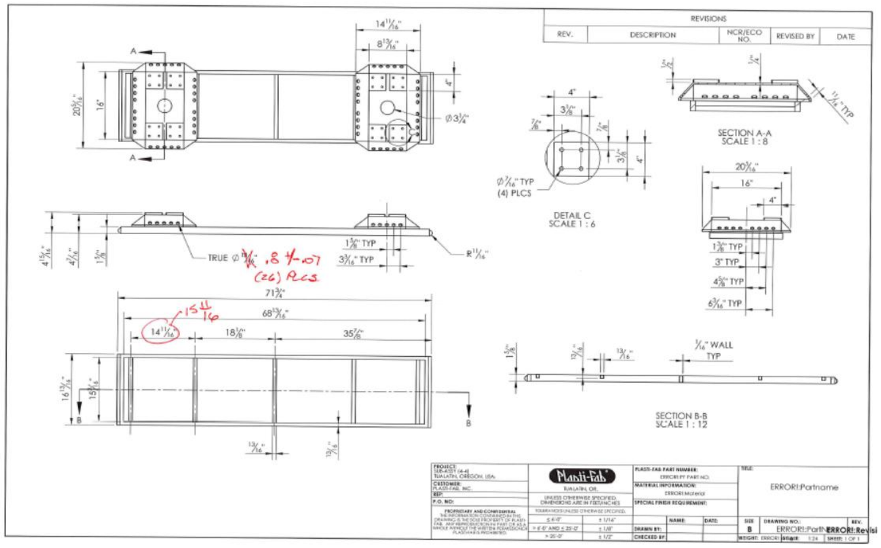
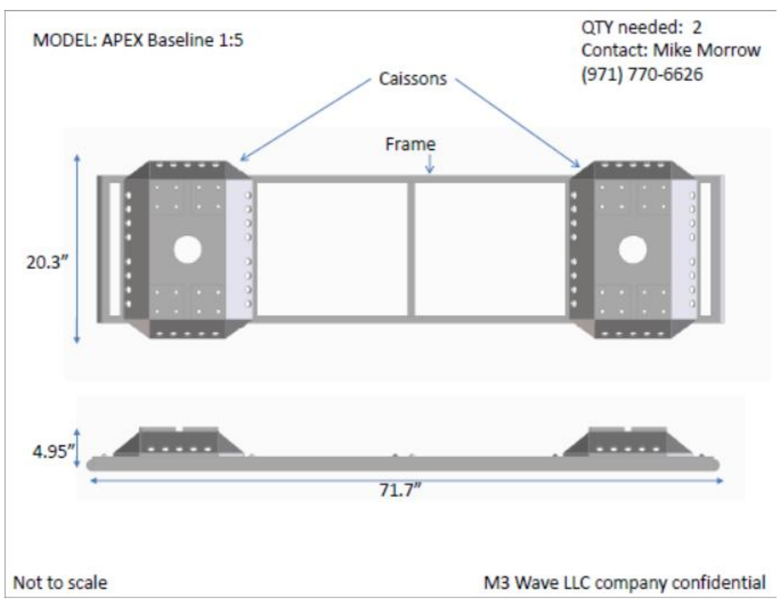
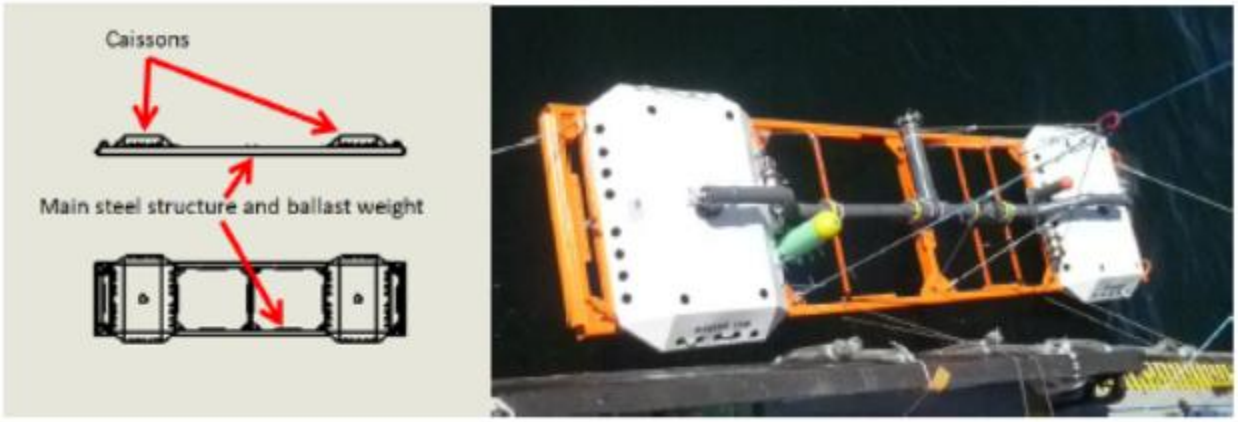
D4.4a Downselection Report
DE-EE-0007345
M3 Wave, LLC

