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Tsunami-Induced Hydrodynamics & Scour around Structures

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Presentation Outline

- Motivation
- Key Objectives
- Numerical Modelling @ uOttawa
- Laboratory Modelling @ UEL
- Mathematical Modelling @ UEL
- Comparison of Results
- Concluding Remarks
- Acknowledgements
- Questions / Comments

Motivation

- About 61% of damaged cost of 2011 Tohoku tsunami was attributed to the building sector (Kazma & Noda, 2012).
- One of the main causes for the failure of buildings and foundations was identified as tsunami-induced scour (e.g. Fernando et al., 2005; EEFIT, 2011; Bricker et al., 2015).
- It was reported that seaward corners of the walls facing the tsunami flow, geometry of the building, bottom shear stress, soil liquefaction play significant roles in development of scour holes (e.g. Nakamura et al., 2008; Yeh & Li, 2008; Nadal et al., 2010; Wilms et al., 2012; Lida et al., 2016).
- Nistor & Palermo (2015) stated geology of the coastline reflects the degree of damage to the areas hit by the 2011 Tohoku tsunami.

Motivation cont'd

- Tsunami-induced boundary layer thickness is a key parameter in evaluating temporal evaluation of tsunami-induced scour depth around circular structures (Larsen et al., 2018).
- The scour failure mechanism of buildings due to tsunamis are still not fully understood by the practitioners.
- There is a limited number of scour depth predictive models on structures and these models depend on fluid, flow, sediment and geometry of the structures (e.g. Tonkin et al., 2003; CSU – Nadal et al., 2010; Chock et al., 2015; Link et al., 2016; Nicholas et al., 2016).

Motivation cont'd (e.g. Local Scour around Buildings)

Key Objectives

- To simulate tsunami hydrodynamics of scour around buildings through numerical modelling.
- To replicate tsunami-induced scour at buildings using laboratory experiments.
- To combine numerical hydrodynamic and laboratory scour data with a simple practical scour depth predictive model.
- To draw preliminary design recommendations for future resilience of buildings in tsunami-prone areas.

Numerical Modelling @ uOttawa

- Numerical model was developed using OpenFOAM v2.3.0 in order to obtain tsunami-induced hydrodynamic conditions such as inundation depths, pressures and flow velocities at the toe of model buildings.

Continuity Eq.

$$\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z} = 0$$

Momentum Eqs.

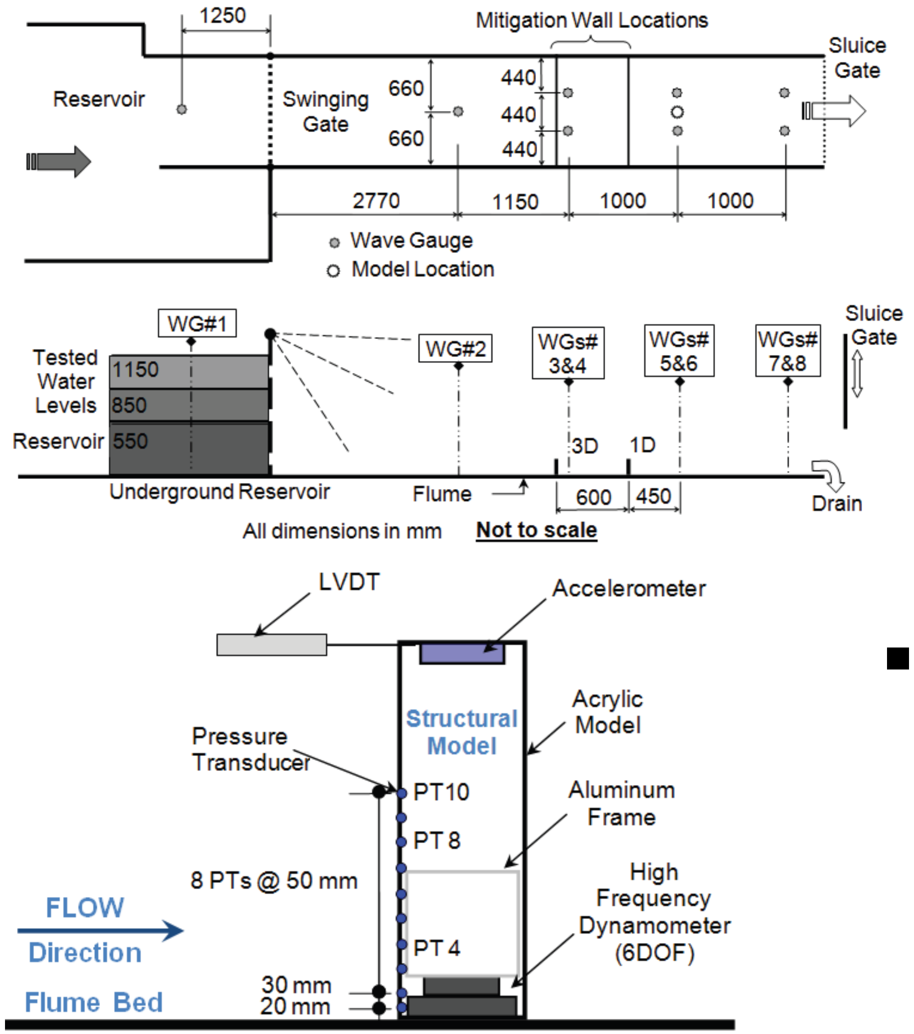
$$\bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} + \bar{w}\frac{\partial \bar{u}}{\partial z} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x} + g_x + \mathrm{v}\left(\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2} + \frac{\partial^2 \bar{u}}{\partial z^2}\right) - \left(\overline{\frac{\partial u'^2}{\partial x}} + \overline{\frac{\partial u'v'}{\partial y}} + \overline{\frac{\partial u'w'}{\partial z}}\right)$$

$$\bar{u}\frac{\partial \bar{v}}{\partial x} + \bar{v}\frac{\partial \bar{v}}{\partial y} + \bar{w}\frac{\partial \bar{v}}{\partial z} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial y} + g_x + \mathrm{v}\left(\frac{\partial^2 \bar{v}}{\partial x^2} + \frac{\partial^2 \bar{v}}{\partial y^2} + \frac{\partial^2 \bar{v}}{\partial z^2}\right) - \left(\overline{\frac{\partial v'^2}{\partial y}} + \overline{\frac{\partial u'v'}{\partial x}} + \overline{\frac{\partial u'w'}{\partial z}}\right)$$

