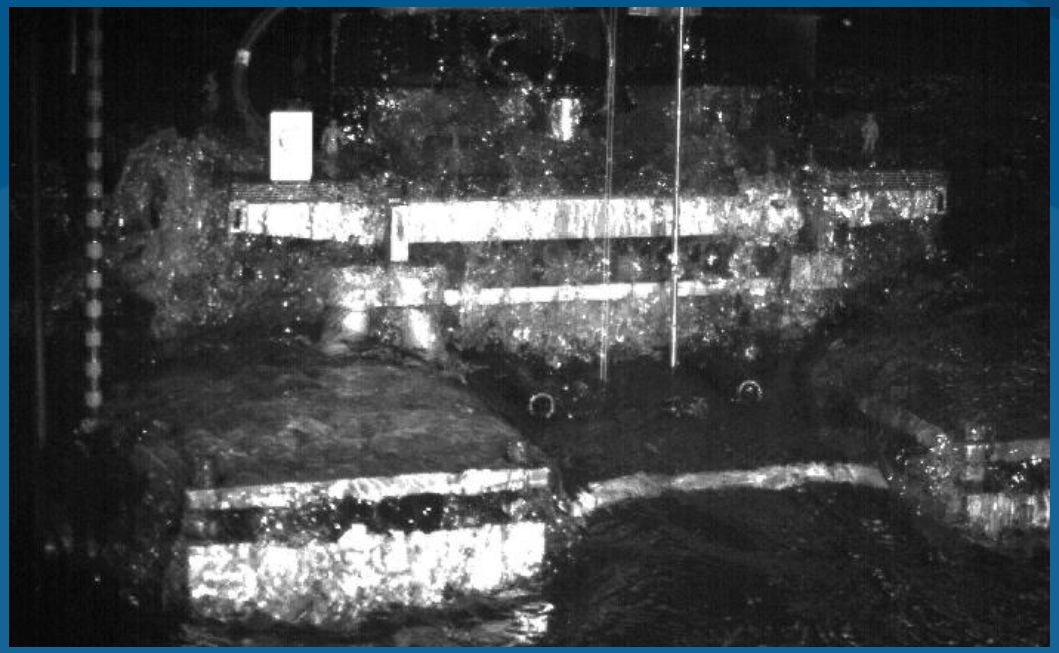
Extreme Wave Pressures and Loads on a Pile-Supported Wharf Deck

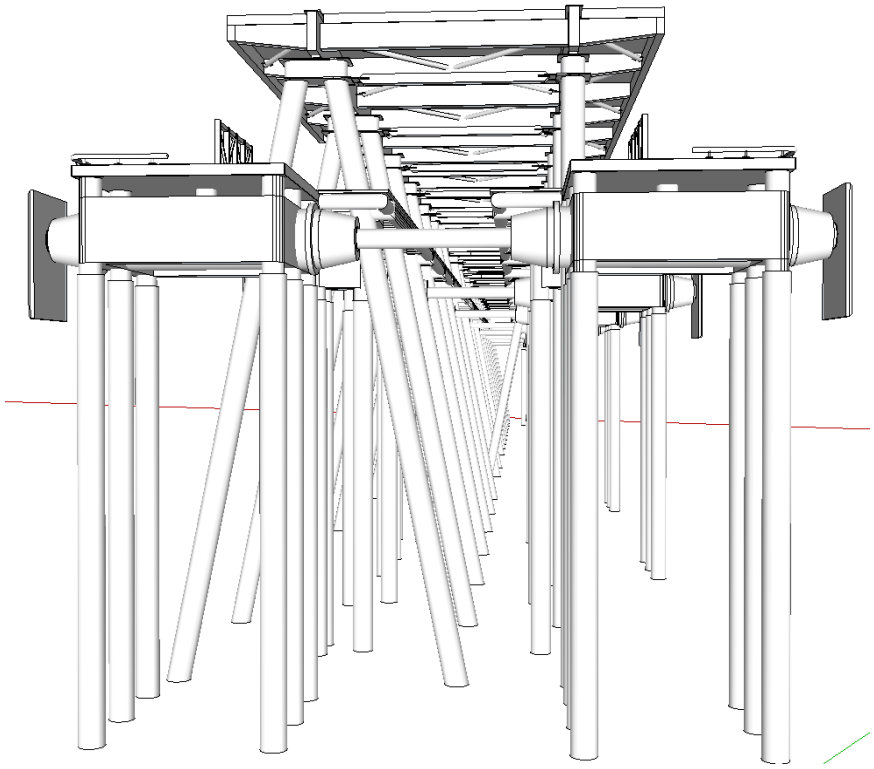


Andrew Cornett

National Research Council Canada - Ocean, Coastal & River Engineering

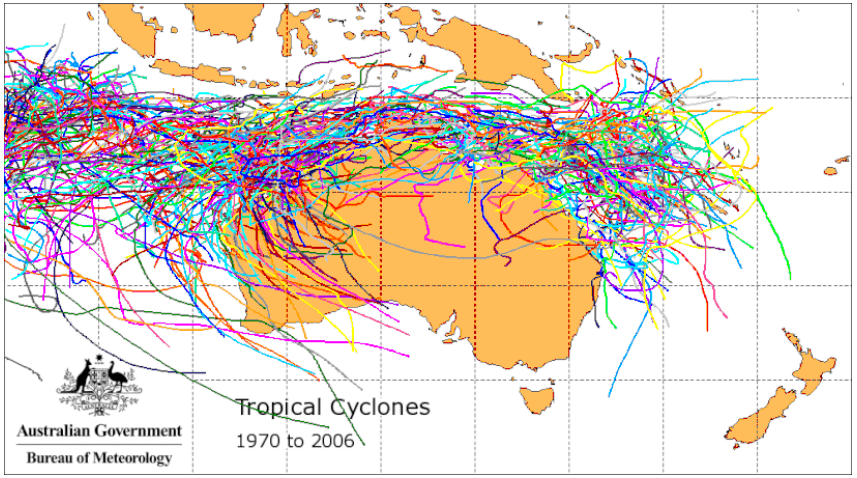
Outline

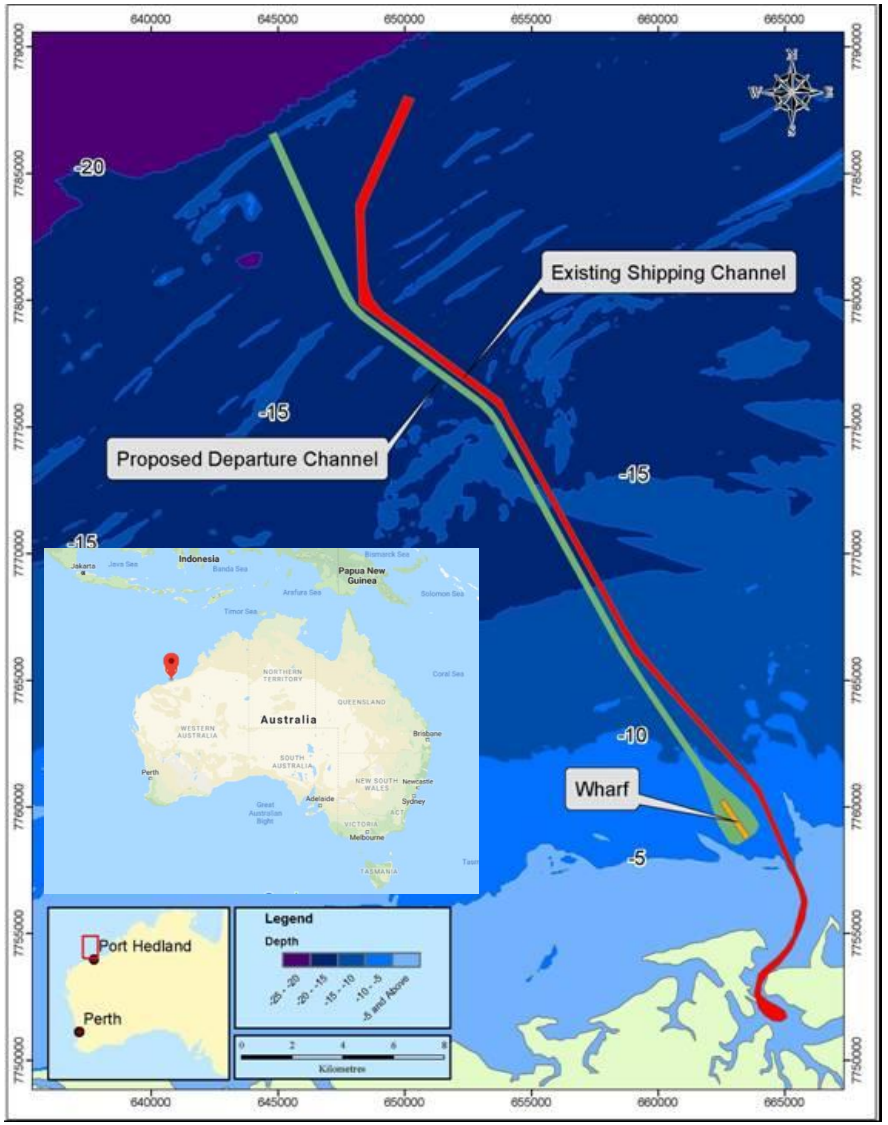
- Background
- Objectives
- Scale Model Tests
- Wave-in-Deck Loading
  - Deck beam pressure
  - Deck slab load
  - Variation with deck clearance
  - Variation with wave direction
- CFD Simulations
- Concluding Remarks



Port Hedland Outer Harbour Wharf project

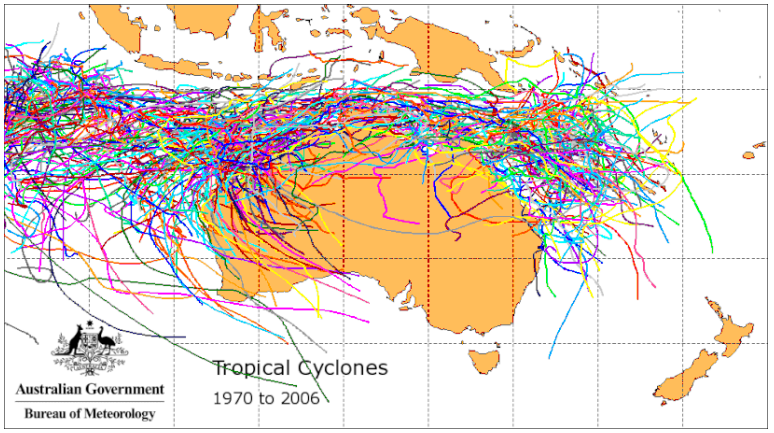
- New loading facility for iron ore located outside Port Hedland, WA
- Finger-type deck-on-pile wharf structure with conveyors and ship loaders
- 4 berths for 250,000 DWT vessels
- Dredged berth pocket and departure channel
- Exposed to cyclonic waves!





