Tsunami-Induced Debris Risks Field, Experimental and Design Lessons

û u Ottawa

L'Université canadienne Canada's university

IOAN NISTOR

Department of Civil Engineering

inistor@uottawa.ca



Université d'Ottawa | University of Ottawa



www.uOttawa.ca

Outline

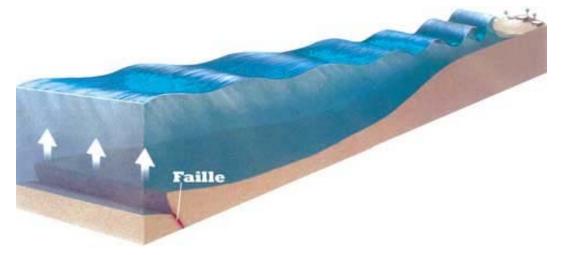
- Introduction
 - What is a Tsunami
 - Hazards of Debris Impact
- Tsunami Design Standards
- Research Needs
- Research Program at the University of Ottawa
 - Field Research
 - Experimental Research
 - Numerical Research
- Conclusions





What is a Tsunami?

- Series of long period (5 to 90 minutes) waves generated by the vertical movement of tectonic plates
- First documented by the Japanese, the term "tsunami" means "harbor wave"





Hazards involving debris motion

- Natural disasters (on-land tsunami flow), extreme weather and aging of infrastructure (dams/dikes breaching) -> extreme flow conditions
- Characteristics of these flows:
 - High energy, high momentum
 - Significant debris entrainment and displacement





Tsunami Effects - Debris Hazards

Debris entrained by flows are **difficult to detect** due to:

Roberson, 2011

- Partial submergence
- Agglomeration and damming of debris

Concerns:

Multiple impact loads onto vertical structures

Disruption of public safety or traffic infrastructure







Debris impacts and forces

- Debris impact forces are difficult to predict and can depend on:
 - Size, shape, and mass of the debris
 - Debris Velocity
 - Duration of impact
 - Position of impact
 - Existing blockages around the debris
 - Type of structure being impacted





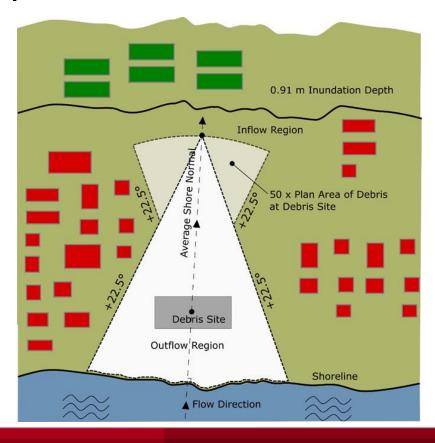
Tsunami Design Standards

- Spreading of debris
 - Limited guidance on debris spreading

Upcoming ASCE 7-16 Standard with chapter "Tsunami Loads and

Effects"

- Field investigation of debris spread
 - Based mostly on post-disaster surveys
 - Estimation of spreading angles
 - Spatial bounds from field evidence (lateral/longitudinal
- Limitations
 - Site specific
 - No experimental validation





Tsunami Design Standardization

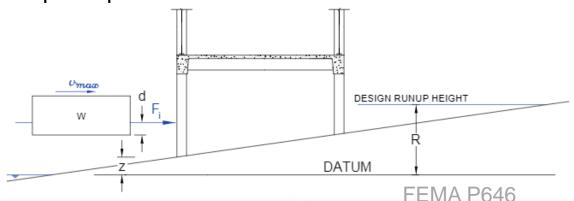
- Impact of debris on vertical structures
 - FEMA P646

$$F_i = C_m u_{max} \sqrt{km}$$

$$F_i = WVC_DC_BC_{str}$$

ASCE 7-16 Chapter 6.
$$F_i = C_0 u_{max} \sqrt{km}$$

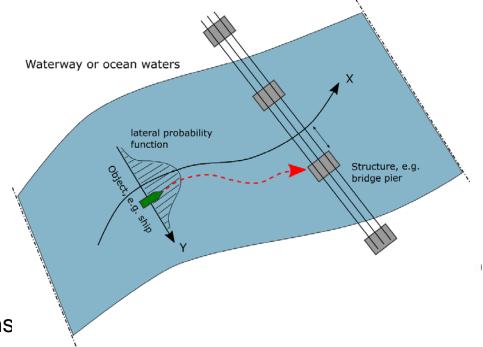
- Limitations
 - No prescriptions for multiple impacts



Tsunami Design Standards

Eurocode EN 1991, Chapter 1-7 (2006): "Accidental Actions on Structures"

- Considerations for impact of:
 - Vehicles and trains
 - Helicopters
 - Ships
- Framework for risk analysis
- Limitations
 - No prescriptions for multiple impacts
 - Does not consider extreme conditions
 - No consideration for cascading effects





Research Objectives

- Investigation of tsunami damage to structures including buildings, bridges, seawalls and harbor facilities
 - Measurement of inundation levels and structural component details of surviving and near-failure building
- Physical and numerical modeling of debris motion and impact forces on structures
 - Research on single and multiple debris impacts
 - Research on debris spread and movement
- Incorporation of observations and lessons into structural design standards being prepared for the ASCE





Post-Tsunami Surveys - Debris Impact

Chile



Japan

(Palermo et al., 2013b)

Indonesia



Nistor, I. (2012)



(Saatcioglu, M., Ghobarah, A., and Nistor, I., 2006b)

December 2004 Indian Ocean Tsunami

Magnitude: 9.0 (USGS), 9.3 (Northwestern

University)

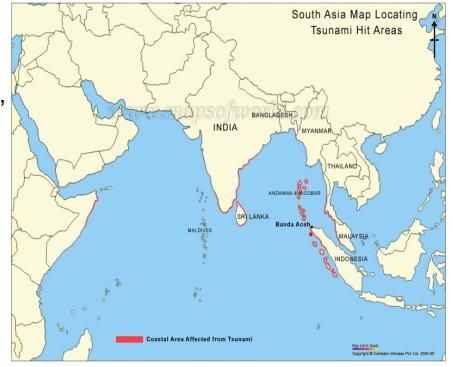
Location: 150 km W of Sumatra 225 km SE of Banda Aceh, Indonesia

• Fault length: 1200 km

Depth: 30 km

Width: 150 km

Uplift: Several meters (reports of 6 to 16 m)





Tsunami Forces on Structures Ottawa U. Tsunami Survey Team – Thailand and Indonesia - January 2005