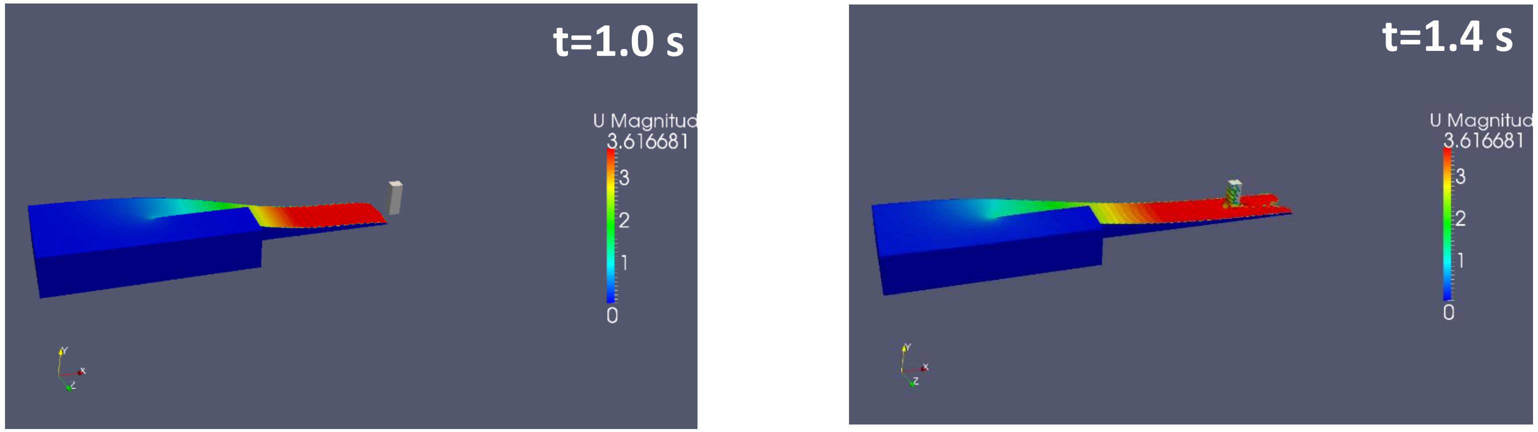
$$\bar{u}\frac{\partial \bar{w}}{\partial x} + \bar{v}\frac{\partial \bar{w}}{\partial y} + \bar{w}\frac{\partial \bar{w}}{\partial z} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial z} + g_x + \mathrm{v}\left(\frac{\partial^2 \bar{w}}{\partial x^2} + \frac{\partial^2 \bar{w}}{\partial y^2} + \frac{\partial^2 \bar{w}}{\partial z^2}\right) - \left(\overline{\frac{\partial w'^2}{\partial z}} + \overline{\frac{\partial w'v'}{\partial y}} + \overline{\frac{\partial u'w'}{\partial x}}\right)$$

- Performance of numerical model was verified by using experimental data (L0.305×W0.305×H1.0 m model building and impounding depths of 0.55, 0.85, 1.15 m) of Al-Faesly et al. (2012) carried out at NRC, Ottawa, Canada.

Numerical Modelling @ uOttawa – Model Performance

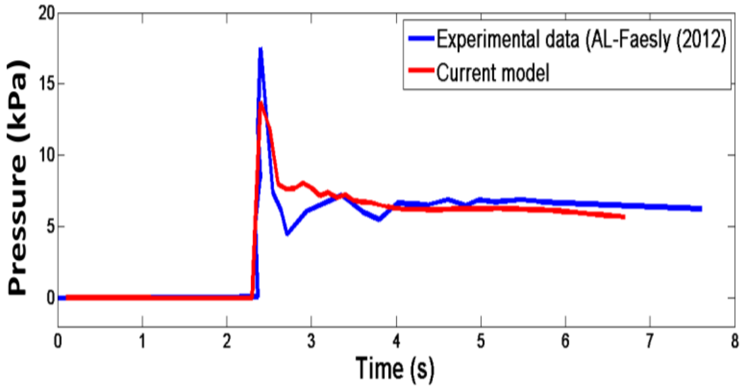


Experimental set-up of Al-Faesly et al. (2012)



