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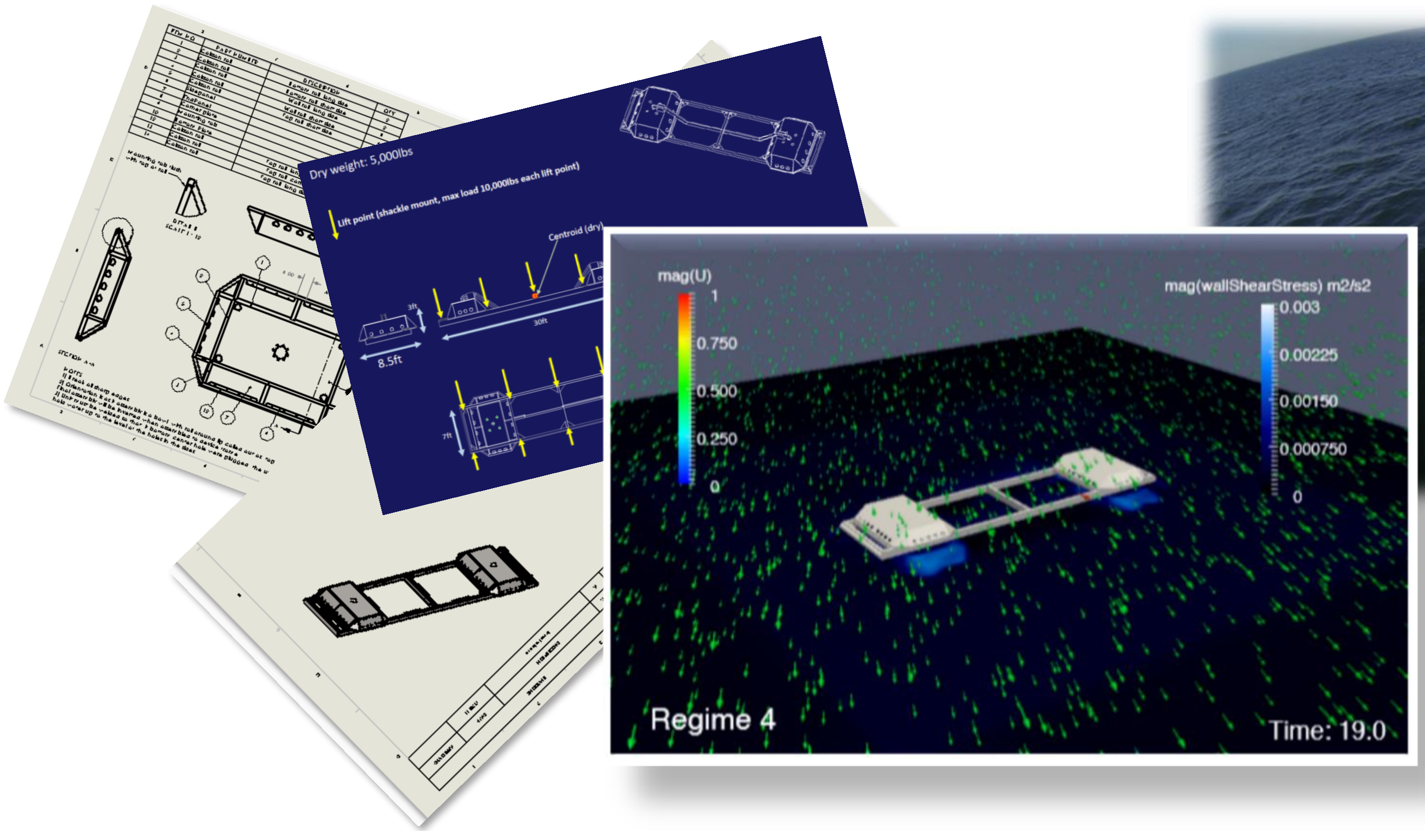