Introduction/Background:

M3 Wave's baseline device configuration is APEX:





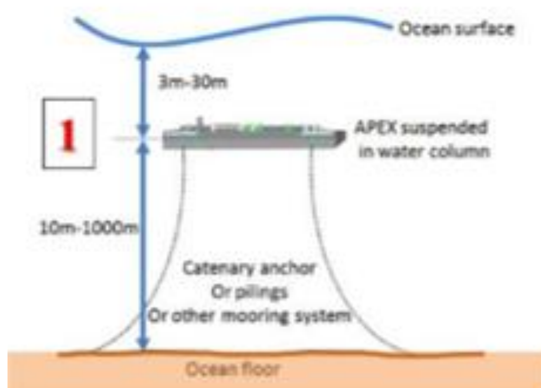


In 2014, open water testing revealed that sediment scour around and under the device was significant and likely interrupted operations. To explore methods to mitigate this phenomenon, M3 developed a number of alternate concepts as detailed in concept sketches (See Appendix A).

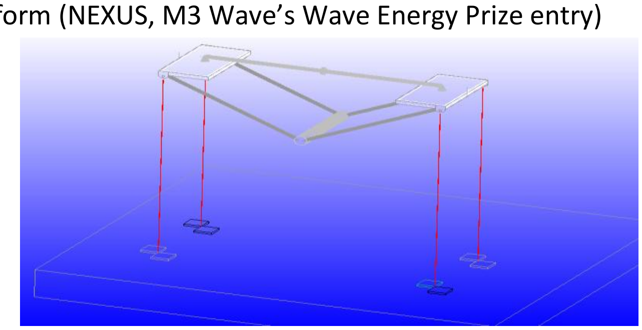
M3 engineers, in collaboration with deployment and fabrication partners, brainstormed a number of methods, configurations, and countermeasures for mitigating sediment transport.

The preliminary list of configurations contained the following methods:

1. Moored off the bottom. Mitigation method: operate away from sediment bed.
    a. Catenary

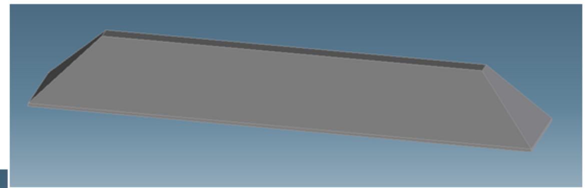


    b. Tension Leg Platform (NEXUS, M3 Wave's Wave Energy Prize entry)

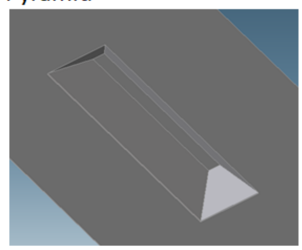


2. Continuous shell covering all of the intricate device geometry. Mitigation method: reduce localized flow accelerations.

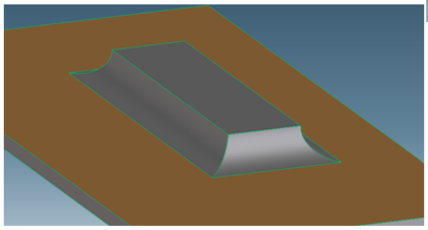
Contiguous Shell
Idea: reduce/eliminate localized regions of accelerated flow under or around device.



