Assessing the impact of dry granular flows on structures

PIONEERING RESILIENCE
Est. 2007

Maria Kontoe, PhD Student

Tiziana Rossetto, Professor

Susana Lopez-Querol, Associate Professor

Landslides

Catastrophic impact on the affected communities and infrastructure

(Luo et al. 2019; M. Papathoma-Kohle 2017)

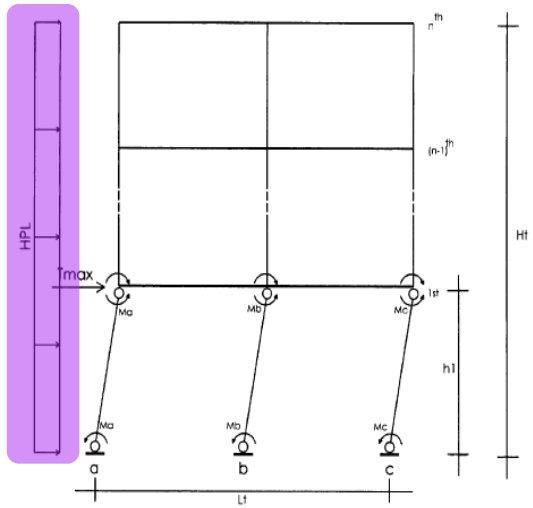
1900-2014 EM-DAT:
Casualties: 65000
Loss: 8.7 billion USD

How to assess the landslide impact on structures?

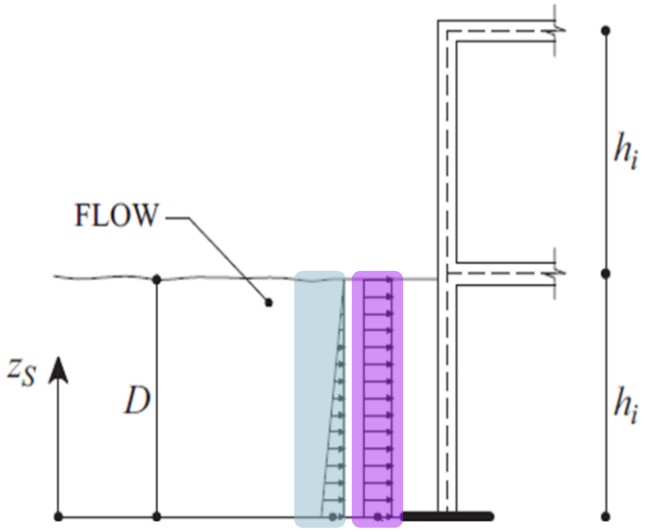
- Empirical Method
- Expert Judgement
- Analytical Method

Flow type landslides: Analytical Methods

- ❑ Sophisticated Non-Linear Models *(e.g. FEM, MPM)*
- ❑ Structural analysis with simplified load patterns



Petrazzuoli and Zuccaro (2004)



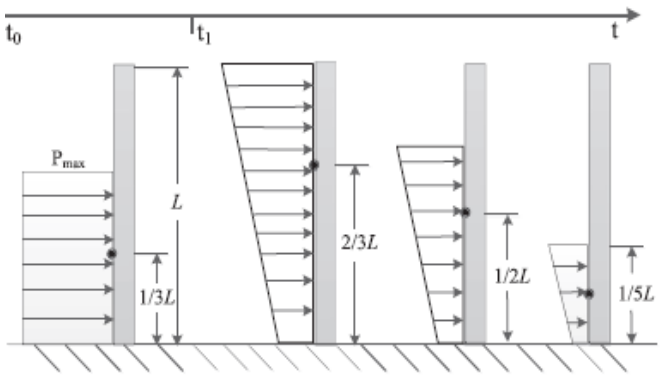
Parisi and Sabella (2017)

- Hydrodynamic UDL
- Hydrostatic load
- Constant application height

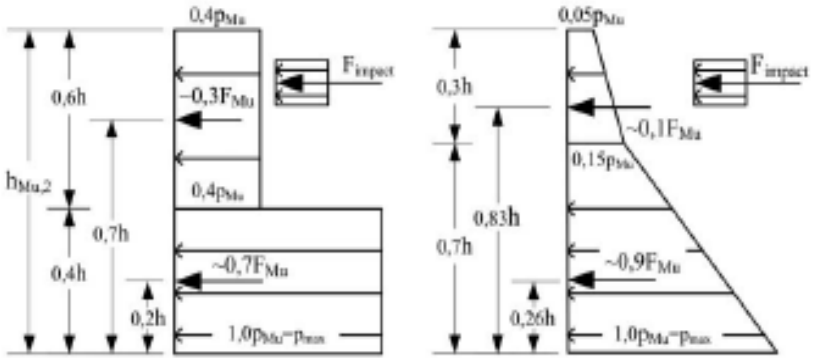
Load pattern adequate to capture SSI with passable obstacles *(buildings)*?