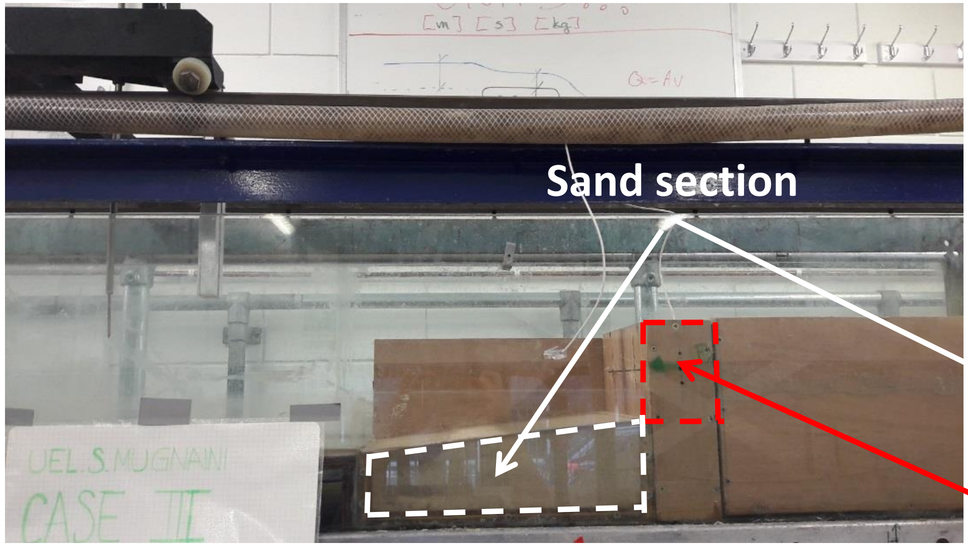
Instantaneous velocities obtained using the OpenFOAM model.

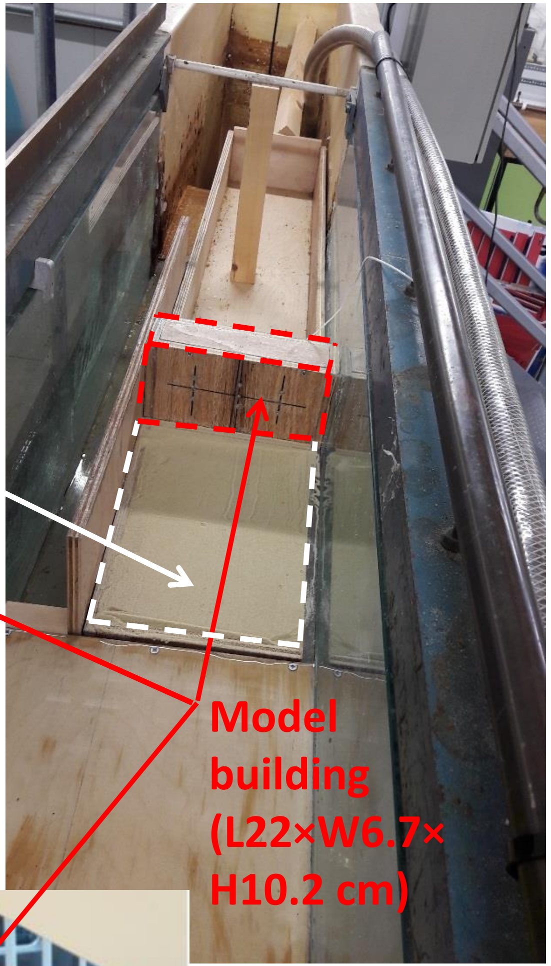
- An unstructured mesh with Δx=1.0 cm and Δt=0.025 s.

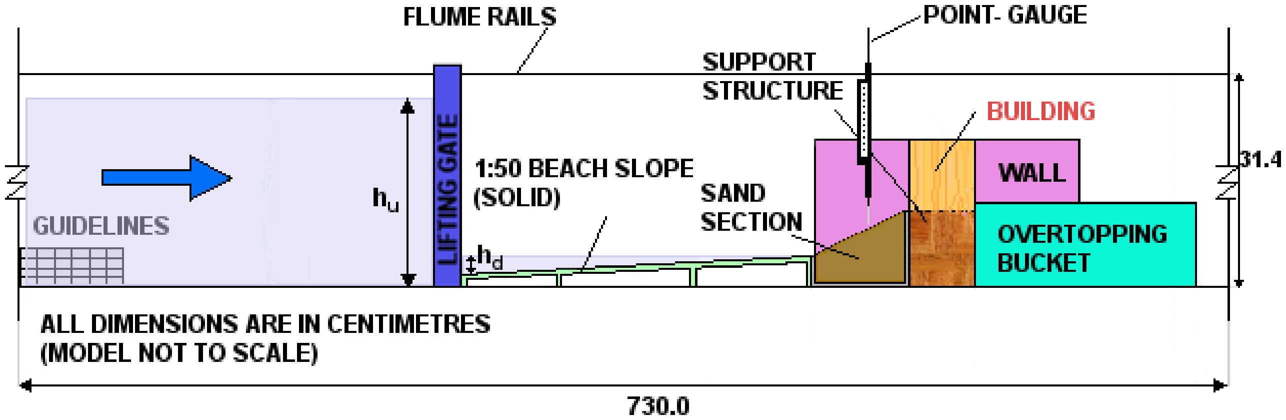


Comparison of experimental pressure data (Al-Faesly et al., 2012) and numerical model (Impounding depth=0.85 m, at 0.05 m from the structure toe).

Laboratory Modelling @ UEL



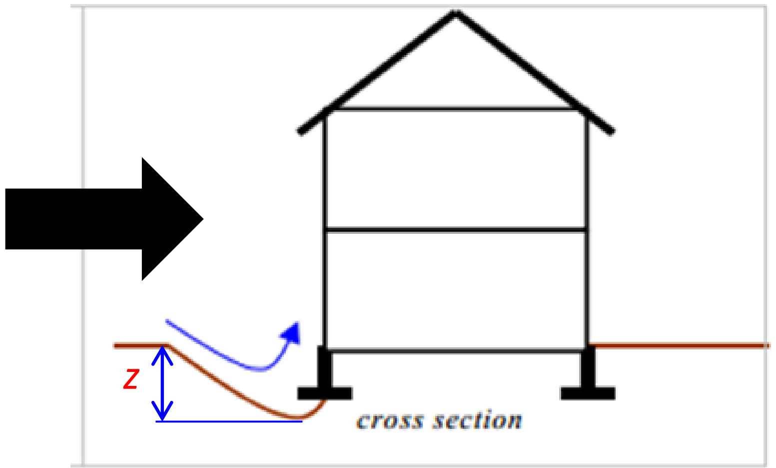




Mathematical Modelling @ UEL

- Nicholas et al. (2016) developed a representative scour depth (Z) model which is related to shear velocity of soil around building, U_* (effective shear stress) and half seaward width of the building, B_h.
- The driving forces in model formulation are tsunami physics and the Buckingham π theorem.