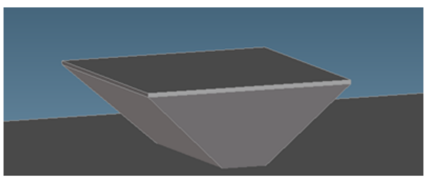
Beveled Contiguous shell "Pyramid"



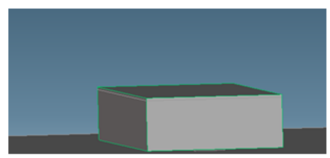
Blended edges



Beveled Contiguous shell "Reverse Pyramid"

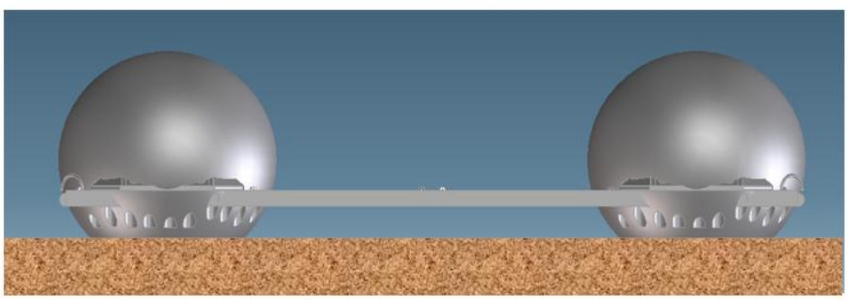


Solid Block



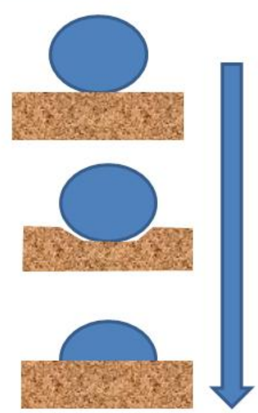
3. Spherical Caissons. Mitigation method: make caissons hydrodynamically neutral.

Symmetric Caisson- Spherical Concept



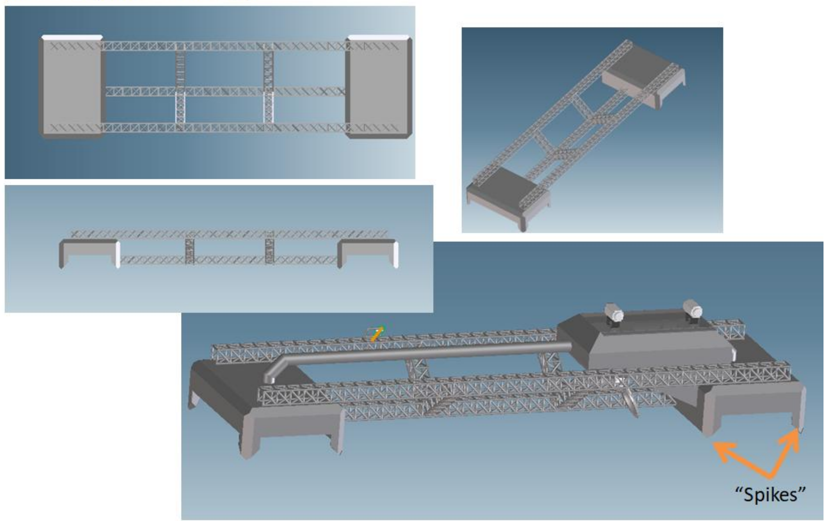
Idea: as sediment accretes or scours, system reaches a stable balance.
Cross structure TBD (design flexibility)

Issues:
Different scour on each end could lead to pitch
Manufacturability



4. Integral embedment framework. Mitigation method: minimize contact points with sediment and reduce cross-section of main structure.

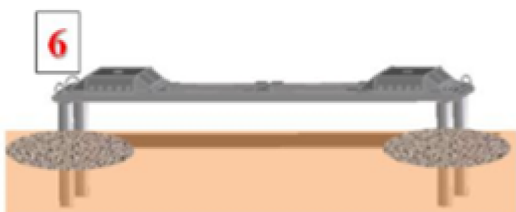
Integral Embedment Framework.
Idea: Caissons have corner “spike” structures that embed into sediment. Cross-structures between caissons are made from structural materials that allow particle pass-thru (lattice structures).



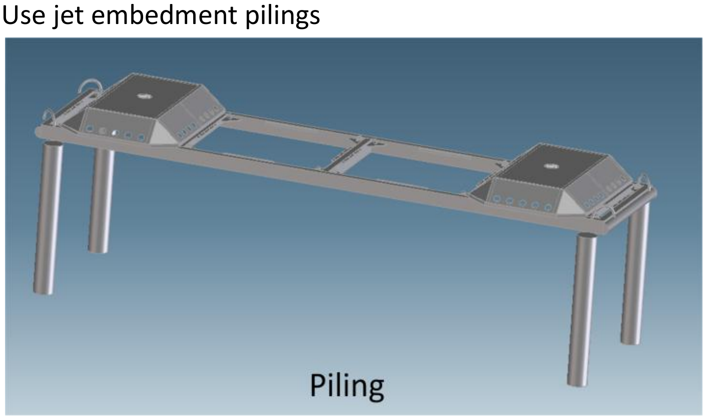
5. Symmetric caissons. Mitigation method: approximate hydrodynamic neutrality.