Extreme metocean conditions

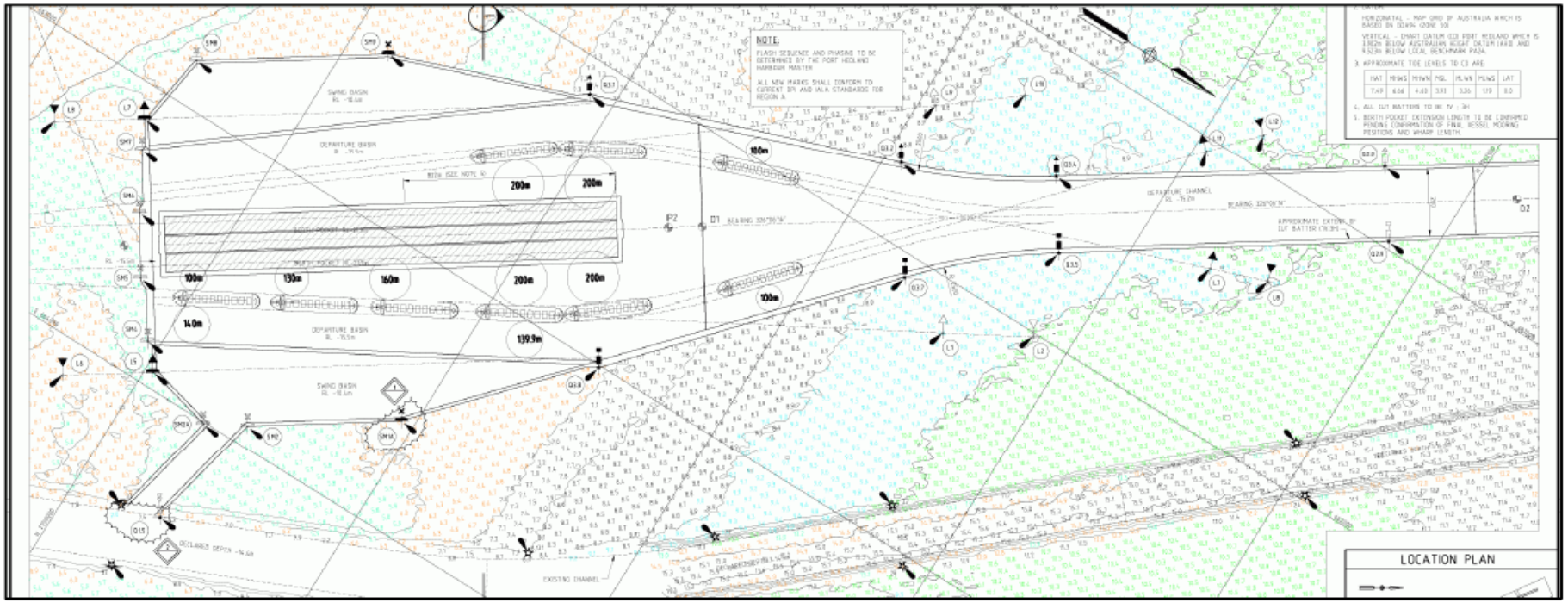
- Local depth 6m - 8m CD
- 7m tide range
- > 8m storm surge
- > 7m H_{m0}



ARI (yr)	H_{m0} (m)	Total WL (m CD*)	Max Crest Elevation (m CD*)
100	6.8	+7.8	+16.5
200	7.0	+8.1	+17.2
500	7.2	+8.4	+18.0
1000	7.4	+8.7	+18.6
2500	7.6	+9.0	+19.4
5000	7.8	+9.2	+20.0
10000	7.9	+9.5	+20.6

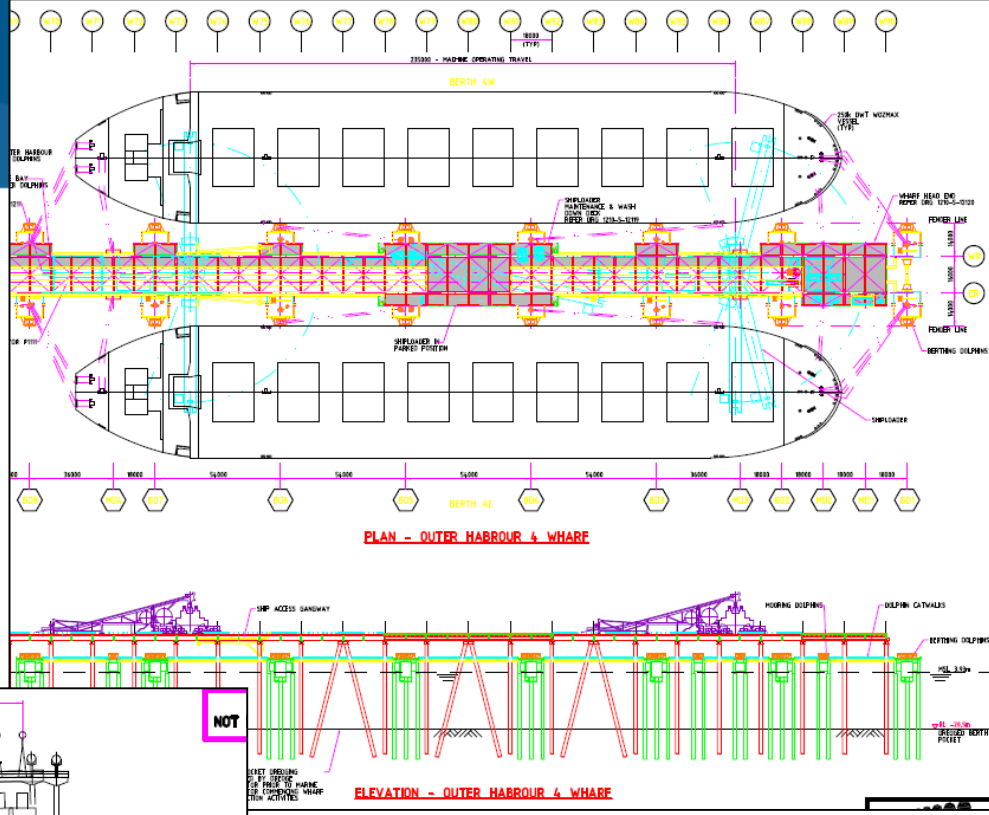
Dredging plan

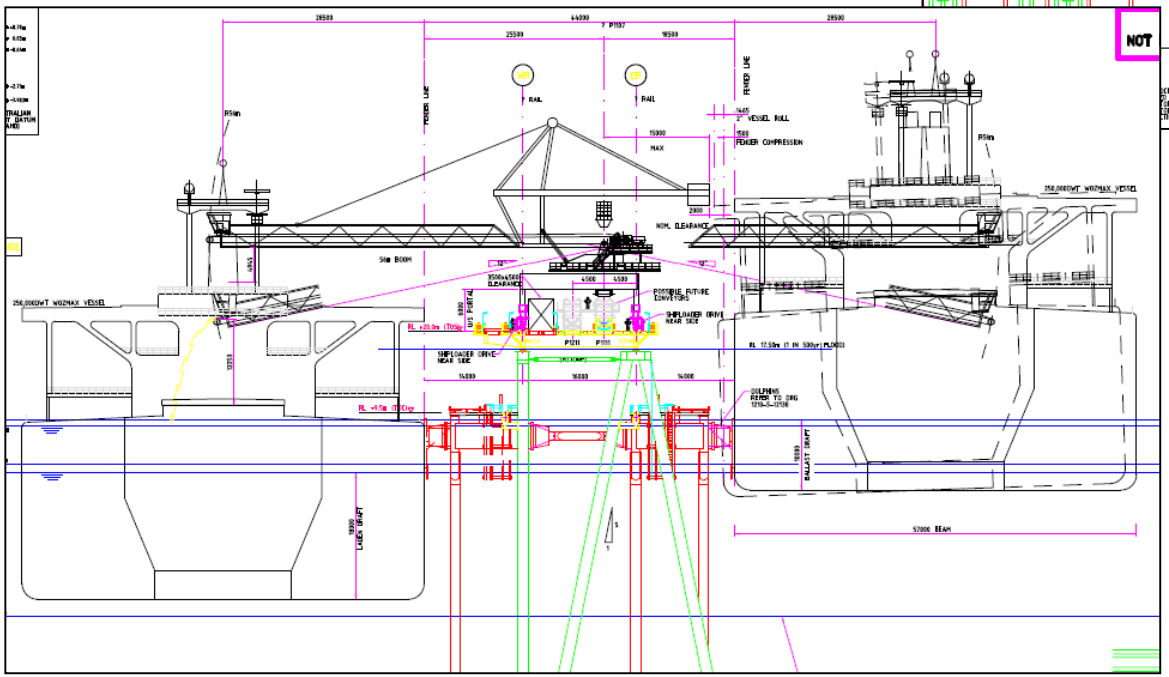
- Native seabed 6 - 8m CD
- Loading wharf located in dredged berth pocket with 21m CD depth
- Dredged departure channel



Wharf design

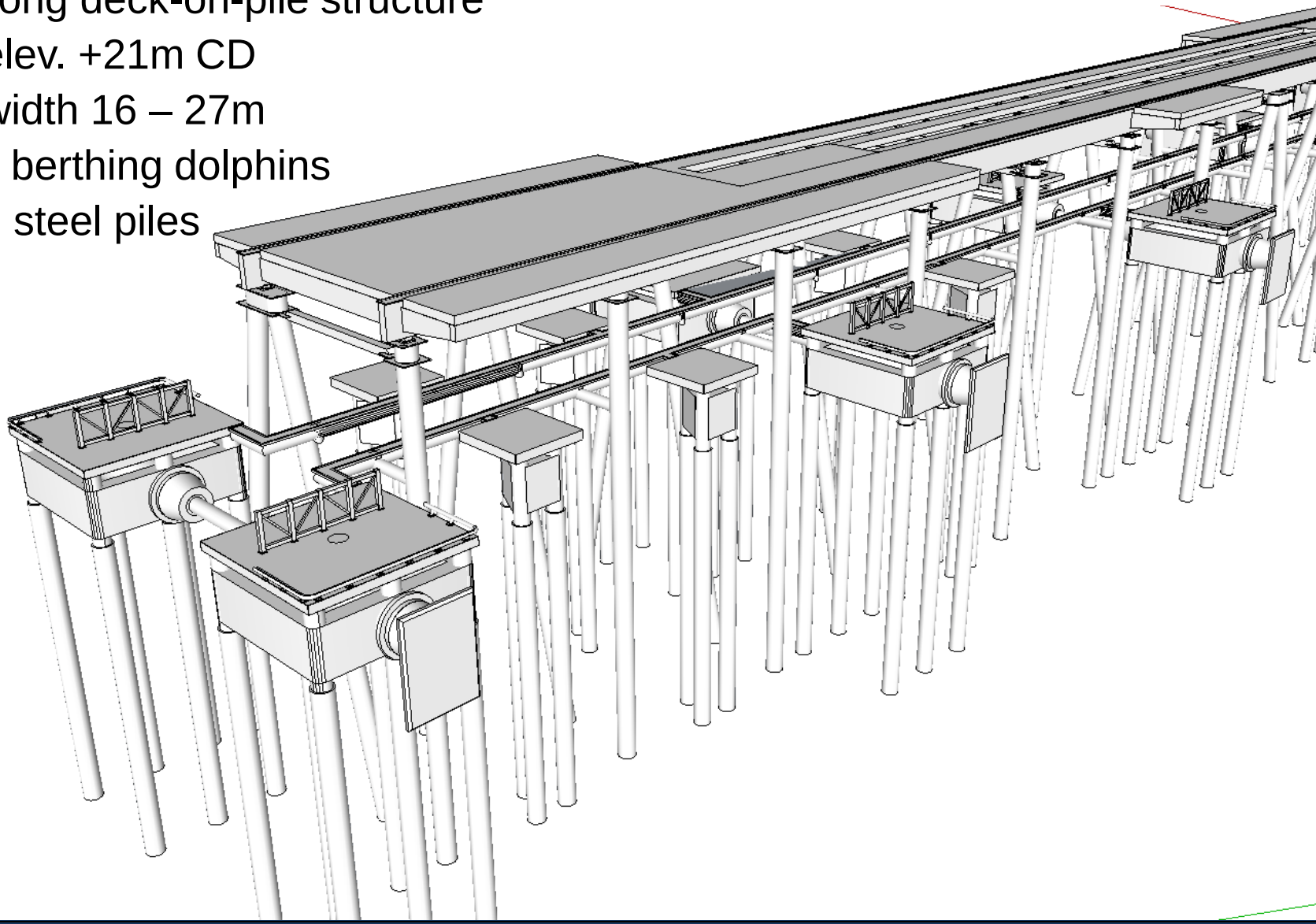
- Design by Flour SKM JV
- >1km long deck-on-pile structure
- Deck elev. +21m CD
- Deck width 16 – 27m
- 6 x 6m berthing dolphins
- ϕ 1.5m steel piles