$$Z = f[g, U_*, B_h]$$



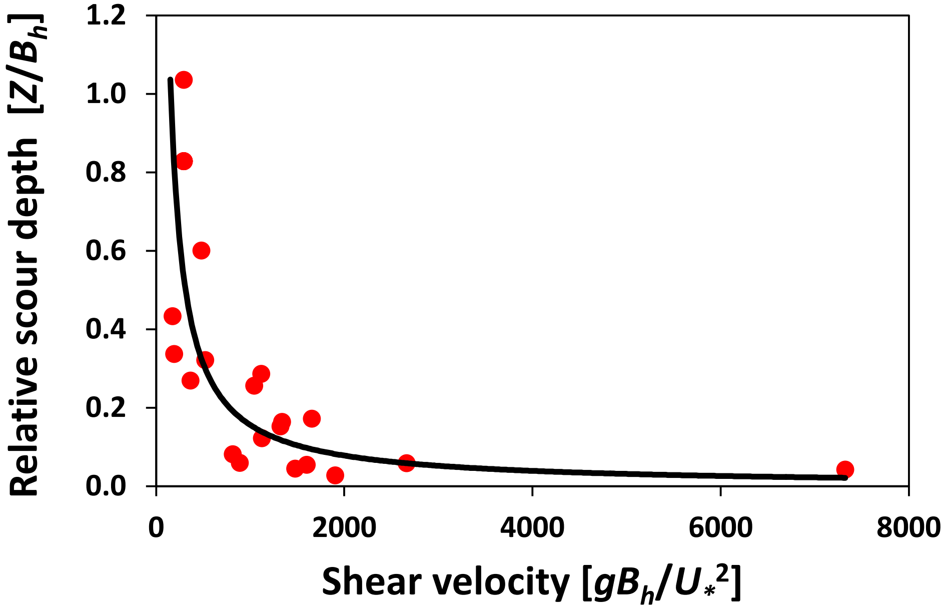
Ref: Nicholas et al. (2016), 35th ICCE, Turkey

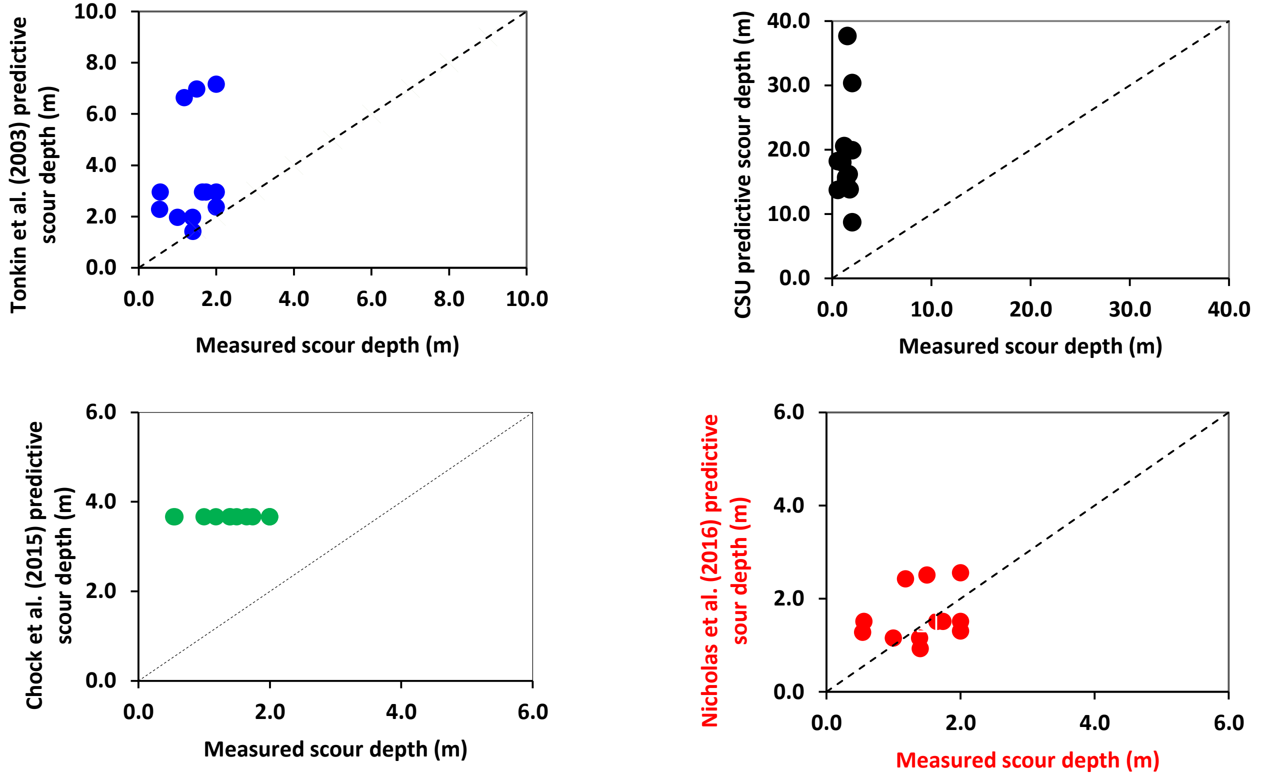
$$\frac{Z}{B_h} = f\left(\frac{B_h}{CK^2 h}\right)$$

$$C = 0.9 n^2 h^{-1/3}$$

- Z: Scour depth
- B_h: Seaward width of building
- C: Darcy-Weisbach frictional coefficient
- h: Inundation depth
- K: Froude number
- n: Manning's roughness coefficient

