ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

uOttawa

Technische Universität Braunschweig

Probabilistic Investigation of Debris Impact Velocities During Extreme Flooding Events

Jacob Stolle, MASc, EIT

Department of Civil Engineering, University of Ottawa, Canada

Co-authors:

Ioan Nistor, Professor, University of Ottawa

Emil Petriu, Professor, University of Ottawa

Nils Goseberg, Professor, TU Braunschweig



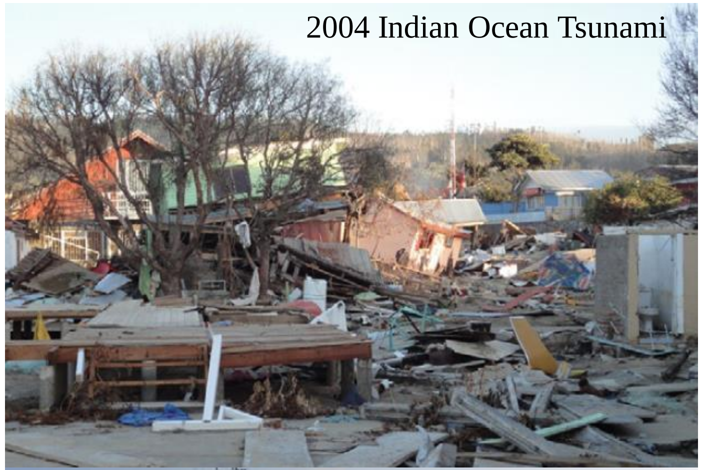


国内観測史上最大 M8.8
大津波警報 各地に被害
仙台
午後4時前
Sendai
Wave height - 12m(39ft)
damage - absolute destruction
fatalities - 1711
沖縄
小笠原
大津波警報
津波警報
津波注意報
20:47

NHK (2011)

Motivation

- Critical infrastructure failed during recent major flooding events.
- A need to revaluate the current methods of addressing loading within these events (Nistor et al., 2009).
- Emphasis placed on a probabilistic approach to addressing tsunami hazards.
- Led to the development of new standards focused on tsunami engineering:
    - SMBTR (2005)
    - FEMA P646 (2012)
    - **ASCE7 Chapter 6 (2016)**


