SAND2017-1957PE

Overview on MHK Loads Study

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Material Design Tools for Marine Hydrokinetic Composite Structures Meeting

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Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

FY17 Goal is mainly to prepare for FY18 & 19 substructure testing:

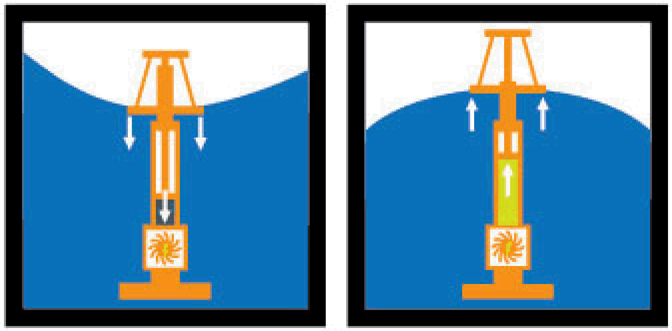
- **Select substructure**
- **Determine testing load**

Sub-structure selection

Several options:

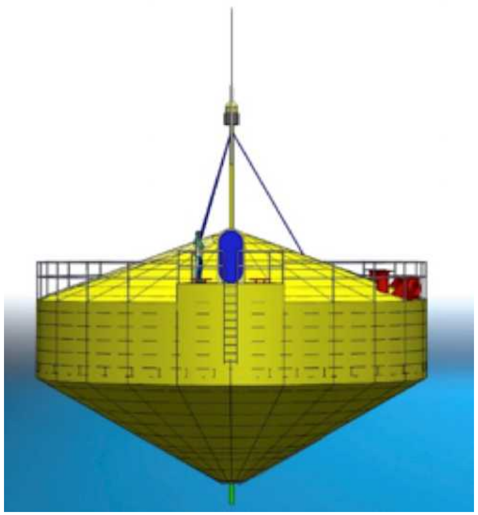
1. Use a DOE–funded device, e.g. Reference models, Sandia's point absorber
2. Use a developer's device already/will be tested in open water
3. Leverage a recent DOE FOA on open water WEC testing
   - 1/4th-1/10th device (not full scale), could also be feasible for lab testing
   - Could potentially eliminate design cost
   - Realistic sea testing data will be obtained

Point absorber



How it works (source: NNMREC)

Sandia's point absorber



AquaHarmonics' point absorber

How do developers estimate load stresses?

- No formal standards on MHK load design
- Guidelines available – some are very general