Alternative Load Patterns

- Experiments on passable obstacles



(Cui et al. 2015)



(Suda et al. 2010)

Simplified Structural Analysis Framework

- Load pattern definition on passable obstacles
- Static Approach

Methodology

Soil Impact forces: Material Point Method *(MPM)*

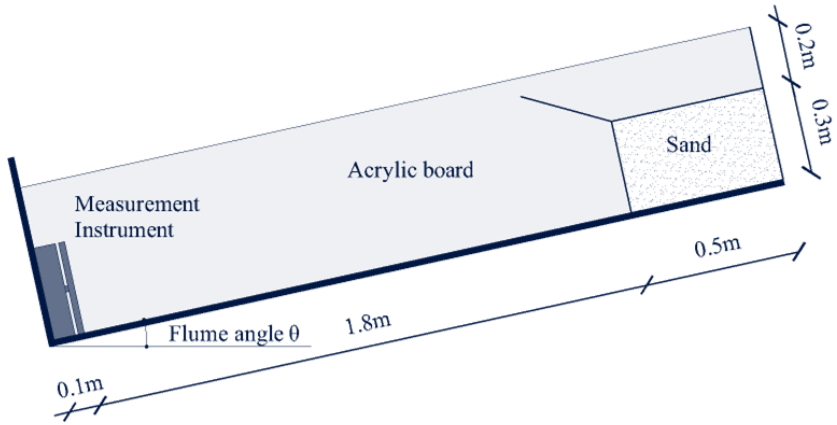
Structural model: OpenSees

Dynamic analysis to the measured soil forces

Validation of static approach for SSI

Push Over Analysis

- Flume test for numerical validation
- Scaling to prototype conditions.
- Modifications in the obstacle to:
  - ✓ Limit overflowing
  - ✓ Induce 100%; 50%; 25% obstruction



Methodology

Soil Impact forces: Material Point Method *(MPM)*

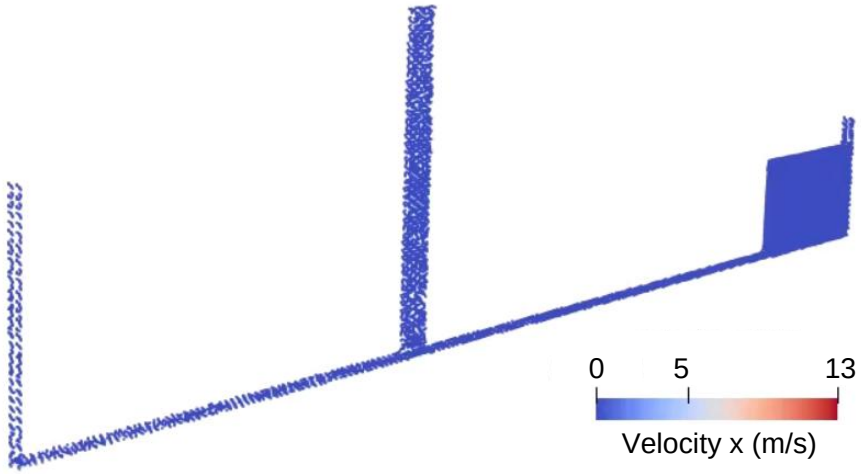
Structural model: OpenSees

Dynamic analysis to the measured soil forces

Validation of static approach for SSI

Push Over Analysis

- Flume test for numerical validation
- Scaling to prototype conditions.
- Modifications in the obstacle to:
  - ✓ Limit overflowing
  - ✓ Induce 100%; 50%; 25% obstruction