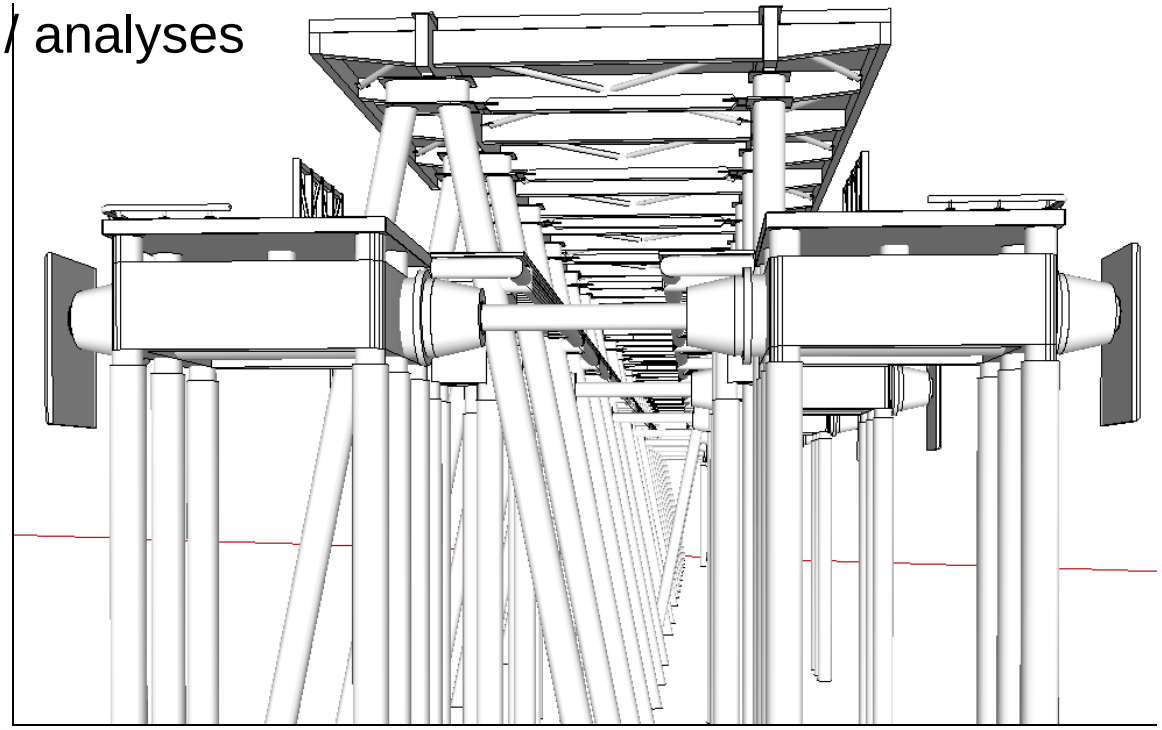
Wharf Design

- >1km long deck-on-pile structure
- Deck elev. +21m CD
- Deck width 16 – 27m
- 6 x 6m berthing dolphins
- ϕ 1.5m steel piles



Physical model study objectives

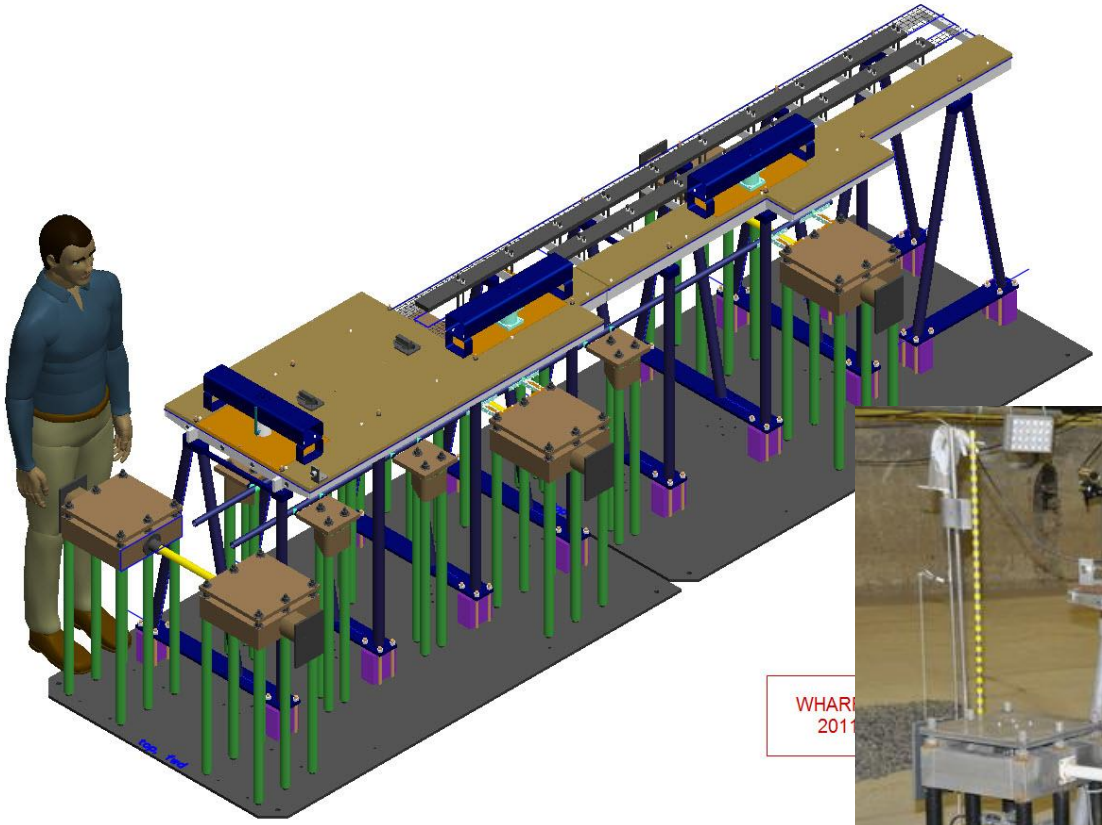
- Support design of new wharf structure
- Understand extreme wave – structure interactions
- Establish final deck elevation
- Establish wave pressures / loads for structure elements
- Establish wave pressures / loads for dolphins
- Validate CFD simulations / analyses



Physical modelling

- 63m x 14m x 1.5m wave basin at NRC, Ottawa, Canada
- 1/36 scale, Froude scaling
- Outer 135m portion of wharf / pier
- Adjustable deck elevation
- Uneven bathymetry (berth pocket)
- Long-crested irregular waves
- Rotating model (different wave headings)

