Determining and Controlling Peak Energy Density Location during Water Wave Deformation

Presenter: Michael Raftery, M.E.

Research Engineer

Stevens Institute of Technology (Stevens)

Office: +1 201 216 8704

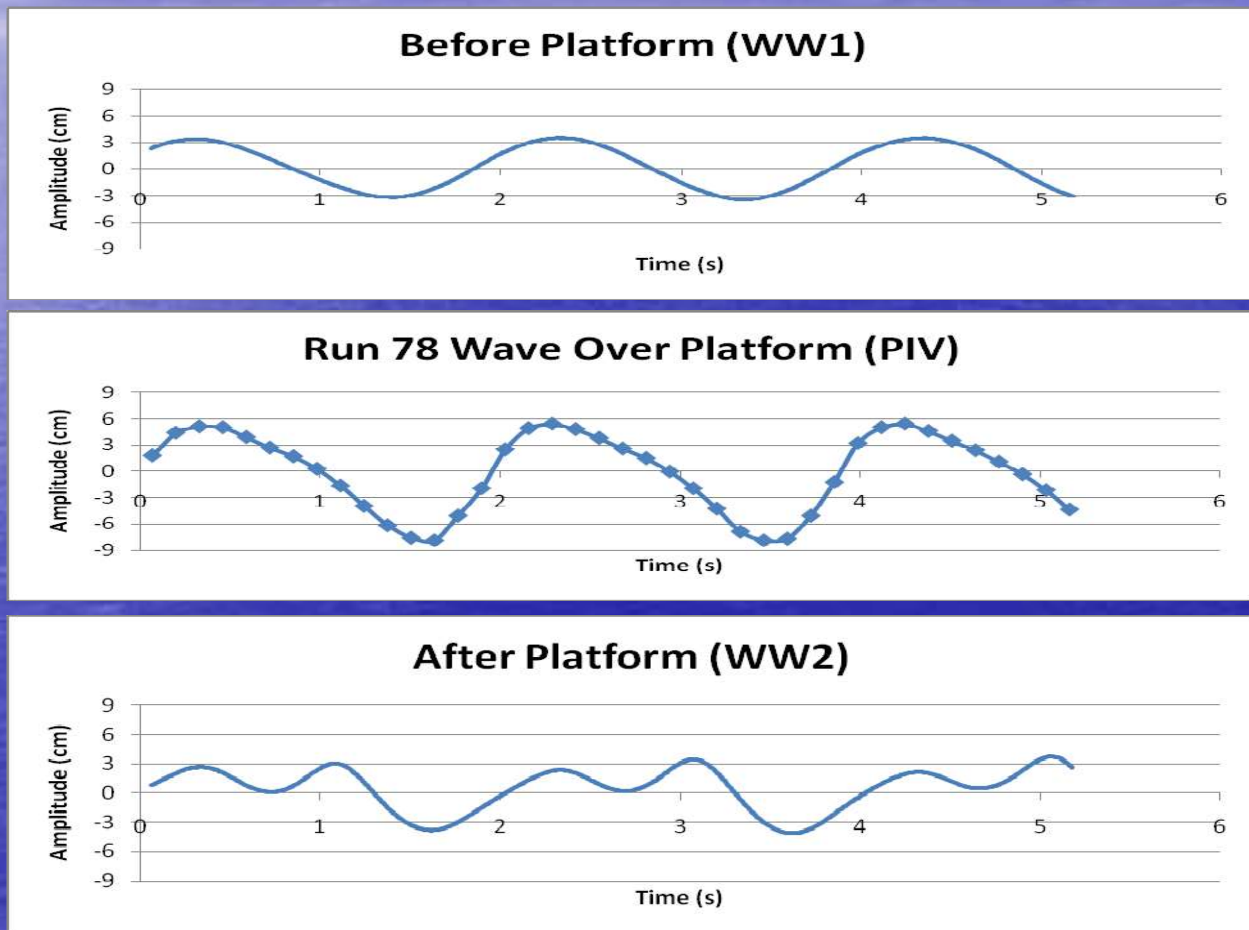
Testing and Research Funded by

The Office of Naval Research

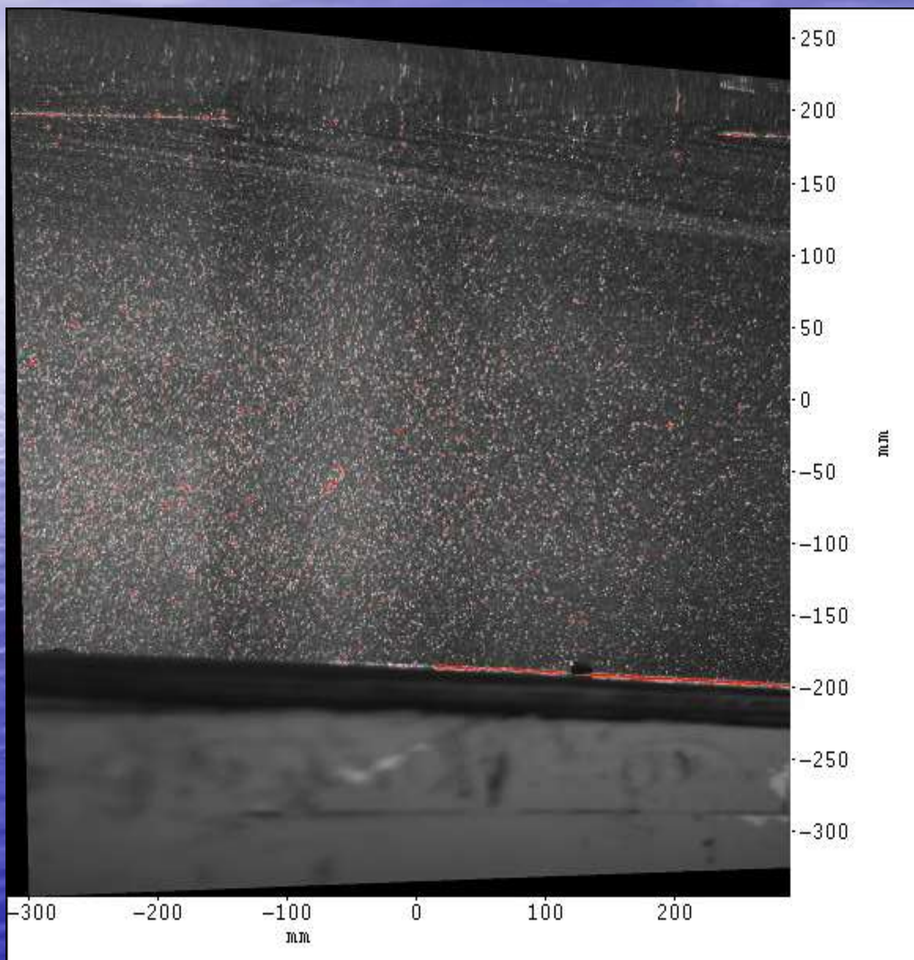
Research Review 2010

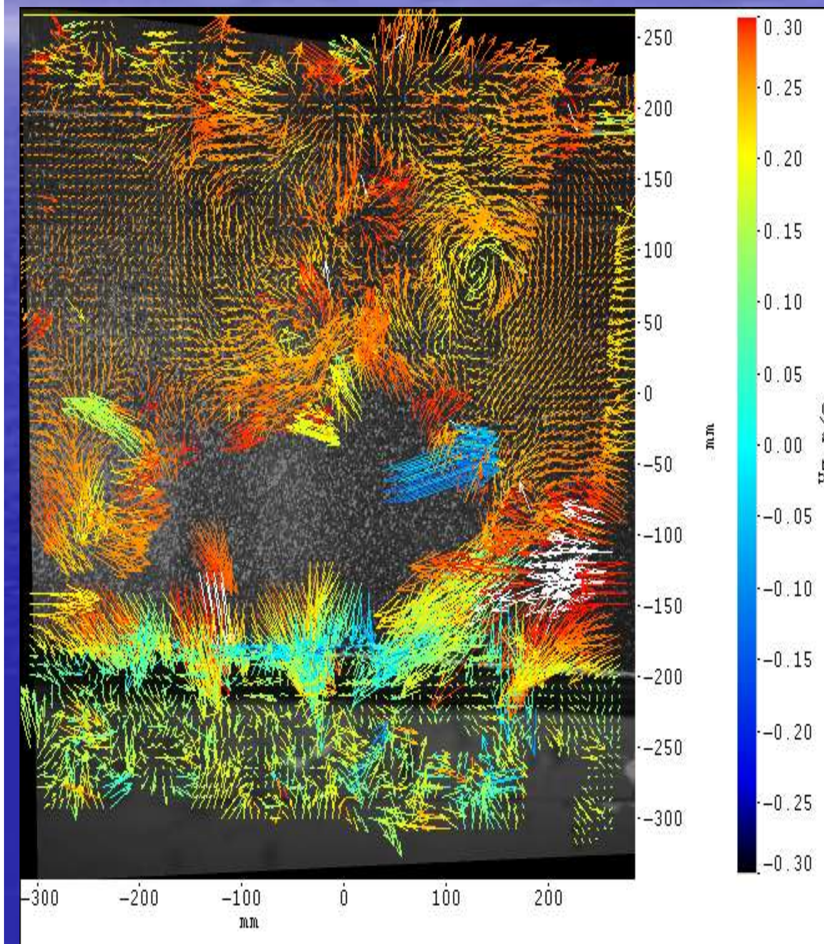
- Particle Image Velocimetry (PIV) was used to record deformation of water waves passing over a fully submerged tension leg platform (TLP) during 200+ test runs in Stevens wave tank facility during 2010. The data documented wave height increases in excess of 150%
- Data from 2010 indicate that wave heights (and corresponding energy densities) increase and peak at various locations over or past a near surface TLP as a function of incident wave periods, wave heights, and platform parameters (e.g. geometry, mass, depth, and orientation). After waves peak, they tend to decay back to near incident wave heights in spectral forms after passing over the platform if no surface piercing structure is tethered to the TLP (see next slide).