Methodology

Soil Impact forces: Material Point Method *(MPM)*

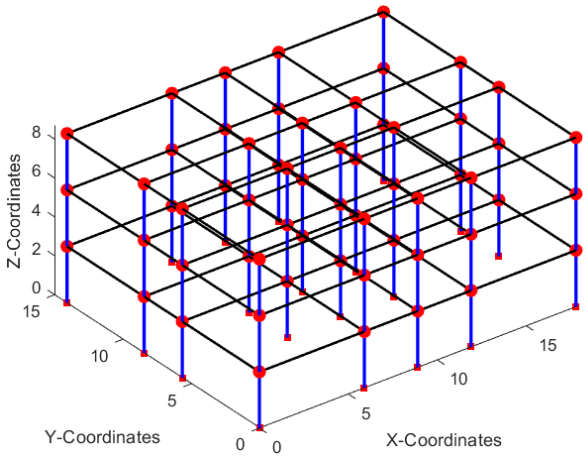
Structural Model: OpenSees

Dynamic analysis to the measured soil forces

Validation of static approach for SSI

Push Over Analysis

High code RC frame structure



Methodology

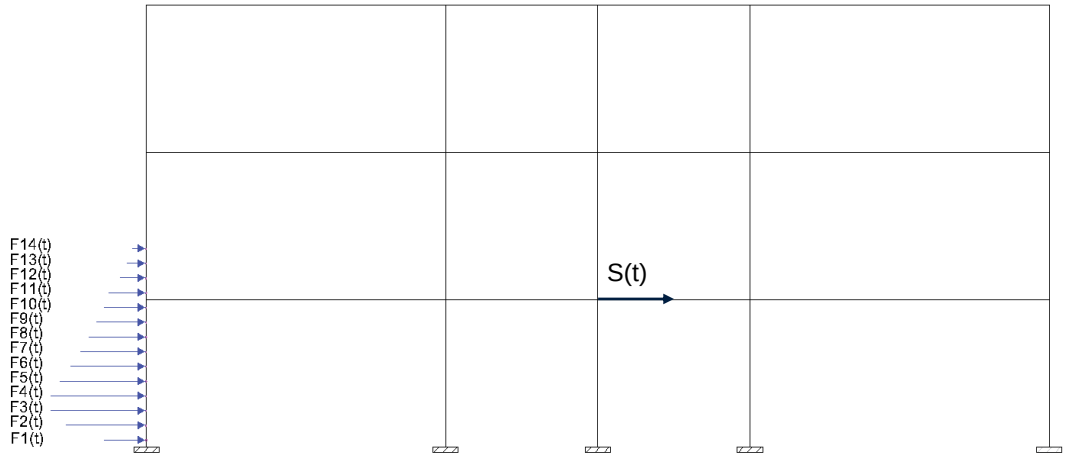
Soil Impact forces: Material Point Method *(MPM)*