Mathematical Modelling @ UEL – Model Verification





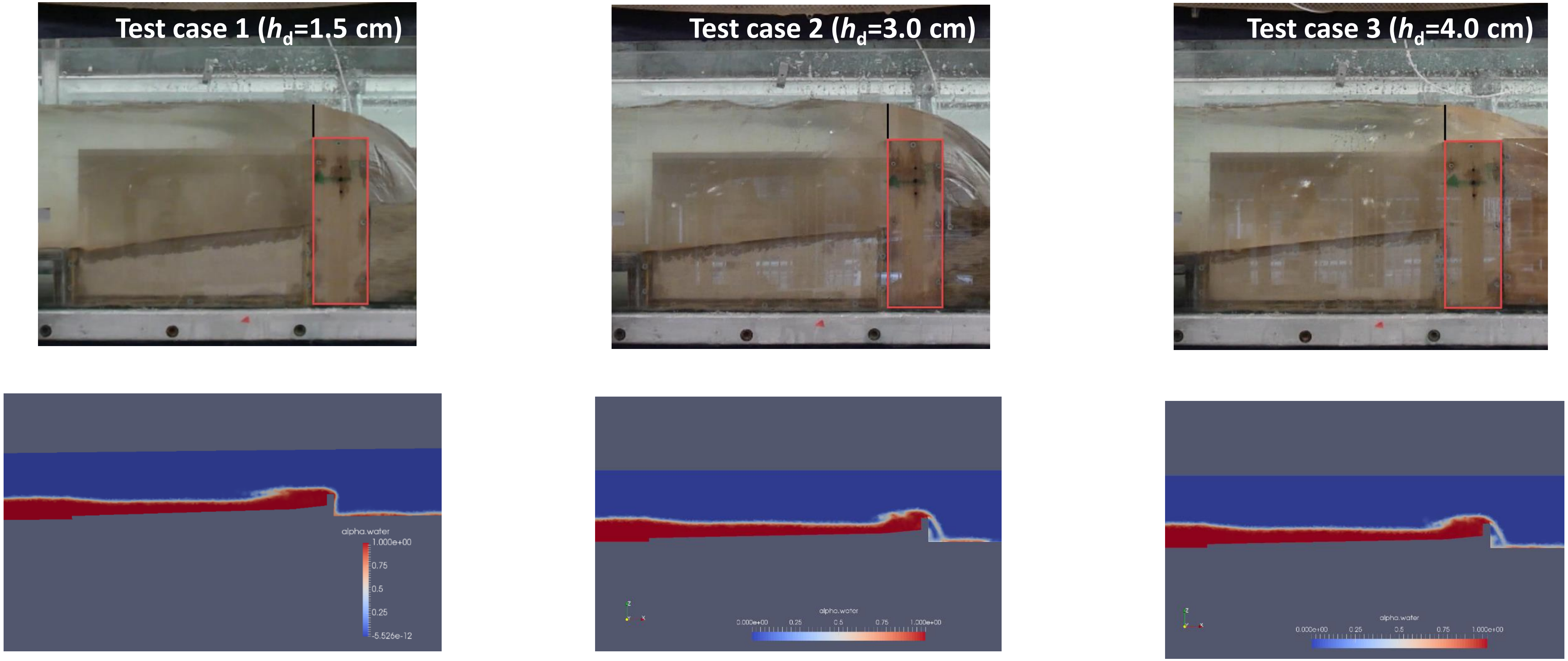
Comparison between different scour predictive models

$$\frac{z}{B_h} = 16\left(\frac{gB_h}{CV^2}\right)^{-1}$$

$$C = 0.9n^2h^{-1/3}$$

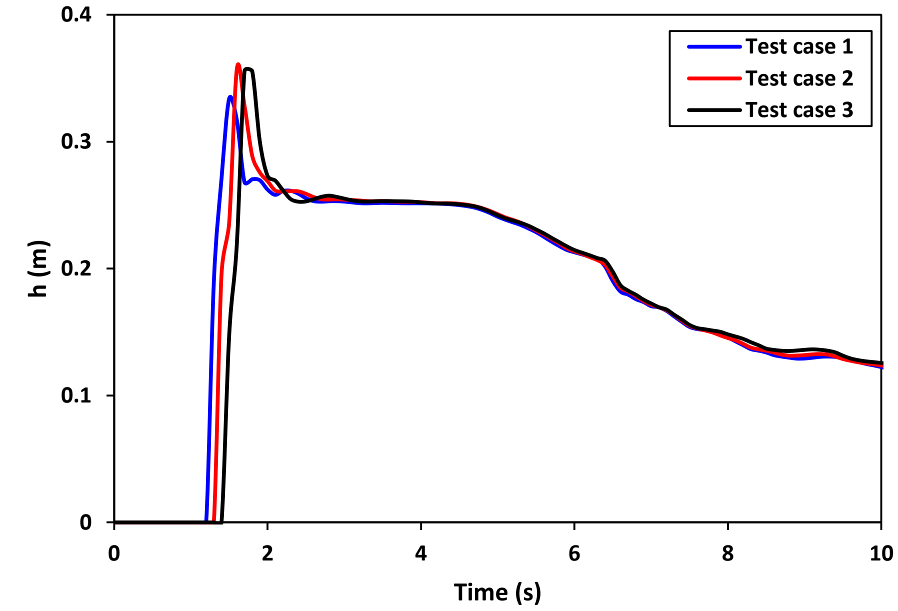
Ref: Nicholas et al. (2016), 35th ICCE, Turkey