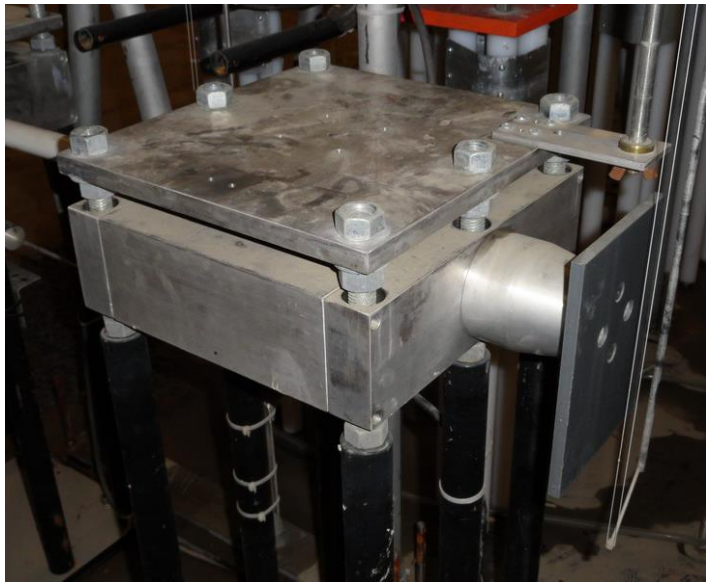
1/36 scale model wharf



CAD design of model structure

1/36 scale model wharf

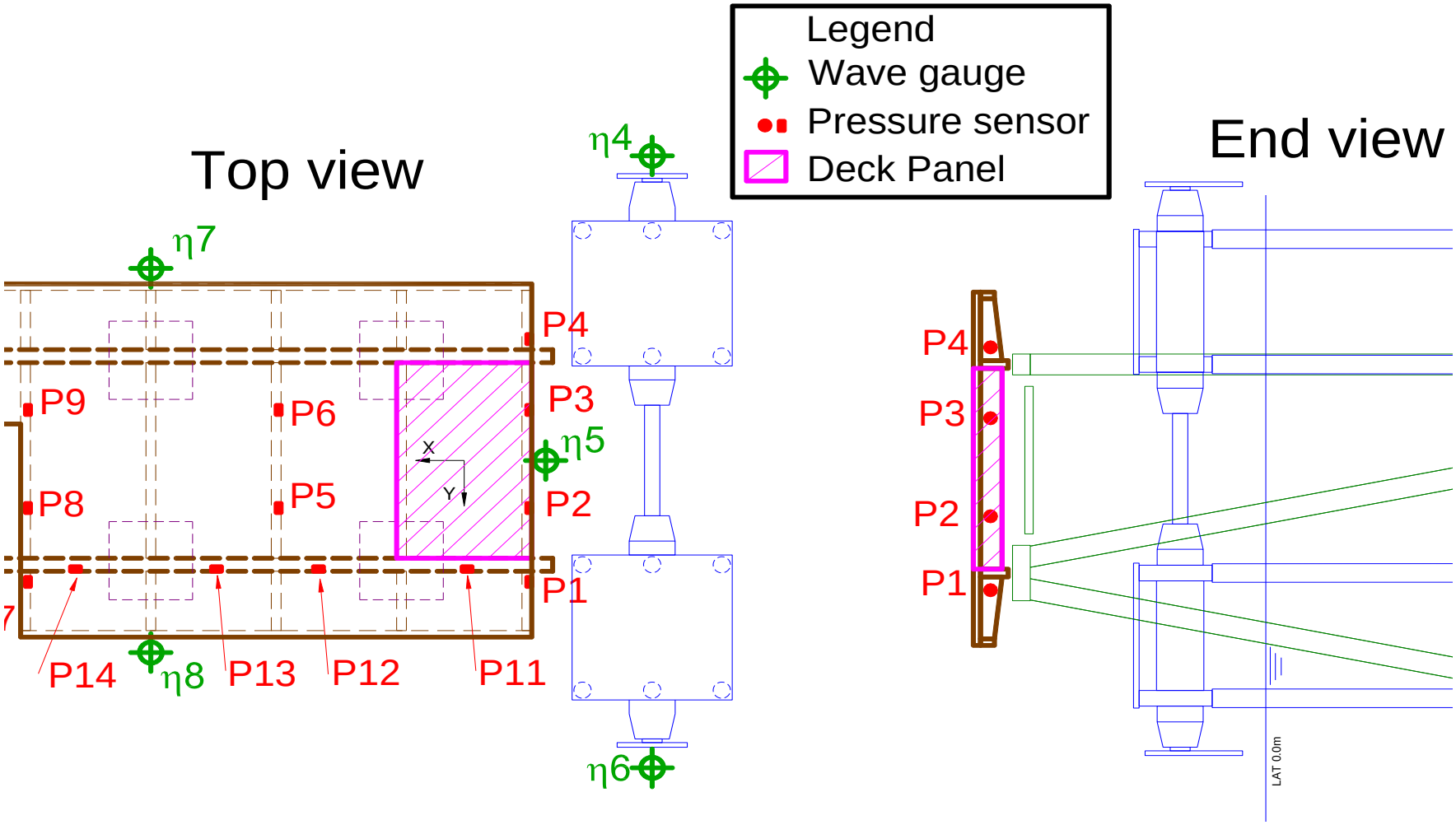
1:36 scale model wharf



Instrumentation systems

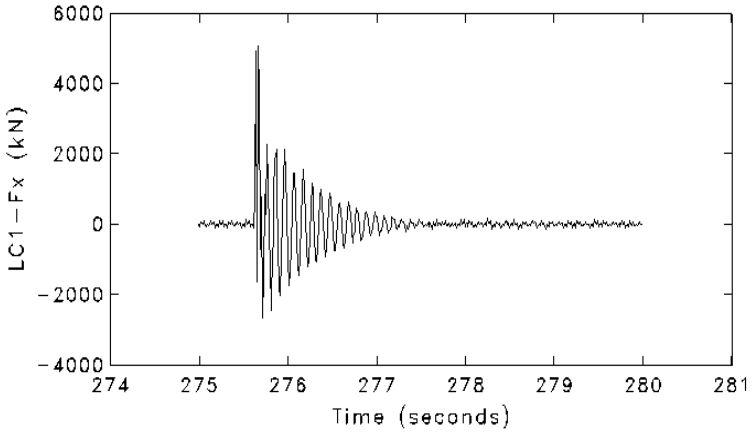
- 32 pressure sensors (deck beams, deck slab, dolphins)
- Forces & moments on structure elements (3 deck panels + 2 dolphins)
- 13 wave gauges
- 4 current meters
- Low and high-speed video

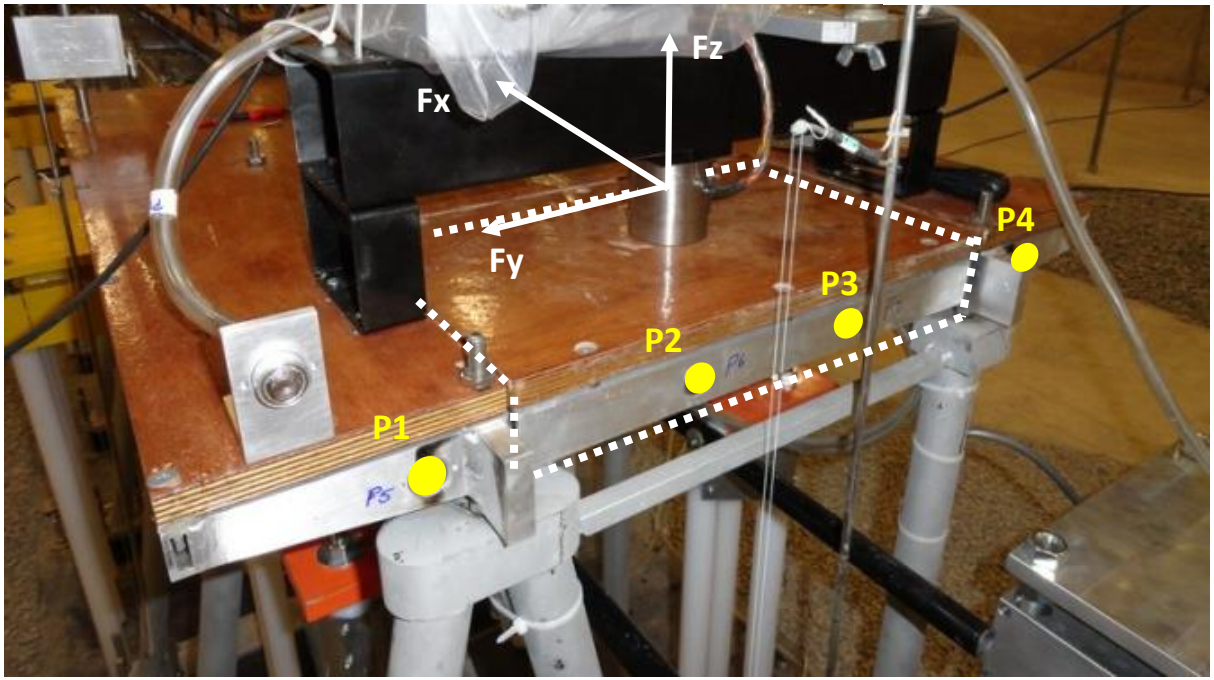
Typical sensor layout

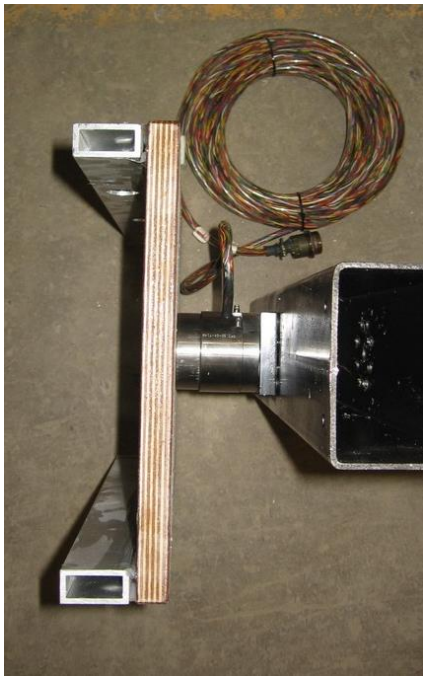


Deck panel 1

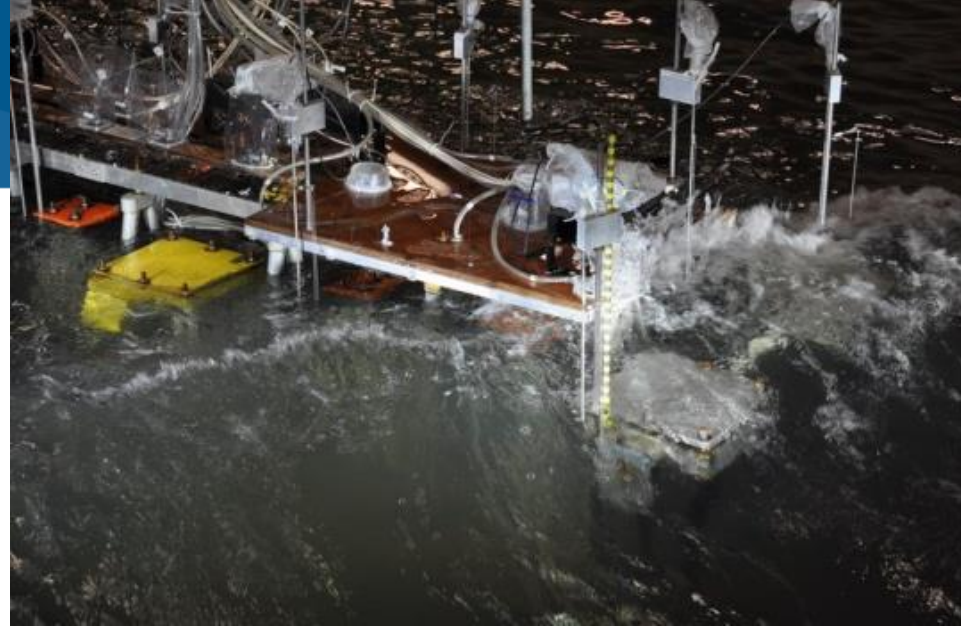
- Located at up-wave end of pier
- 6 d-o-f forces and moments
- Solid deck + 2 transverse beams
- A_X = 34 m^2, A_z = 145 m^2
- f_N > 10Hz full scale