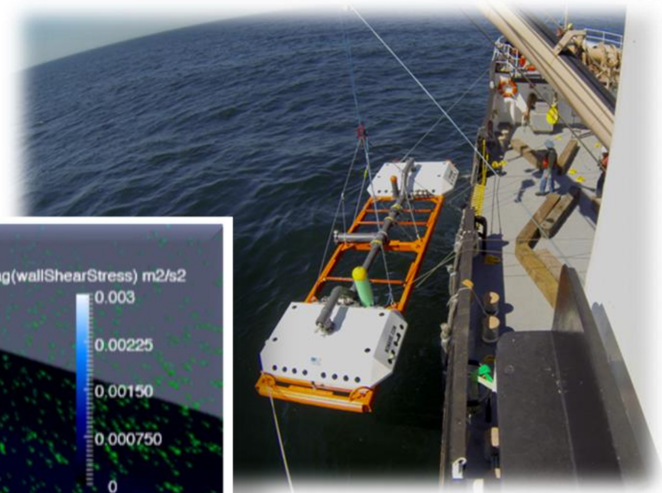

Improved Survivability and Lower Cost in Submerged Wave Energy Device

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Improved Survivability and Lower Cost in Submerged Wave Energy Device:

M3 Wave's APEX is a submerged, stationary wave energy "area absorber" that harnesses the pressure wave under ocean waves and swells. Based on open-water pilot testing in 2014, **sediment scour** was identified as a critical impediment to long term survivability and operations and maintenance (O&M) cost for the system.

There are limited analytical tools and minimal historical knowledge for bottom-mounted complex geometries in the near-shore environment. This project is developing a **new generation of analytical tools** that can be applied to different near-shore structures including surge flappers, shallow water area absorbers, and similar structures. The project will utilize 1:10 scale tank testing, complete with sediment, **to validate the numerical models**.

Partners:
- Oregon State University (OSU)/Northwest National Marine Renewable Energy Center (NNMREC): Wave tank testing and modeling collaboration
- Ershigs: Fabrication and analysis of larger models
- DNV-GL: Risk Framework
- Sandia National Laboratories/National Renewable Energy Laboratory (NREL): Modeling collaboration

Program Strategic Priorities

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Technology Maturity

- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- **Conduct R&D for Innovative MHK systems & components**
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

Deployment Barriers

- Identify potential improvements to regulatory processes and requirements
- Support research focused on retiring or mitigating environmental risks and reducing costs
- Build awareness of MHK technologies
- Ensure MHK interests are considered in coastal and marine planning processes
- Evaluate deployment infrastructure needs and possible approaches to bridge gaps

Market Development

- Support project demonstrations to reduce risk and build investor confidence
- Assess and communicate potential MHK market opportunities, including off-grid and non-electric
- Inform incentives and policy measures
- Develop, maintain and communicate our national strategy
- Support development of standards
- Expand MHK technical and research community

Crosscutting Approaches

- Enable access to testing facilities that help accelerate the pace of technology development
- Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets
- Exchange of data information and expertise