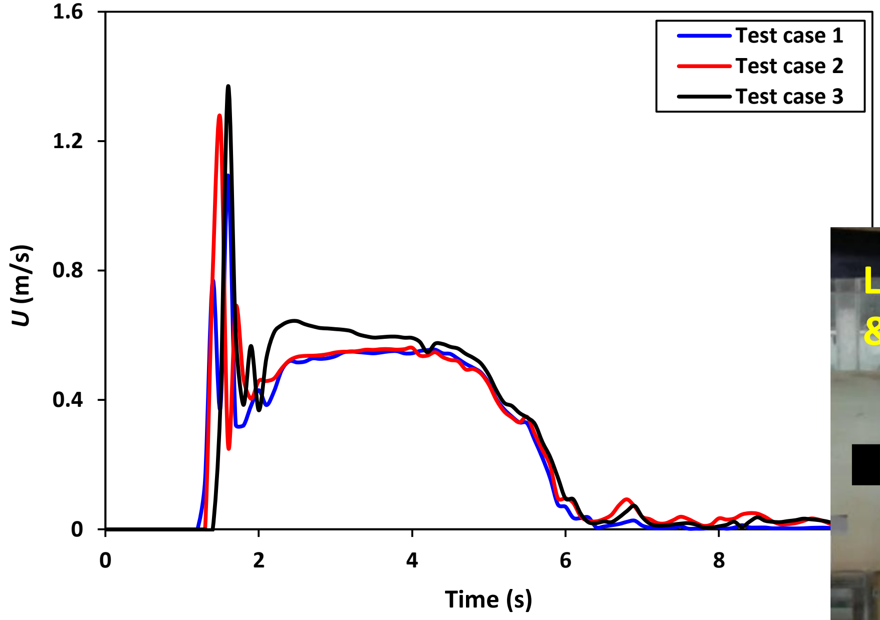
Comparison of Results (Hydrodynamics)

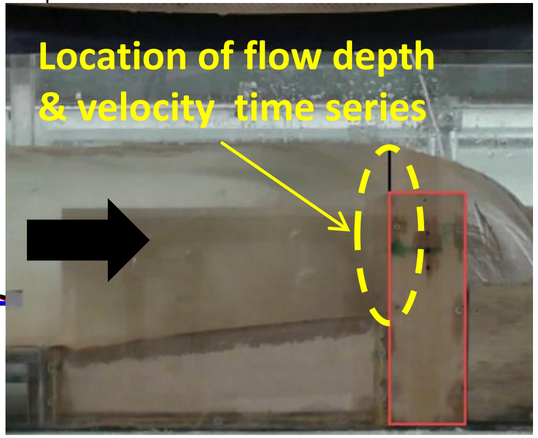


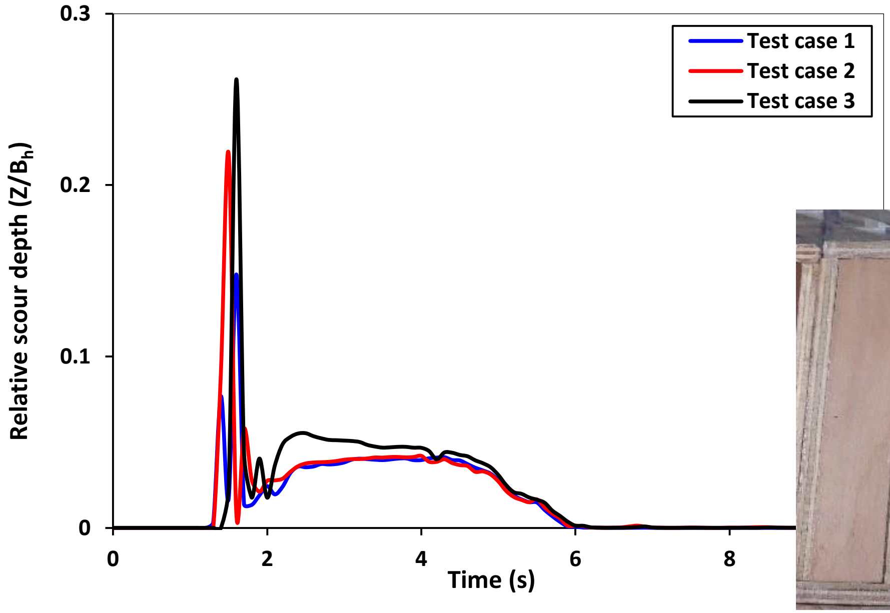
Dam-breaking wave propagation over the model building (Experiments vs. Numerical model)

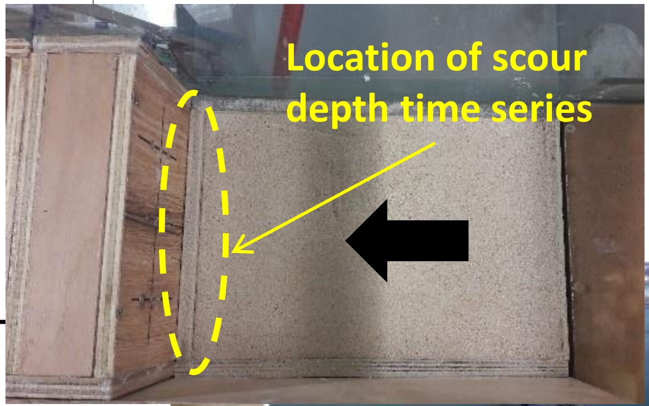
Comparison of Results (Hydrodynamics & Local Scour)