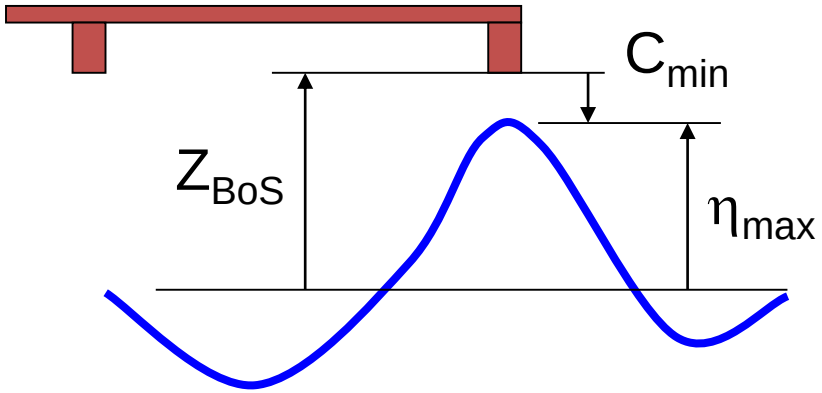


Test program

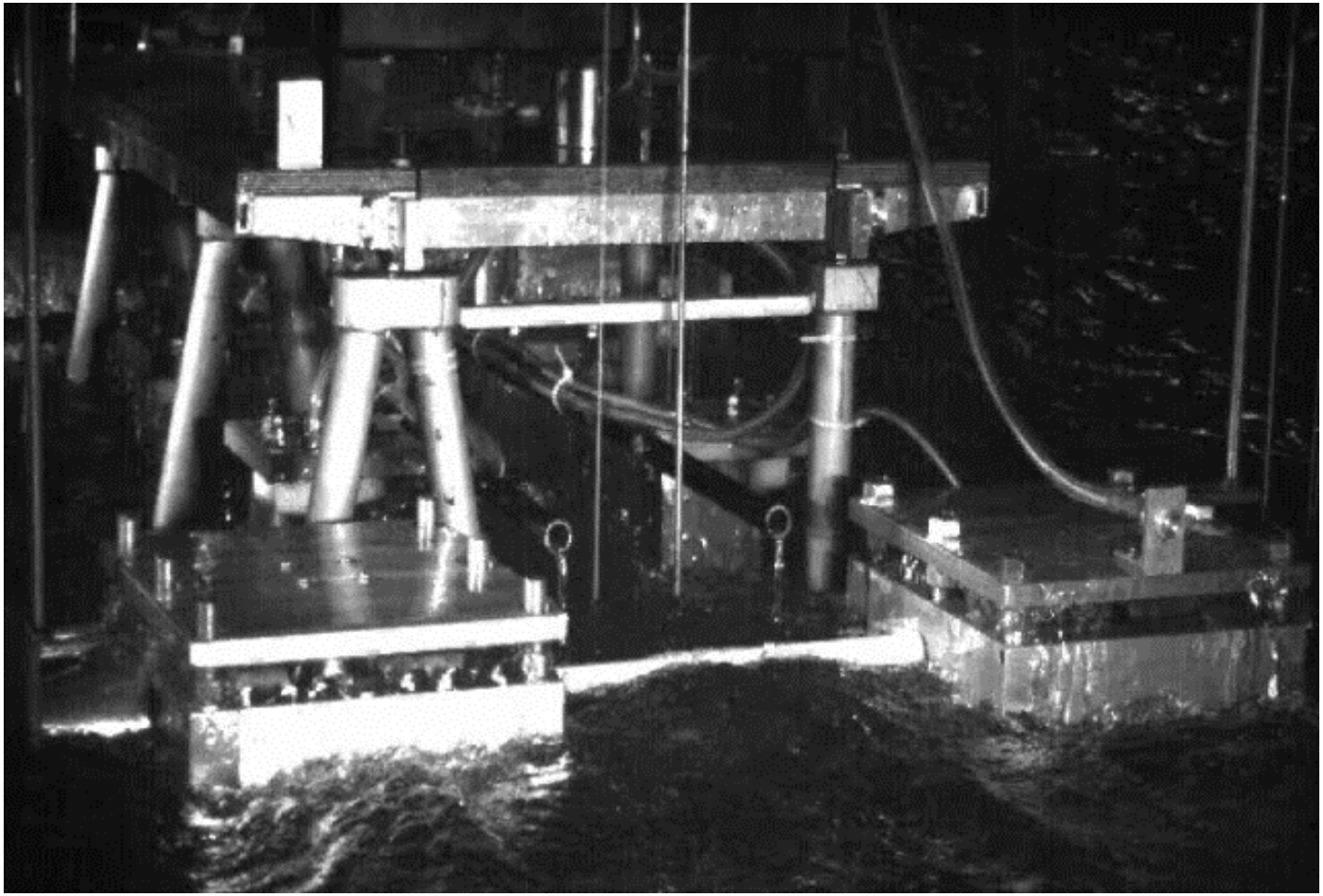


- 23 test series, >300 tests
- 3 wave directions: 0°, 25°, 45°
- Hs: 3.5 - 7.5m, Tp: 8 - 12s
- 180 min duration: (>1,000 waves)
- Deck elevation, Z_{BoS}: 13.9 - 18.5m
- Water level: 4.0 - 11.2m
- Min deck clearance, C_{min}: +3.7 to -5.7m
- Mooring dolphins in / out
- Berthing dolphins in / out

$$C^*_{\min} = C_{\min} / H_s = (Z_{BoS} - \eta_{\max}) / H_s$$



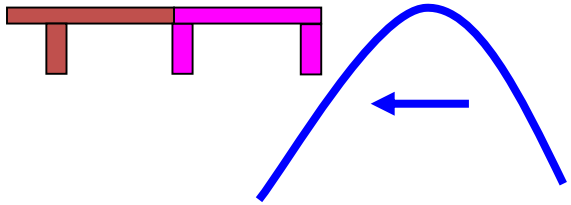
High-speed video, C_{min} ~ 0m

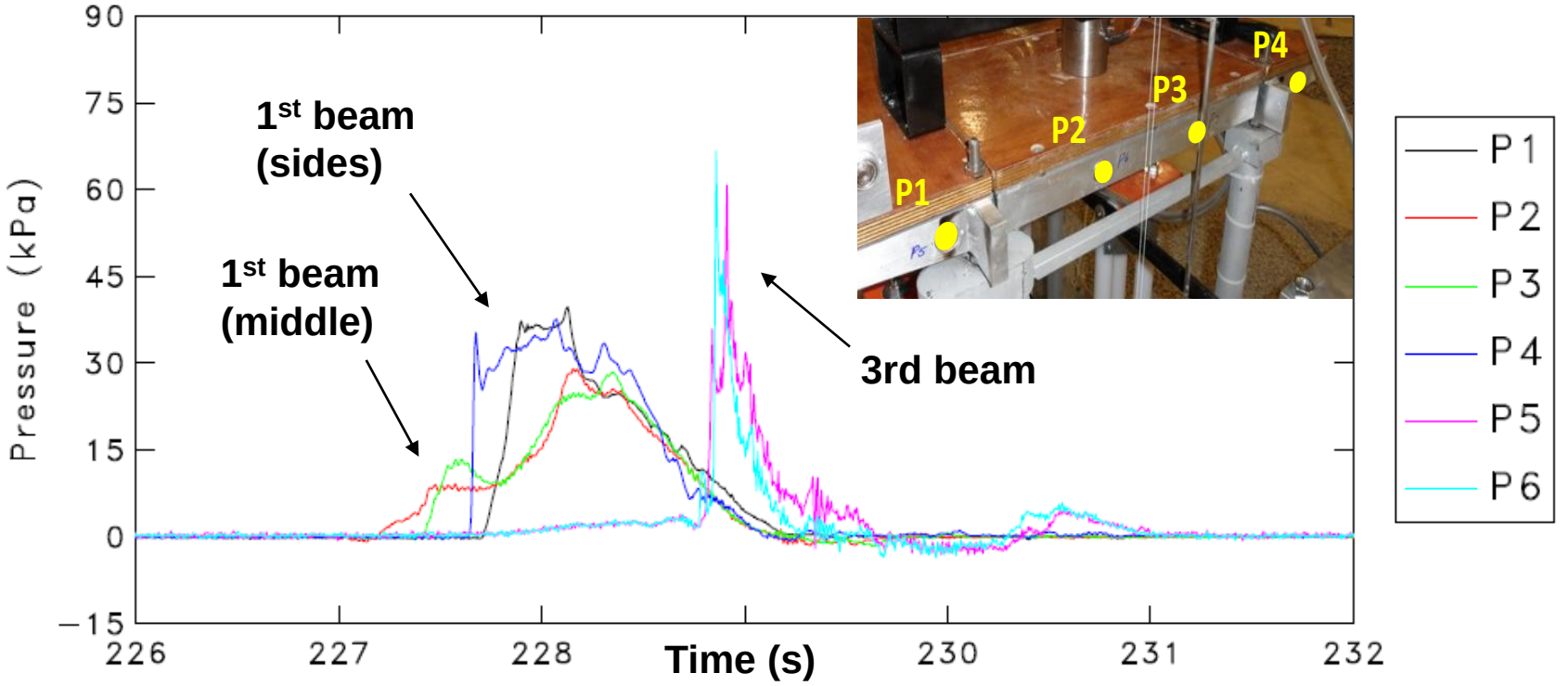


High speed video, C_{min} ~ -4m

Pressures on deck beams

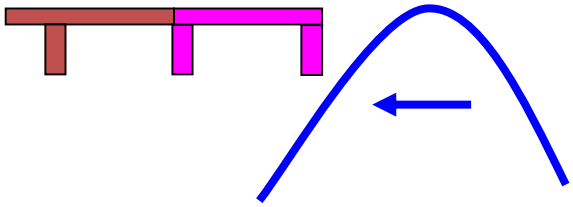
- Largest pressures are highly impulsive
- High spatial variability
- Peak pressure decreases with increasing area
- Confinement → higher peak pressure

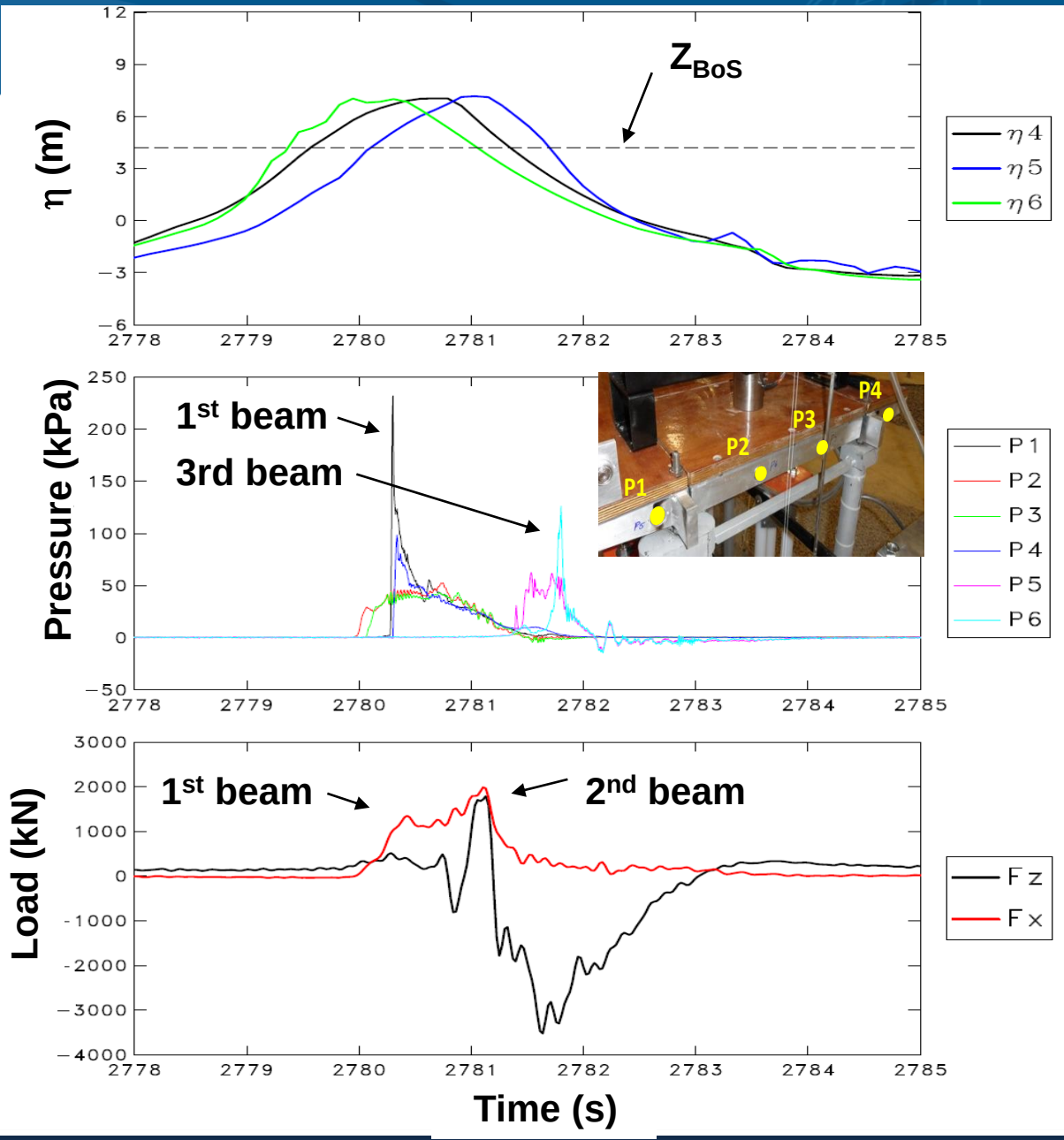




Typical loading event

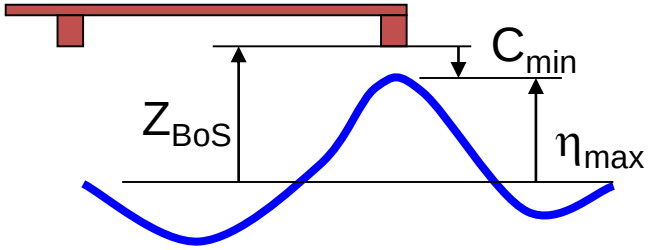
- Horizontal & uplift forces maximized when water contacts second transverse beam