6.1cm (2.4in) 2s Incident Waves with 30cm Platform Depth

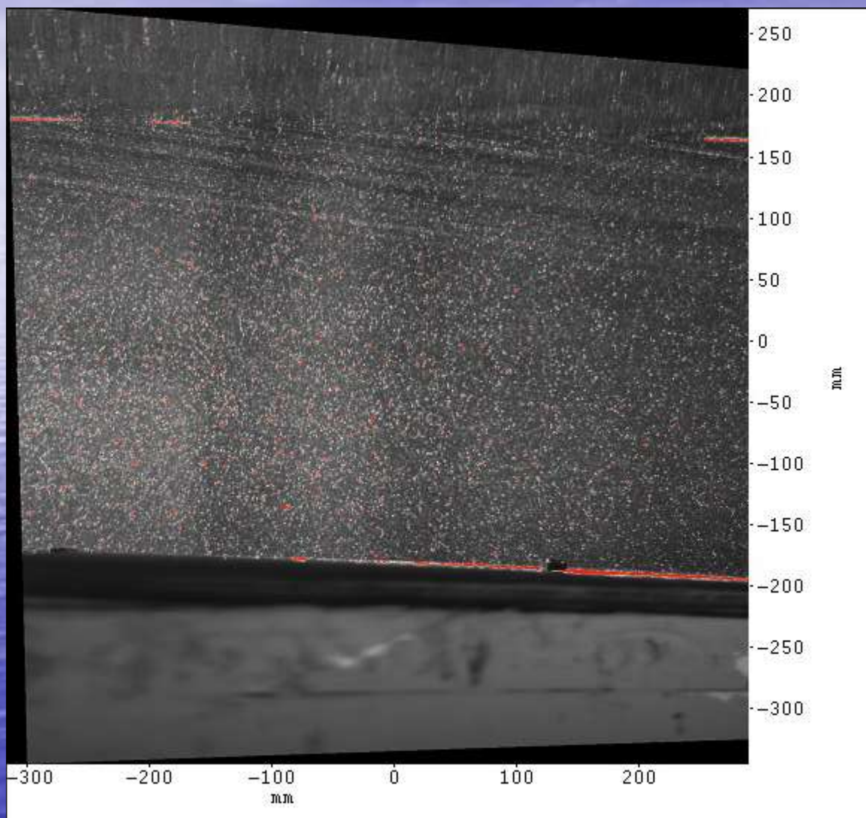


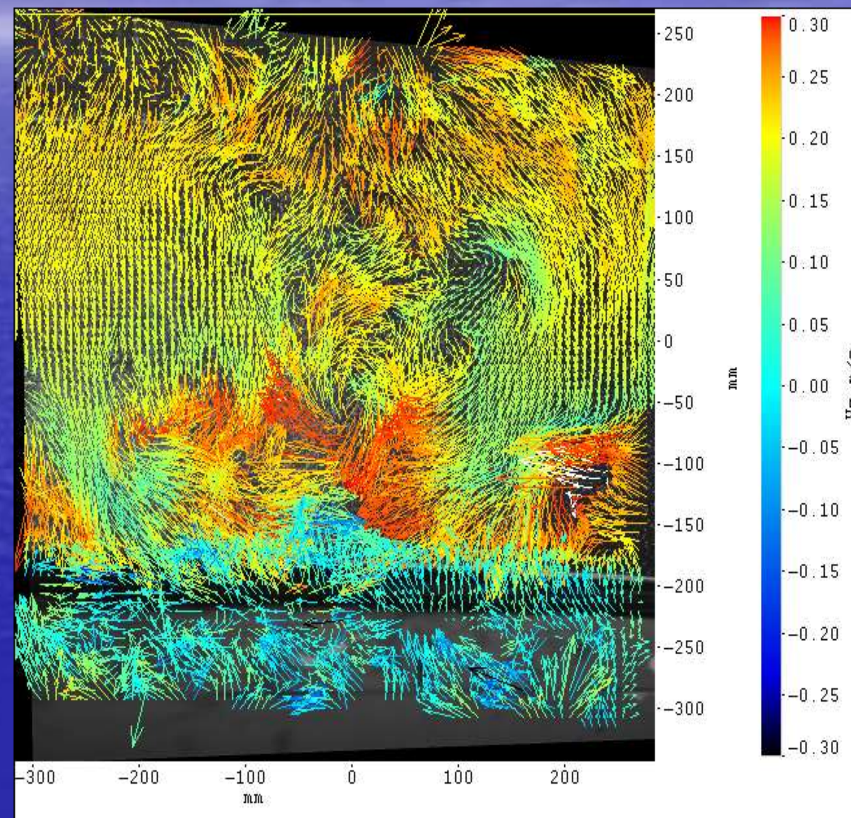
6.1cm, 2s incident waves, 30cm platform depth, PIV records a +5.3cm wave amplitude at 15cm from the leading edge of the TLP, free surface (FS) at 180mm



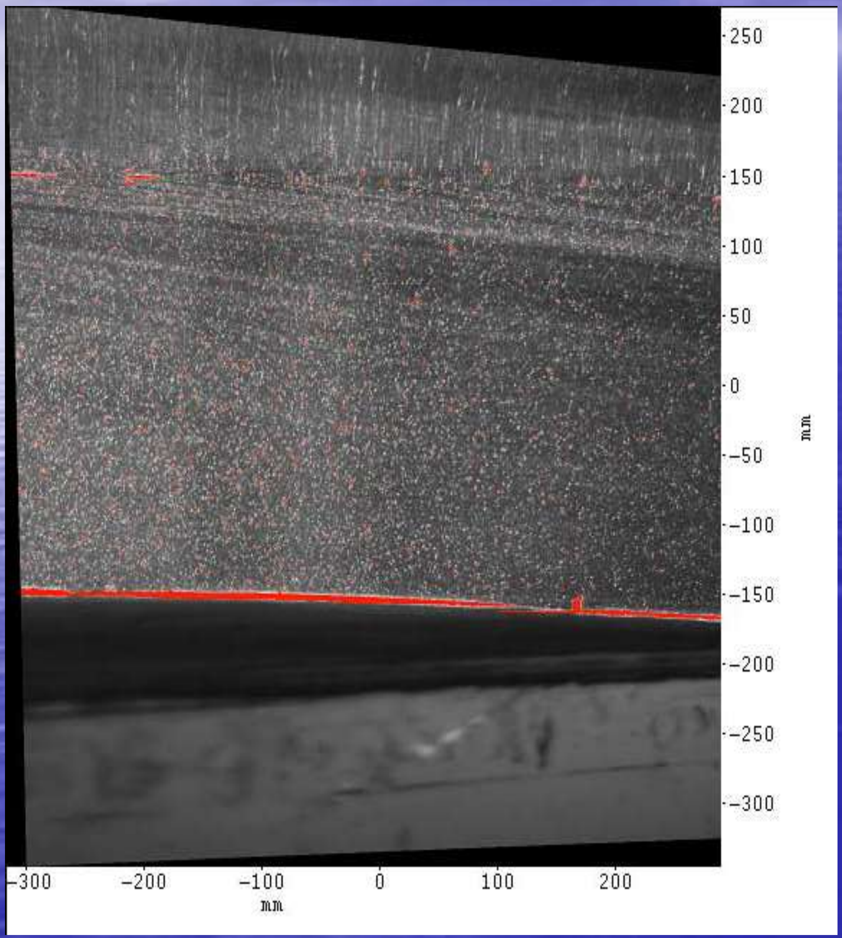


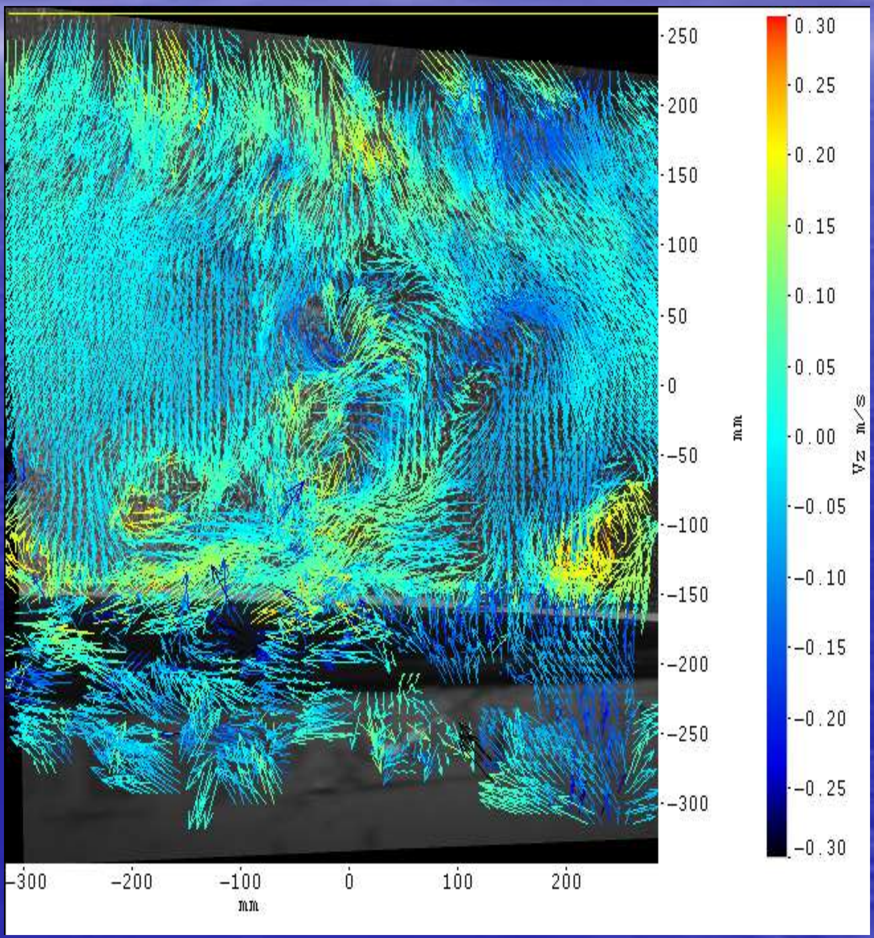
PIV corrected image and vector diagram with wave amplitude of +3.3cm，FS at 160mm



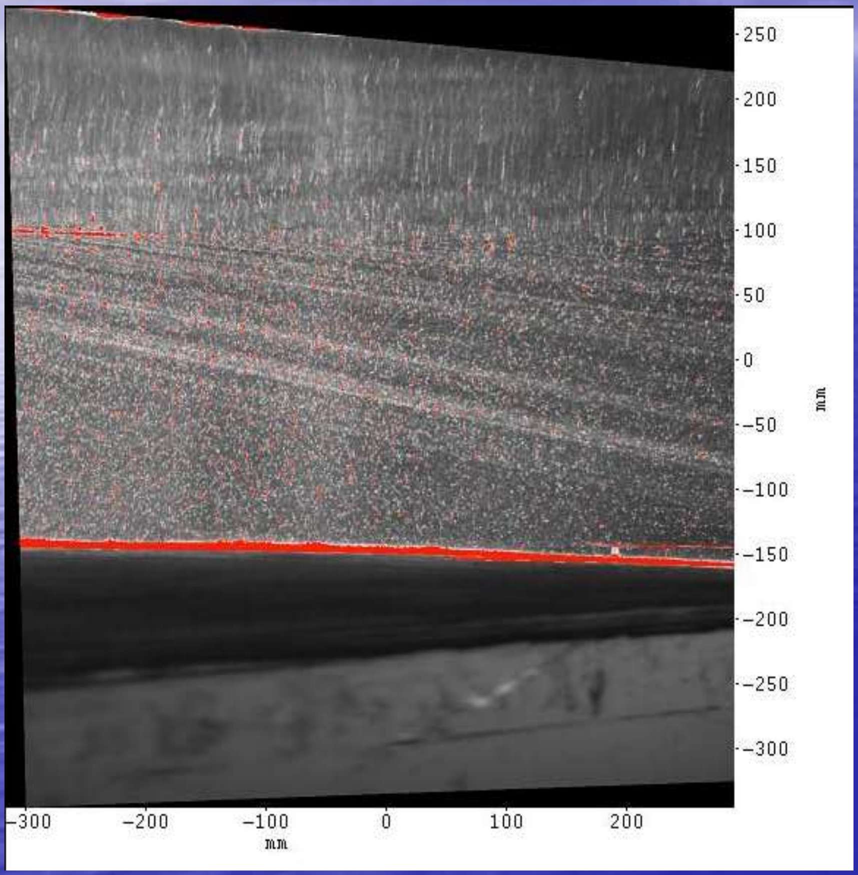


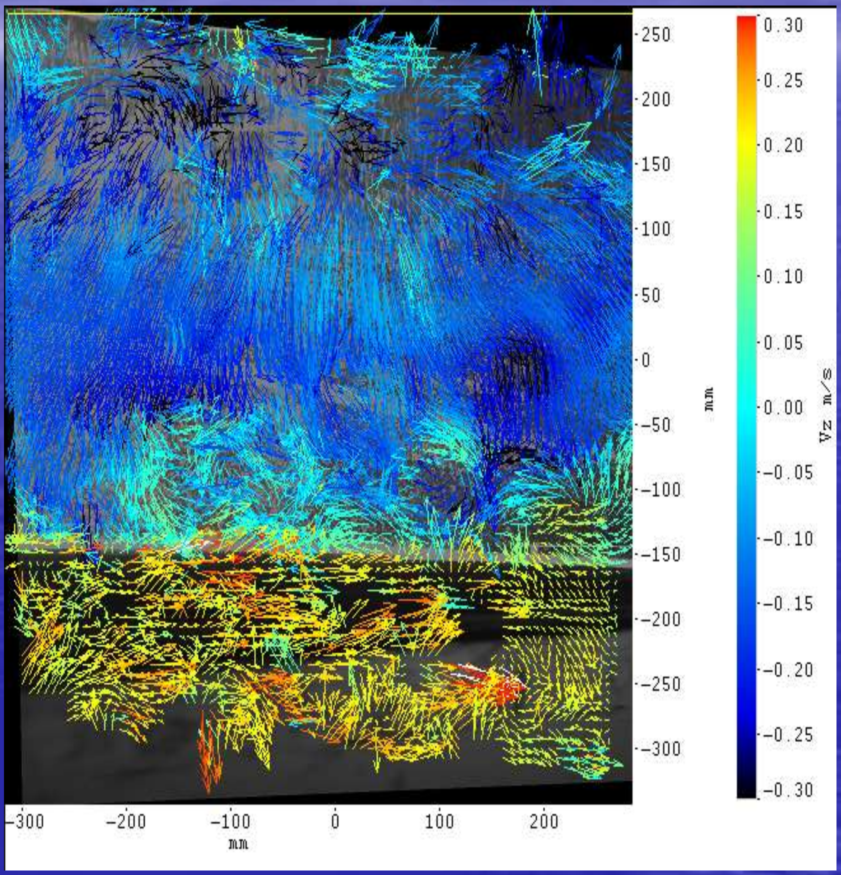
PIV corrected image and vector diagram with wave amplitude of +0.3cm (~SWL), FS at 130mm



