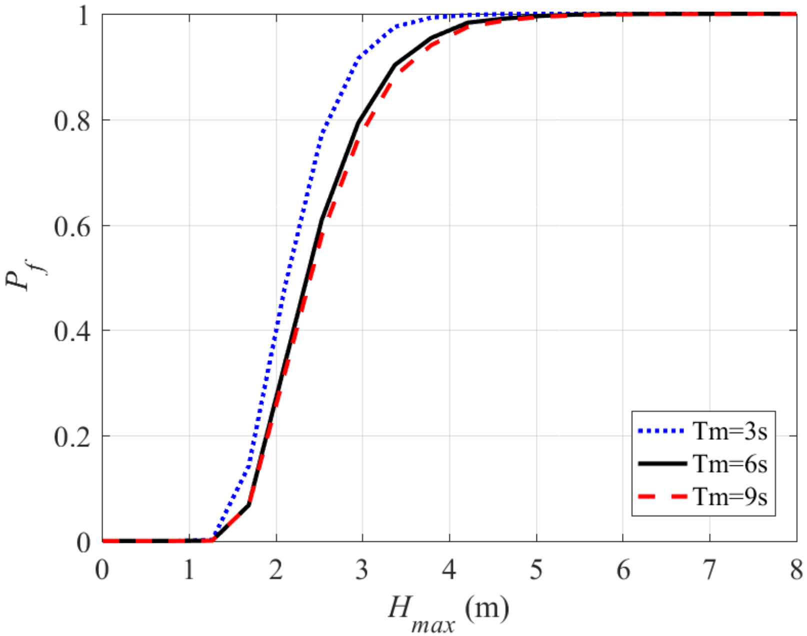
Uplift probability

$Z_C = -1.15$ m and $H_{max} = 2.11$ m

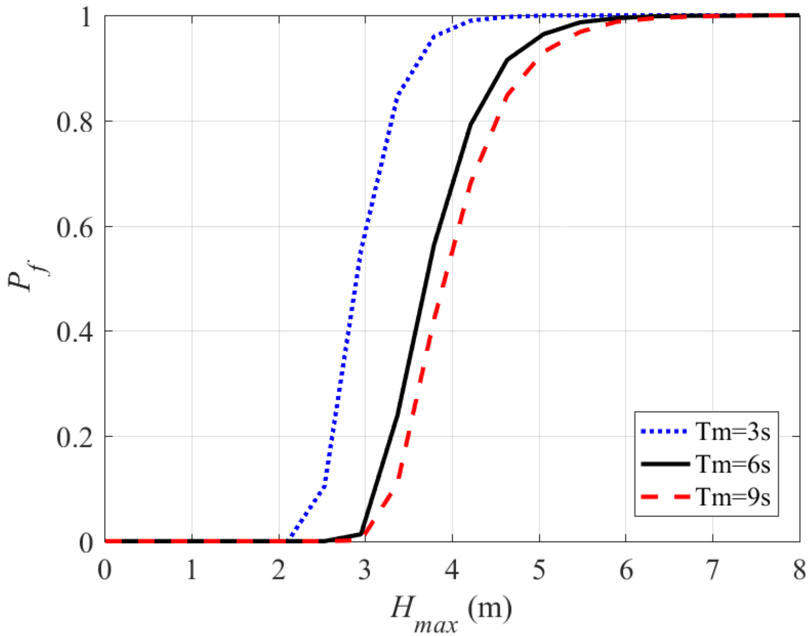
(SM=Seaward, IM=internal)







Fragility curve for $Z_C = -1.15$ m (Seaward Deck, PM-OUT connection)



Fragility curve for $Z_C = +1.15$ m (Seaward deck, PM-OUT connection)

Conclusions

1. This study
   - sheds light on the fragility of pile-supported port connections subjected to coastal hazards (fragility curves)
   - explores how different wave loading conditions affect their performance
2. Rapid increase of uplift probability with the increase of the storm surge
3. Sharper changes are expected to the uplift probability for a seaward deck
4. Sufficient anchorage of dowels can prevent deck uplift during coastal extreme events

Future Work

1. Comparative analysis for different wave models → examine the role of epistemic uncertainty in affecting the fragility models
2. Parameterized fragility models → apply these models across a region (regional risk assessment)

$$p_f(uplift|X, IM) = \frac{\exp(g(X, IM))}{1 + \exp(g(X, IM))}$$

3. Fluid structure interaction (FSI) → capture full characteristics of the wave loading

Acknowledgements

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Shell Center for Sustainability

THANK YOU