Symmetric caisson concept

6. Rigidly mount structure off bottom. Mitigation method: operate away from sediment bed.
    a. Use rock or other reinforcement at base of mounting structure (pilings)

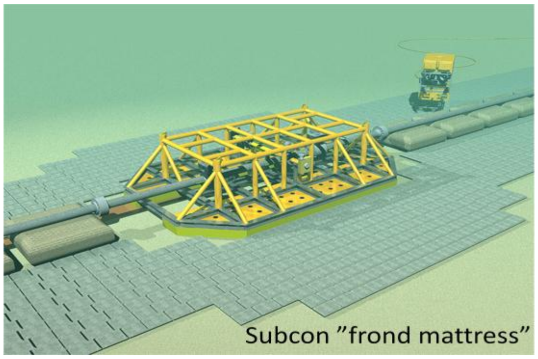


    b. Use jet embedment pilings



7. “Snow Fence” style defenses around the APEX device. Mitigation method: disrupt particle velocities approaching device.

8. Cobble skirt or sediment armor around base of standard APEX. Mitigation method: prevent localized sediment transport.
   a. Example: Subcon “frond mattress”



9. Minimalist caissons, aka “the Skeleton.” Mitigation method: minimize available geometry that can interact with particle velocities.

10. Separate caissons. Mitigation method: remove localized velocity accelerations due to cross-structure.

Preliminary downselect.

An initial review of literature, preliminary modeling results, and industry experts resulted in an initial consolidation of the list.

Moored (moving body) systems were ruled out due to the added cost and complexity of mooring as well as the challenges observed with a moored (TLP) system called NEXUS which was M3 Wave’s Wave Energy Prize Finalist candidate.

Defensive measures like armoring the sediment bed, installing snow fences, or deploying large quantities of cobble were ruled out due to deployment complexity and the conclusion that these might only afford temporary protection. Based on discussions with industry experts, many of these systems become ineffective once covered completely by sand or undermined near their perimeter, resulting in higher maintenance costs. Such systems are not well suited for nearer shore high-transport regimes.

Initial modeling results showed that symmetric designs including the spherical caissons were not effective countermeasures when wave direction shifted and flow velocities were not in line with the device. This, coupled with the anticipated expense of larger, more complex structures, led to these concepts being ruled out.

Summary matrix of downselection candidates:

Concept	Survival Strategy	Downselect/Survivability conclusions	Particle motion	Body dynamics	Deployme nt	Manufact urability	Anticipated LCOE impact
APEX Default	N/A	BASELINE: Sediment Scour resulted in performance impacts that affect AEP					Survivability-Scour
Mid-column Catenary moored	Avoid sediment	Solves sediment issue, but with significant adverse cost and non-sediment survivability impact		Moving system	Mooring	Size, material	Anchor mass
Mid-column Tension Leg Platform	Avoid sediment	Solves sediment issue, but with significant adverse cost and non-sediment survivability impact		Moving system	mooring	Dynamic structural loads	High mooring loads
Continuous Shell (blended, beveled, solid block, etc	Allow sediment to flow over and around	Preliminary modeling indicates worse sediment issues.	More structure in flow			material	MFG; Survivability
Spherical Caisson	Allow sediment to flow over and around	Preliminary modeling indicates worse sediment issues due to variable nature of flow. Added manufacturing cost.	Local acceleratio n		Planarity concerns	Complex geometry	MFG; Survivability
Integral embedment framework lattice structure	Minimize amount of structure that can interact with sediment	Expect same issues as default caissons; less issues in connecting structure. Added mfg cost.	Lattice interaction s with particles			Complex Lattice	survivability
Symmetric APEX caissons	Allow sediment to flow over and around	Expect APEX performance or worse due to variable nature of flow.	Local acceleratio n				survivability
Rigid mounting off sea bed	Avoid sediment	Solves sediment issue, but cost and deployment tradeoffs need to be further explored.			pilings	FRP	deployment
Snow fence or other surrounding defenses	Intercept sediment before reaching device	Performance of external defensive structures expected to decline over time as they sediment up. Cost and deployment concerns.	Temporary aid		Placement; permitting		Deployment; O&M
Cobble skirt or armor around perimeter	Slow the rate of scour	Performance of external defensive structures expected to decline over time as they sediment up. Cost and deployment concerns.	Temporary aid		Placement; permitting		Deployment; O&M
Minimalist APEX Caisson	Minimize amount of structure that can interact with sediment	Potential for improved survivability and reduced cost. Risk of bag interactions without side protection	Connecting structure				
Separate Caissons	Minimize amount of structure that can interact with sediment	Expect same issues as default caissons; less issues in connecting structure. Added deployment risk			planarity		Still sediment concern but CAPEX improved