Project Strategic Alignment

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Technology Maturity

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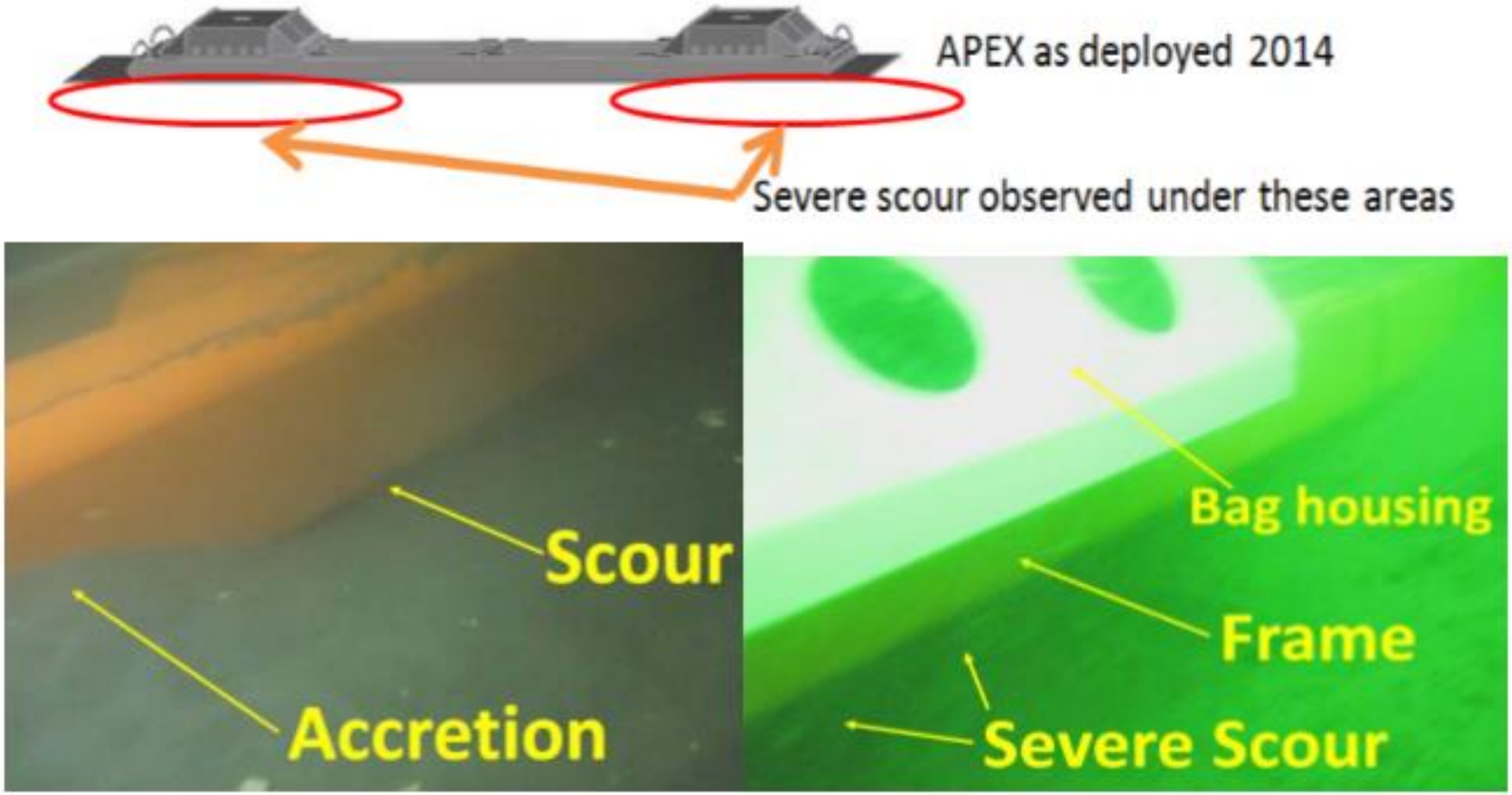
The Impact

- Improvements in sediment transport mitigation are expected to more than double annual energy production (AEP) while reducing CAPEX (-25%) and O&M (-30%), resulting in a lower overall levelized cost of energy (LCOE).
- The evaluation tools developed during this project (computational fluid dynamics [CFD] model, validation techniques) will be made available for the benefit of the broader near-shore/shallow water WEC industry.
- Final products created at the end of this project include the CFD sediment transport tools, as well as modifications to the APEX system that improve survivability and robustness to sediment-induced failure.