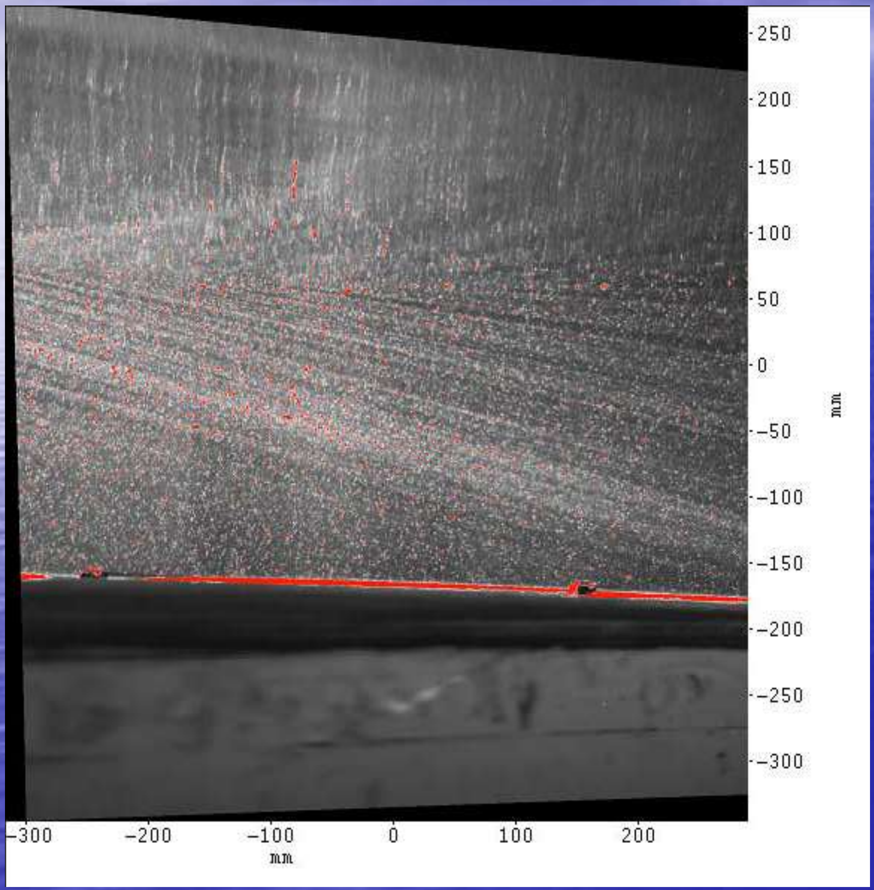


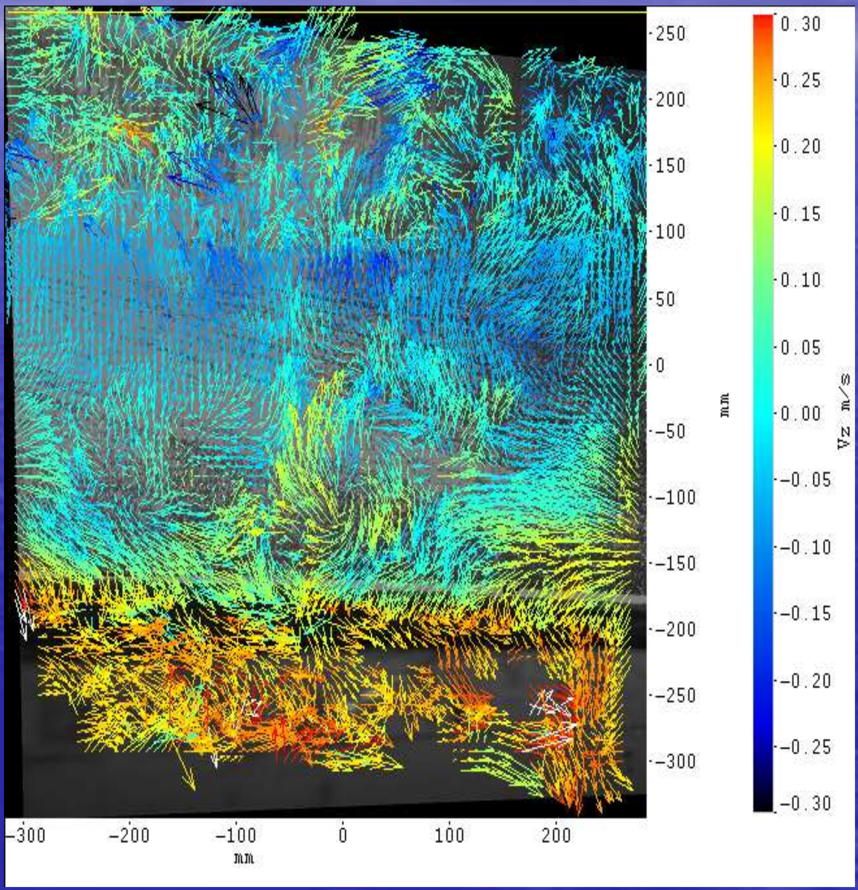
PIV corrected image and vector diagram with wave amplitude of -4.8cm， FS at 80mm



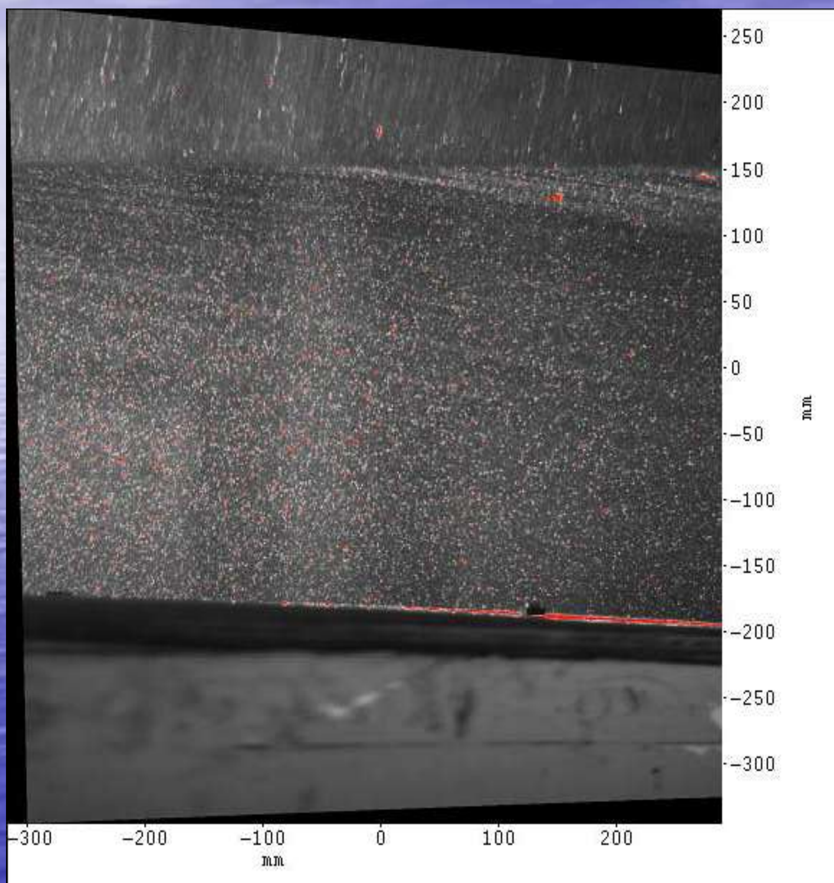


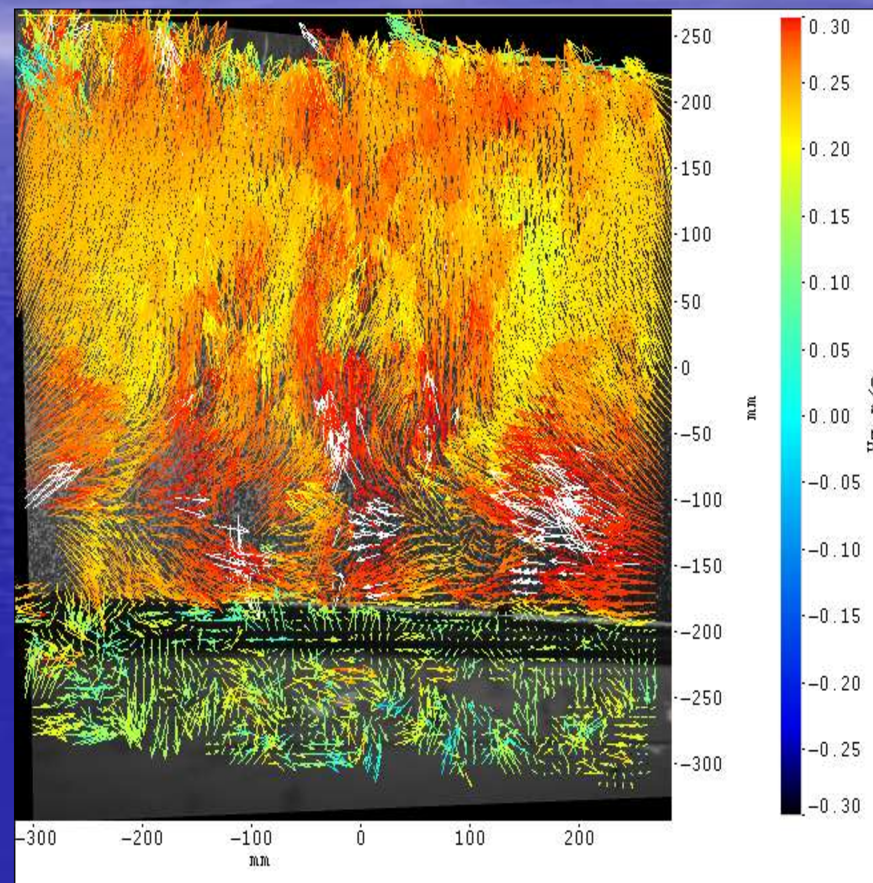
PIV corrected image and vector diagram with wave amplitude of -7.9cm (wave trough), FS at 50mm