Final candidates

The final candidates were selected for testing at 1:5 scale:

1. Default APEX (baseline).

A. Local Particle motion/ Fluid Flow
    a. Computer modeling revealed that localized particle accelerations were happening under the caissons, resulting in the scour patterns observed in the ocean. Additional regions of deceleration near structural cross-members were contributing to minor accretion in those areas.
B. Body dynamics
    a. Because the default design is stationary, structural body dynamics are not a factor. Numerical modeling and subscale testing was used to determine if motion of the lower bag surface contributed to additional dynamics or particle accelerations. All modeling and empirical testing results indicated no contribution from bag dynamics.
C. Anticipated Design Improvements
    a. N/A for baseline.
D. Impact on LCOE
    a. Baseline LCOE.

2. Minimalist APEX, nicknamed “Skeleton.” This is a modified default APEX with much of the side structure of the caissons removed to allow flow through and around the caissons.

A. Local Particle motion/ Fluid Flow
    a. Computer modeling revealed that localized particle accelerations were happening under the caissons, resulting in the scour patterns observed in the ocean. The theory behind the skeleton design was that particle flow would not be accelerated by hydrodynamic effects of vertical or beveled sides if the sides were removed. Instead, localized particle motion would pass through the structures, allowing sediment particles to pass through as well.

B. Body dynamics
    a. Because the design is stationary, structural body dynamics are not a factor.

C. Anticipated Design Improvements
    a. The Skeleton should reduce material cost and possibly reduce manufacturing complexity. However, the structural loads placed on the remaining structure may require stronger localized structures. This may drive up costs slightly. There are concerns about exposing bags to lateral hydrodynamic loads in the Skeleton design and this may result in the need for additional cost to mitigate any fatigue or dynamic bag issues.

D. Impact on LCOE
    a. The skeleton design should have a modest improvement in LCOE. Anticipated improvements include AEP (reduction in scour-induced performance degradation), CAPEX (less material in caissons). There is the potential for adverse LCOE impact due to possibly higher bag costs (due to exposed bag sides). Because the Skeleton APEX still requires steel mass for self-anchoring, the overall material/CAPEX savings may be too modest to achieve target improvements.

3. APEX rigidly mounted off the floor, aka APEX II.

A. Local Particle motion/ Fluid Flow
    a. Computer modeling revealed that localized particle accelerations were happening under the caissons, resulting in the scour patterns observed in the ocean. The theory behind APEX II was that particle flows would not interact with the main structure at all if the system was elevated off the ocean floor. Particle motion- and subsequently sediment flow- would simply pass under the device. The only areas of sediment interaction would be around the piling bases and this interaction is well understood for deeper water.
B. Body dynamics
    a. Because the design is stationary, structural body dynamics are not a factor.
C. Anticipated Design Improvements
    a. By using piles to both elevate the structure as well as anchor into the sea bed, APEX II de-couples anchoring from structural considerations. This means structural materials are not limited to steel since the device is not relying on self-anchoring. Additionally, using variable depth piling techniques such as Suction Embedment Anchoring opens up the potential for device leveling during deployment. This could simplify construction and improve efficiency since the closer to level the device is, the better the performance.
D. Impact on LCOE
    a. APEX II is anticipated to have improvement in CAPEX, AEP, and O&M. Potential risks include higher deployment and recovery cost (although recovery does not factor into all financial models).

These final 3 candidates were tested at 1:5 scale, including the baseline design APEX to provide an opportunity to replicate the scour seen in ocean testing as well as in earlier modeling work as part of this project.