THE ISSUE: Severe Sediment Transport was Observed During Open Water Test

THE PLAN: Develop Sediment Transport Modeling tools to Aid in Major Redesign



Technical Approach

<u>Phase I (underway)</u>: Develop Sediment Transport Model

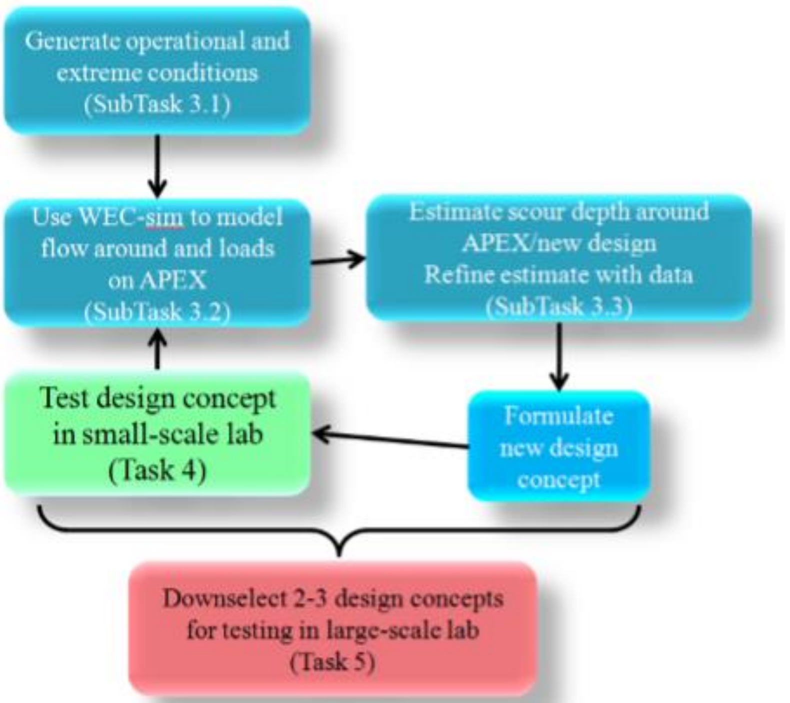
- Methodology: Use CFD modeling to predict shear stresses and relate them to sediment movement
- Use model to evaluate various design changes/concepts
- Collaboration between M3 Wave, OSU, NREL, and Sandia.

<u>Phase II and III (2017)</u>: Conduct scale model testing

•Empirical testing with actual sediment.
•Validate and correlate numerical and physical models.

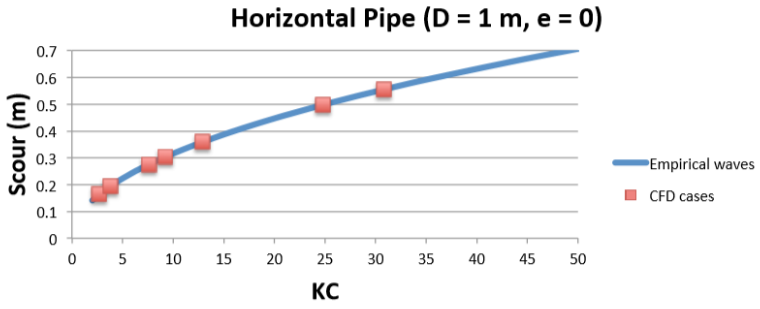
<u>END GOALS:</u>

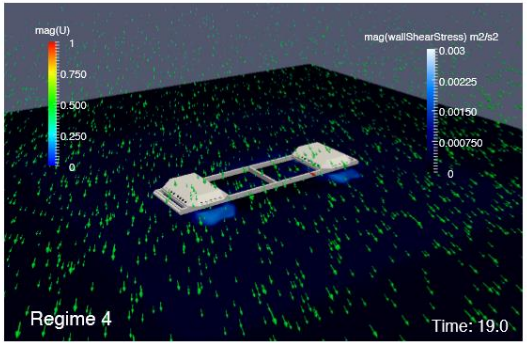
1) Publicly available Sediment Transport Model and methodology
2) Improved APEX design that can avoid sediment issues during longer duration deployments.