Nan Thong, Thailand, 2004

Banda Aceh, Indonesia, 2004





Saatcioglu and Nistor - 2005



Phi Phi Island, Thailand - debris accumulation





Banda Aceh, Indonesia - Debris impact





Banda Aceh, Indonesia - Debris impact





2010 Chile Tsunami - Ottawa U. Field Survey

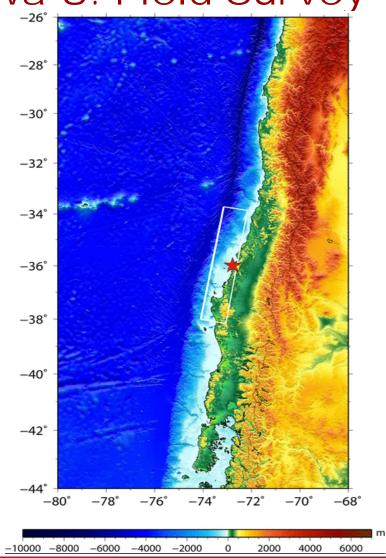
Magnitude: 8.8 Richter

Aftershocks: 421 (as of March 18 2010)

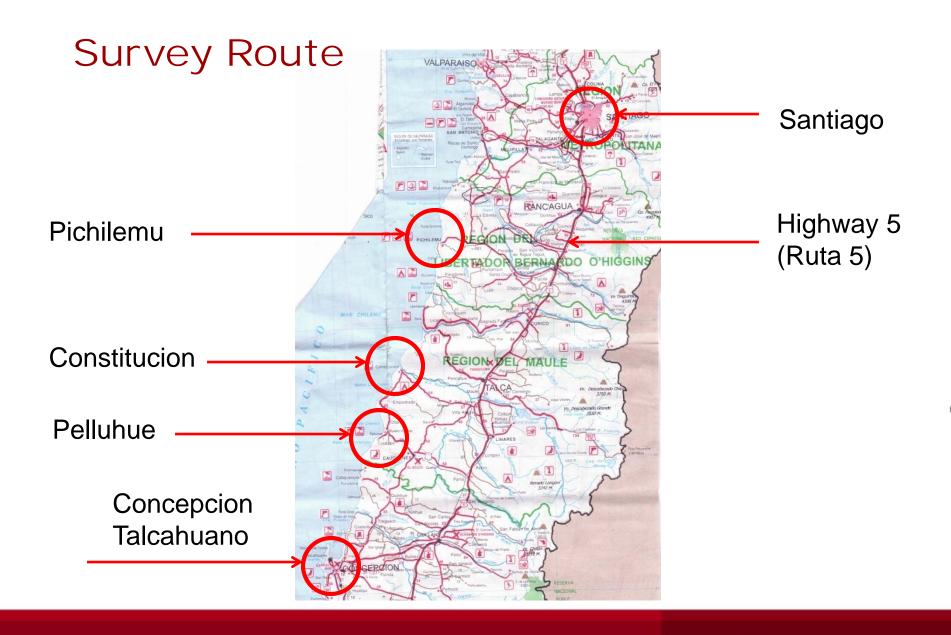
Location: Offshore Maule

• Fault line: 1000 x 200 km

Significant coastal inundation height: several meters









Tsunami Forces on Structures Ottawa U. and CSCE Field Survey Team - Chile February 2010