2004 Indian Ocean Tsunami

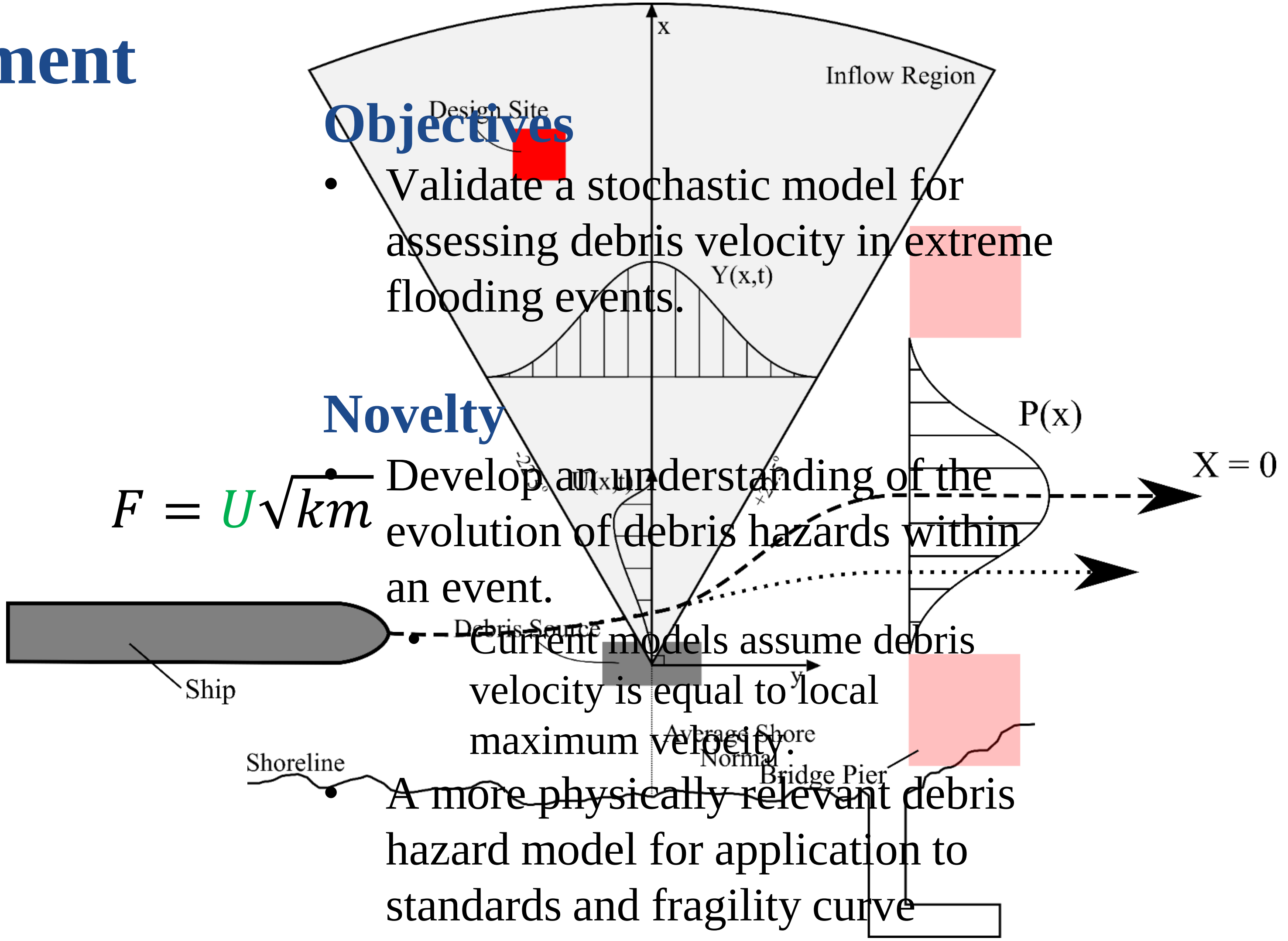

2011 Tohoku Tsunami


2017 Hurricane Maria

Debris Hazard Assessment

- Eurocode 1: Accidental Actions
  - Analogous situations
    - Vessel impacting a bridge pier.
    - Vehicle crashing into a structure.
- Focusing on debris impact (Haehnel and Daly, 2004).
- Need to address
  - Probability of impact occurring.
  - Debris impact velocity.
- Fit within the current ASCE7 Chapter 6 model (Naito et al., 2014).

$$F = U\sqrt{km}$$



Objectives

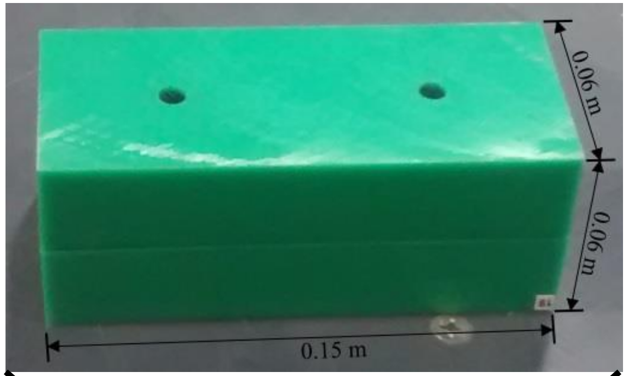
- Validate a stochastic model for assessing debris velocity in extreme flooding events.

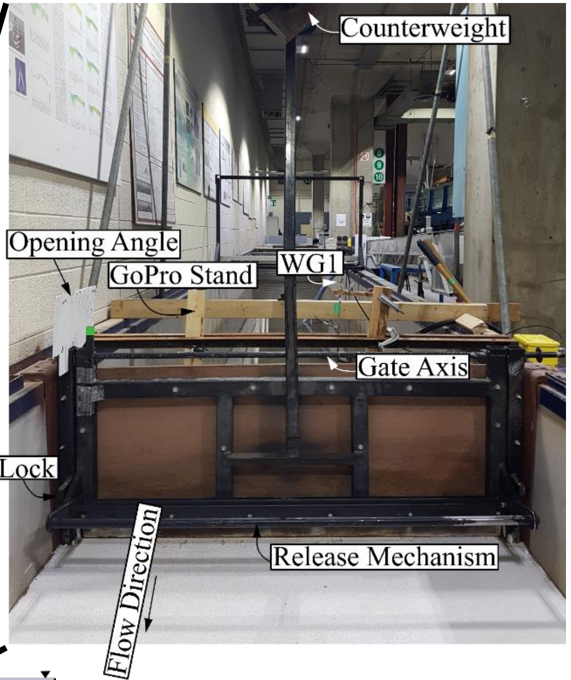
Novelty

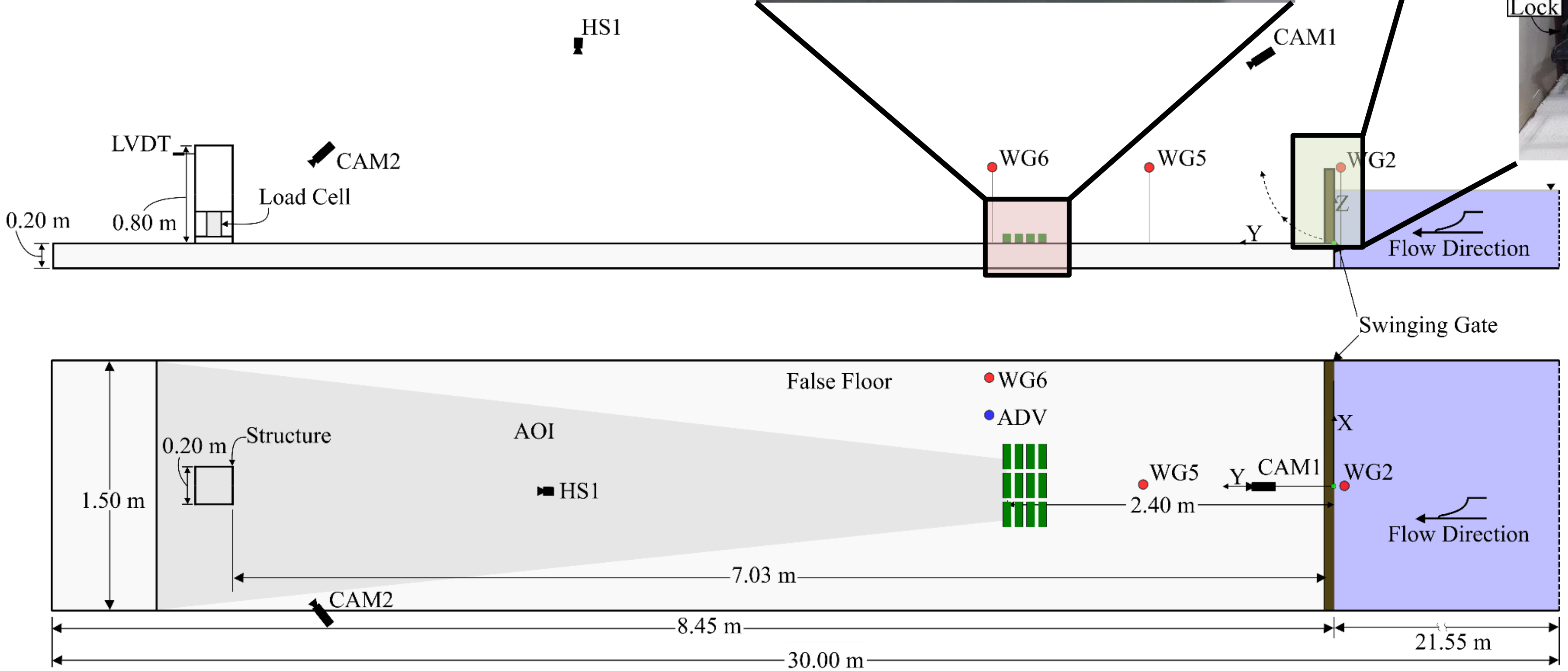
- Develop an understanding of the evolution of debris hazards within an event.
  - Current models assume debris velocity is equal to local maximum velocity.
- A more physically relevant debris hazard model for application to standards and fragility curve analysis.