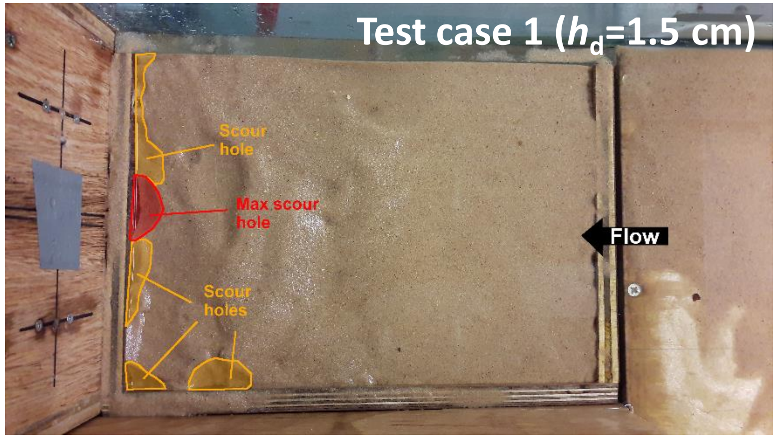


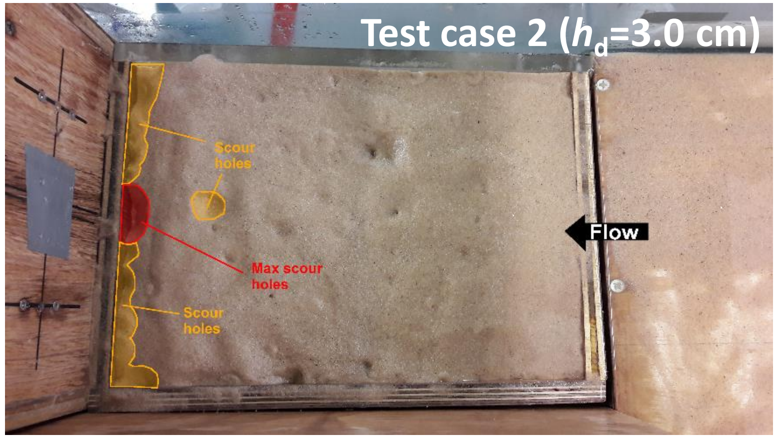


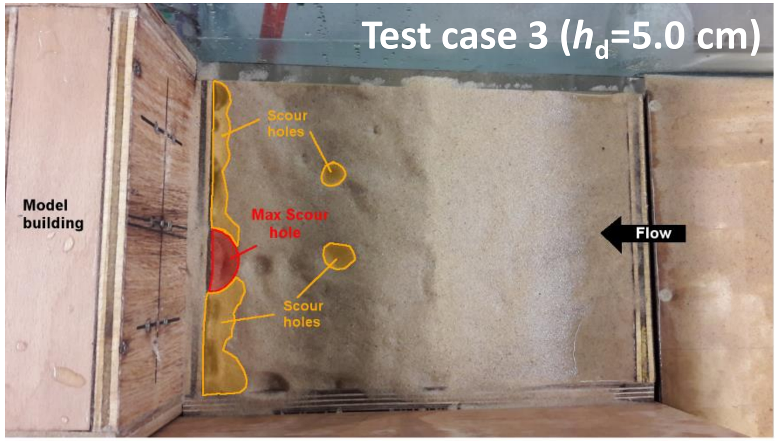


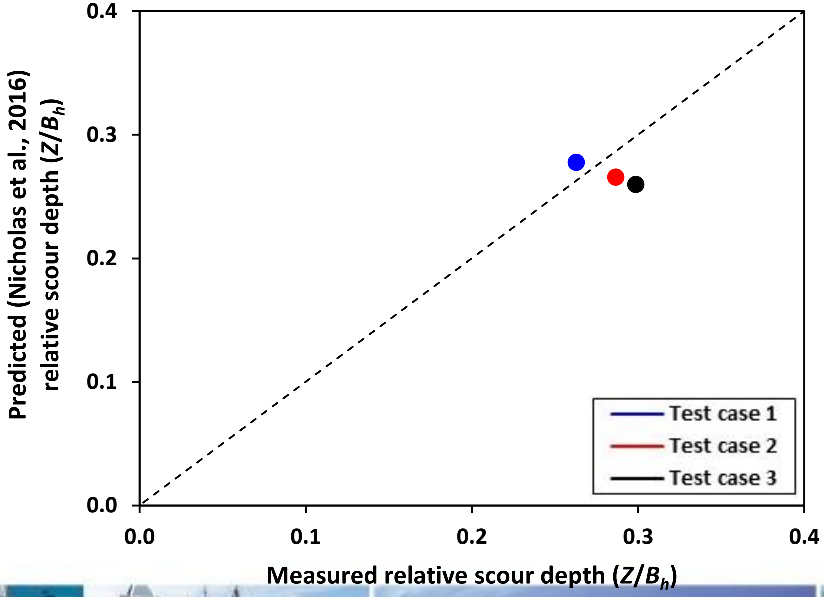


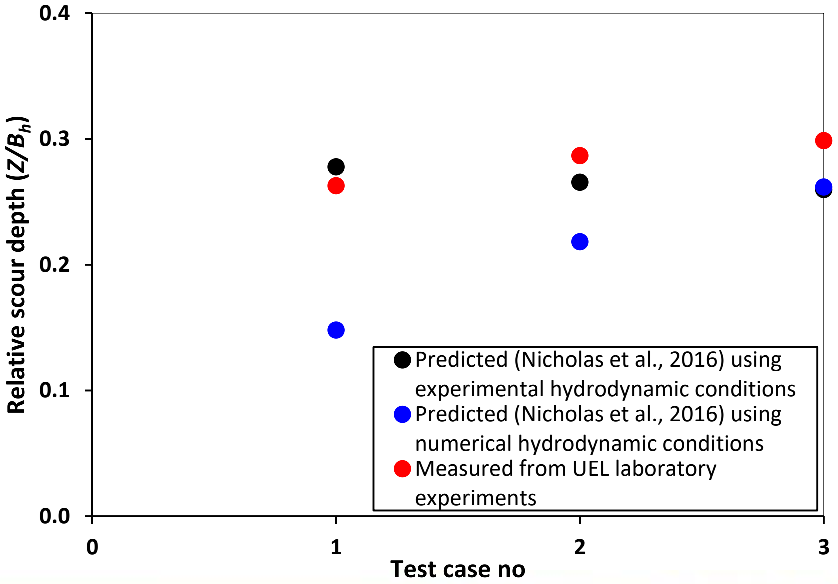
Comparison of Results (Local Scour)