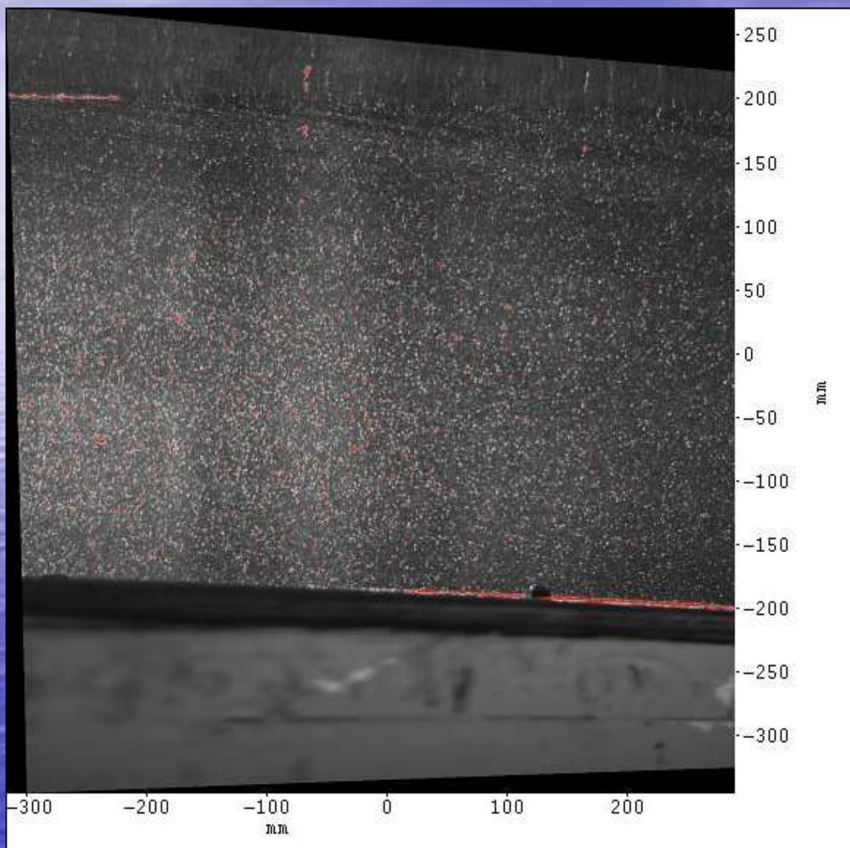


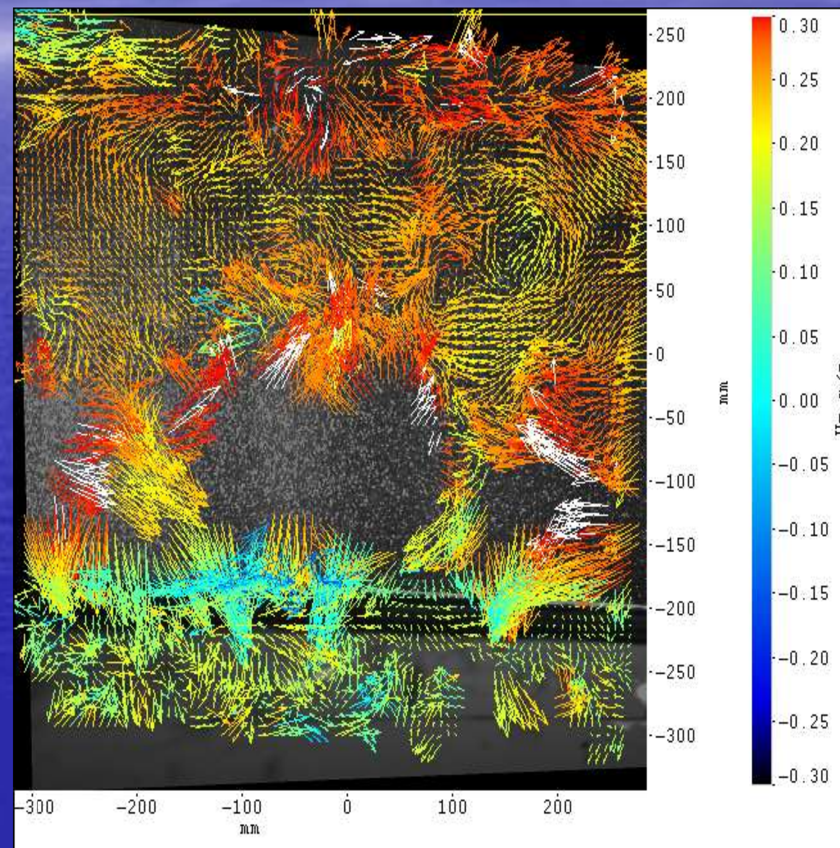
Wave amplitude of +0.3cm (~SWL), FS at 130mm, out-of-plane flow direction towards the beach





Wave amplitude of +5.3cm (wave crest), FS at 180mm, flow field is similar to first wave crest image





Maximum Water Particle Velocities from Linear Wave Theory

$$u = -\frac{\partial \phi}{\partial x} = \frac{H\omega}{2} . \frac{\cosh\ k(h+z)}{\sinh\ kh} \cos(kx - \omega t)$$

$$w = -\frac{\partial \phi}{\partial z} = \frac{H\omega}{2} . \frac{\sinh k(h+z)}{\sinh kh} \sin(kx - \omega t)$$

Fix location and time to zero @ SWL, assume u max = w max at SWL

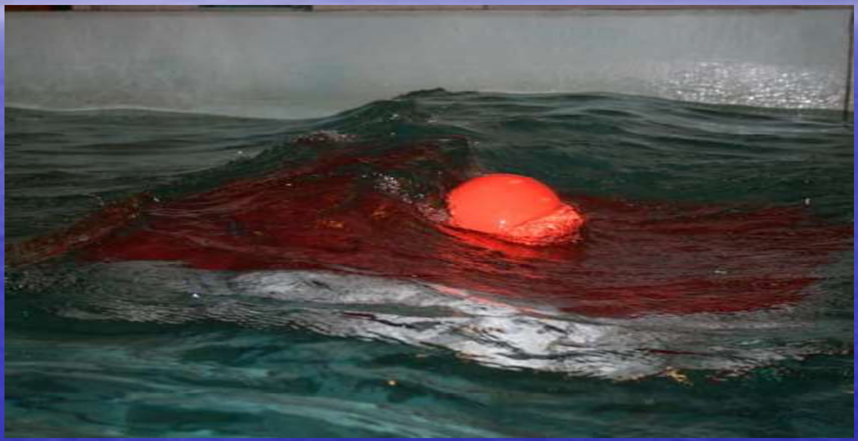
$$u\max = -\frac{\partial \phi}{\partial x} = \frac{H\omega}{2} . \frac{\cosh k(h)}{\sinh kh} (1)$$

For 0.061m, 2s monochrome waves:
Theoretical U max = 0.1m/s

PIV recorded velocities exceed 0.3m/s due to wave deformation and platform motions

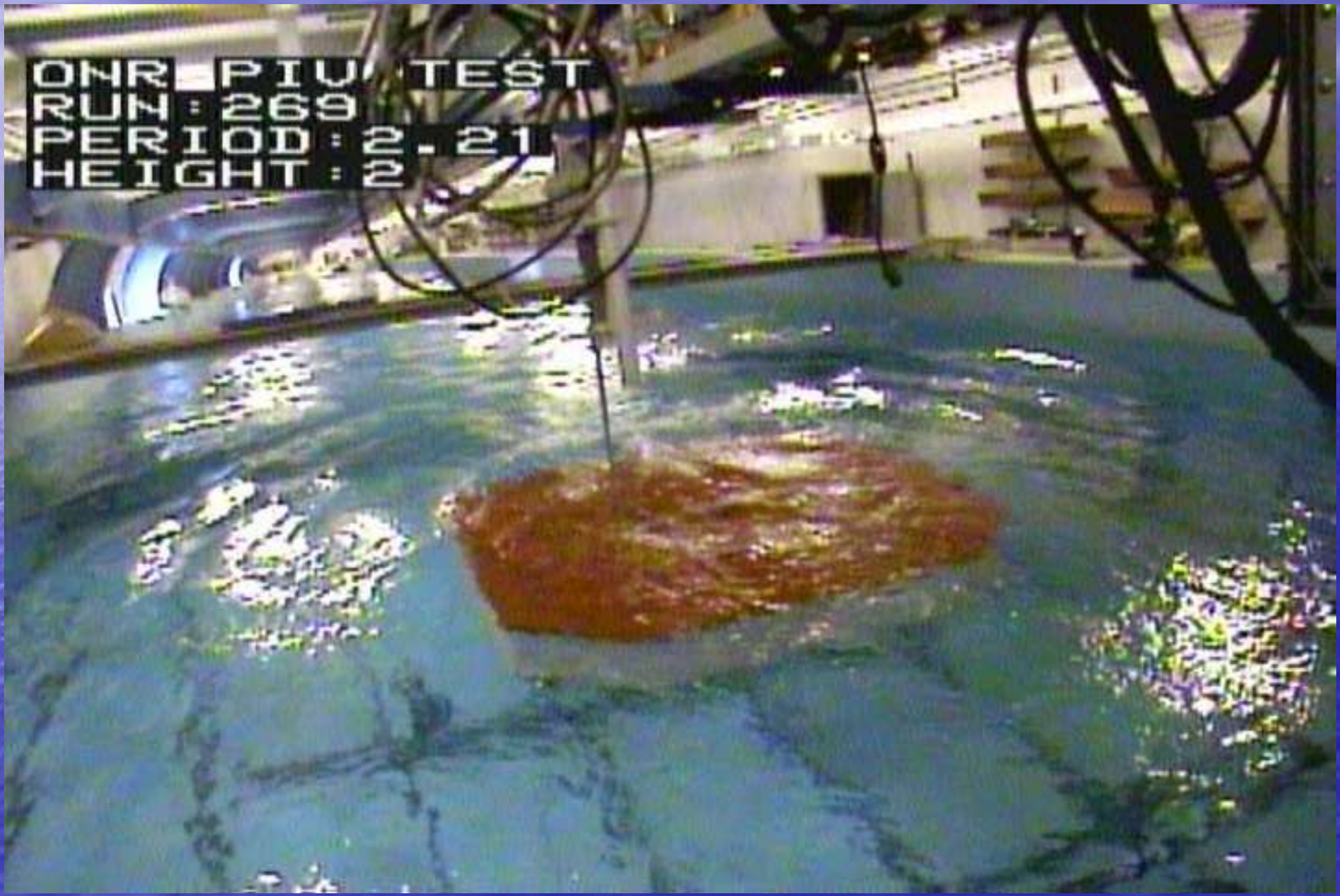
Wave Form Changes

TLP Shoals
10cm Wave over
a 20cm Buoy



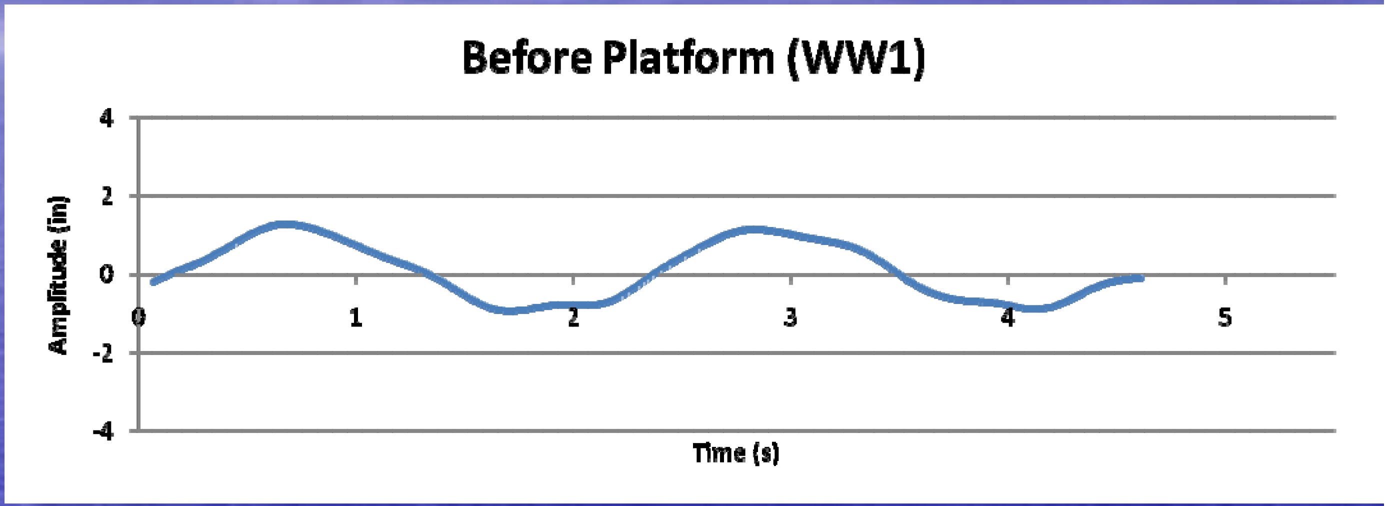
Surface Piercing
Structure Motion
Increases with
Wave Steepness