Experimental Setup

- The experiments were performed in the University of Ottawa dam-break flume.
  - 30 m × 1.5 m × 0.70 m

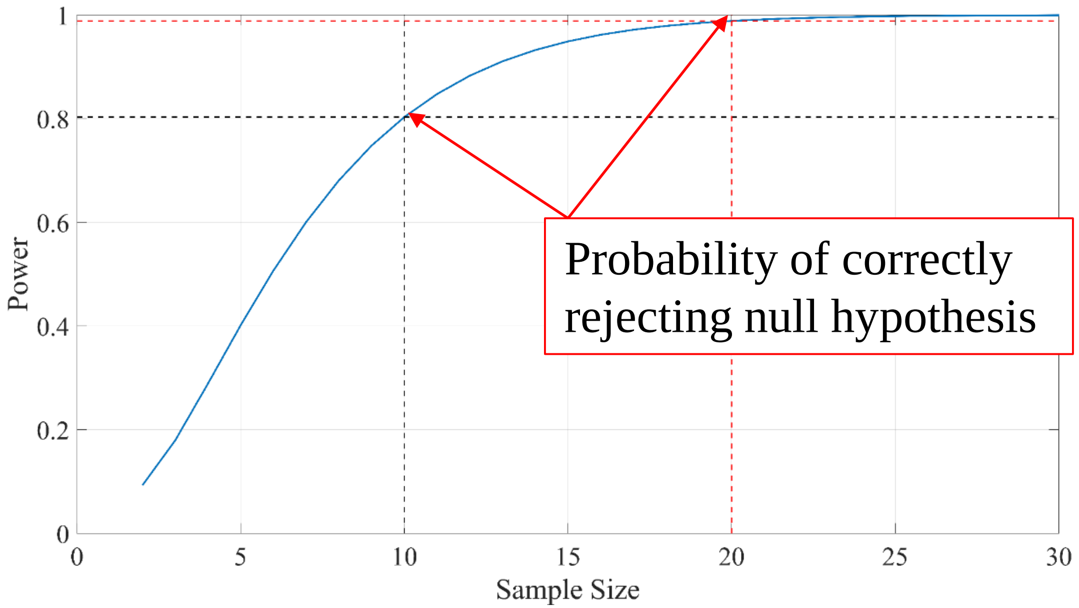






Experimental Protocol

- Investigated several variables:
  - **Number of Debris**
  - **Impoundment Depth**
  - Initial Configuration
  - Debris Material
- Minimum of 10 repetitions per experimental condition.



Impoundment Depth (h_0) **[m]**	**Number of Debris** (N) **[-]**	**Debris Orientation** (θ) **[º]**	**Repetitions [#]**
0.40	1	0	20
0.20	1	0	10
0.40	1	90	20
0.40	3	0	10
0.20	3	0	10
0.40	6	0	20
0.20	6	0	20
0.40	12	0	20
0.20	12	0	20

- For a single debris, spreading characteristics (Stolle et al., 2018):
  - Mean: ~ 0.00 m
  - Standard Deviation: ~ 0.06 m