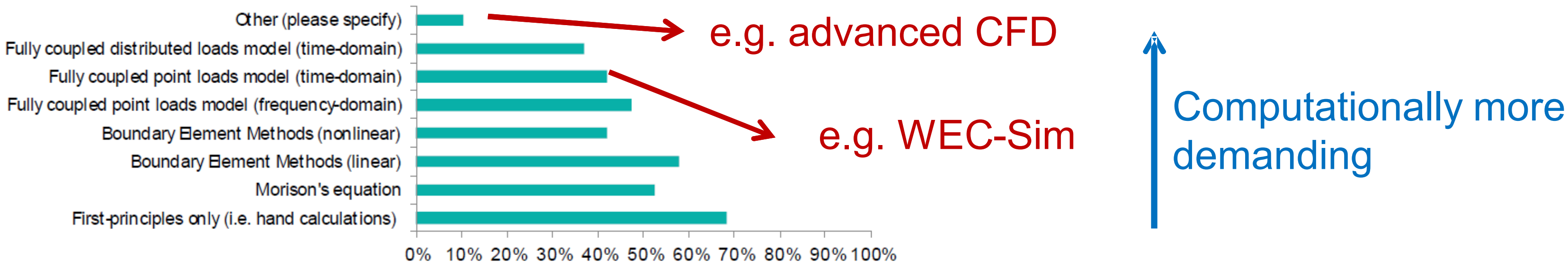


Figure 5 Baseline formulations used in load calculation exercises by respondents

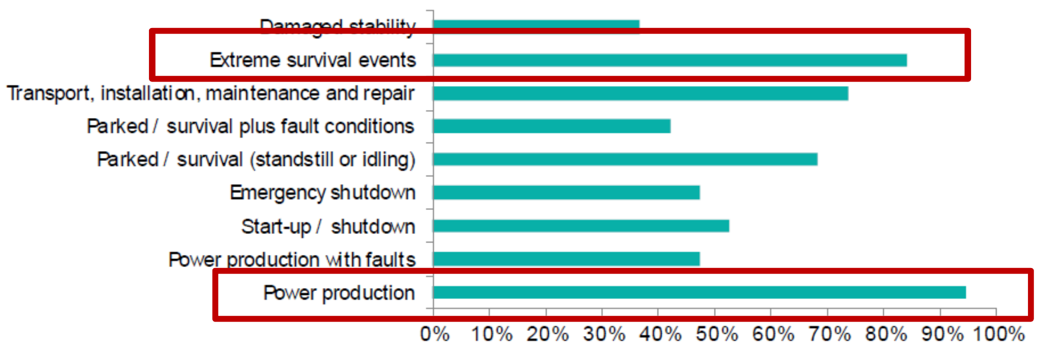


Figure 6 Design situations addressed to date by respondents

Source: Wave Energy Scotland 2016

Design loads – Wave Energy Scotland's report

Select a few design load cases (DLCs):

- 1.1. power production mode, normal sea state, for ultimate strength analysis
- 6.1. parked mode, extreme sea state (50-year significant wave height), for ultimate strength analysis

Design situation	DLC	Wave conditions	PTO conditions	Other conditions	Type of analysis	Partial safety factors
1. Power Production	1.1	*NSS*	*Power Production*	NCM	F U	* N
	1.2	*RNSS*	*Power Production*	NCM MCD	U	N
	1.3	*RNSS*	*Power Production*	Range of spectral shapes, including bimodal seas	U	N
	1.4	*FWG*	*Power Production*		U	E
	1.5	*FWG*	*Power Production*	Grid Loss	F U	* E
	1.6	*RNSS*	*Power Production*	Marine growth or freeboard ice accumulation	U	N
2. Power production plus occurrence of fault	2.1	*RW* *FWG*	*Power Production*	Fault in control system(s)	U	N
	2.2	*RW* *FWG*	*Power Production*	Fault in safety system or preceding internal electrical fault	U	A
	2.3	*RW* *FWG*	*Power Production*	Fault in the control or safety system(s)	F	*
3. Start-up	3.1	*RNSS*	*Start-up Procedure*		F U	* N
4. Normal shut-down	4.1	*FWG*	*Normal Shutdown Procedure*	Vary shut-down time to different points during the wave group	F	*
	4.2	H_{s1}	*Normal Shutdown Procedure*		F U	* N
5. Emergency shut-down	5.1	*FWG*	*Power Production*		U	N
6. Parked (standstill or idling)	6.1	*ESS* - H_{s1}	*Parked*	NCM	U	N
	6.2	*ESS* - H_{s50}	*Parked*	Tide height/current due to storm surge	U	A
	6.3	*ESS* - H_{s50}	*Parked*	Grid loss	U	A
	6.4	*NSS*	*Parked*		F	*

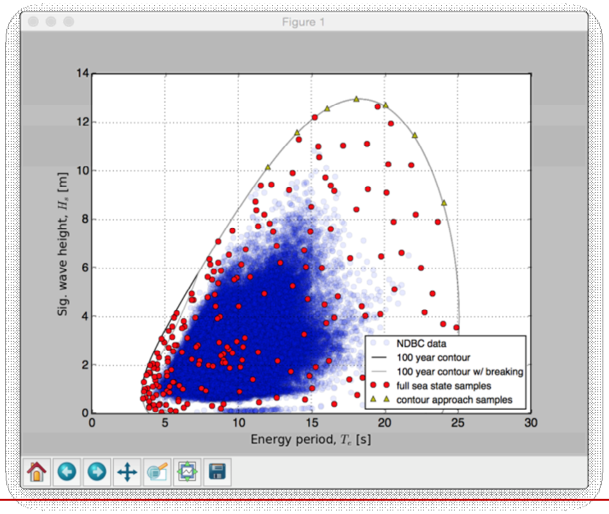
NSS Normal Operational Sea States
U Ultimate strength analysis
F Fatigue strength analysis
H_{s50} Significant wave height with a recurrence period of 50 y

