EFFECT OF OVERFLOW NAPPE NON-AERATION ON TSUNAMI BREAKWATER FAILURE

Photo: PARI

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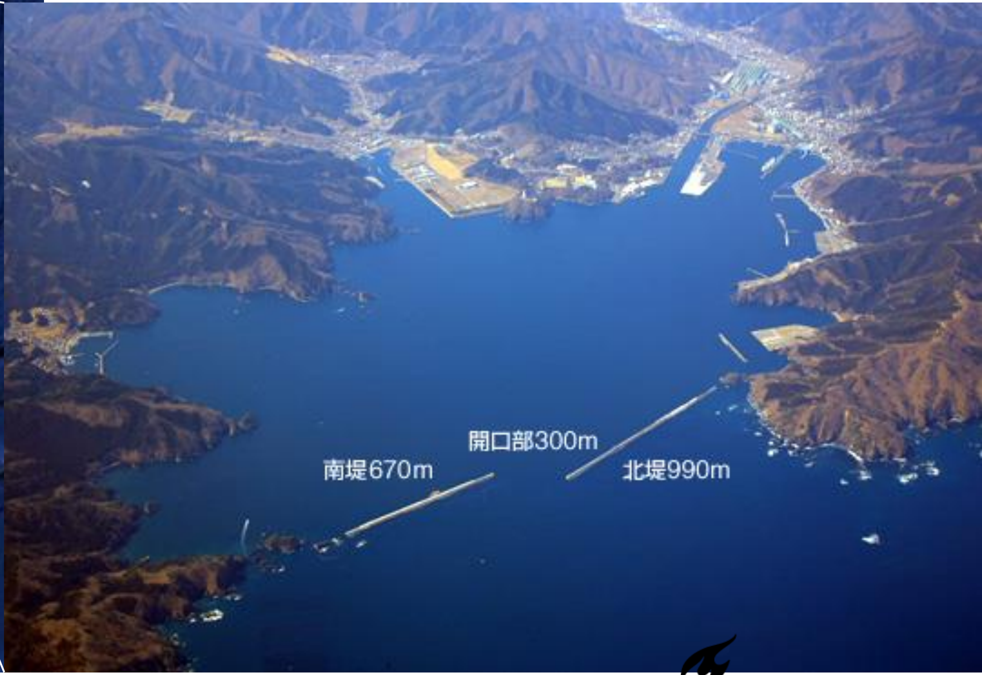
Outline

- Motivation
  - Kamaishi breakwater during the 2011 Japan tsunami
  - CFD simulation of forces on the Kamaishi breakwater
- Cavity sub-pressure
  - Laboratory experiment
  - Integral conservation of momentum
- Necessary steps

Kamaishi Bay

Source: MLIT



Kamaishi breakwater plan

図4－2 釜石港湾口地区防波堤（南堤）深部２区標準断面図

ケーソン諸元（１）

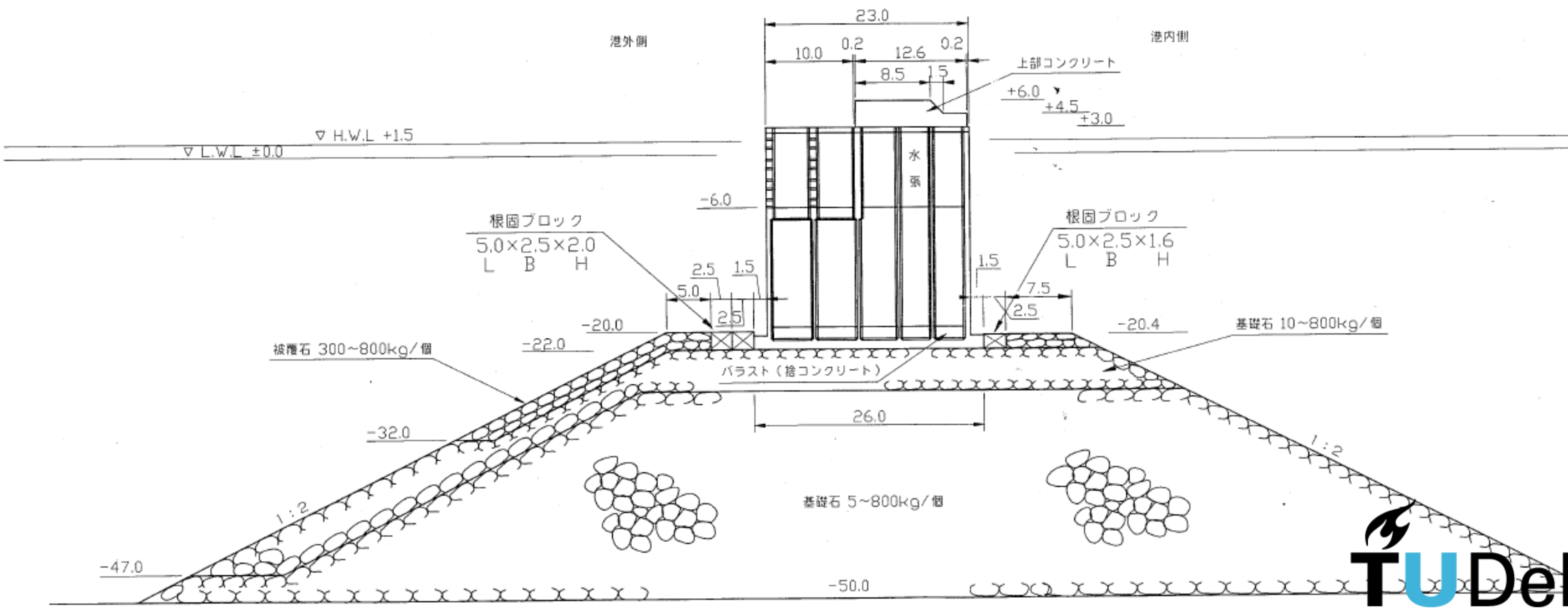
	体積（m³）	重量（tf）
ケーソン	4,243.52	10,396.62
カウンター材	608.92	1,400.51
中詰材	7,462.57	14,178.89
水張り	2,480.54	2,554.95
捨コンクリート	452.85	1,041.55
上部工	983.25	2,261.48
合計		31,834.00