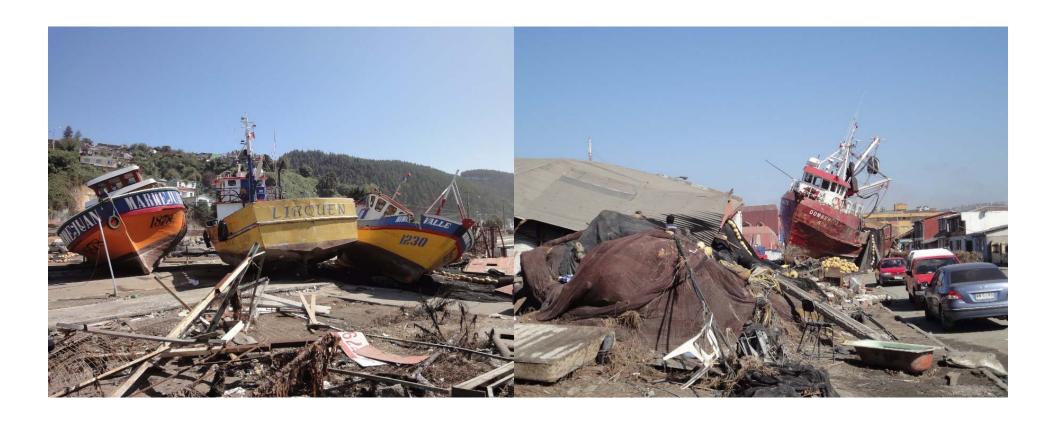




Nistor, Palermo, Saatcioglu - 2010



Talcahuano - Port City - Suburb of Concepcion - Debris impacts

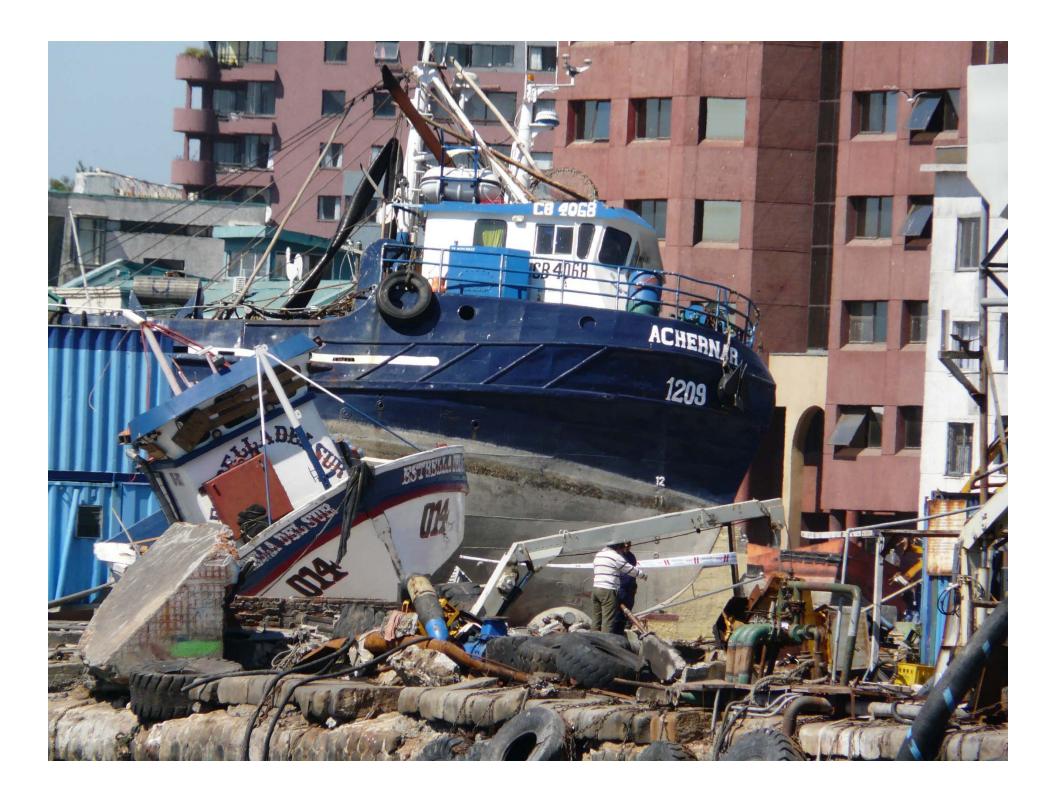




Talcahuano - Port City - Suburb of Concepcion







March 2011 Japan Tsunami – ASCE-JSCE Post-tsunami Survey

Magnitude: 9.0 Richter

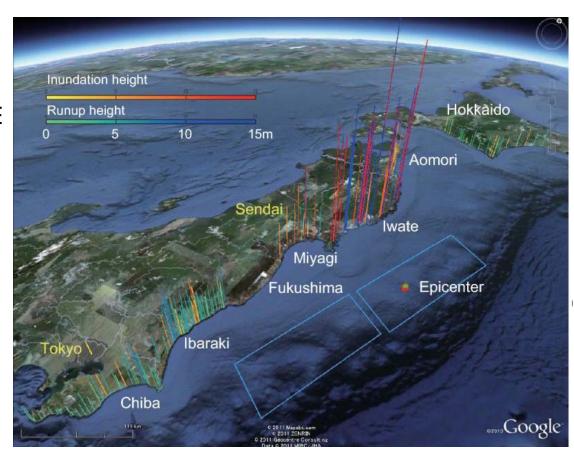
Location: 38.322° N, 142.369° E

Depth: 32 km

Horizontal Displacement: 500 km x 200 km

Vertical ocean bottom displacement: 10 to 20 m

Runup height: up to 40 m!

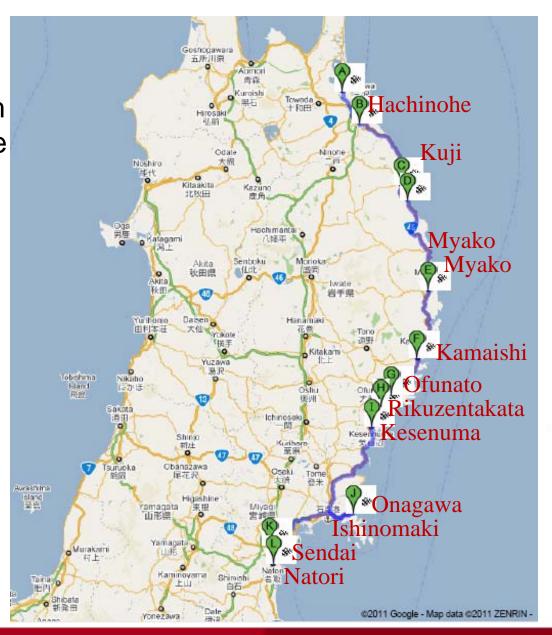




Survey Route

 Group 1 started at the North end of the Tohoku Coastline at Hachinohe and visited most coastal communities from there to Natori in the South (9 days in 12 cities)







Tsunami Forces on Structures ASCE Field Survey Team – Japan April 12-24, 2011

Onagawa



Kriebel, 2011

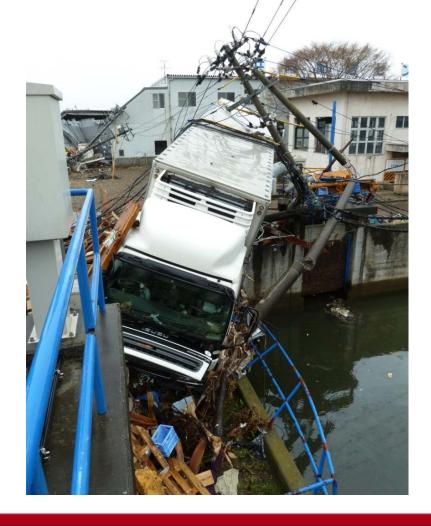
Otsuchi

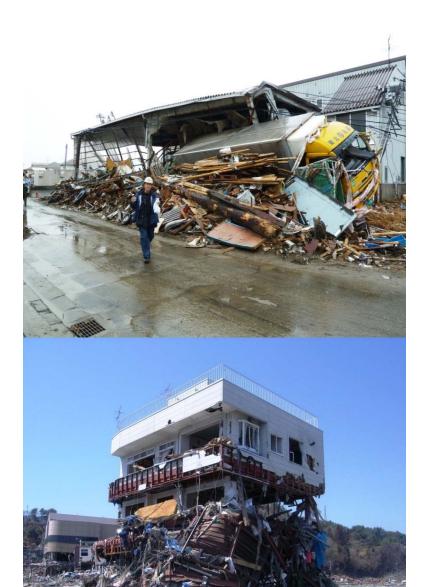


Nistor, 2011



Sendai Port – debris







Sendai Port - Ship Impacts







Non-Intrusive Debris Tracking - "Smart" Debris

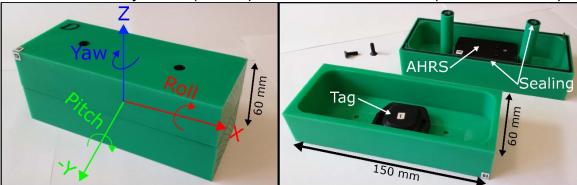
- Motivation for innovation
 - Characteristics of extreme flow conditions
 - Low visibility through sediment-laden fluid
 - Turbulence-induced whitish surge/bore front
 - Occlusions through grouped debris



- "smart" debris Non-intrusive 6 degrees-of-freedom debris tracking
 - Sensor-fusion of miniaturized instruments
 - Motion sensors (AHRS)
 - Real-time Location System (RTLS)

(3 rotations)

(3 translations)

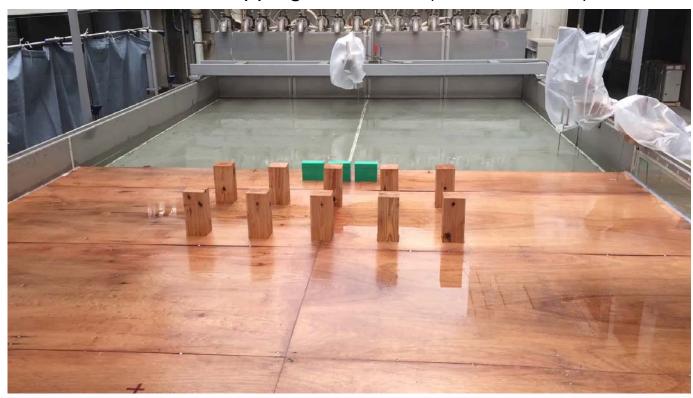


Nistor et al. 2016, J. Waterway, Port, Coastal, Ocean Eng.