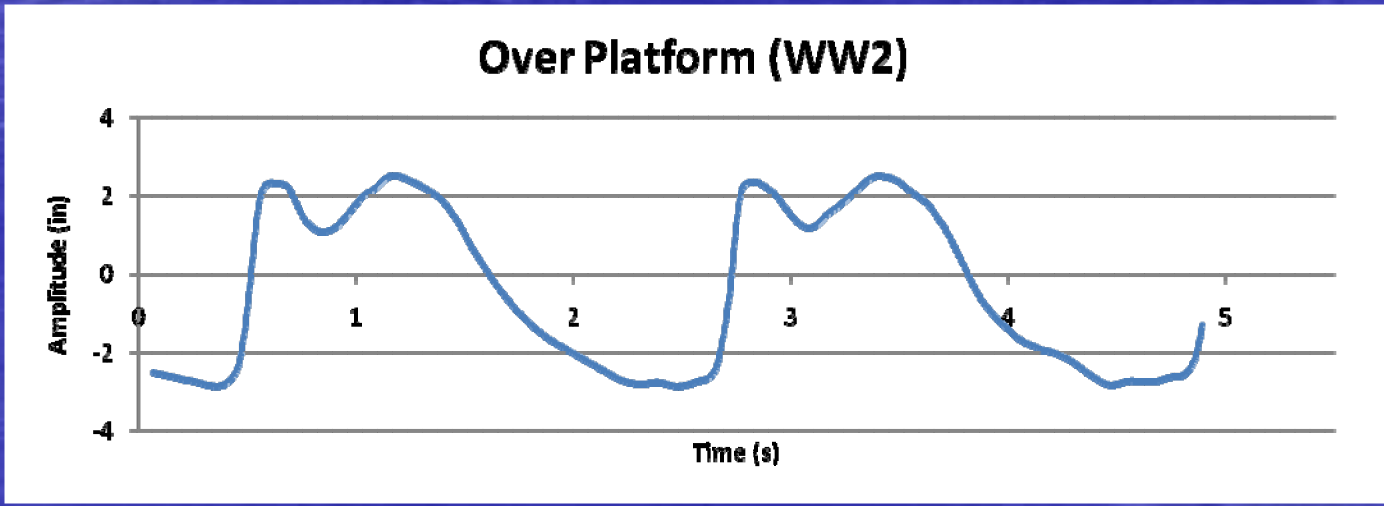
Quantifying Wave Form Changes without Surface Piercing Objects



5.1cm (2 inch) , 2.21s Waves – 15cm Platform Depth

Wave Heights:
•Before Platform:
•5.1cm (2.0 in)
•Over Platform:
•12.7 cm (5.0 in)
•Wave Height Increase: 150%





5.1cm Wave Results

H =0.051m (2.0in)

Cg = 1.97 m/s at 1.98m tank depth

E = 3.27 J/m^2

P = 6.43 W/m

Shoaled Wave

H = 0.127m (5.0in)

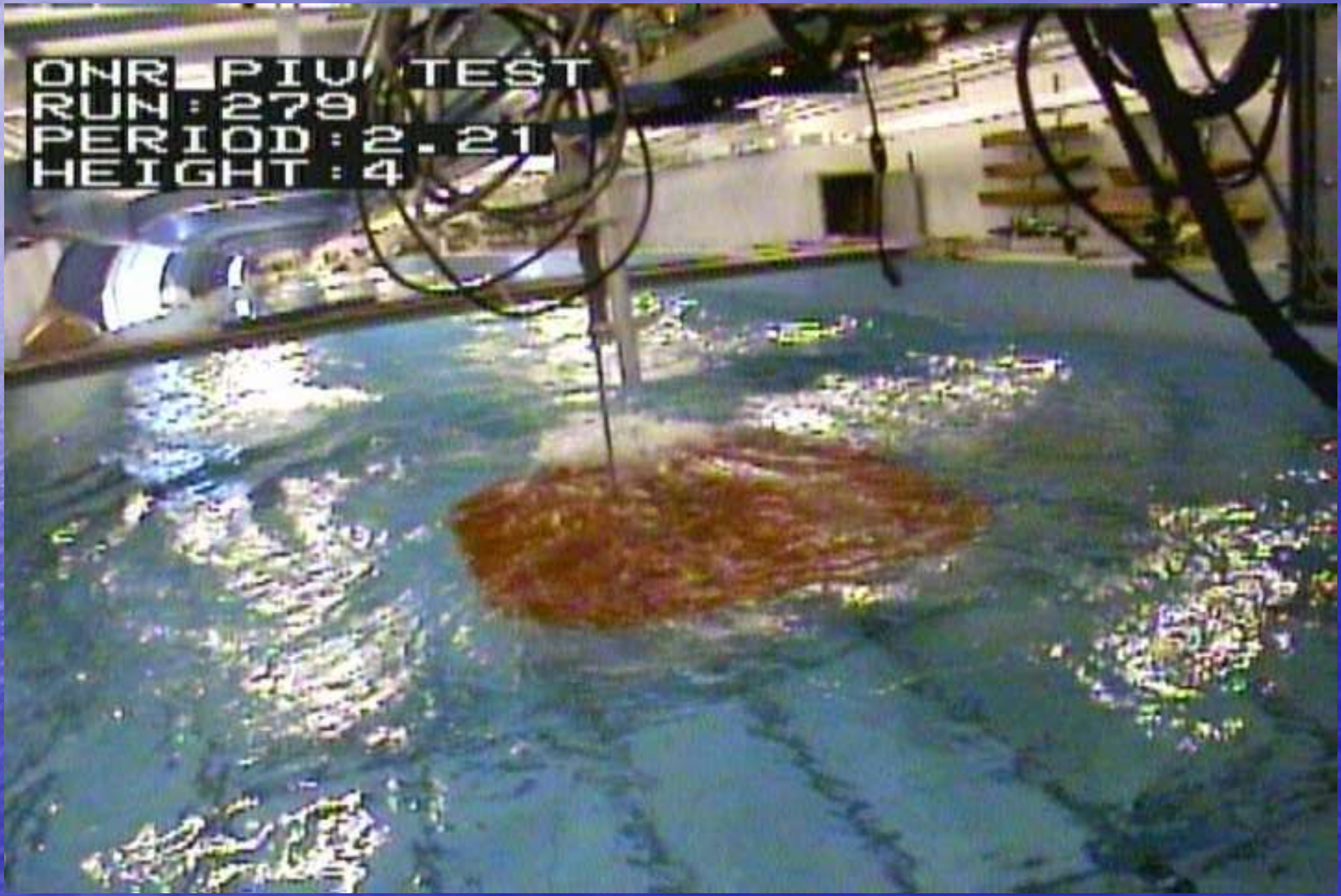
Cg = 1.14 m/s at 0.15m platform depth

E = 20.25 J/m^2

P = 23.07 W/m

259% increase in power density

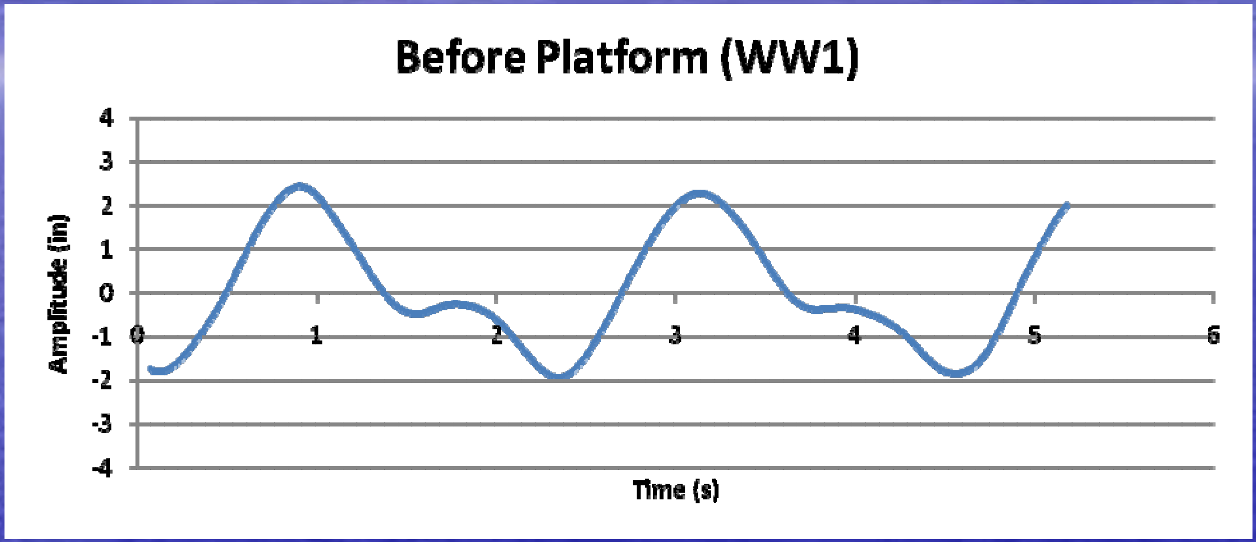
10.4cm (4.1 inch) Waves

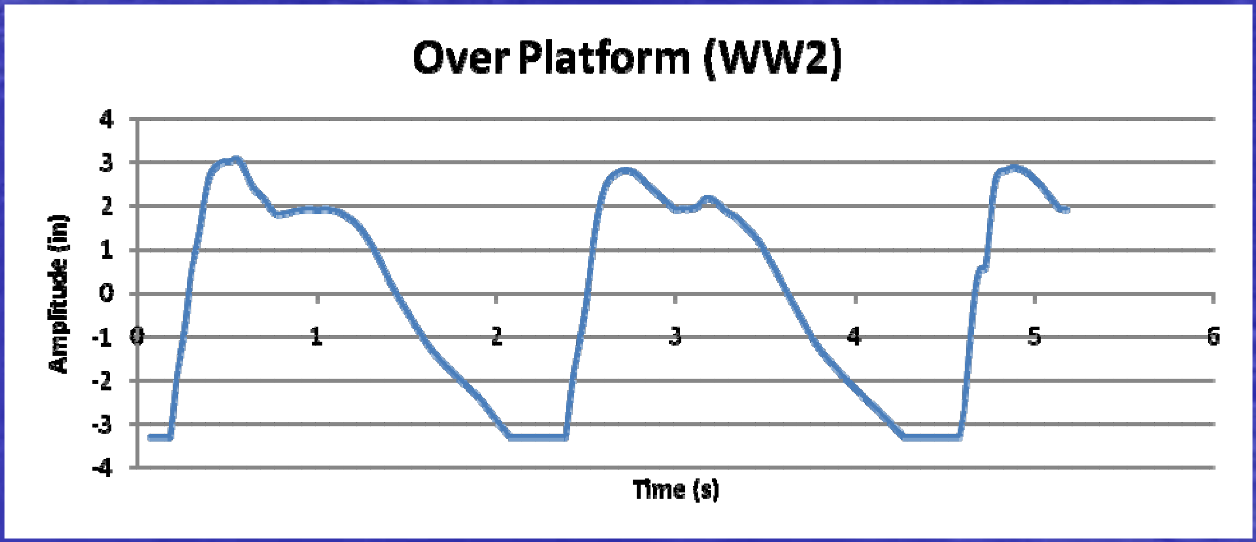


10.4cm Wave – 15cm Platform Depth

Wave Heights:

- Before Platform:
- 10.4 cm (4.1in)
- Over Platform:
- 17.8 cm (7.0 in)
- Increase in Wave Height: 71%
- Note: waves dropped below the wave wire over the platform resulting in an apparent “flat” bottom





10.4cm Wave Results

H = 0.104m (4.1in)
Cg = 1.97 m/s at 1.98m tank depth
E = 13.58 J/m^2
P = 26.74 W/m
Shoaled Wave
H = 0.178m (7.0in)
Cg = 1.14 m/s at 0.15m platform depth
E = 39.78 J/m^2
P = 45.32 W/m
69% increase in power density

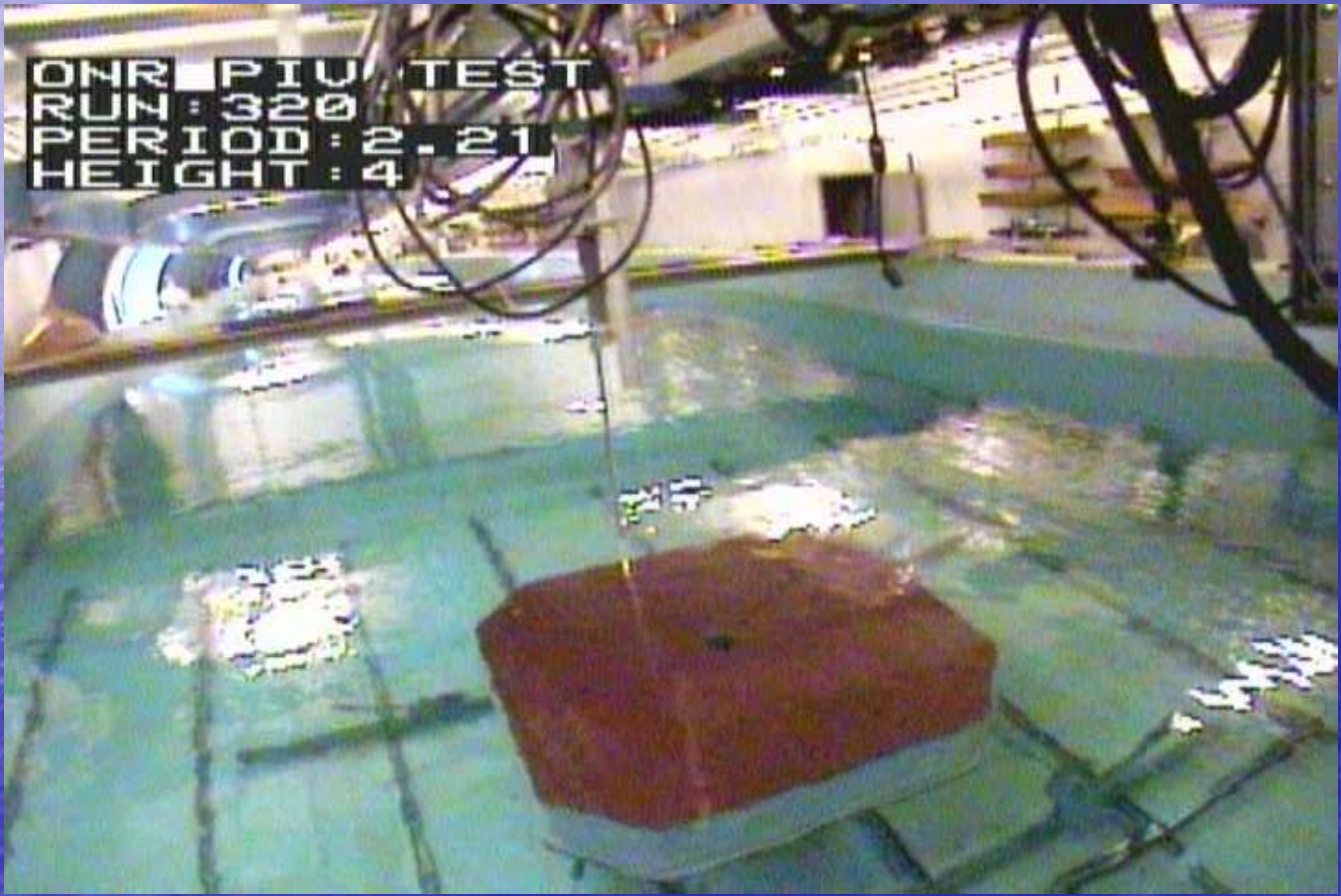
Scaling Power Concentration @ 1:10

- 0.51m, 7s = 2.04kW/m
- 1.27m tuned power = 7.30kW/m
- 1.04m, 7s = 8.47kW/m
- 1.78m tuned power = 14.34kW/m
- Note: Froude scaling is used as power take-off estimates are based on the wave making resistance of a surface float

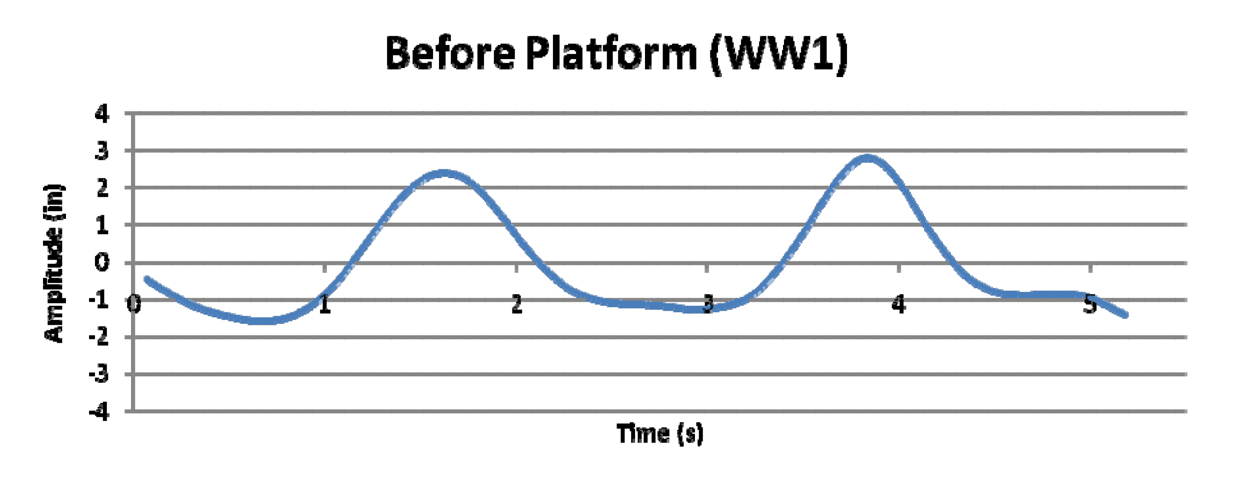
Wave Load Avoidance

- Wave loading can be reduced by lowering the TLP away from the free surface

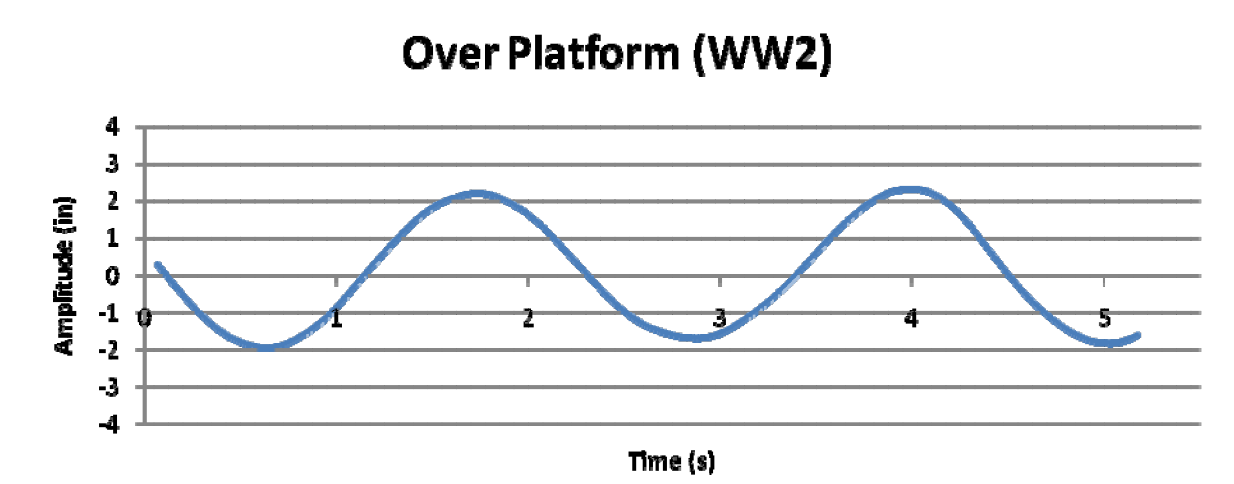
10.4cm Wave – 110cm Platform Depth



10.4cm Wave – 110cm Platform Depth



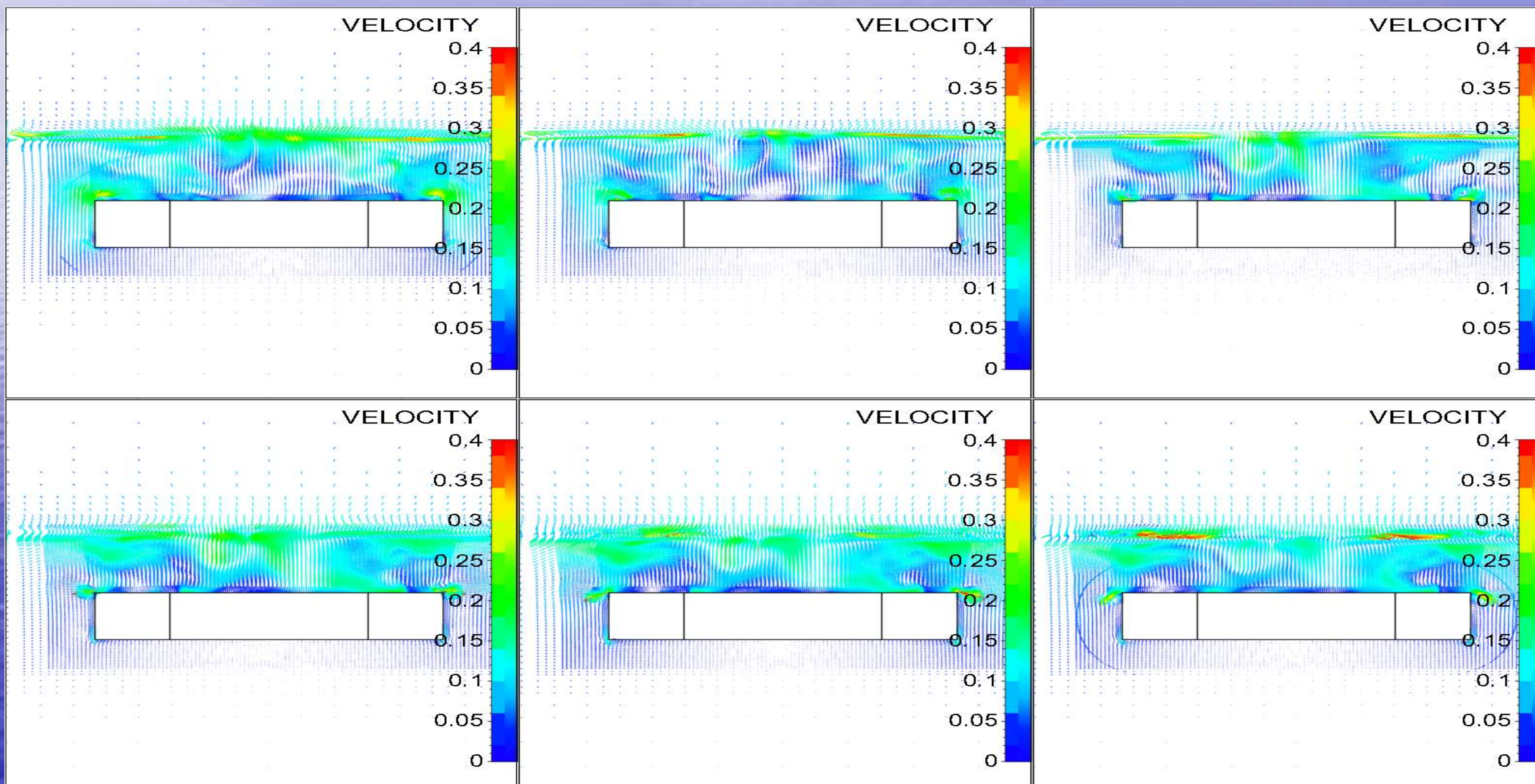
Wave Heights:
- Before Platform:
- 10.4 cm (4.1 in)
- Over Platform:
- 10.4 cm (4.1 in)