Progress to-date:

Modeling and correlation of "representative bodies"





Performance of benchmarks relative to targets is still under evaluation (project is only 25% complete)

Awards: One of the sediment transport mitigating designs, NEXUS, was a Wave Prize Finalist.

WAVE ENERGY PRIZE
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Project Plan & Schedule

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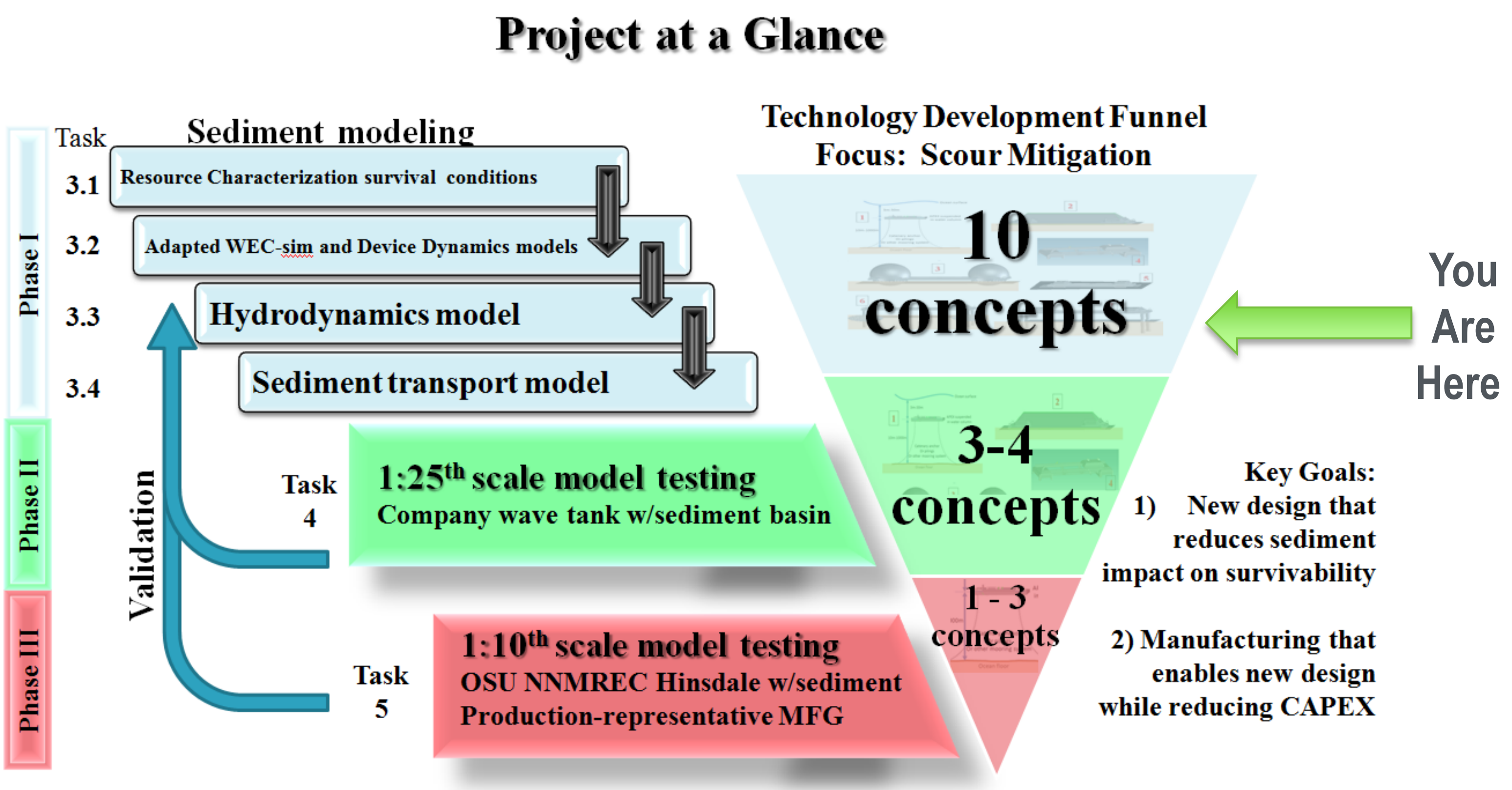
- Project start/end: April 2016/September 2017
- Milestones and schedule: Project is on track
- Go/No-Go decision points for FY14, FY15, FY16: None