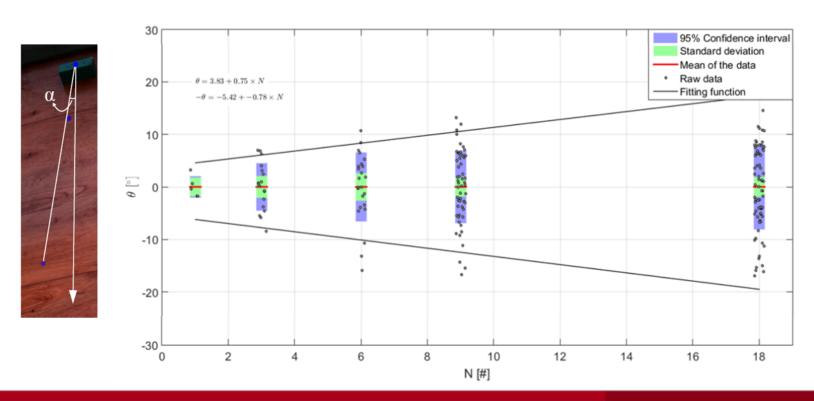
Non-Intrusive Debris Tracking

- Model of a harbour setting accomplished at Waseda University, 2014
 - Horizontal apron and horizontal sea bead
 - Tsunami-like inflow condition
 - 1:40 scaled-down shipping containers ("smart" debris)



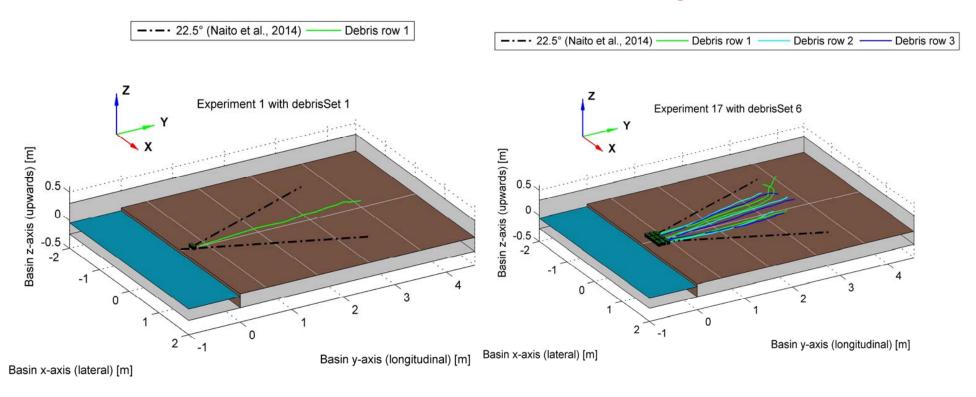
Non-Intrusive Debris Tracking

- How can designers reliably determine debris impact prone zones?
 - ASCE 7–16 suggests zones with ±22.5° bounds
- Debris dynamics on horizontal surfaces (Nistor et al., 2016, in press)
 - Inland displacement
 - Debris spreading / dispersion





Non-Intrusive Debris Tracking - Motion

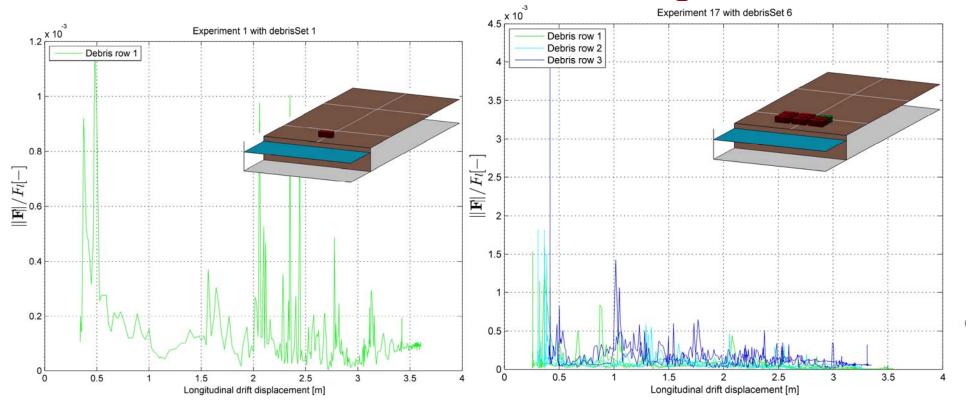


- Compared to assumptions by Naito et al. (2014)
 - ∓22.5° spreading angle

Goseberg et al. 2016, J. Hydraul. Eng.



Non-Intrusive Debris Tracking - Forces

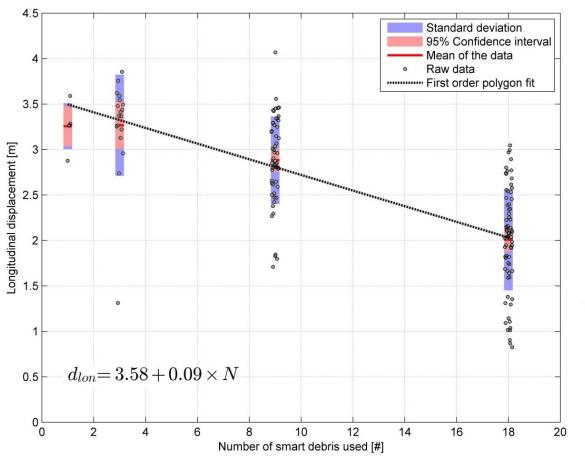


- Forces normalized using Cross (1967).
 - Wave height and velocity.