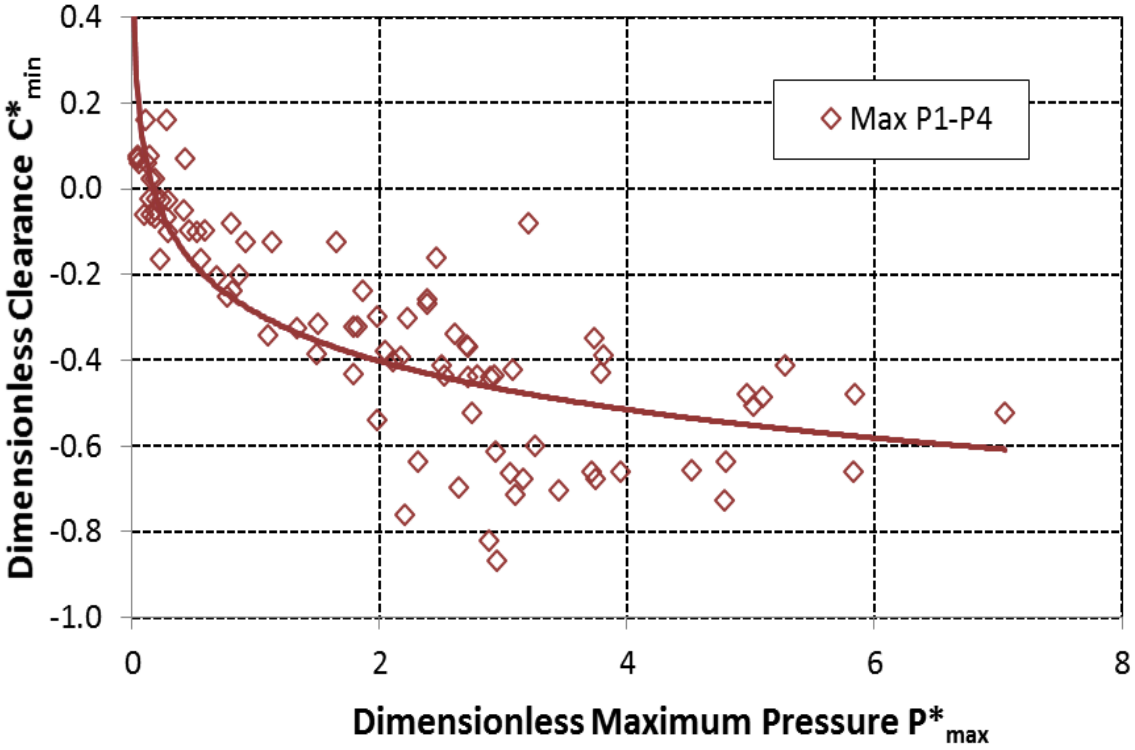




Peak pressure on 1st deck beam - variation with deck clearance

- Non-dimensional pressure, $p^* = p/\rho g H_s$
- Non-dimensional deck clearance: $C^*_{\min} = C_{\min} / H_s = (Z_{BoS} - \eta_{\max}) / H_s$
- p^*_{max} reaches maximum for C^*_{min} ~ -0.6





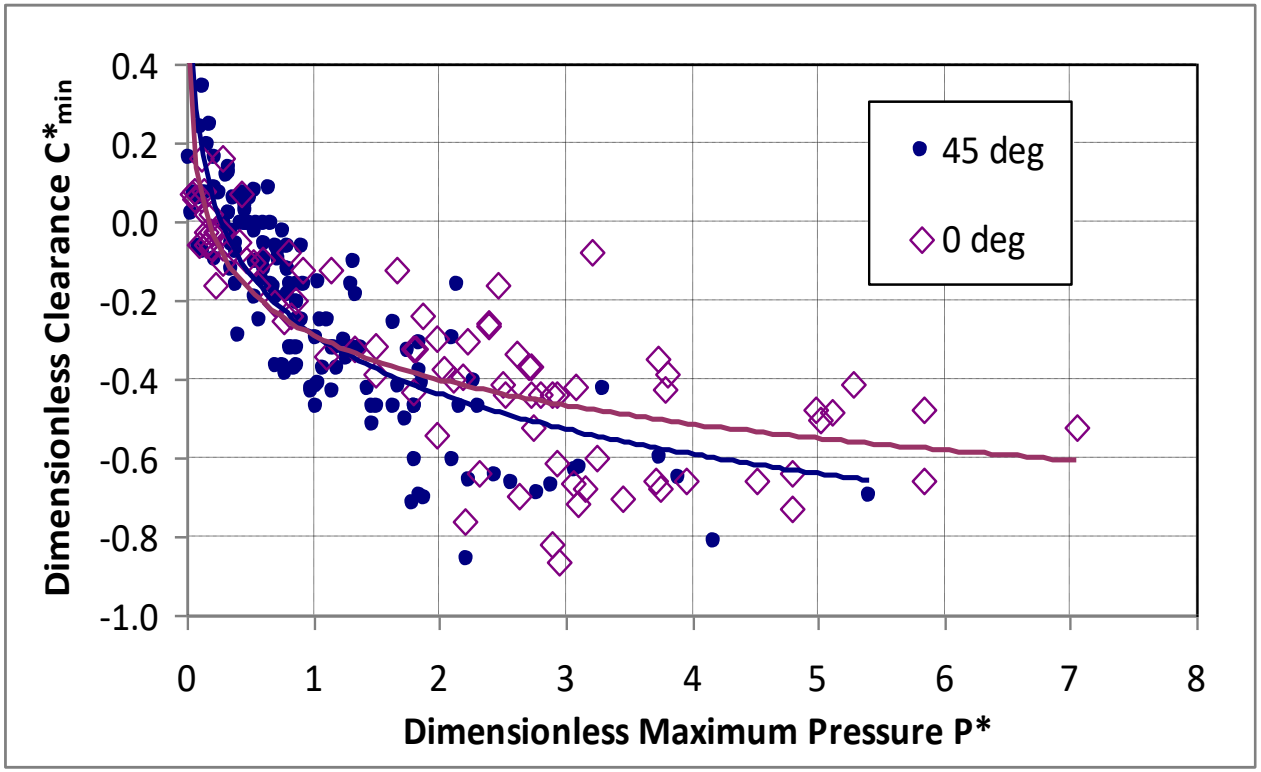
$$C^*_{min} = a - (p^*_{max})^b$$

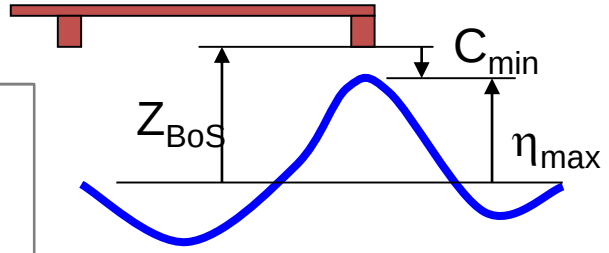
$$p^*_{max} = (a - C^*_{min})^{1/b}$$

$$a = 0.7, \qquad b = 0.14$$

Influence of wave direction on peak pressure

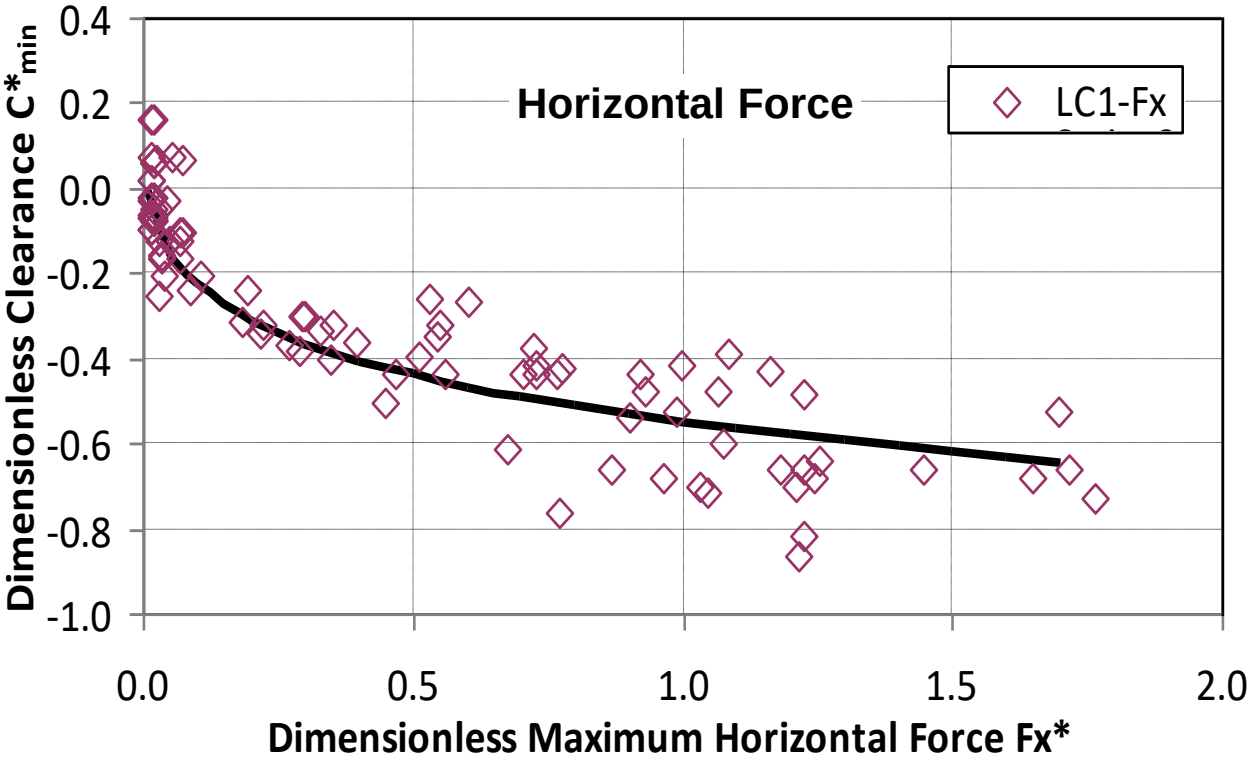
- Very similar trend for oblique waves
- Slightly reduced peak pressure for $C^*_{min} < -0.5$

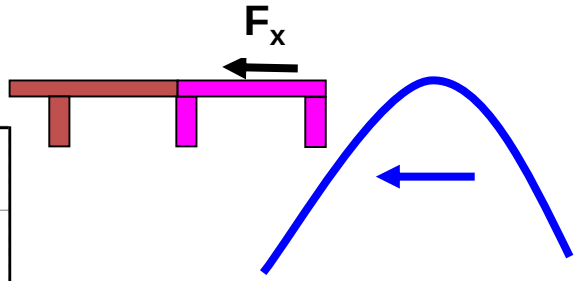




Peak horizontal force on deck panel 1 - variation with deck clearance

- Dimensionless horizontal force: $F^* = F/\rho g H_s A_x$, A_x=34m^2
- Peak horizontal force increases rapidly for C^*_{min} < -0.2