ケーソン諸元（2）

寸法(m)	B 26.0(23.0)×L 30.0×H 25.0
重量(tf)	11,849(止水蓋 51.4tf 含む)
喫水(m)	16.48m

２工区　設置水深　-22.0m　矩形

安定計算結果		波圧時	地震時外→内	地震時内→外
滑動		1.313>1.2	(0.926)	(0.926)
転倒		1.735>1.2	1.675>1.1	1.892>1.1
端趾圧	P1（t/m²）	66.42<70	76.14<80	57.62<80
	作用幅B（m）	14.57	14.76	19.50
支持力	H.W.L 時	1.223>1.0	―――	―――
	L.W.L 時	1.244>1.0	―――	―――
円形すべり		1.666>1.2	―――	―――



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Damage to breakwater

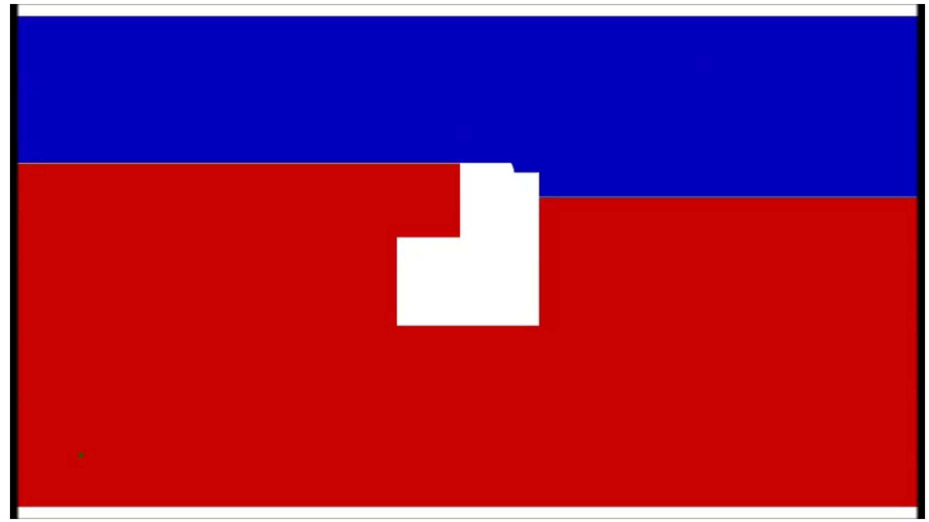
- Caissons displaced toward land
- Rubble mound experienced scour (Arikawa et. al., 2011)
  - From overtopping flow
  - From flow through gap between caissons
- Bearing capacity exceedance (Bricker et al., 2013)

Multibeam SONAR - Tomita et. al., 2012

図-1　東北地方太平洋沖地震津波後の釜石湾口防波堤周辺の海底地形図

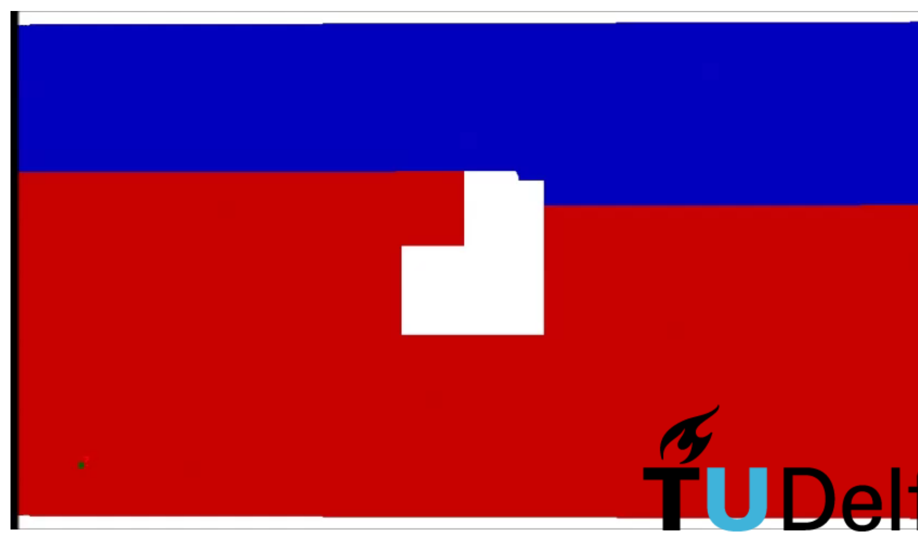
OpenFOAM free surface simulation (Bricker et al., 2013)

Standard k-epsilon turbulence model



- However, experiments (Mitsui et al, 2012) show the overtopping jet does not pull up close to the caisson.
- Possible reason: Continuous eddy viscosity across air-water interface used by VOF allows too much entrainment of air into the impinging jet (an area of strong turbulence).
- Solution: reduce eddy viscosity at interface by neglecting all turbulence in the air phase.