Non-Intrusive Debris Tracking - Debris Displacement

- Displacement in flow direction from initial position
- Decrease in displacement with increase in debris

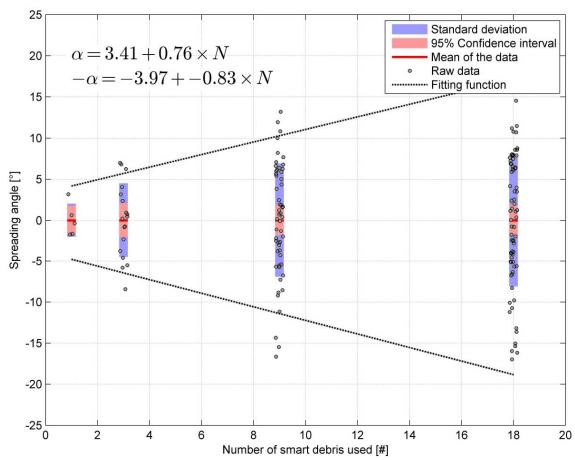


Nistor et al. 2016, J. Waterway, Port, Coastal, Ocean Eng.



Non-Intrusive Debris Tracking – Debris Spread

- Angle from centroid of initial position of container
- Increase in spreading angle with increase in debris

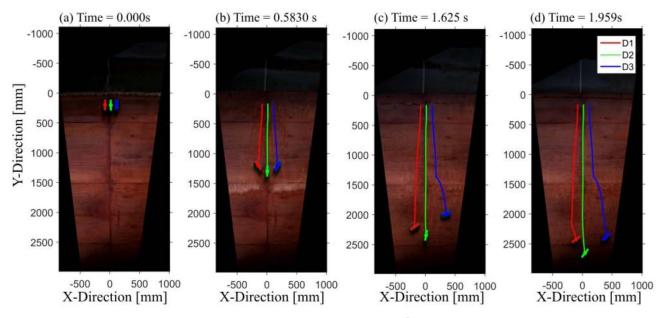


Nistor et al. 2016, J. Waterway, Port, Coastal, Ocean Eng.



Optical Non-Intrusive Debris Tracking

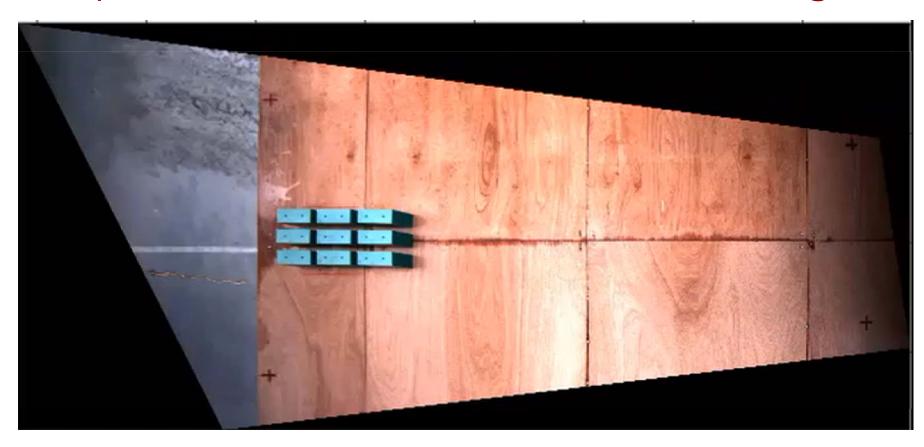
- Based on image capture from motion
- Algorithm detects and tracks debris
 - Color space conversion and color thresholding
 - Kalman-filter and Hungarian algorithm