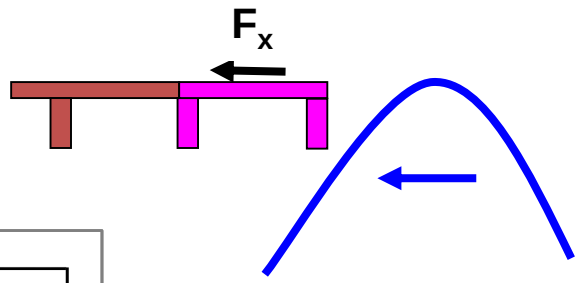
$$C^*_{\min} = a - (F^*)^b$$

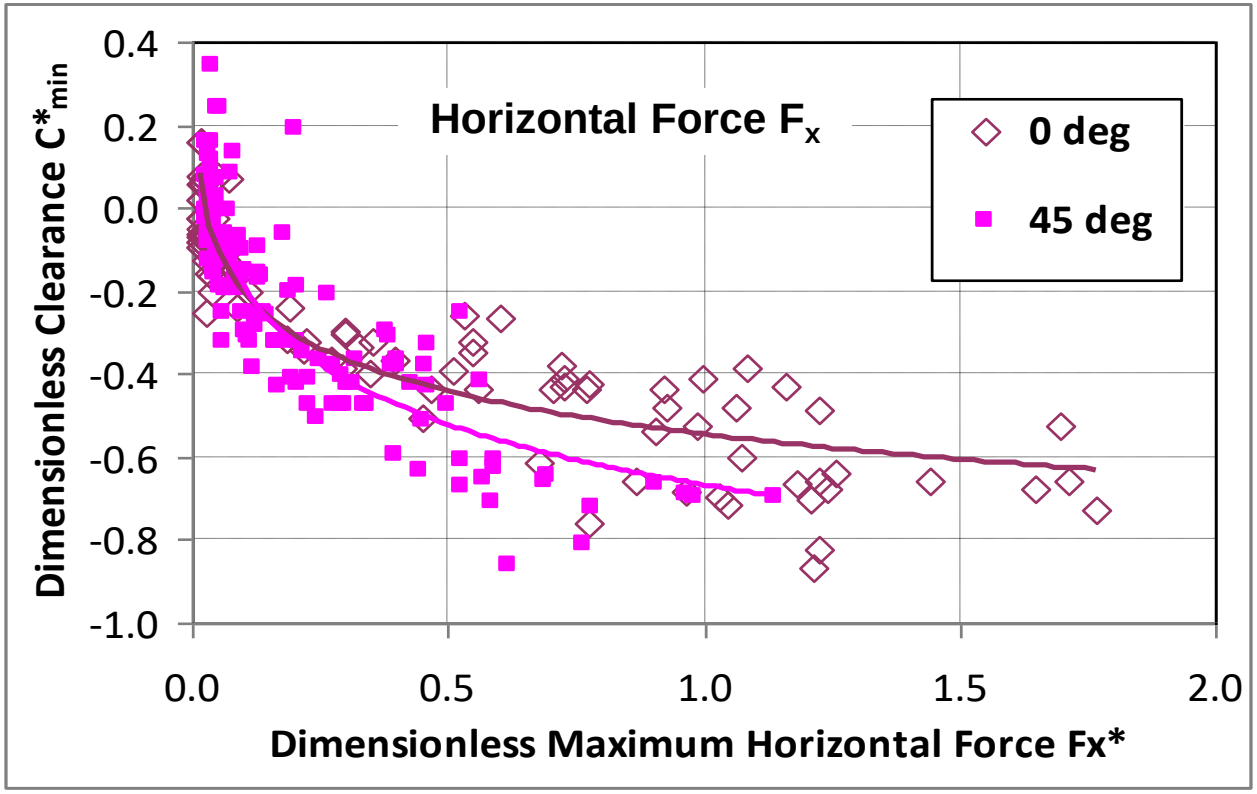
$$F^* = \left(a - C^*_{\min}\right)^{1/b}$$

a = 0.45, b = 0.17

Peak horizontal force Fx on deck panel 1 - influence of wave direction

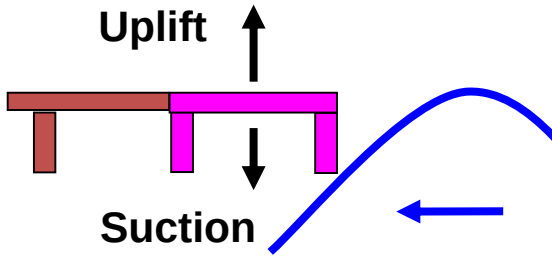
- Very similar trend for oblique waves
- Smaller peak loads for $C^*_{min} < -0.5$





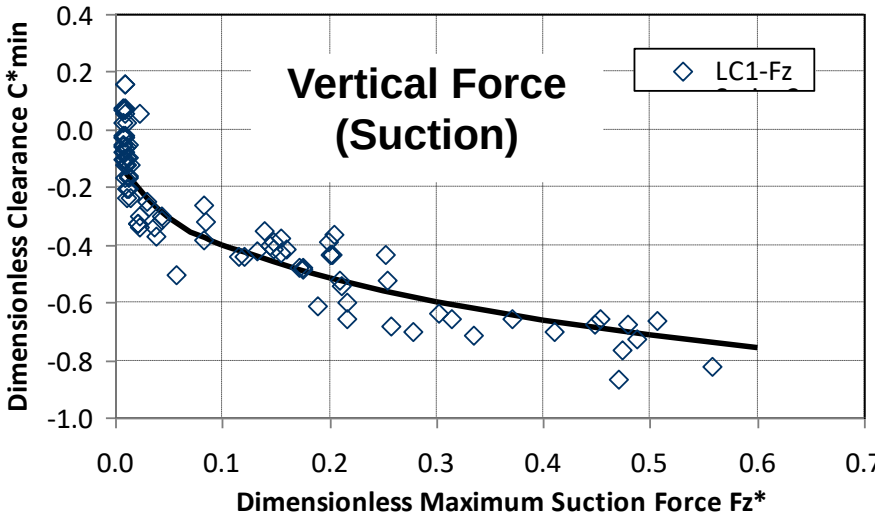
Peak vertical force on deck panel 1 - variation with deck clearance

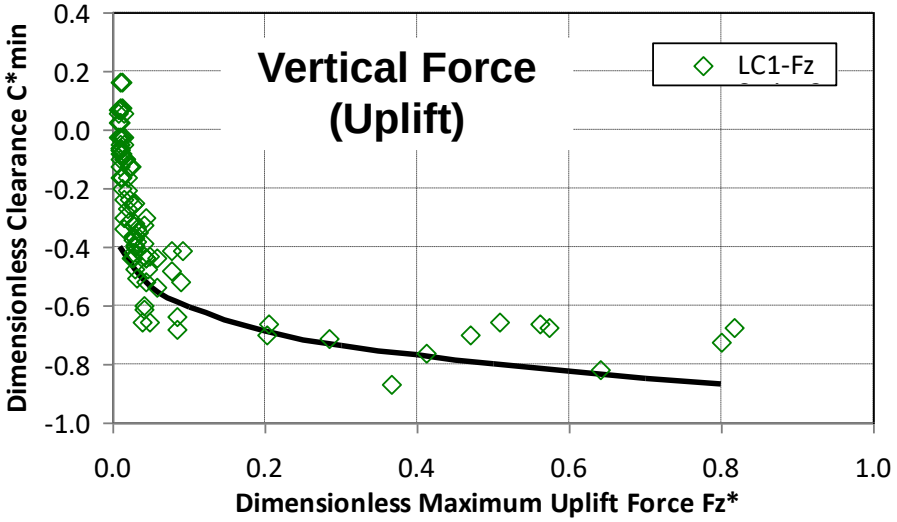
- Dimensionless vertical force: $F^* = F/\rho g H_s A_z$, A_z=145m^2
- Peak suction force increases rapidly for $C^*_{min} < -0.3$
- Peak uplift force increases rapidly for $C^*_{min} < -0.6$
- Suction > Uplift for $C^*_{min} > -0.8$



$$C^*_{\min} = a - (F^*)^b \qquad F^* = \left(a - C^*_{\min}\right)^{1/b}$$

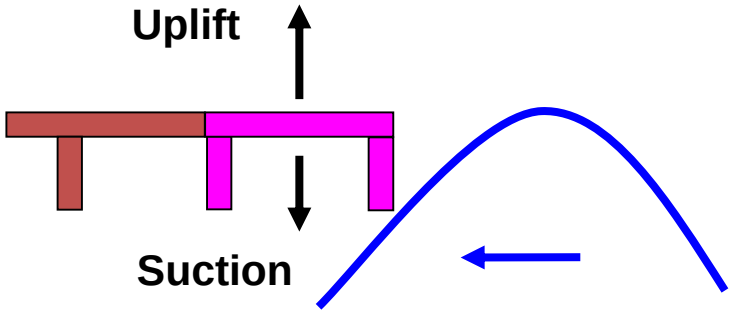
Force component	a	b
F_x*	0.45	0.17
F_z* uplift	0.10	0.15
F_z* suction	0.10	0.30