Standard k-epsilon turbulence model in water, no turbulence in air



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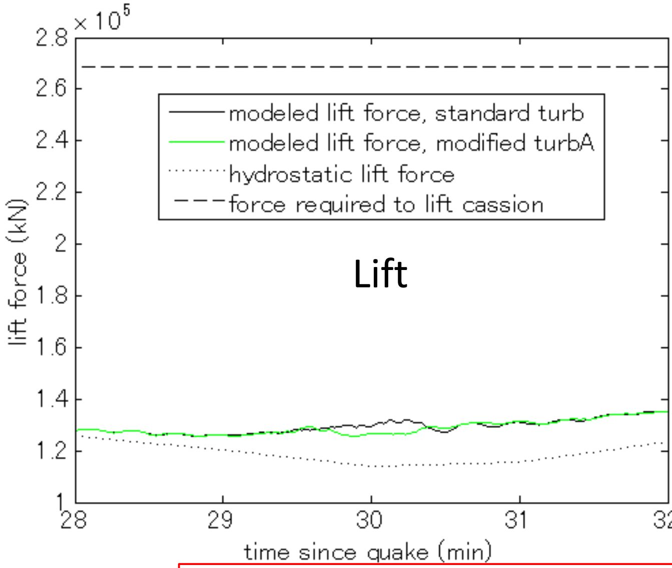
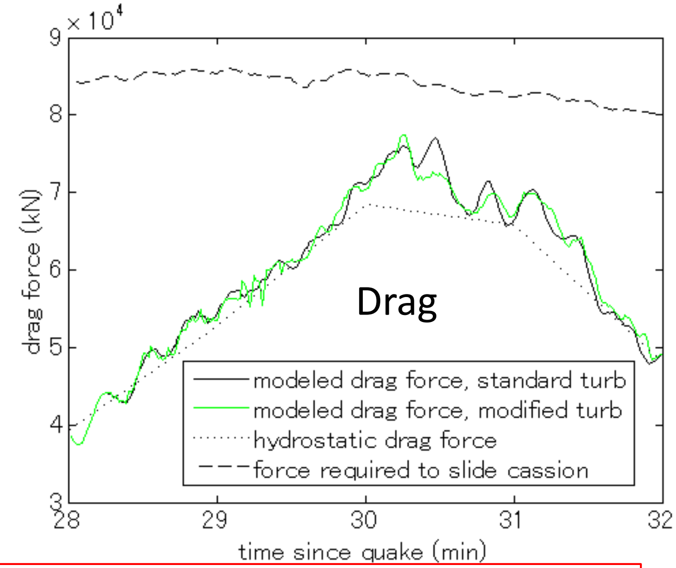
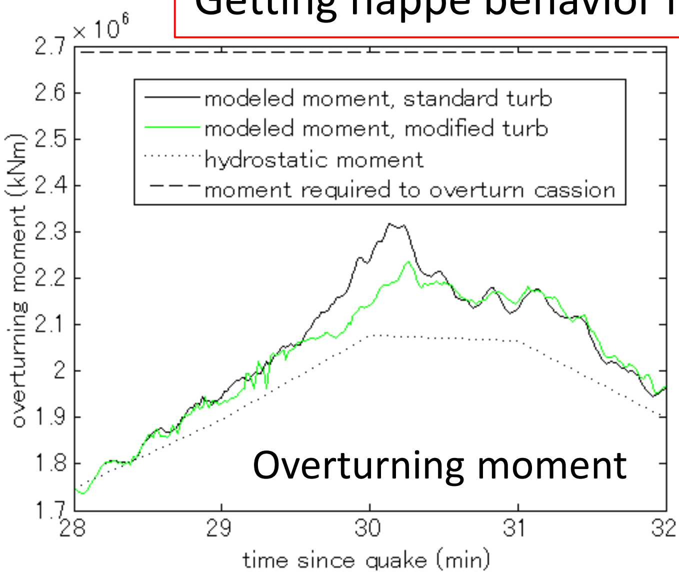
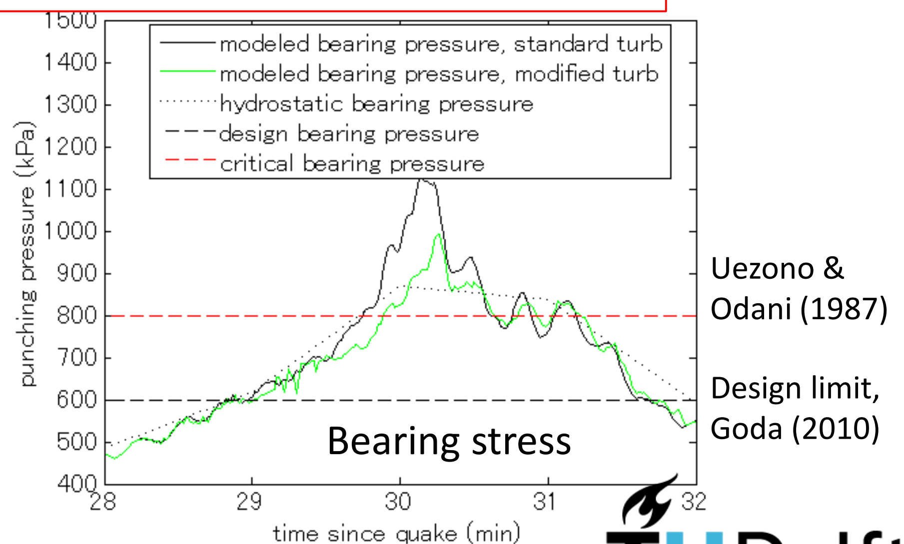
OpenFOAM simulation result (Bricker et al., 2013)