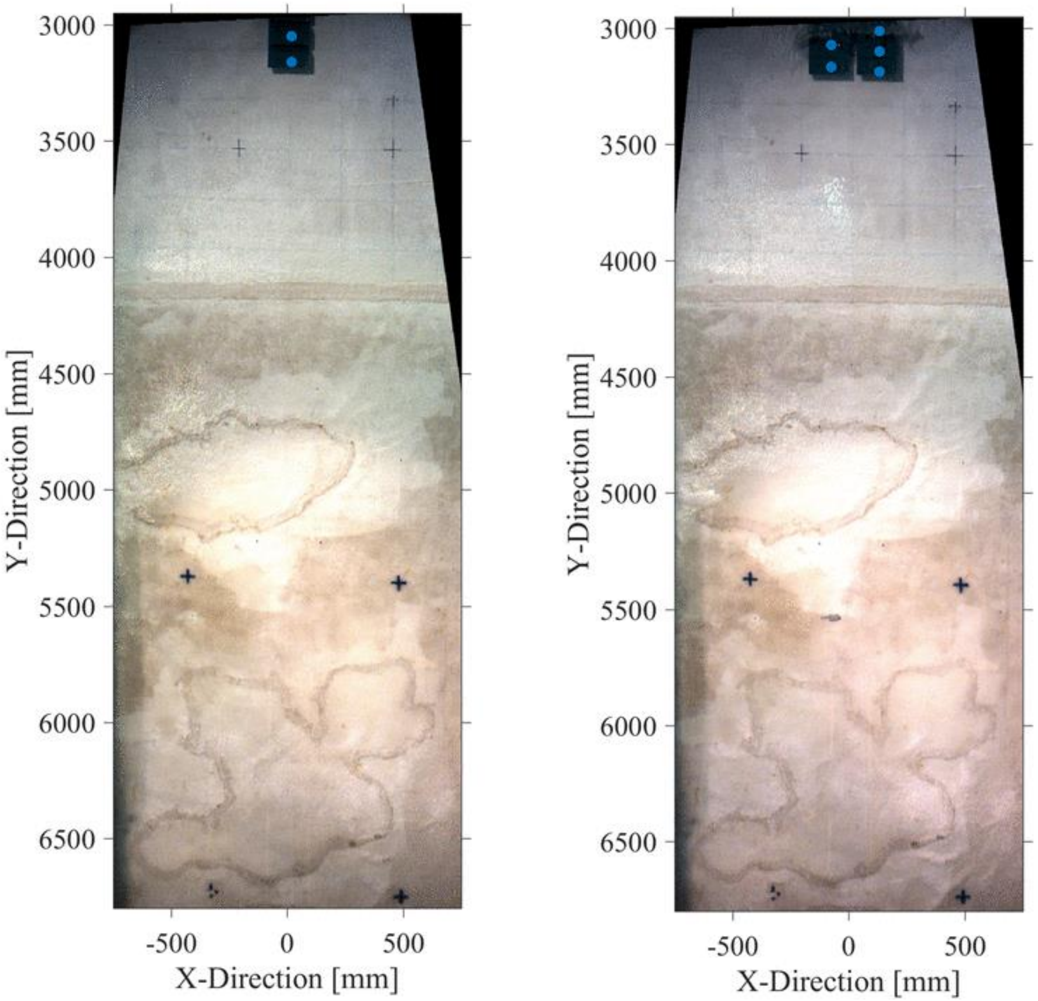
Debris Tracking

- Based on the object tracking algorithm from Stolle et al. (2016).
    - Limited by the number of container needed to be tracked.

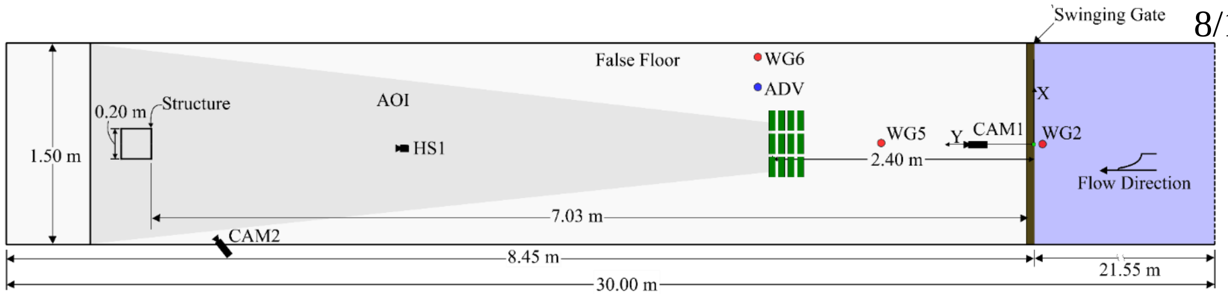
- Focus on the identification of the individual containers.
    - Limit the need to maintain unique identifier of the individual containers.

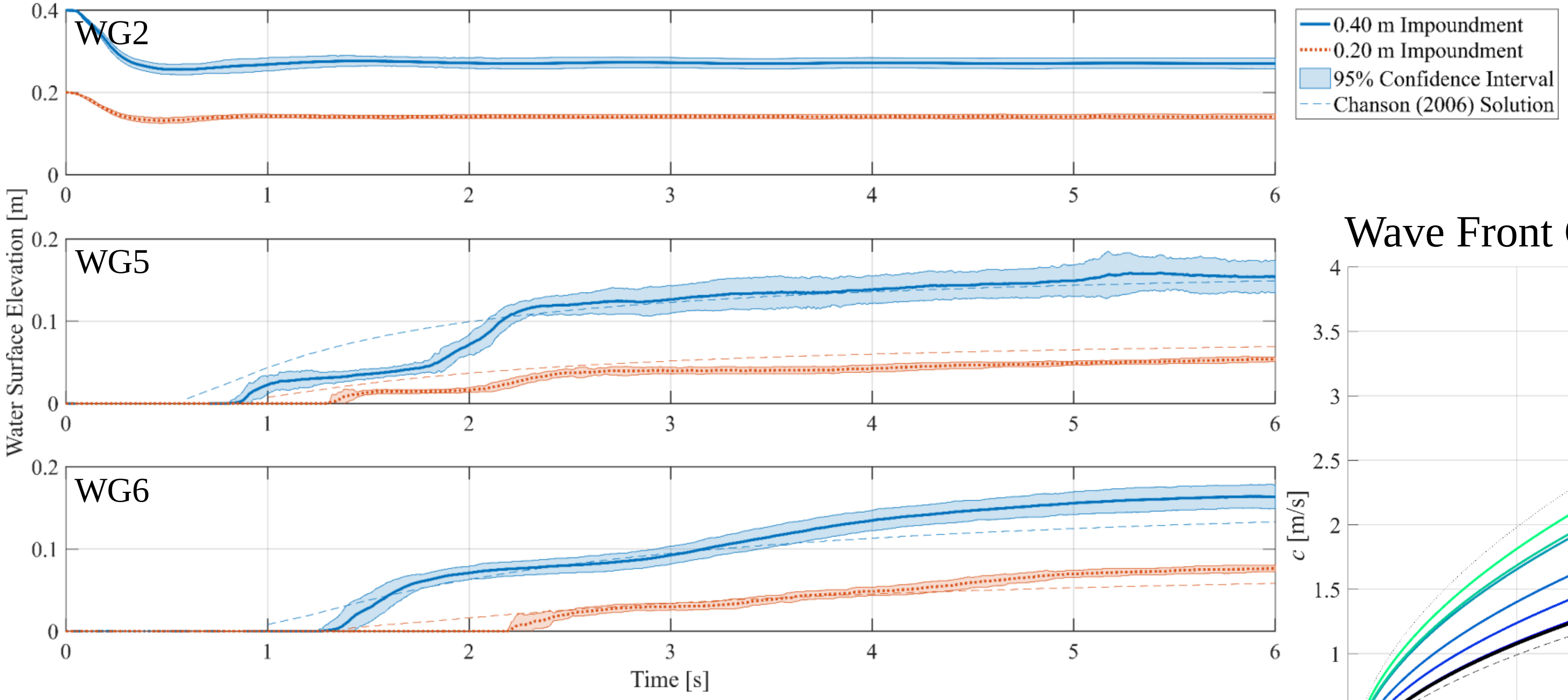
- Disadvantage:
    - Lose the individual information related to the debris:
        - Trajectory
        - Velocity
        - Orientation