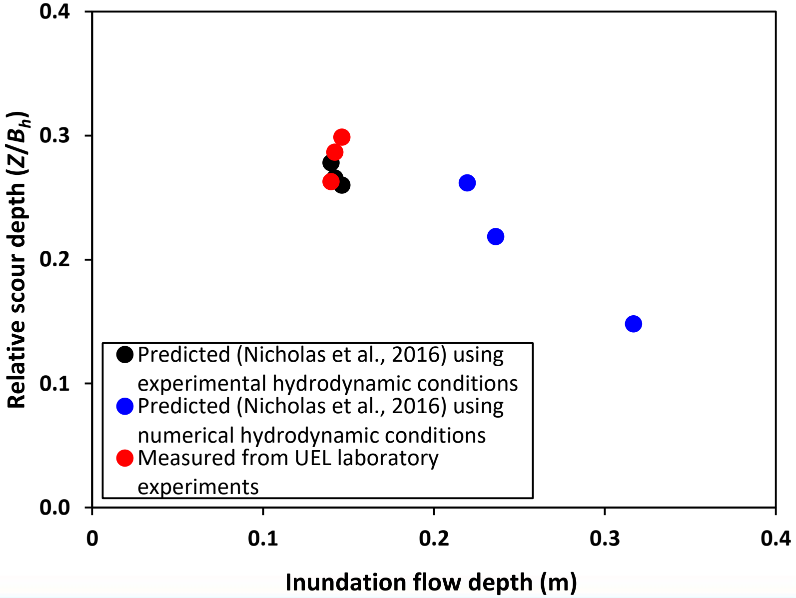












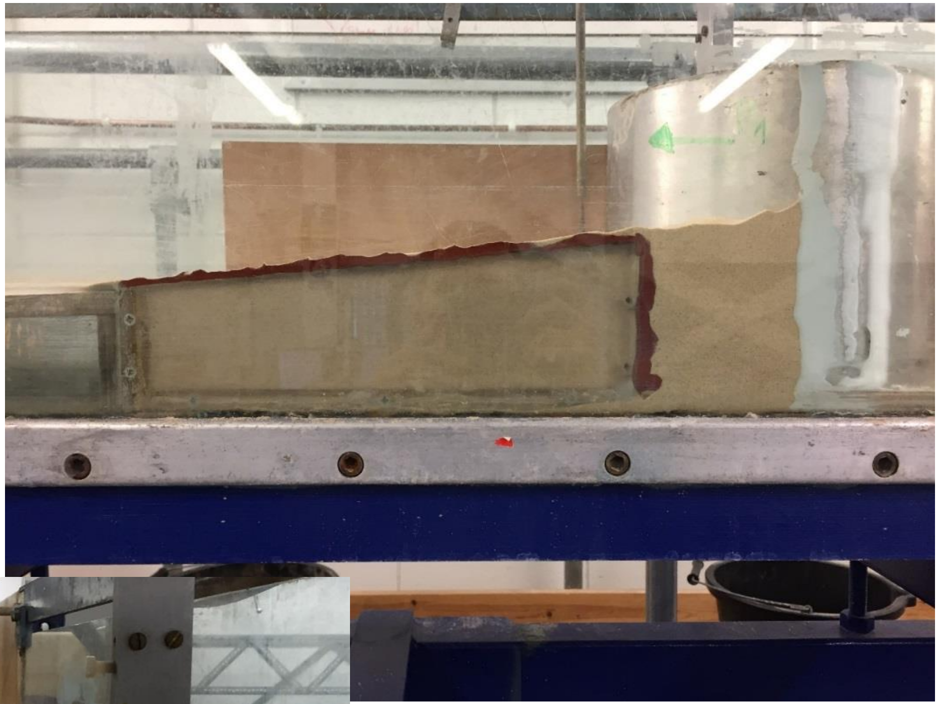
Concluding Remarks

- Numerical, laboratory and mathematical modelling techniques were applied to study tsunami-induced hydrodynamics and local scour around buildings.
- Experimental and mathematical model results match well though numerical model under-predicts the simulated hydrodynamic conditions.
- The experimental scour depth increases as the downstream depth increases while keeping upstream impoundment depth constant; i.e. representative scour depth is sensitive to tsunami hydrodynamic conditions.
- Increased time of immersion is related to an increase in scour depth, both the incoming tsunami wave and return flow.
- Local scour holes were developed more centrally than corners of the tested building.

Concluding Remarks cont'd

- Local scour depth was roughly equally to twice the inundation flow depth for the current laboratory tests.
- Local maximum scour depth in the vicinity of a building can be predicted with reasonable accuracy based on the following parameters; tsunami inundation depth (h), flow velocity (V) and geometrical properties (B_h).
- Observations and preliminary findings provide basis to further extend research on tsunami-induced scour around different structure geometries.

Future Study (Local Scour around Circular Buildings)



Acknowledgements

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Questions/Comments