Structural Model: OpenSees

Dynamic analysis to the measured soil forces

Validation of static approach for SSI

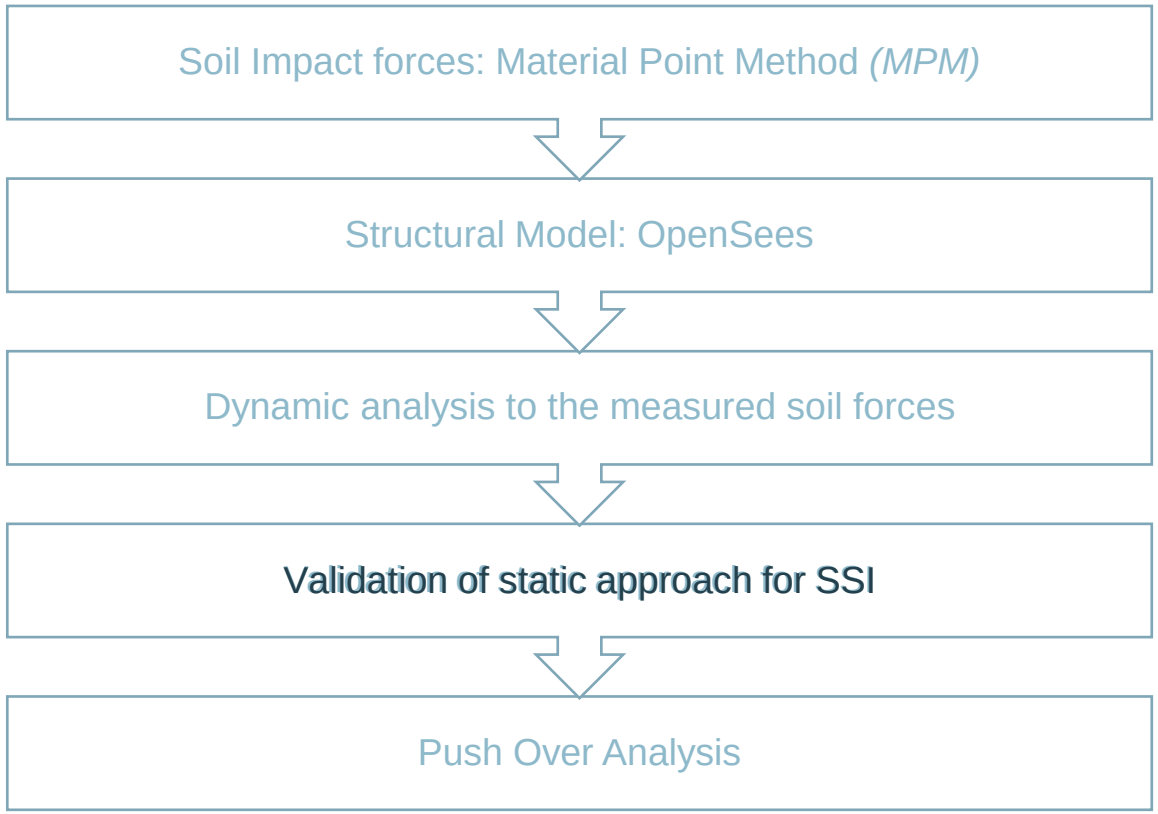
Push Over Analysis



Normal Force, $F_i(t)$
Measured at different levels along the height of the obstacle

Shear Force, *S(t)*
Measured at the storey level

Methodology



Methodology

Soil Impact forces: Material Point Method *(MPM)*

Structural Model: OpenSees

Dynamic analysis to the measured soil forces

Validation of static approach for SSI

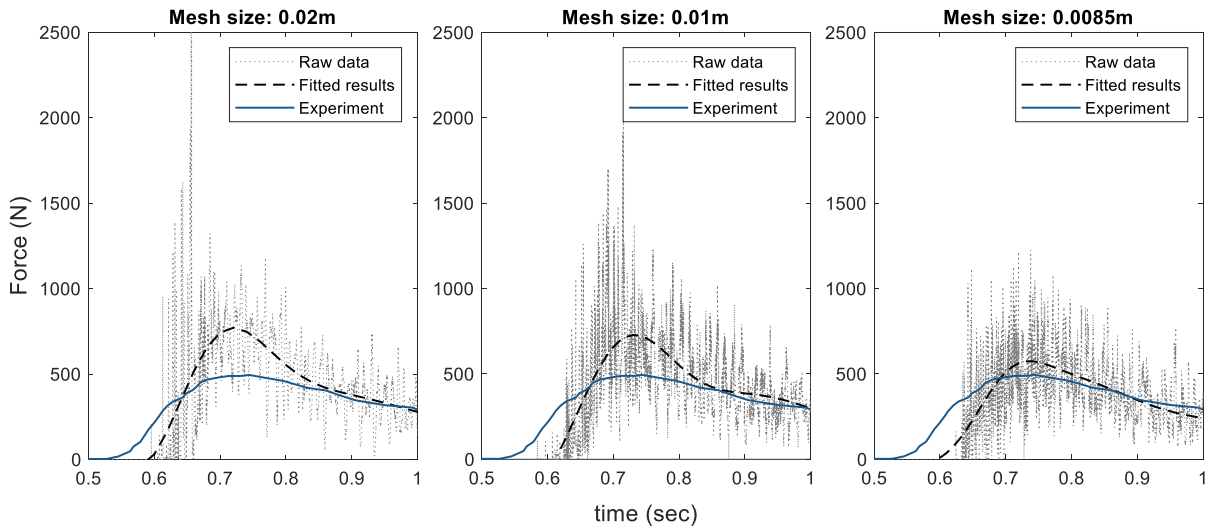
Push Over Analysis

Comparison of structural performance:
- Seismic actions
- Landslide Loads

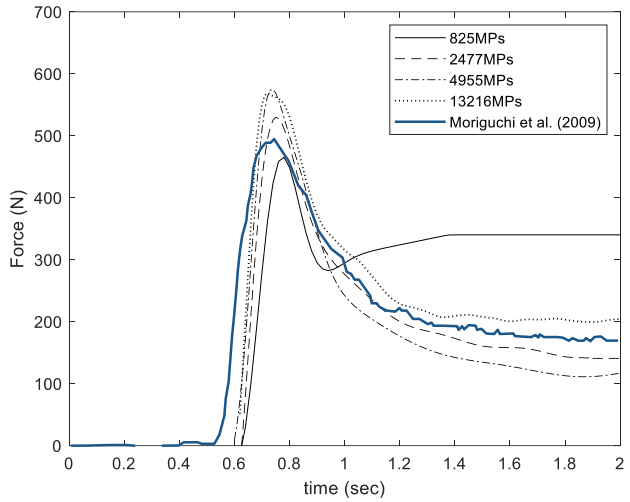
Modelling Assumptions & Validation

- Moriguchi et al. (2009) experiments
- MPM approach integrated in Anura3D
- Material Properties as per Cuomo et al. (2020)
- Sensitivity Analysis on Mesh Size & Number Material Points