Object Detection



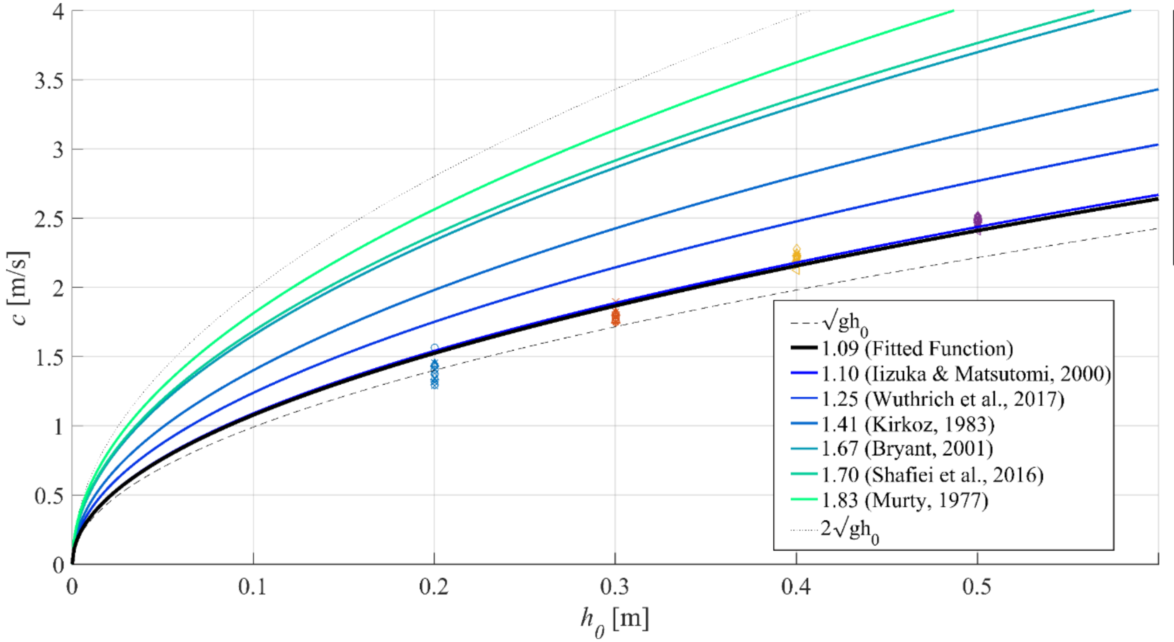
Hydrodynamics





Wave Front Celerity (c)