Stolle et al. 2016, Resilient Infrastructure



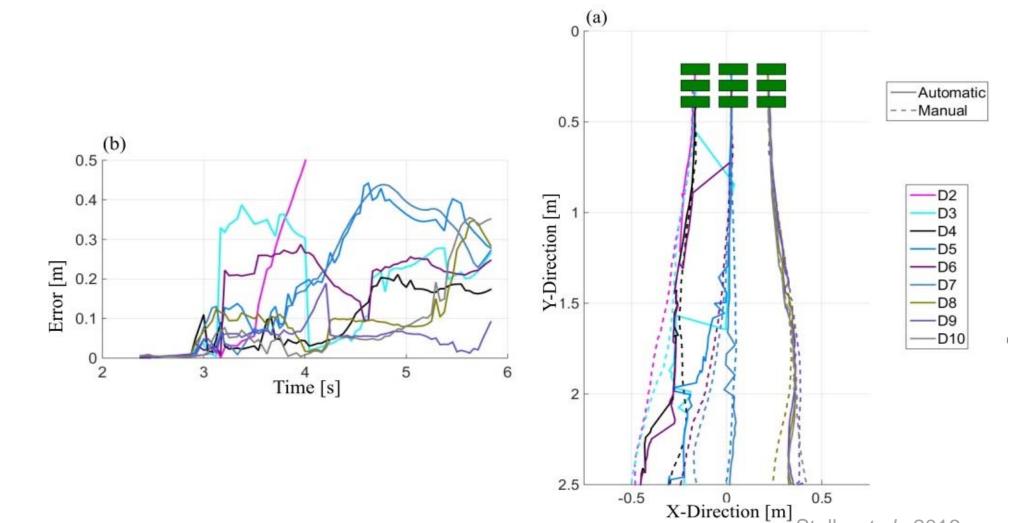
Optical Non-Intrusive Debris Tracking



Goseberg, 2016



Optical Non-Intrusive Debris Tracking - Motion

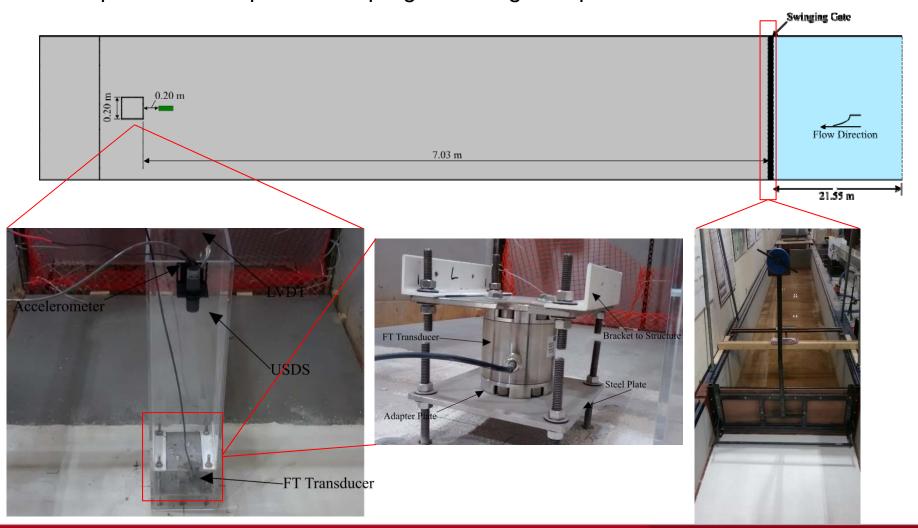




Stolle et al., 2016

Dam break test - University of Ottawa

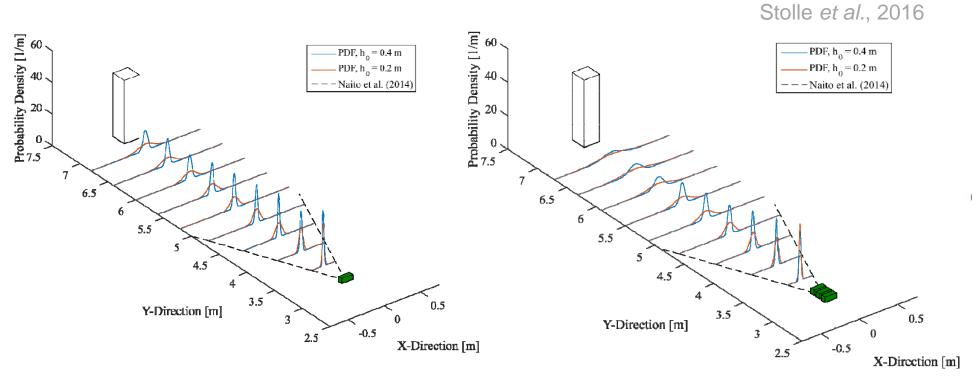
Comprehensive experimental program using multiple debris events





Optical Non-Intrusive Debris Tracking - Motion

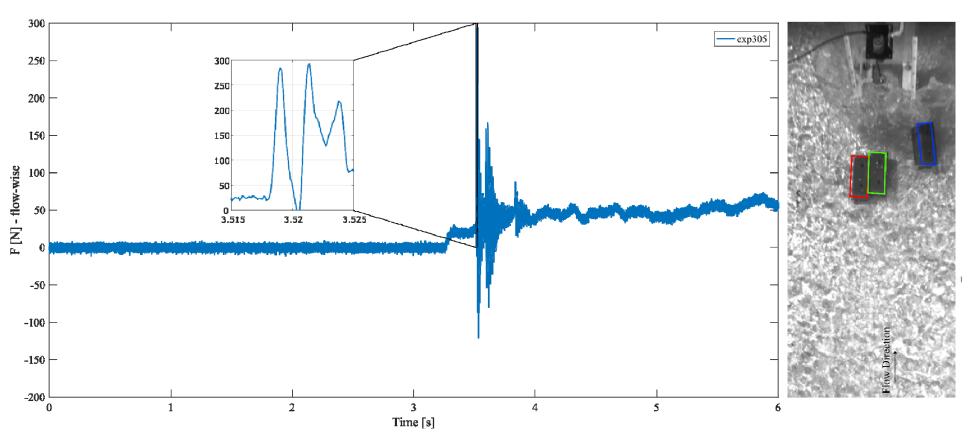
Examined a normal probability density function of the debris motion against longitudinal displacement



Within Naito et al. (2014) guidelines



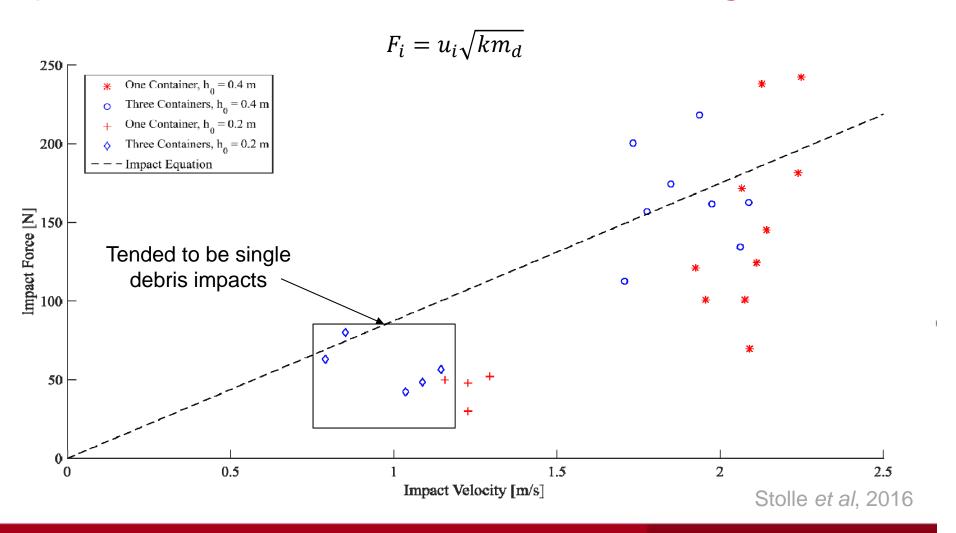
Optical Non-Intrusive Debris Tracking - Forces





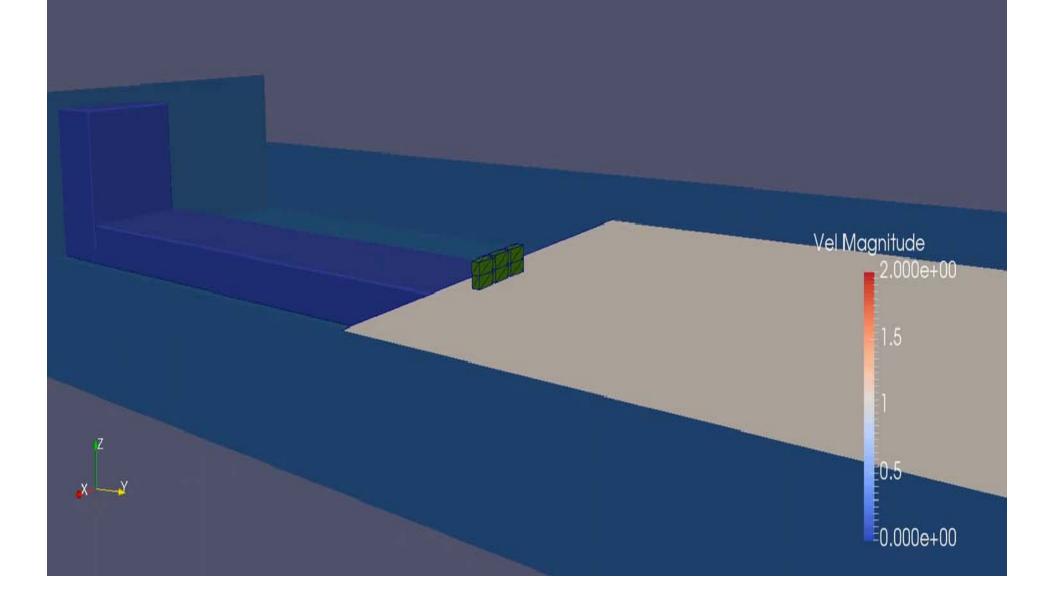


Optical Non-Intrusive Debris Tracking - Forces



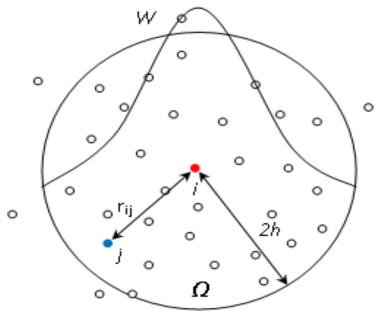


Research Program Numerical Modelling of Debris Motion



DualSPHyiscs Smoothed Particle Hydrodynamics

- Meshfree Lagrangian particle-based method
- Particles are represented by a set of arbitrarily distributed points