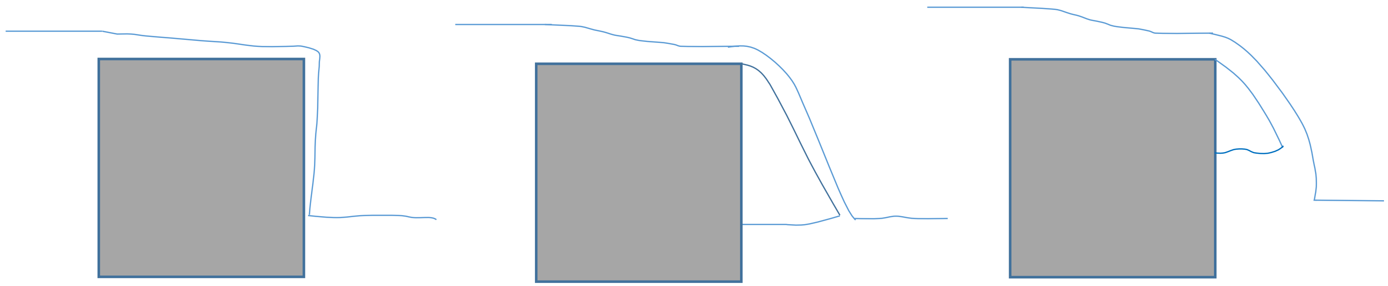
Getting nappe behavior right is important for getting forces right!