Project Budget

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Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0k	$0k	$0k	$0k	$109k	$10k

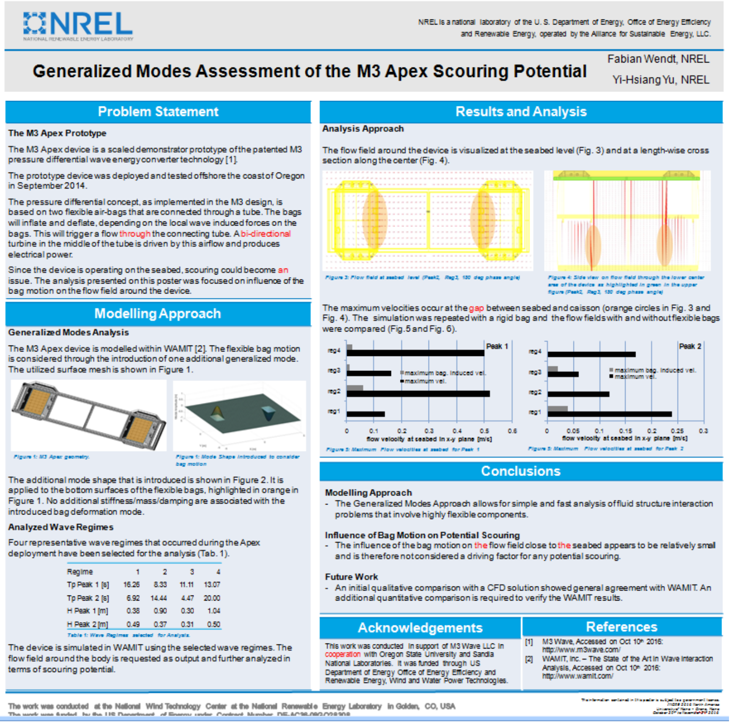
- Minor variance to-date: Shifting small portion of funds from 1:25 scale modeling to numerical modeling; success of numerical modeling reduced the number of designs requiring testing at 1:25 scale
- Approximately 20% of budget and 30% of schedule had been expended by the end of FY2016
- Additional funding sources for 2017: State of Oregon (Oregon BEST program) and in-kind from Industry partners

Partners, Subcontractors, and Collaborators:

- Sandia National Lab (Ryan Coe, Jesse Roberts, S. Olson, Chris Chartrand)
- NREL (Yi-Hsiang.Yu, Fabian Wendt)
- DNV-GL (Ben Child, Jarett Goldsmith)
- Oregon State University/NNMREC (Tuba Ozkan-Haller)
- Ershigs (Steve Spencer)

Communications and Technology Transfer:

Poster presented at International Network on Offshore Renewable Energy by NREL



NREL NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U. S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Generalized Modes Assessment of the M3 Apex Scouring Potential

Fabian Wendt, NREL
Yi-Hsiang Yu, NREL

Problem Statement

The M3 Apex Prototype

The M3 Apex device is a scaled demonstrator prototype of the patented M3 pressure differential wave energy converter technology [1].

The prototype device was deployed and tested offshore the coast of Oregon in September 2014.

The pressure differential concept, as implemented in the M3 design, is based on two flexible air-bags that are connected through a tube. The bags will inflate and deflate, depending on the local wave induced forces on the bags. This will trigger a flow through the connecting tube. A bi-directional turbine in the middle of the tube is driven by this airflow and produces electrical power.