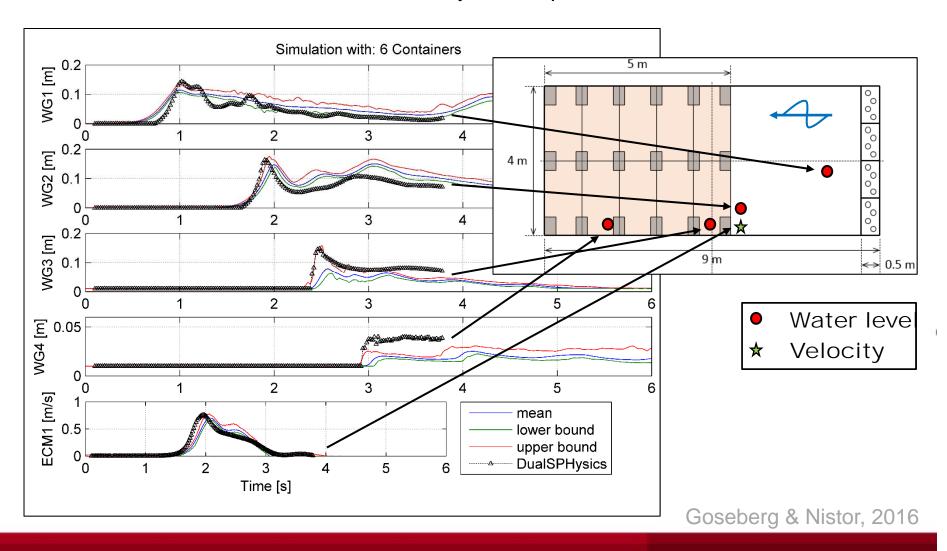


 The model uses a particle approximation to represent a function as the summation of all the particles within the influence domain

$$f(x_i) = \sum_{j=1}^{N} \frac{m_j}{\rho_j} f(x_j) W(x_i - x_j, h)$$

Debris motion - SPH model

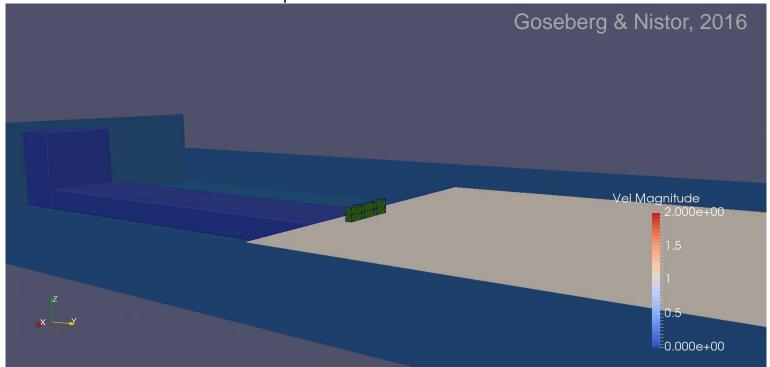
Validation of water levels and velocity with experimental data





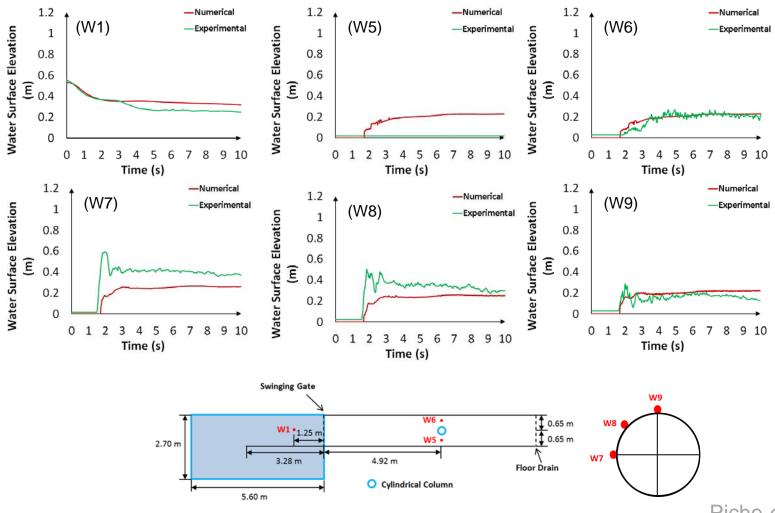
Debris motion - SPH model

- Simulating debris dynamics on a harbor apron
- 6 shipping containers, 3x2 side-by-side arrangement
- Model parameters:
 - 9,788,181 particles
 - Initial particle spacing d_p = 0.5 mm





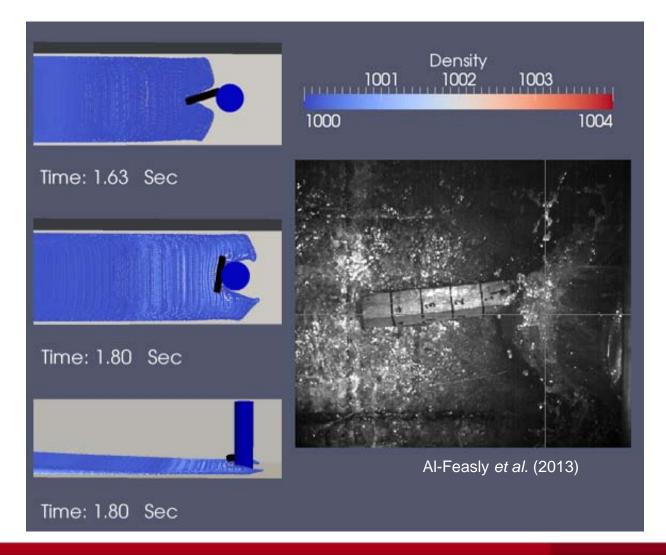
SPH Debris Impact - Ottawa U. (2014)



Piche et al, 2014



Debris Impact - SPH model



Piche et al, 2014



Conclusions

- Current design documents for the estimation of tsunami impacts show deficiencies
- Tsunami field surveys provide unmatched opportunities for data collection to verify and improve existing formulations
- Debris accumulation occurs rapidly once structures are encountered. Design loads must consider debris damming and blockage
- Debris spreading appears to be dependent on the number of debris and its hydrodynamic condition
- Physical models showed that the increasing the amount of debris increased their spreading angle and decreased the length of their longitudinal displacement
- The presence of obstacles reduced the longitudinal displacement of the debris but did not impact the spreading angle



Acknowledgements



Dan Palermo Ottawa U.