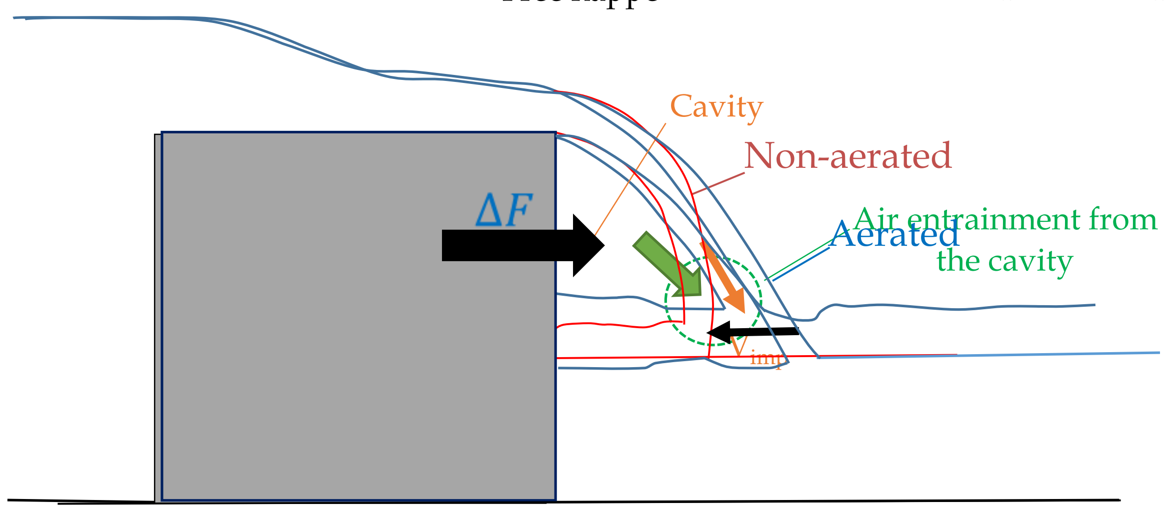


Nappe types

Development of ΔF

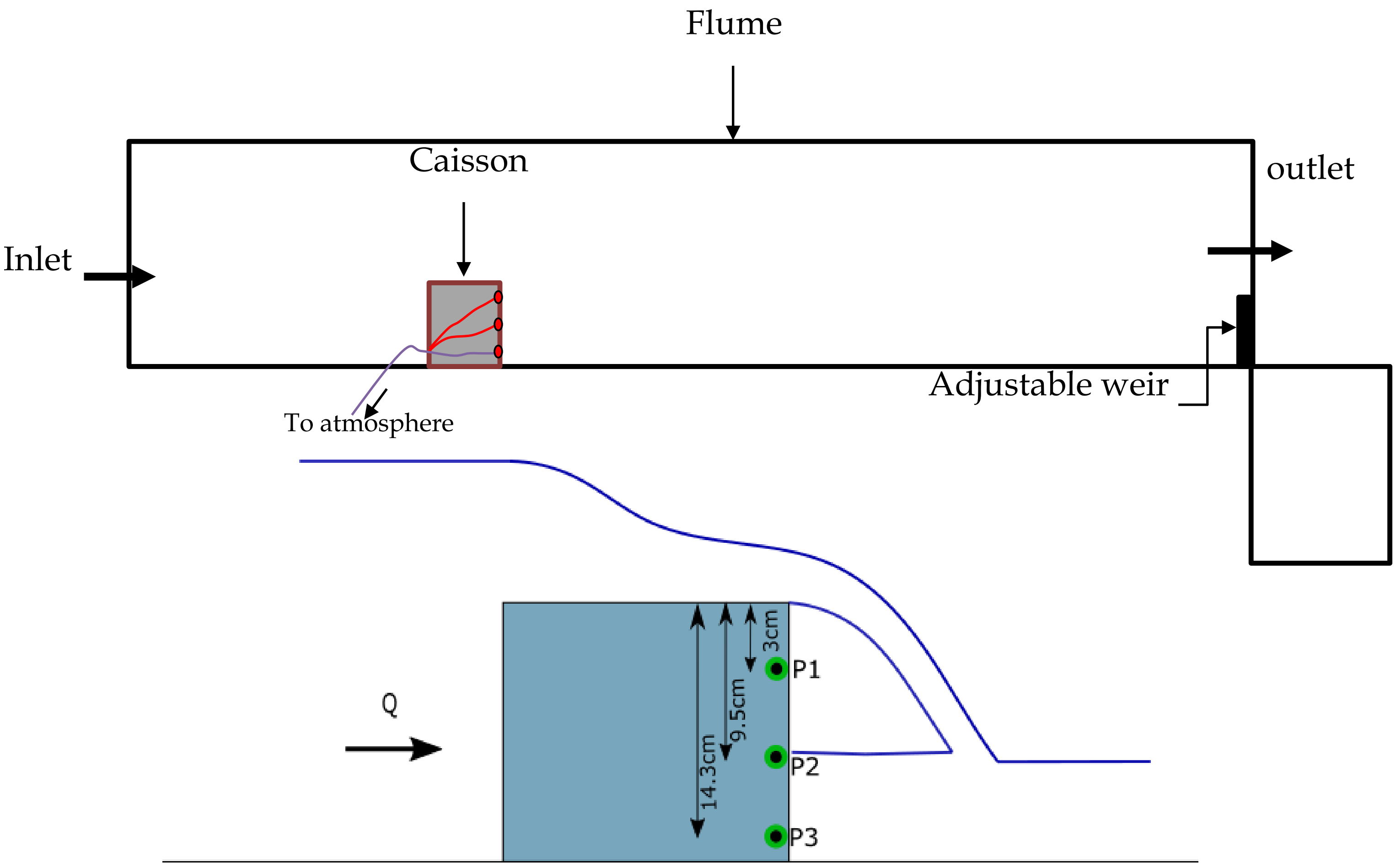


Clinging nappe Free nappe Depressed nappe



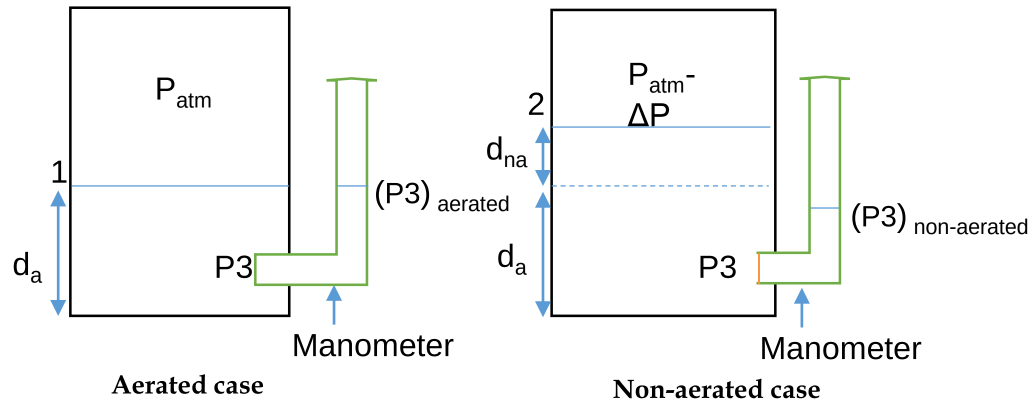
ΔF will increase the sliding force acting on the caisson affecting the stability