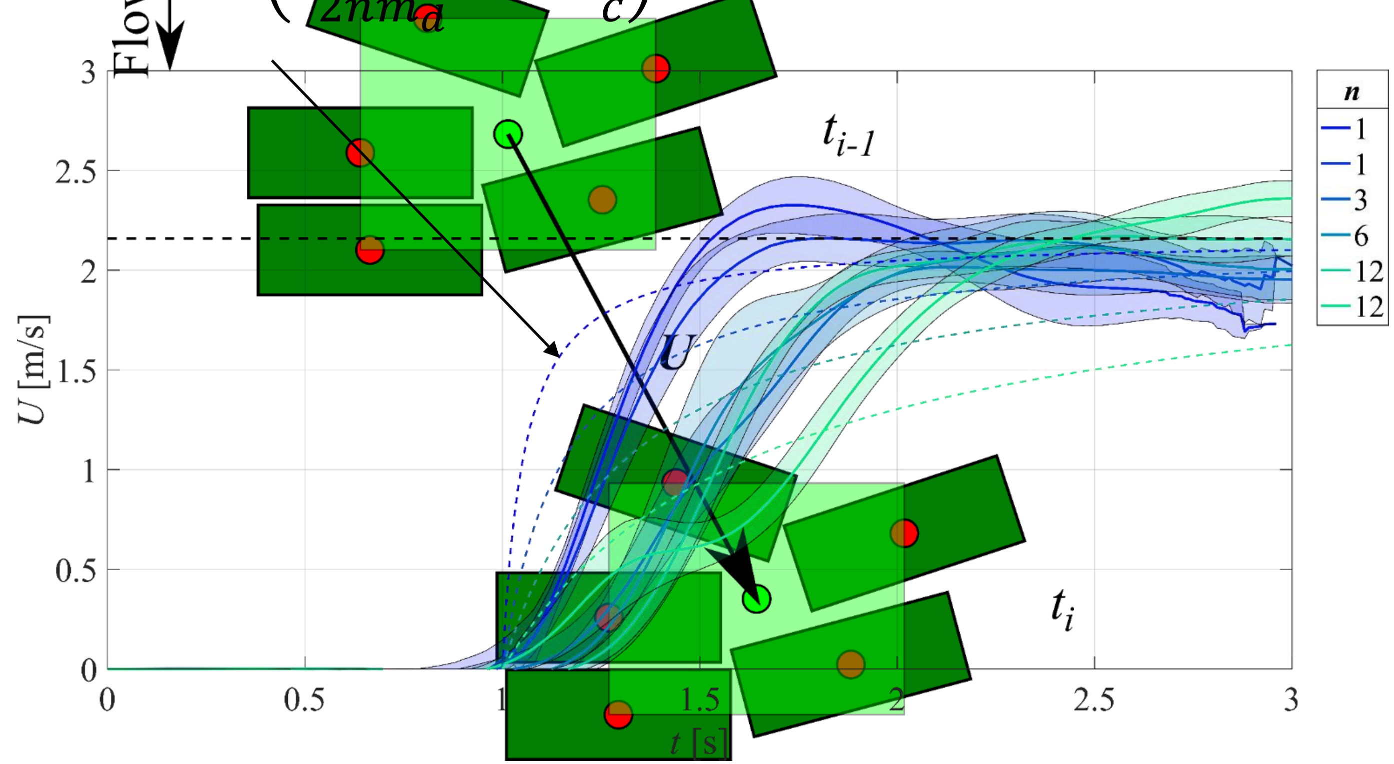
$$c = \alpha\sqrt{gh_0}$$



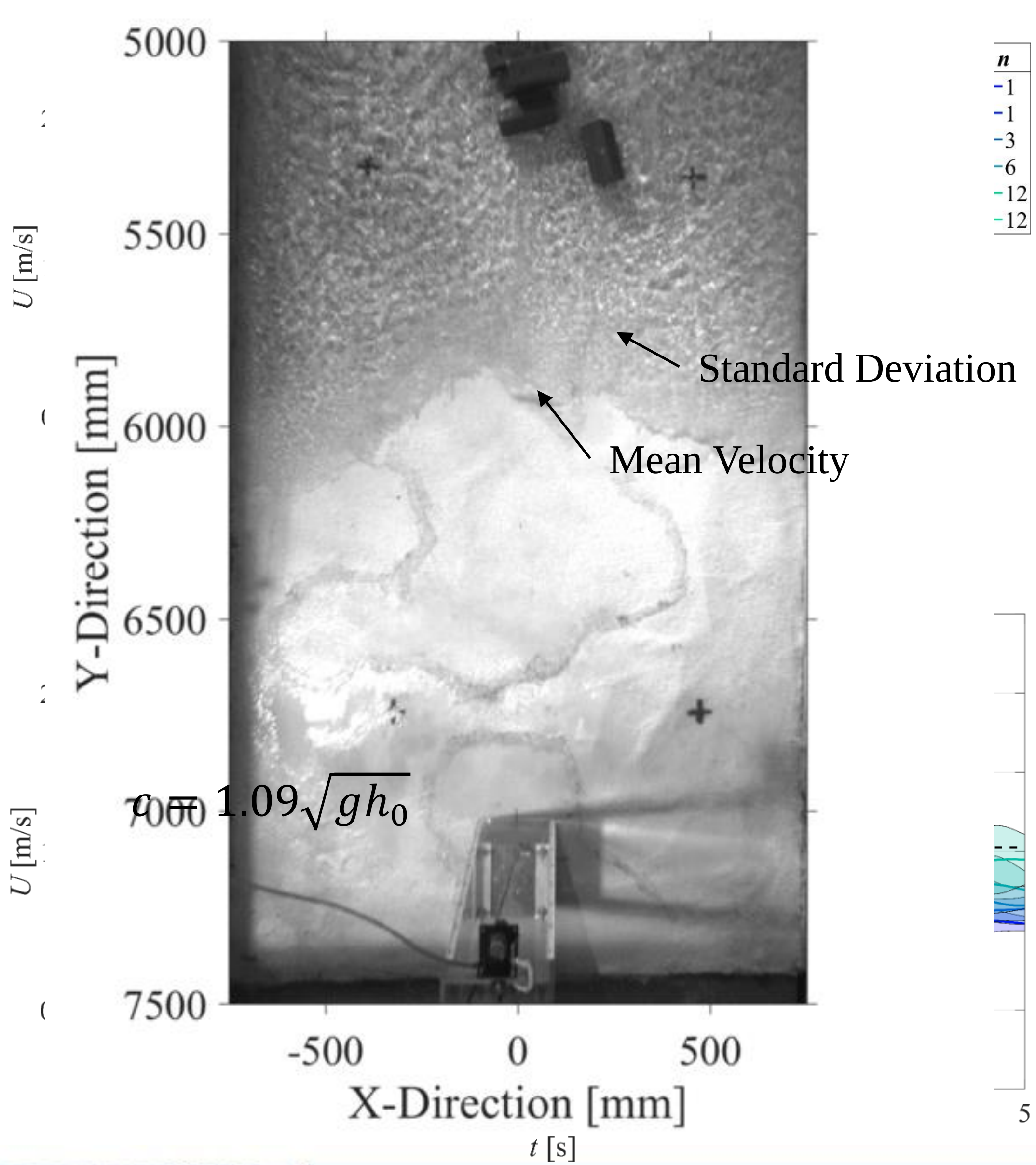
Debris Velocity

- Due to limitations of the tracking algorithm, the velocity was evaluated as the average velocity of the group. (Shafiei et al., 2016; Stolle et al., 2017)