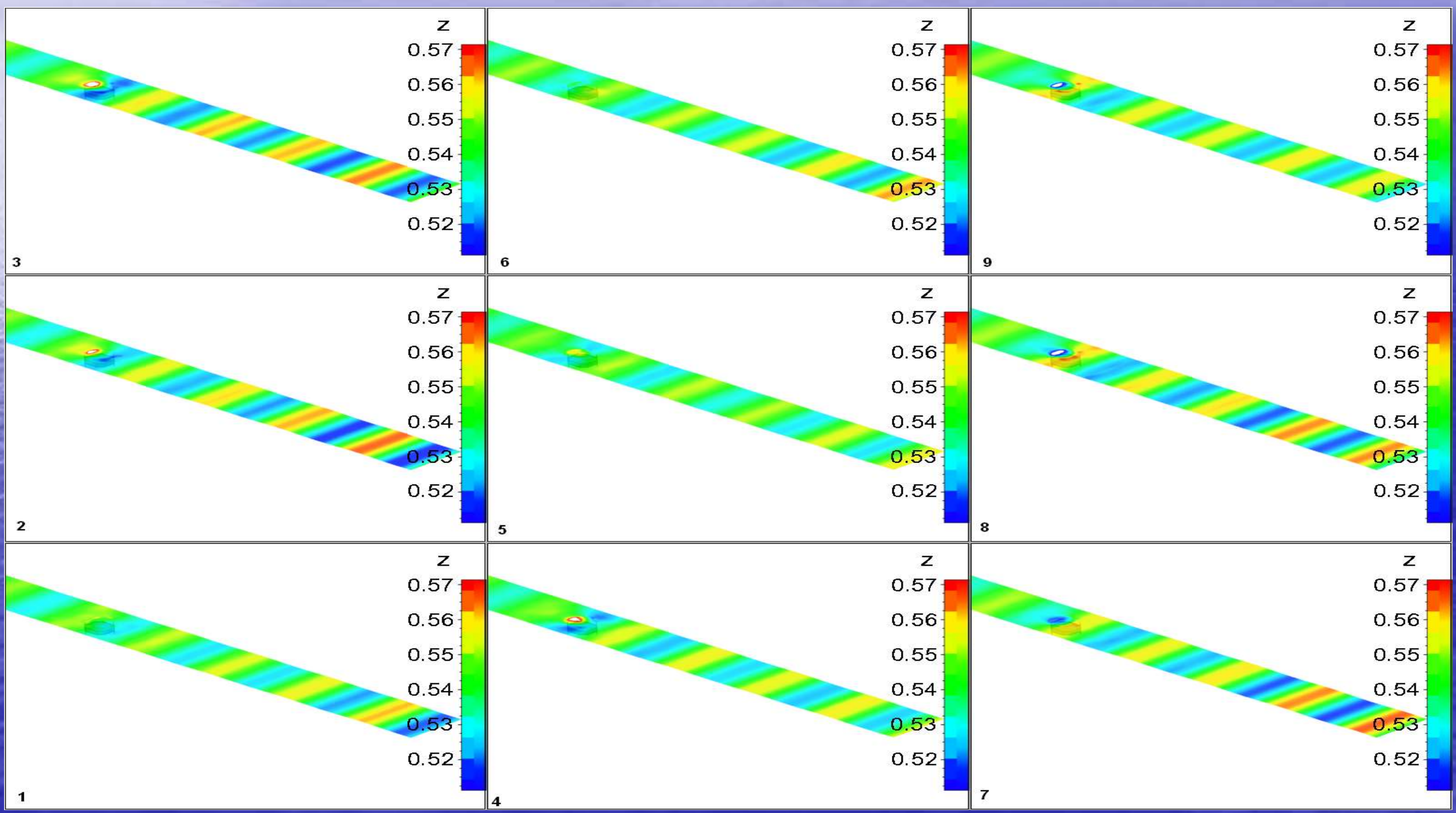
Numerical Wave Tank Results

- A numerical grid of the wave tank at Stevens was generated by Romain Garo and Len Imas
- Geometry and mass properties of the TLP were used to develop a numerical grid of the TLP
- The wave-TLP interactions were simulated using the given locations and calculated mooring stiffness of four mooring tendons

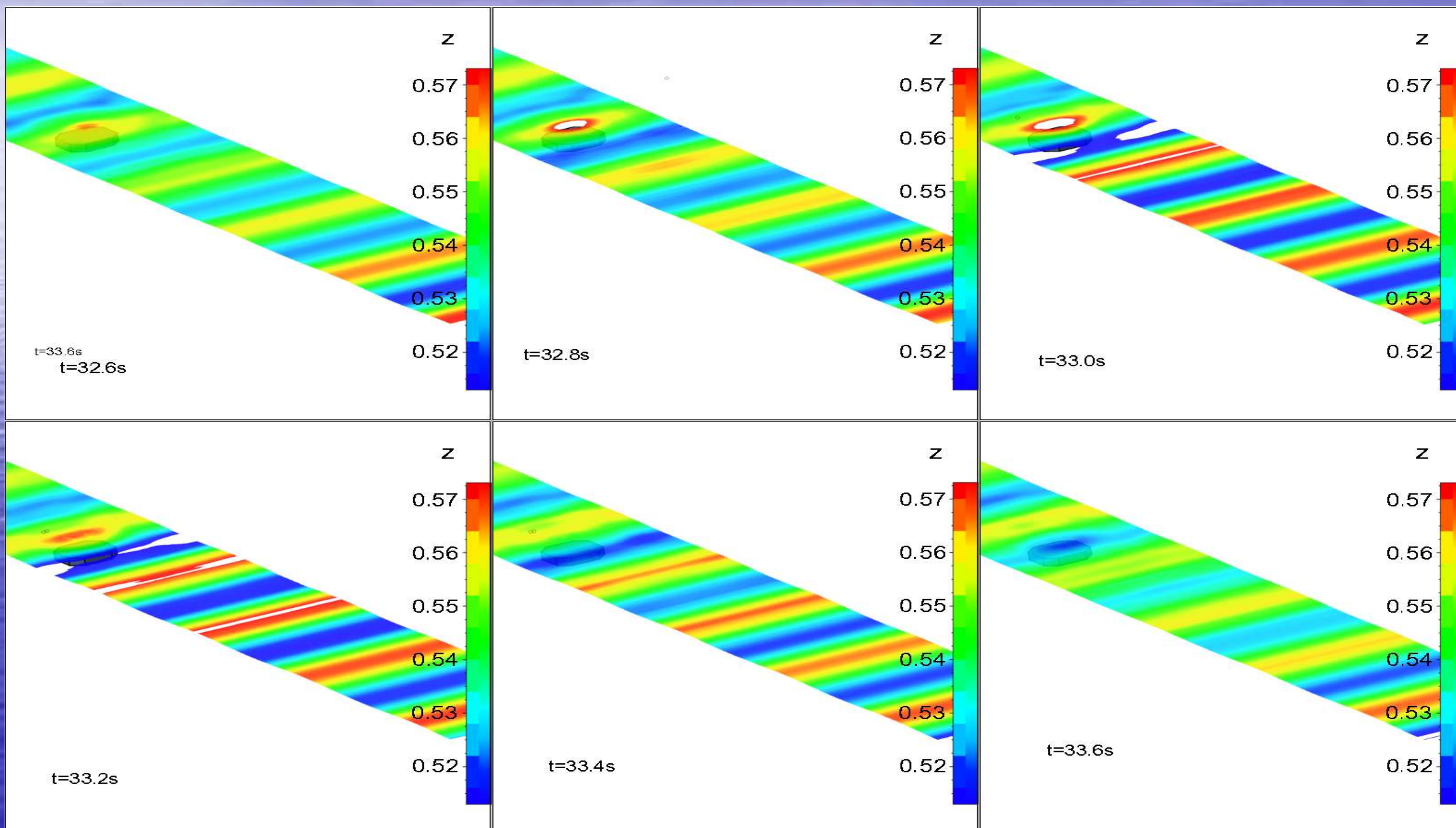
NUMECA 1.5s 2inch Waves



NUMECA FS Elev. In Tank 3



NUMEACA Outputs at TLP



Research Goals

- Determine and control the location of peak wave energy density over or past a TLP as a function of wave period, wave height, and platform parameters.
- Determine wave height, wave period, and platform parameters required to generate peak energy density at the transverse centerline of a fully submerged TLP
- Use data to validate a numerical wave tank (CFD)
- Use validated CFD to determine platform parameters required to generate peak energy density at the transverse centerline of numerical TLPs
- Quantify incident wave power using accelerometers, structure mass and displacement properties, and a hydraulic power take-off system (under construction)

Contact Information

Michael Raftery, M.E.
Research Engineer
Stevens Institute of Technology
Davidson Marine Laboratory
711 Hudson St.
Hoboken, NJ 07030
Email: michael.raftery@stevens.edu
Phone: 201 216 8704
Fax: 201 216 8214