Laboratory physical model



Geometric scale= 1:150

Measured nappe sub-pressure

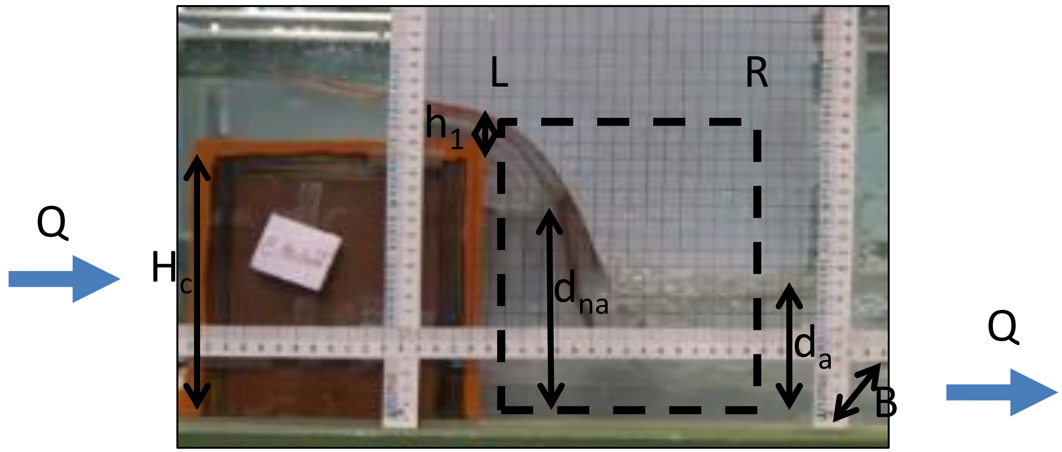


$$d_a \rho g + P_{atm} = (P_3)_{aerated} + P_{atm}$$

$$d_a \rho_{eff} g + d_{na} \rho_{eff} g + (P_{atm} - \Delta P) = (P_3)_{non-aerated} + P_{atm}$$

$$\Delta P = \frac{\rho_{eff}}{\rho} (P_3)_{aerated} - (P_3)_{non-aerated} + d_{na} \rho_{eff} g$$

Theoretical nappe sub-pressure from momentum conservation over integral control volume



x-direction integral momentum equation over control volume

$$\overrightarrow{F_s} + \overrightarrow{F_b} = \frac{d}{dt}\int_{CV} \vec{u}\rho dV + \int_{CS} \vec{u}\rho\vec{u}\cdot\overrightarrow{dA}$$

$$\int_{CS} \vec{u}\rho\vec{u}\cdot\overrightarrow{dA} = \rho Q(u_R - uL) \qquad u_R = \frac{Q}{Bd_a} \qquad u_L = \frac{Q}{Bh_1}$$

$$F_{sL} = \int_0^{d_{na}} \rho_{eff}\, gB(d_{na} - z)dz \;-\; \Delta P B H_c + \int_0^{h_1} \rho\, gB(h_1 - z)dz$$

$$F_{sR} = -\int_0^{d_a} \rho\, gB(d_a - z)dz$$

$$\Delta P = \frac{\frac{1}{2}\rho g B({h_1}^2 - da^2) + \frac{1}{2}\rho_{eff} g B {d_{na}}^2 - \frac{\rho Q^2}{B}\left(\frac{1}{d_a} - \frac{1}{h_1}\right)}{BH_c}$$