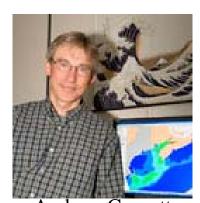
Tomoya Shibayama Waseda U, Japan



Tad Murty Ottawa U.



Murat Saatcioglu Ottawa U.



Andrew Cornett
Ottawa U. & NRC



Nils Goseberg Ottawa U. & Hannover U.

Graduate students at Ottawa U.

Philippe St-Germain, MASc Stephanie Piche, PhD Steven Douglas, PhD Taofiq Al-Faesly, PhD Jacob Stole, PhD Younes Nouri, MASc Safinaz El-Sohl, MASc





References

- Al-Faesly T., Nistor I., Palermo D., and Cornett A. (2013). "Experimental Study of Structures Subjected to Hydrodynamic and Debris Impact Forces." Canadian Society of Civil Engineers.
- ASCE/SEI (ASCE/Structural Engineering Institute). (2016). "Minimum design loads for buildings and other structures." ASCE/SEI 7-16, Reston, VA.
- Eurode (2006). Actions on Structures Part 1-7: General Actions Accidental Actions. BS EN 1991-1-7:2006.
- FEMA (2011). Coastal Construction Manual FEMA P55, Federal Emergency Management Agency.
- FEMA (2012). Guidelines for Design of Structures for Vertical Evacuation from Tsunamis-Second Edition. FEMA P646, Federal Emergency Management Agency
- Goseberg, N., Stolle, J., Nistor, I., and Shibayama, T. (2016). Experimental Analysis of Debris Motion due the Obstruction from Fixed Obstacles. Coastal Engineering, Elsevier, (accepted, in-press)
- Goseberg, N., Nistor, I., Mikami, T., Shibayama, T., Stolle, J. (2016). "Non-Invasive Spatio-temporal "smart" debris Tracking in Turbulent Flows with Application to debris-laden Tsunami Inundation." J. of Hydraulic Eng., ASCE, 04016058.
- Naito, C., Cercone, C., Riggs, H. R., and Cox, D. (2013). "Procedure for site assessment of the potential for tsunami debris impact". J. of Waterway, Port, Coastal and Ocean Engineering, ASCE, 140(2), 223-232.



References

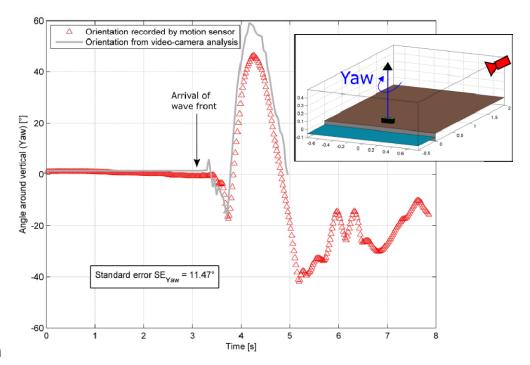
- Nistor, I., Goseberg, N., Mikami, T., Shibayama, T., Stolle, J., Nakamura, R., and Matsuba, S. (2016). Hydraulic Experiments on Debris Dynamics over a Horizontal Plane, J. of Waterway, Port, Coastal and Ocean Engineering, ASCE, (accepted, in press).
- Piche S., Nistor I., Murty T., (2014) "Numerical Modeling of Debris Impacts Using the SPH Method." Coastal Engineering, ICCE
- Stolle, J., Nistor, I., and Goseberg, N. (2016). "Optical Tracking of Floating Debris in a Wave Basin." Coastal Engineering Journal, JSCE, 1650005.
- Stolle. J. Nistor, I., and Goseberg, N. (2016) "Debris Dynamics and Impact Forces in Extreme Hydrodynamic Conditions, 7th International Tsunami Symposium



Non-Intrusive Debris Tracking - "Smart" Debris

"smart" debris in action

- Accurate tracking positions of 9 shipping containers in a wave basin simultaneously
- Tracking container rotation along vertical axis during flow



Impact and potential future application

- Application to various other disciplines beyond civil engineering
 - Tracking of floating objects (e.g. plastics, large wood debris) in rivers
 - Automated tracking of coastal armour layers (e.g. tetrapods)
 - Monitoring of transport user behaviour (e.g. pedestrians)
 - Profiling of riparian fauna (e.g. in ecologic studies)

Goseberg et al. (2016) Journal of Hydraulic Engineering



Development of a new Tsunami Loads and Effects Design Standard by ASCE

- No standard for engineering design for tsunami effects written in mandatory language exists. There is no comprehensive construction standard comparable to seismic or wind building codes for structures.
- The Tsunami Loads and Effects Subcommittee (TLESC) was established in February 2011 – Chair: Gary CHOCK
- The of the ASCE/SEI 7 Standards Committee is developing a new Chapter 6 - Tsunami Loads and Effects, with Commentary, for the March 2016 Edition of the ASCE 7 Standard.
- Review by ASCE 7 Main Committee in 2014-2015
- Tsunami Provisions would then be referenced in the International Building Code IBC 2018



Outline of the New Design Method

- Probabilistic tsunami hazard analysis based criteria
- Energy-based methodology for calculating tsunami inundation depth and velocity at a site
- Structural loadings derived from research and validated
- Analysis techniques for determining building performance
- Multi-hazard performance-based approach for regions governed by local subduction earthquakes
- The proposed ASCE 7 provisions for Tsunami Loads and Effects are consistent with tsunami physics and performance based engineering, with substantial load validation from posttsunami case studies of structures.



Principal Tsunami Design Strategies Chapter 6 - Tsunami Loads and Effects

- Select a site appropriate and necessary for the building
- Select an appropriate structural system and perform seismic design first
- Determine flow depth and velocities at the site based on the tsunami design zone map
- Check robustness of expected strength within the inundation height to resist hydrodynamic forces
- Check resistance of lower elements for hydrodynamic pressures and debris impacts to avoid progressive collapse
- Foundations to resist scour at the perimeter of the building
- Elevate critical equipment as necessary