$$U = c - \left(\frac{C_d \rho_w A_d}{2nm_a} t + \frac{1}{c}\right)^{-1}$$



$c = 1.09\sqrt{gh_0}$



Debris Velocity Distribution

- One of the most challenging aspects of debris transport is the stochastic nature of debris transport (Matsutomi, 2009).
- Lin and Vanmarcke (2010) developed a statistical model for assessing debris transport in extreme wind events.

Mean Velocity

$$\bar{U} = \frac{U}{c} = 1 - \left(\frac{C_d \rho_w A_d}{2 n m_d} ct + 1\right)^{-1}$$

Dispersion

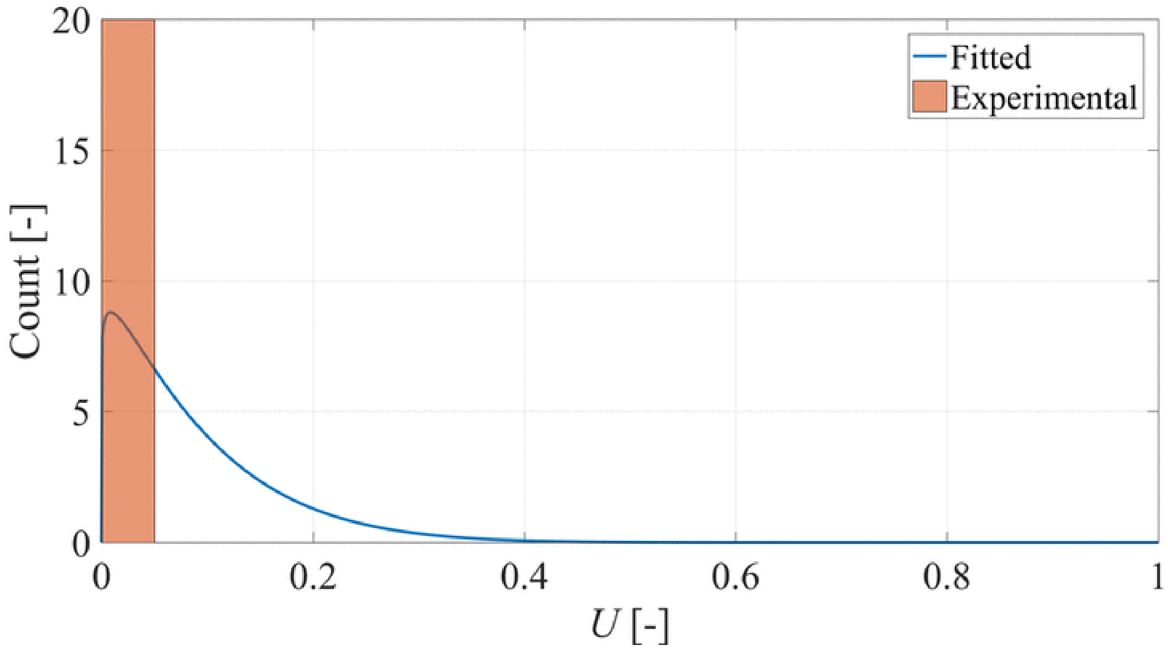
Free Parameter

$$\eta = \max\left(\frac{1}{\bar{U}}, \frac{1}{1-\bar{U}}\right) + \gamma$$

- Used a two-parameter Beta Distribution, due to its bounded nature [0,1], for single debris.
- Where:

$$a = \bar{U}\eta$$
$$b = (1-\bar{U})\eta$$

- Fitted using a Root-mean squared error evaluation:



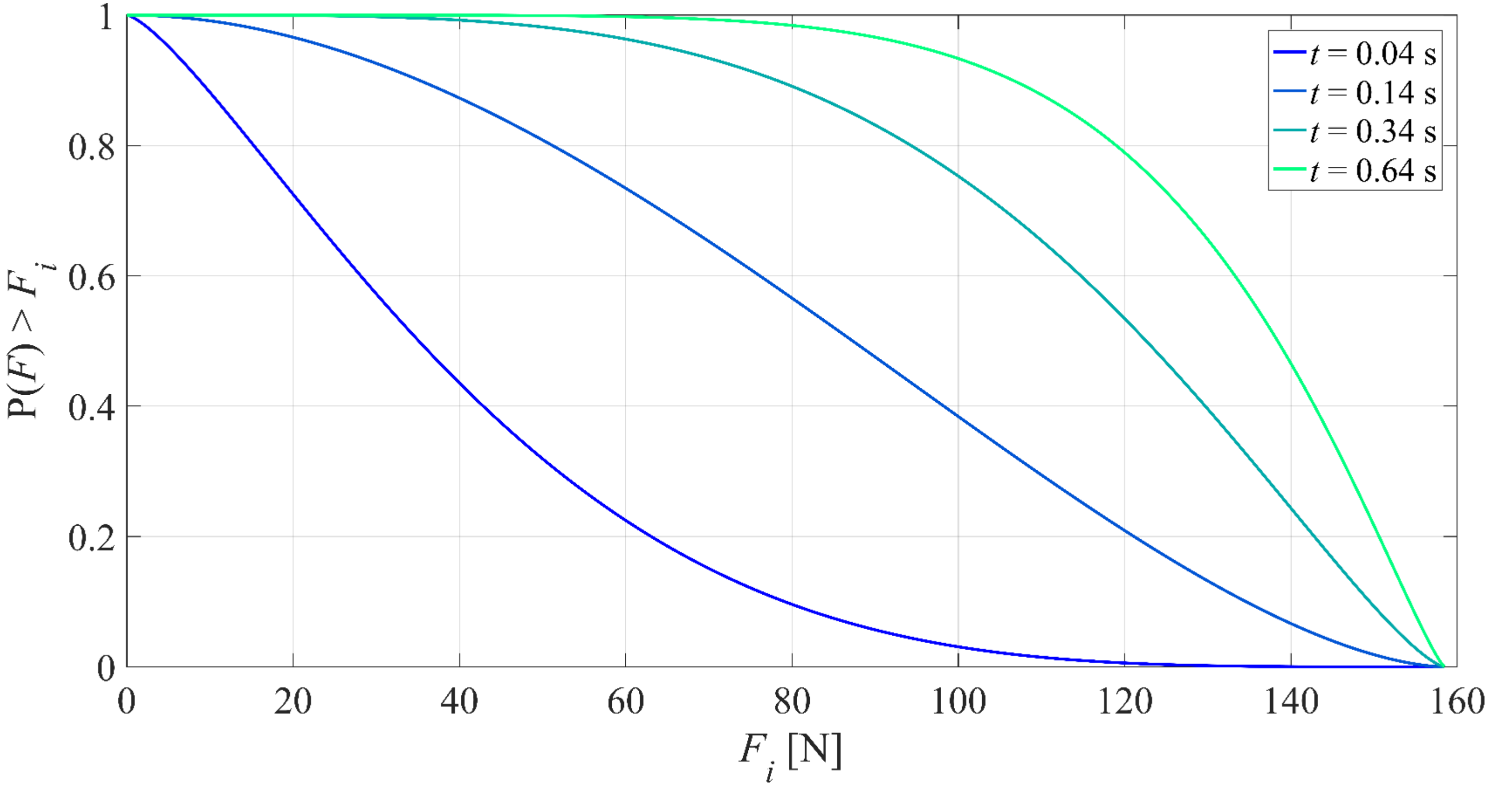
Application to Debris Guidelines

- Debris velocity is the only parameter in the impact equation considering the hydraulic conditions:

$$F = U\sqrt{km}$$

- The Beta distribution can be used to estimate the **likelihood of exceedance**.

Probability that the impact force (F_i) will exceed design magnitude.



Conclusions

- The maximum debris velocity can be estimated using **the wave front velocity**.
  - For an idealized case, does not consider flow accelerations due to obstacles or topography.
- The debris velocity profile dependent on the **number of debris** present.
  - Limitations regarding the initial entrainment of the debris.
- Using the Lin and Vanmarcke (2010) model, the probabilistic debris velocity profile can be estimated using a Beta distribution.

Next Steps

- Extend the single debris model to the **multiple debris** by considering the debris-debris interaction.
- Develop the model considering the **spreading of debris** for a detailed debris hazard assessment.

Thank you for your attention!

Jacob Stolle, M.A.Sc., EIT
University of Ottawa
Email: jstol065@uottawa.ca

References

Chock, G.Y., (2016). Design for tsunami loads and effects in the ASCE 7-16 standard. *Journal of Structural Engineering* 04016093.

Haehnel, R.B., & Daly, S.F., 2004. Maximum impact force of woody debris on floodplain structures. *Journal of Hydraulic Engineering* 130, 112–120.

Matsutomi, H. (2009). Method for estimating collision force of driftwood accompanying tsunami inundation flow. *Journal of Disaster Research*, 4(6), 435–440.

Naito, C., Cercone, C., Riggs, H. R., & Cox, D. (2014). Procedure for site assessment of the potential for tsunami debris impact. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 140(2), 223–232.

Nistor, I., Nouri, Y., Palermo, D., & Cornett, A., 2009. Experimental investigation of the impact of a tsunami-induced bore on structures, in: *Proceedings Coastal Engineering Conference*. pp. 3324–3336.

Shafiei, S., Melville, B.W., Shamseldin, A.Y., Beskhyroun, S., & Adams, K.N., 2016. Measurements of tsunami-borne debris impact on structures using an embedded accelerometer. *Journal of Hydraulic Research* 54, 1–15.

Stolle, J., Nistor, I., & Goseberg, N. (2016). Optical Tracking of Floating Shipping Containers in a High-Velocity Flow. *Coastal Engineering Journal*, 1650005.

Stolle, J., Goseberg, N., Nistor, I., & Petriu, E. (2018). Probabilistic Investigation and Risk Assessment of Debris Transport in Extreme Hydrodynamic Conditions. *Journal of Waterways, Ports, Oceans and Coastal Engineering*, 144(1), 04017039.

Stolle, J., Nistor, I., Goseberg, N., Mikami, T., & Shibayama, T. (2017). Entrainment and Transport Dynamics of Shipping Containers in Extreme Hydrodynamic Conditions. *Coastal Engineering Journal*, 59(3), 1750011.