Example approach

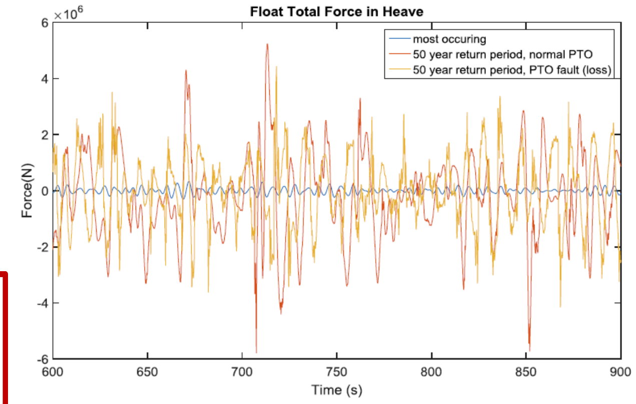
Processes

1. Select device and substructure
2. Select deployment site, and the corresponding environmental condition (e.g. measurement)
3. Select a DLC, e.g. parked device, and 50-year significant wave height
4. Determine wave spectra using selected Hs & Te
5. Select a DLC, e.g. parked device, and 50-year significant wave height
6. Determine wave spectra using selected Hs & Te
7. Determine load at a substructure using numerical modeling
8. Compare simulated load and measured ultimate load

Tools



WEC Design Response Toolbox (WDRT)



WEC-Sim

Plan forward

FY17

- Familiarize with tools
- Select device & substructure

FY18&19

- Determine load for each DLCs using numerical model
- Conduct coupons and substructures testing
- Compare measured and modeled loads

Acknowledgements

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NSS	Normal Operational Sea States
RNSS	Reduced Range Normal Operational Sea States
RW	Regular Waves
FWG	Focused Wave Group
ESS	Extreme Operational Sea States
H_{s1}	Significant wave height with a recurrence period of 1 y
H_{s50}	Significant wave height with a recurrence period of 50 y
H_{s_T}	Significant wave height for transport
NCM	Normal Current Model
MCD	Multiple Current Directions
U	Ultimate strength analysis
F	Fatigue strength analysis
*	Fatigue partial safety factor
N	Normal partial safety factor
E	Extreme partial safety factor
A	Abnormal partial safety factor

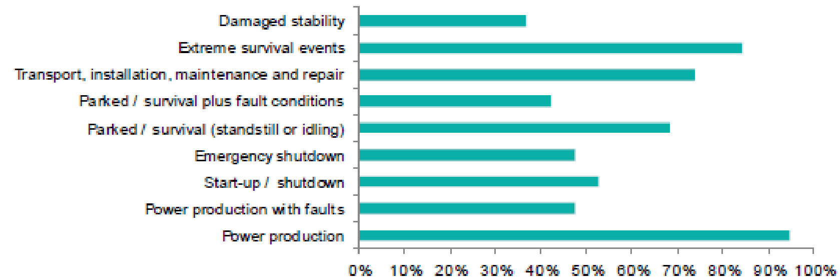

Figure 6 Design situations addressed to date by respondents

Normal Operational Sea States: These correspond to irregular wave sea states covering the standard operational scatter diagram for the WEC (binned by significant wave height, *Hs* and energy period, *Te*). The range of *Hs, Te* combinations is restricted by the wave breaking criteria (steepness and depth limitations, where relevant). If the WEC is axisymmetric, a single mean wave direction may be considered. For each *Hs, Te* pair, a single unimodal spectral shape is assumed. The effect of the spectral shape on the ultimate loading is considered separately under a reduced subset.

Table 12 Critical assessment of the baseline load calculation formulations

	Baseline Formulations: Load Calculation							
Design Situation	First-Principles	BEM (linear)	BEM (nonlinear)	Morison's Equation	Point loads (freq.-domain)	Point loads (time-domain)	Distributed loads (time-domain)	Others (advanced methods)
1. Power production	4	3	3	2	2	1	1	1
2. Power production plus faults	5	5	4	3	5	2	3	3
3. Start-up	5	4	4	2	4	1	2	2
4. Normal shut-down	5	4	4	2	4	1	2	2
5. Emergency shut-down	5	5	4	3	5	3	3	2
6. Parked (standstill or idling)	5	5	4	3	5	3	3	2
7. Parked plus fault conditions	5	5	4	3	5	3	3	3
8. Transport, installation, maintenance and repair	4	4	4	3	4	3	4	3
9. Accidental / abnormal events	5	5	3	4	5	4	4	3
10. Damaged stability	5	5	3	4	5	4	4	3

Rating System Key

1	2	3	4	5
Formulation fundamentally suitable	Formulation suitable with minor development efforts	Formulation suitable with significant development efforts	Formulation suitable with major development efforts	Formulation fundamentally unsuitable