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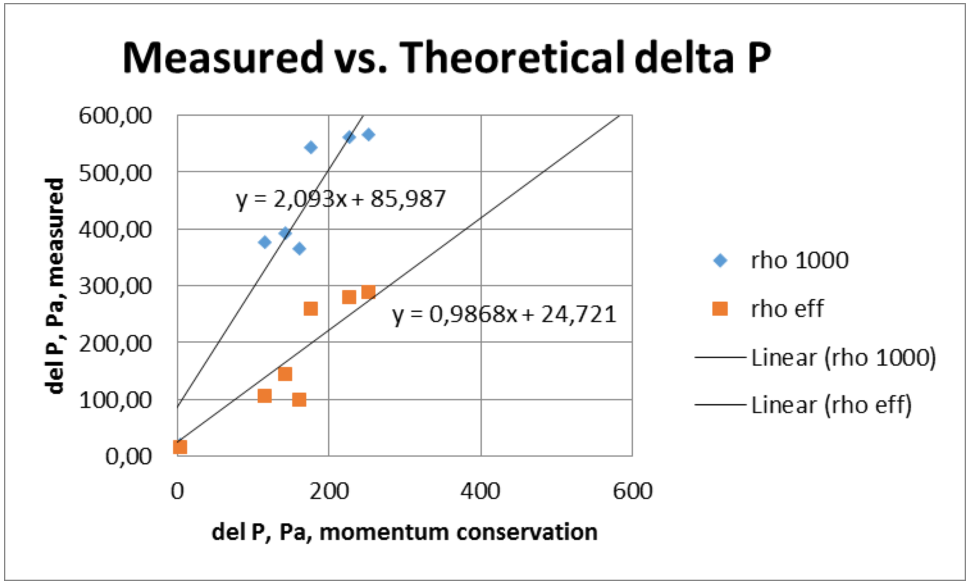
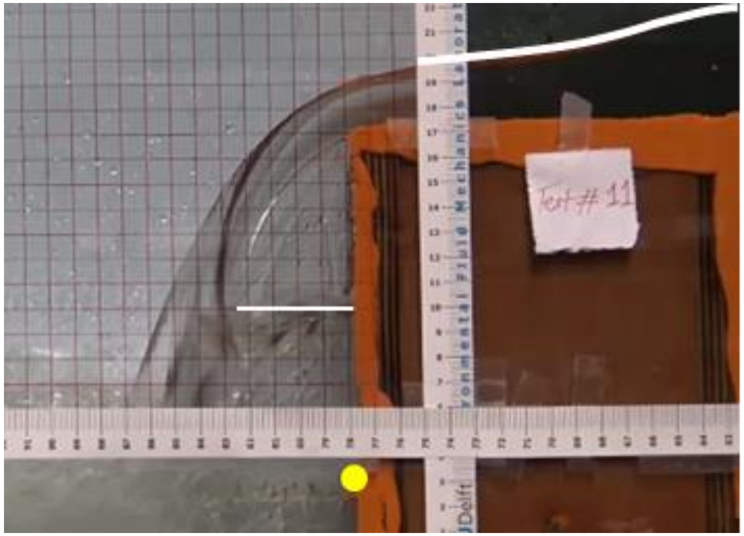
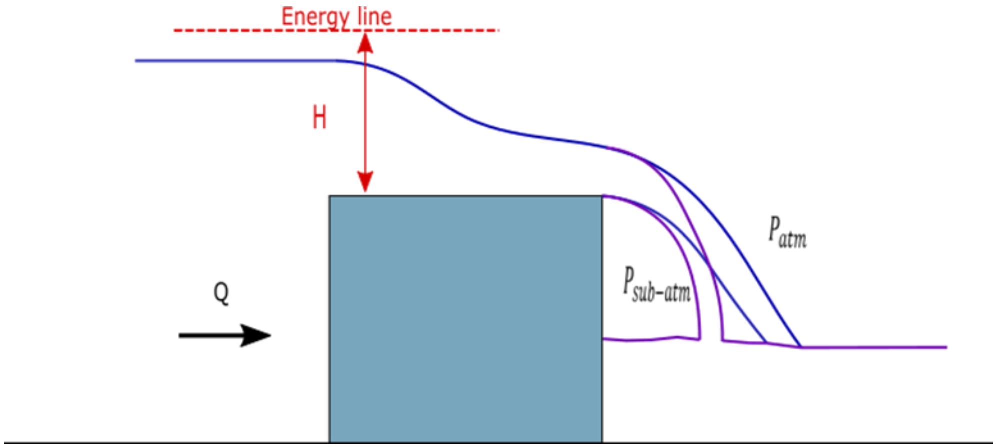
Effect of density ρ_{eff} = 800 kg/m^3 in non-aerated case

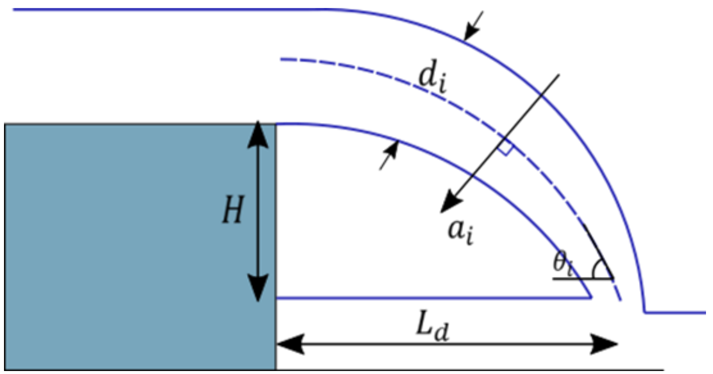




Non-aerated jet trajectory

Tan (1984) via Chanson (1996) considered vertical component of subpressure-induced acceleration in ballistic trajectory, but here consider both components.





$$a_i = \frac{\Delta P}{\rho d_i}$$

$$\Delta x_i = u_{i-1}\Delta t - \frac{1}{2}(a_{i-1}\sin\theta_{i-1})\,\Delta t^2 \qquad {u_i}^2 = {u_{i-1}}^2 - 2(a_{i-1}\sin\theta_{i-1})\Delta x_i$$

$$\Delta y_i = -v_{i-1}\Delta t + \frac{1}{2}\{g + a_{i-1}\cos\theta_{i-1}\}\,\Delta t^2 \qquad {v_i}^2 = {v_{i-1}}^2 + 2\{a_{i-1}\cos\theta_{i-1} + g\}\Delta y_i$$