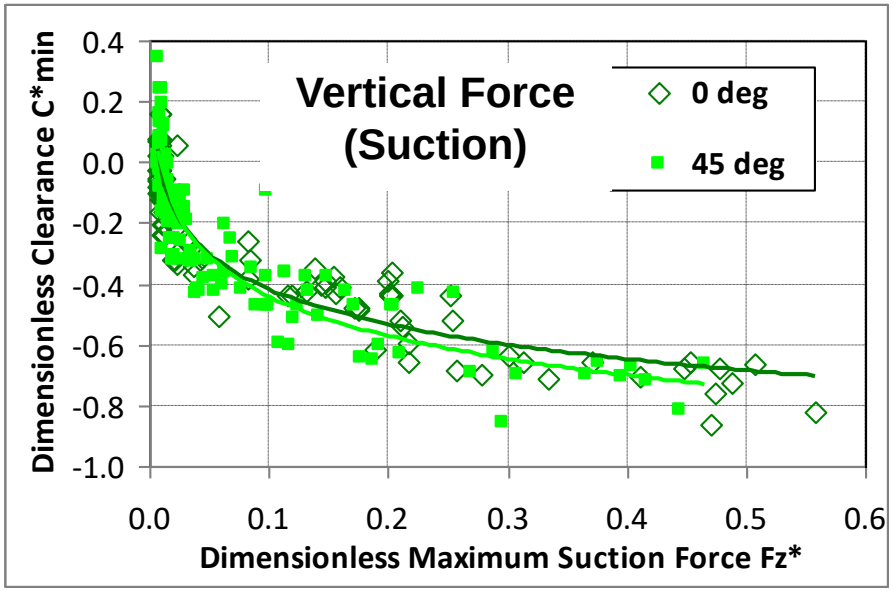


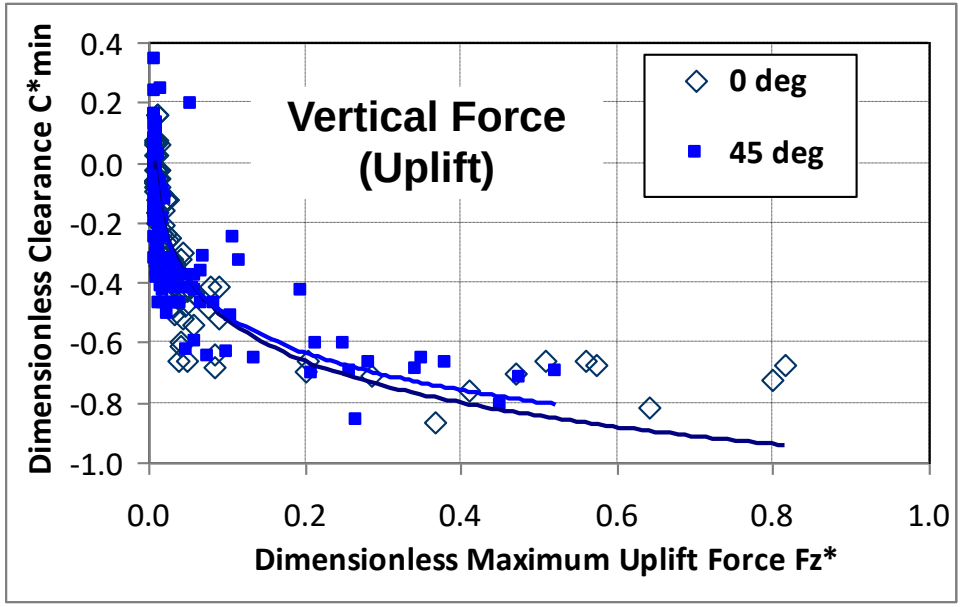


Peak vertical force on deck panel 1 - influence of wave direction

- Identical results for oblique waves

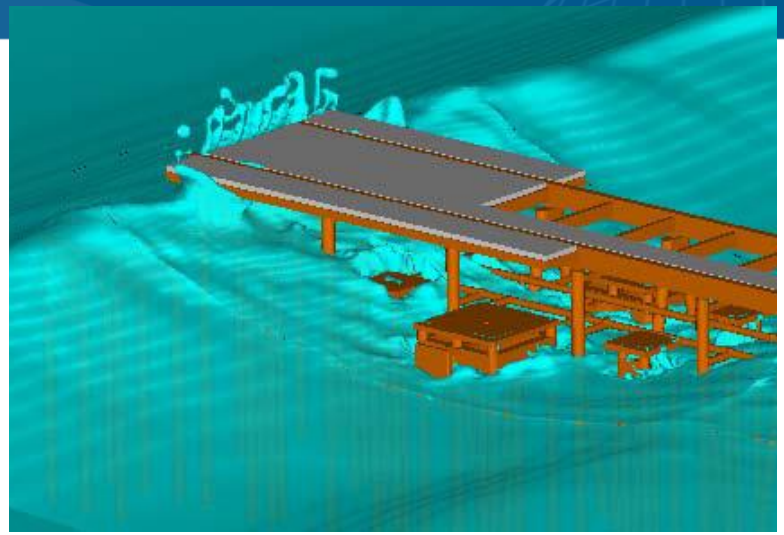


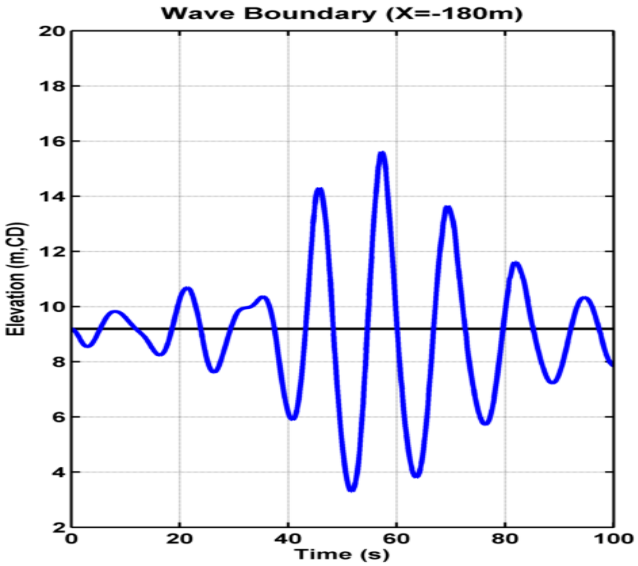


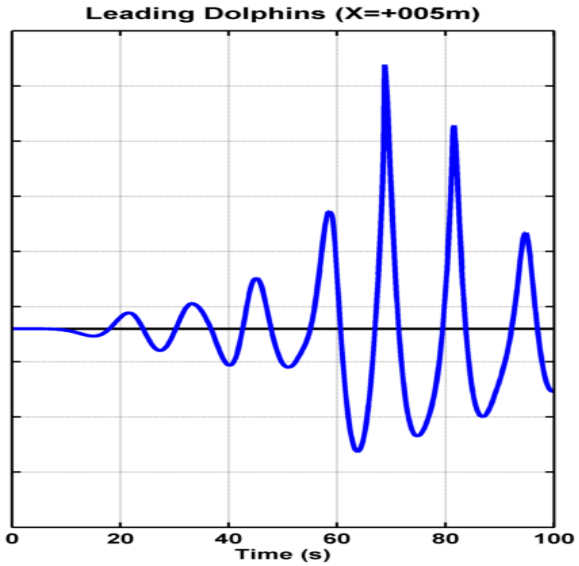


CFD Simulations

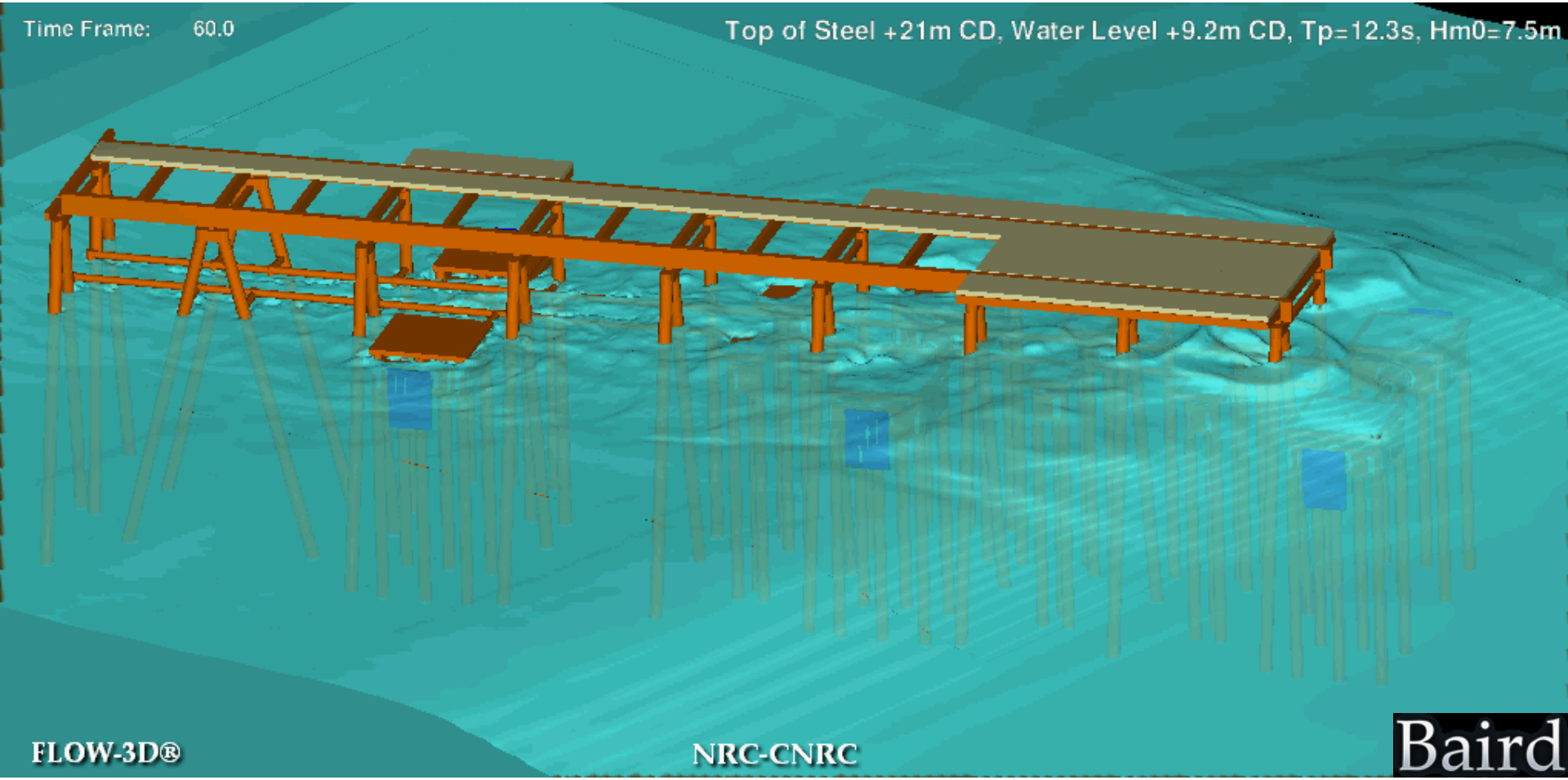
- FLOW-3D® model
- ~7.8 million cubic cells
- 4 nested grids
  (0.5m, 1m, 2m, 4m)
- 90s simulations of nonlinear wave groups







CFD Simulation, waves from 25°



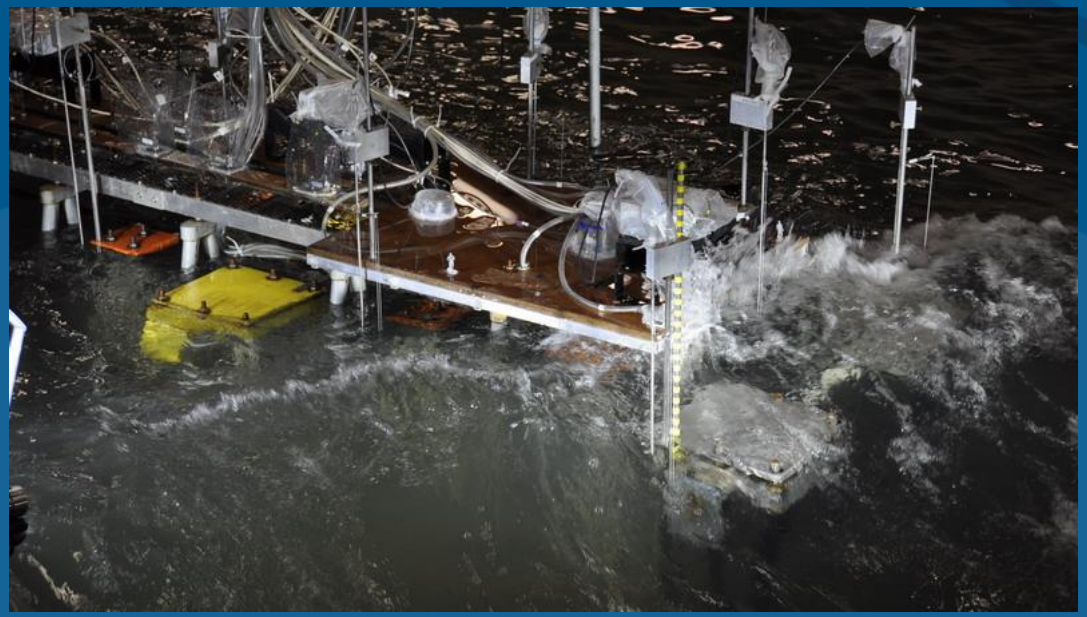
Conclusions

- Pressures and forces due to wave-in-deck flows are complex and highly variable
- Peak pressures are impulsive and localized
- Confinement increases peak pressures
- Peak wave-in-deck loads and pressures increase with decreasing deck clearance in a predictable manner

$$F^* = \left(a - C^*_{\min}\right)^{1/b}$$

- Very similar trends in variation of peak pressure/load with deck clearance for head-on and oblique waves
- Scale model tests useful for establishing pressures and loads for design, but caution advised due to uncertainties related to scaling

Thanks for listening!



Baird

BHP

Andrew Cornett PhD PEng
Ocean, Coastal & River Engineering
National Research Council Canada
Andrew.Cornett@nrc-cnrc.gc.ca