Since the device is operating on the seabed, scouring could become an issue. The analysis presented on this poster was focused on influence of the bag motion on the flow field around the device.

Modelling Approach

Generalized Modes Analysis

The M3 Apex device is modelled within WAMIT [2]. The flexible bag motion is considered through the introduction of one additional generalized mode. The utilized surface mesh is shown in Figure 1.

Figure 1: M3 Apex geometry.

Figure 1: Mode Shape introduced to consider bag motion

The additional mode shape that is introduced is shown in Figure 2. It is applied to the bottom surfaces of the flexible bags, highlighted in orange in Figure 1. No additional stiffness/mass/damping are associated with the introduced bag deformation mode.

Analyzed Wave Regimes

Four representative wave regimes that occurred during the Apex deployment have been selected for the analysis (Tab. 1).

Regime	1	2	3	4
Tp Peak 1 [s]	16.26	8.33	11.11	13.07
Tp Peak 2 [s]	6.92	14.44	4.47	20.00
H Peak 1 [m]	0.38	0.90	0.30	1.04
H Peak 2 [m]	0.49	0.37	0.31	0.50

Table 1: Wave Regimes selected for Analysis.

The device is simulated in WAMIT using the selected wave regimes. The flow field around the body is requested as output and further analyzed in terms of scouring potential.

Results and Analysis

Analysis Approach

The flow field around the device is visualized at the seabed level (Fig. 3) and at a length-wise cross section along the center (Fig. 4).

Figure 3: Flow field at seabed level (Peak2, Reg3, 180 deg phase angle)

Figure 4: Side view on flow field through the lower center area of the device as highlighted in green in the upper figure (Peak2, Reg3, 180 deg phase angle)

The maximum velocities occur at the gap between seabed and caisson (orange circles in Fig. 3 and Fig. 4). The simulation was repeated with a rigid bag and the flow fields with and without flexible bags were compared (Fig.5 and Fig. 6).

Peak 1
reg4
reg3
reg2
reg1
maximum bag. induced vel.
maximum vel.
0 0.1 0.2 0.3 0.4 0.5 0.6
flow velocity at seabed in x-y plane [m/s]

Figure 5: Maximum Flow velocities at seabed for Peak 1

Peak 2
reg4
reg3
reg2
reg1
maximum bag. induced vel.
maximum vel.
0 0.05 0.1 0.15 0.2 0.25 0.3
flow velocity at seabed in x-y plane [m/s]

Figure 5: Maximum Flow velocities at seabed for Peak 2

Conclusions

Modelling Approach

- The Generalized Modes Approach allows for simple and fast analysis of fluid structure interaction problems that involve highly flexible components.

Influence of Bag Motion on Potential Scouring

- The influence of the bag motion on the flow field close to the seabed appears to be relatively small and is therefore not considered a driving factor for any potential scouring.

Future Work

- An initial qualitative comparison with a CFD solution showed general agreement with WAMIT. An additional quantitative comparison is required to verify the WAMIT results.

Acknowledgements

This work was conducted in support of M3 Wave LLC in cooperation with Oregon State University and Sandia National Laboratories. It was funded through US Department of Energy Office of Energy Efficiency and Renewable Energy, Wind and Water Power Technologies.

References

[1] M3 Wave, Accessed on Oct 10th 2016: http://www.m3wave.com/
[2] WAMIT, Inc. – The State of the Art in Wave Interaction Analysis, Accessed on Oct 10th 2016: http://www.wamit.com/

The work was conducted at the National Wind Technology Center at the National Renewable Energy Laboratory in Golden, CO, USA

Next Steps and Future Research

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FY17/Current research:

FY17 Milestones: Concept down selection, public release of modeling tools, final technical reports

Proposed future research:

-Refinement and Open Water Testing of final optimized design that is developed during this project

-Application of sediment transport model to other near-shore technologies.