$$d_i = \frac{Q}{B_C * \sqrt{{u_{i-1}}^2 + {v_{i-1}}^2}}$$

$$\theta_i = \tan^{-1}\frac{\Delta y_i}{\Delta x_i}$$

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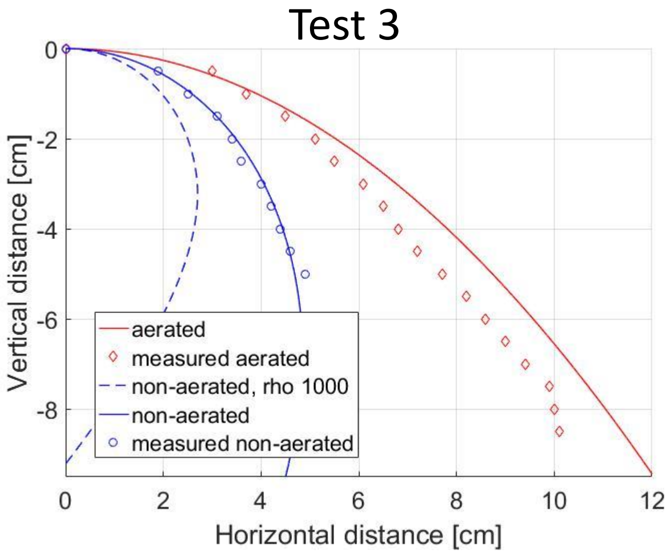
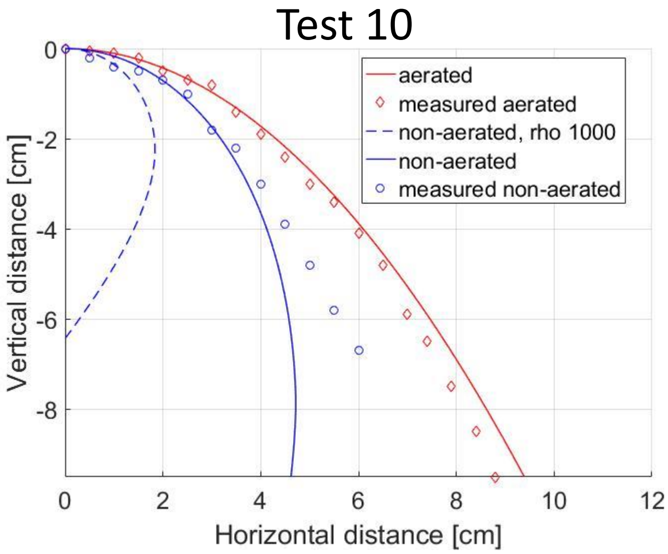
Non-aerated nappe trajectory



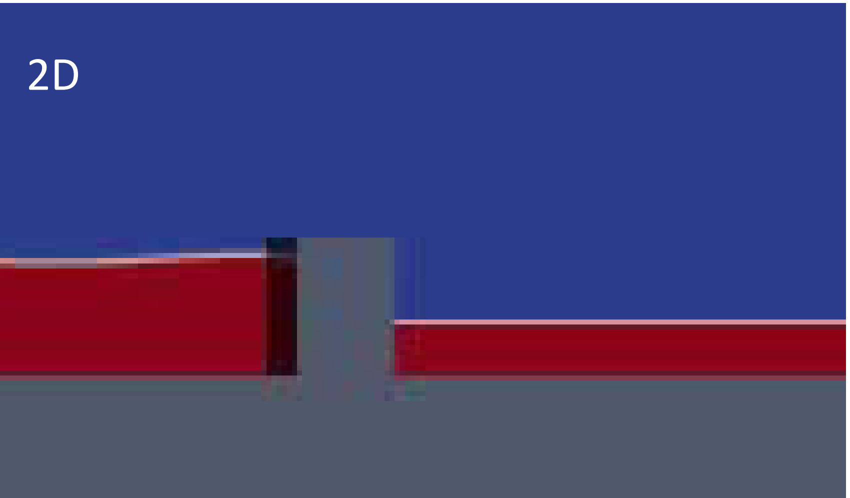


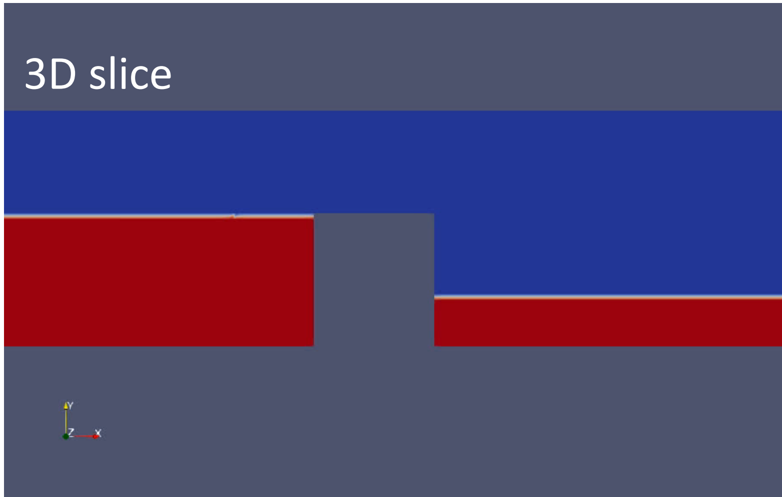
Conclusions

- Cavity sub-pressure affects jet trajectory and forces on caisson
- CFD models have difficulty modeling this due to bubbling and air entrainment
- The water column under a non-aerated nappe may have a lower density than under an aerated nappe due to bubbling

Future work

- Measure cavity sub-pressure directly
- Develop a relation between overflow surcharge and cavity sub-pressure, building on Chanson (1996)
- Extend to unsteady flows
- Investigate what is needed in CFD to get this right (2-D vs. 3-D simulations, turbulence models, bubble physics)





Future Work

- 3D simulation
- Contracted nappe, air enters at sides
- Is that all?