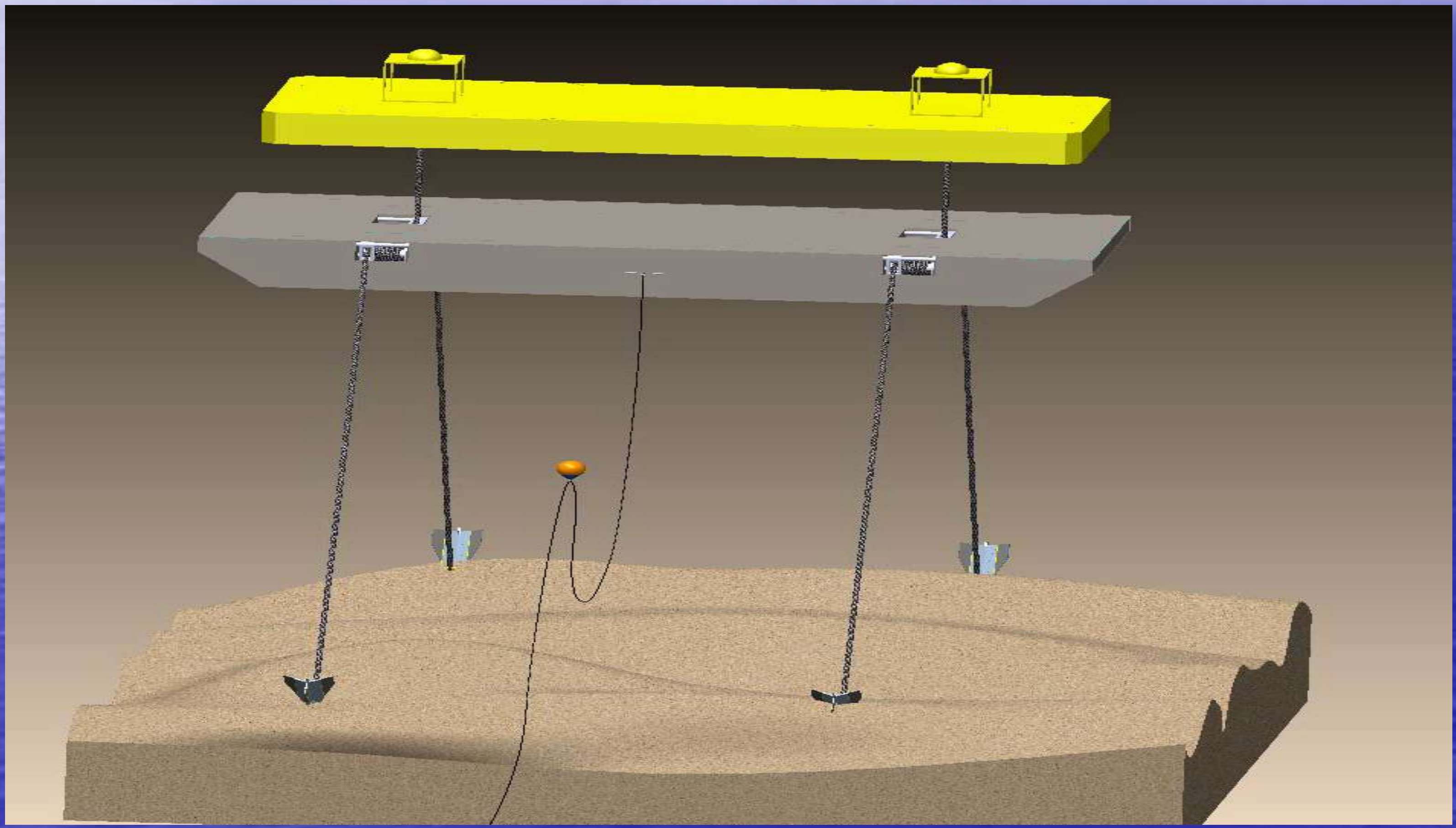
Appendix

- Benefits for Existing Designs
- Full Scale Development
- Broader Impact Goals
- Wave Resource off NE USA

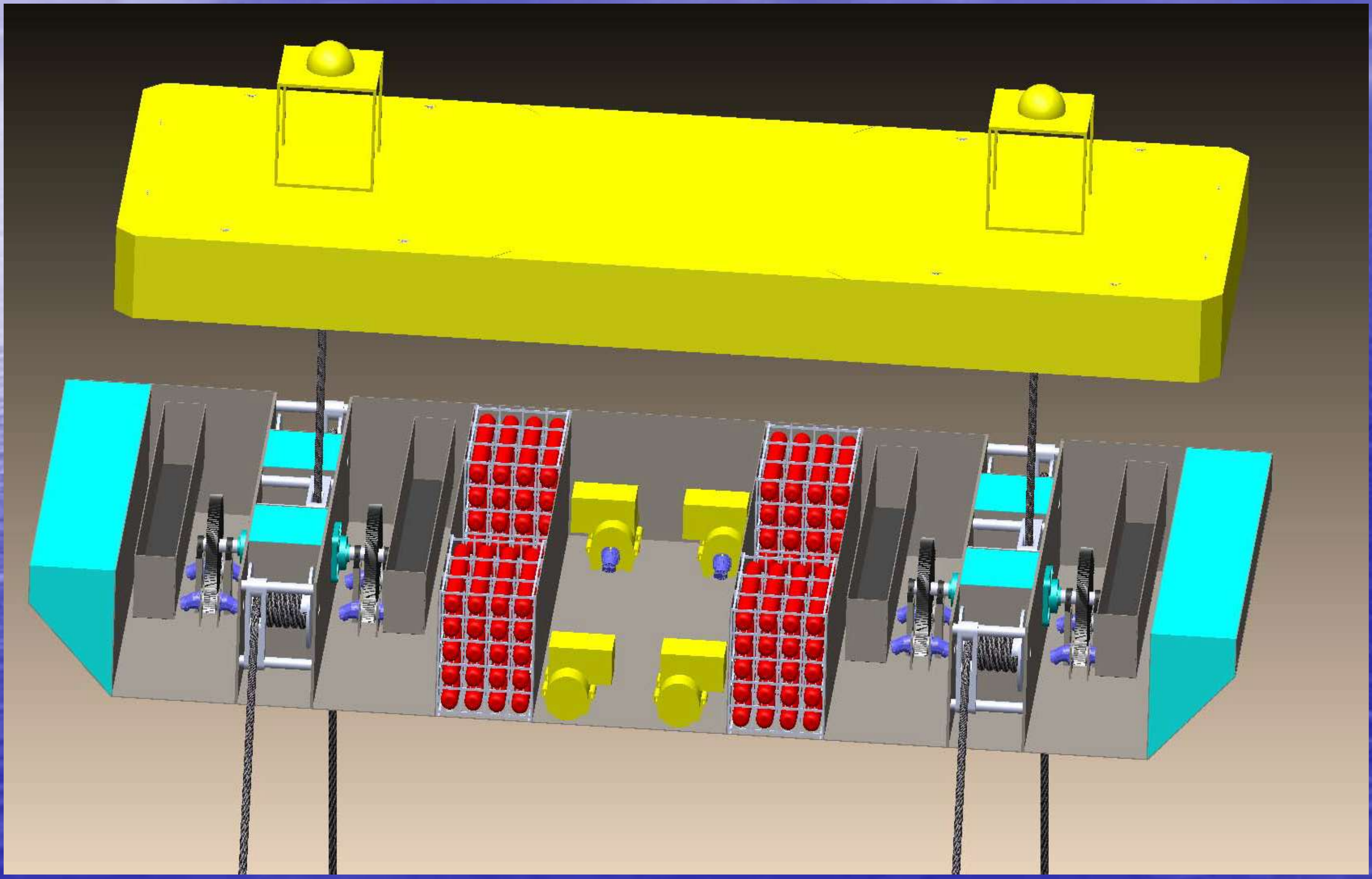
Benefits for Existing Designs

- Submerged TLPs can provide steeper waves to existing systems such as the "Powerbuoy" developed by Ocean Power Technologies (OPTT), and the "Pelamis" developed by Pelamis Ltd.
- Existing wave energy conversion systems can damp waves more effectively using submerged TLPs to protect offshore and shore based structures

WEHD-Full Scale Design



WEHD – Redundant Systems



Energy Storage System

- 30m long full scale platform
- Storage volume, 80 – 300L Accumulators
- = 24m^3 = 12m^3 working volume
- Storage pressure = 3000psi (200 bar)
- Adiabatic Storage capacity = 303kWh (1.09GJ)

Charge Rate with 28m Wide Surface Structure at 35% Efficiency

- 28m x 7.30kW/m x .35 = 71.5kW
- 28m x 14.34kW/m x .35 = 140.5kW
- Mild waves charge the energy storage system in 4 hours 15 minutes
- Moderate waves charge the energy storage system in 2 hours 10 minutes

Discharge Rates

- 75kW for 4 hours
- 150kW for 2 hours
- 300kW for 1 hour
- 600kW for 30 minutes
- 1.2MW for 15 minutes
- 2.4MW for 7 minutes 30 seconds
- 4.8MW for 3 minutes 45 seconds

Why 5MW Plate Capacity?

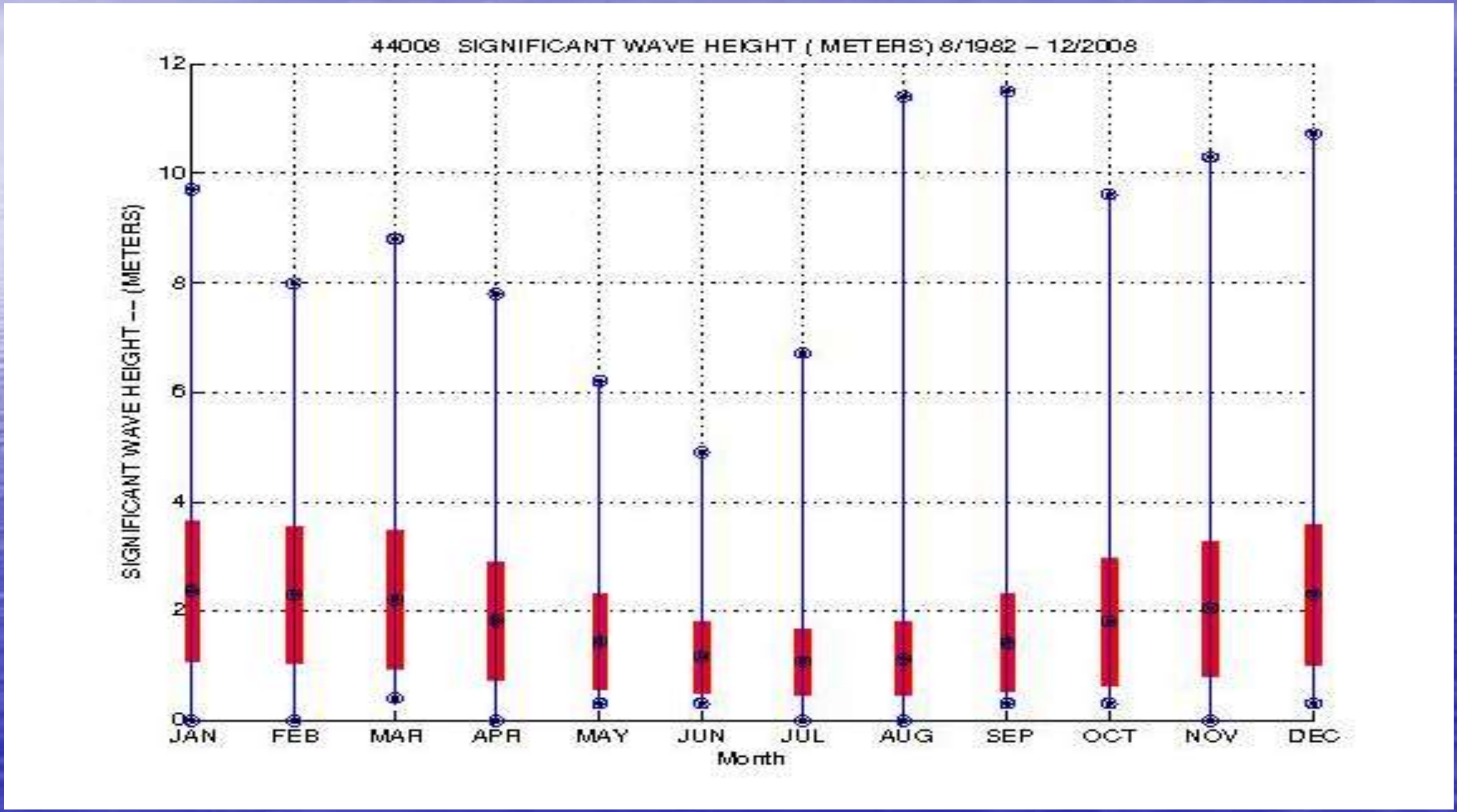
- MS Excel Demo
- @ 100m depth
- 2m-8s incident waves ~ 300kW @ 35% efficiency
- 3m-8s incident waves ~ 690kW
- 4m-8s incident waves ~ 1.2MW
- Tuned wave platform depth = wave height
- 2m tuned to 4m ~1.1MW @ 35% efficiency
- 3m tuned to 6m ~2.8MW
- 4m tuned to 8m ~5.4MW

Broader Impact Goals

- Mild and moderate waves can be converted to electric power efficiently given sufficient wave tuning and energy storage capabilities
- Redundant systems with foam-filled compartments provide buoyant integrity and eliminate single point failures
- Variable depth platforms provide the capability to avoid extreme loads during storms

Northeast Wave Energy Region

44008-Wave Height 54NM offshore



44008 Dominant Period