- Mesh Size: Reduce Oscillations



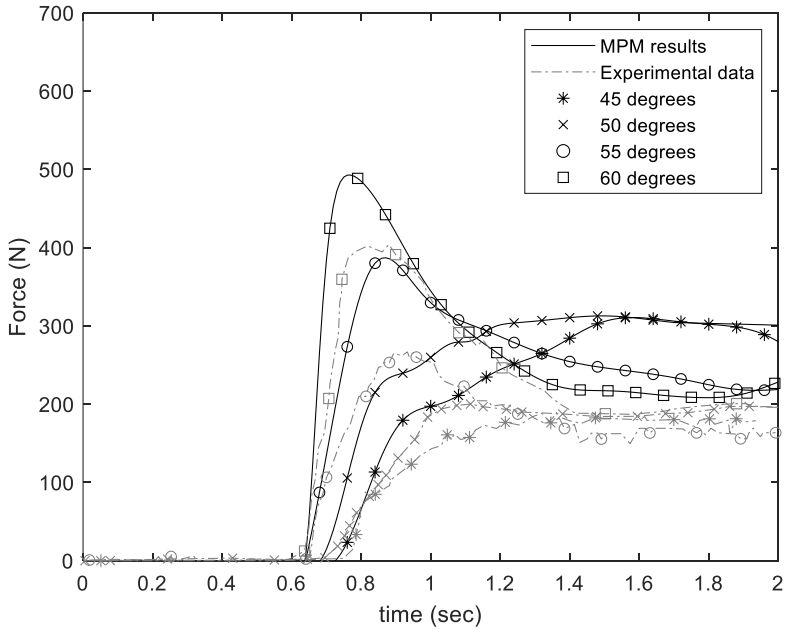
- Material Points: Convergent Solution



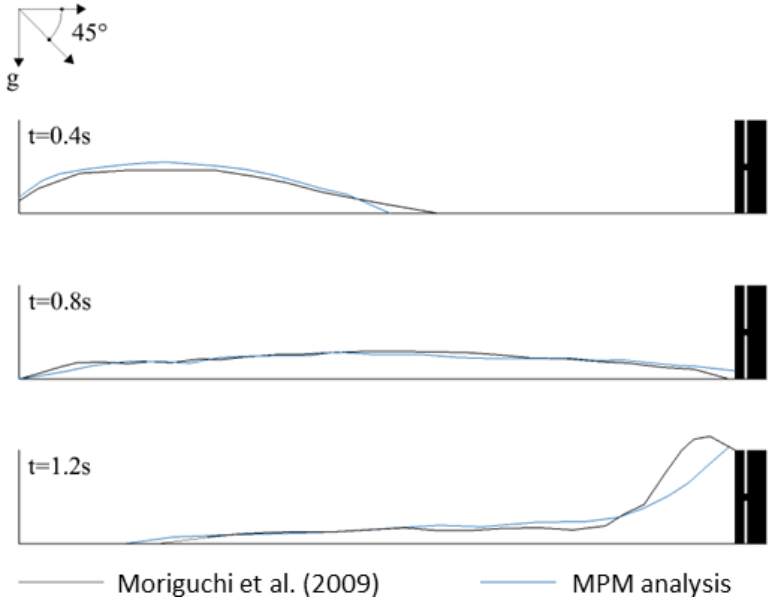
Modelling Assumptions & Validation

- Moriguchi et al. (2009) experiments
- MPM approach integrated in Anura3D
- Material Properties as per Cuomo et al. (2020)
- Sensitivity Analysis on Mesh Size & Material Points

Impact Force

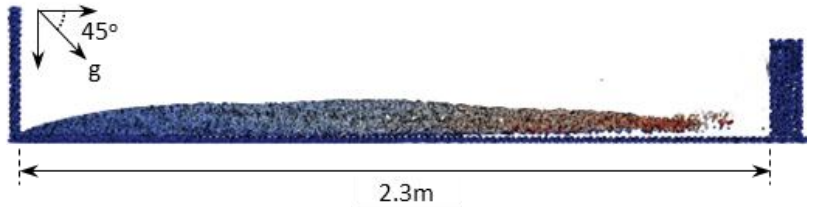


Deformed shape

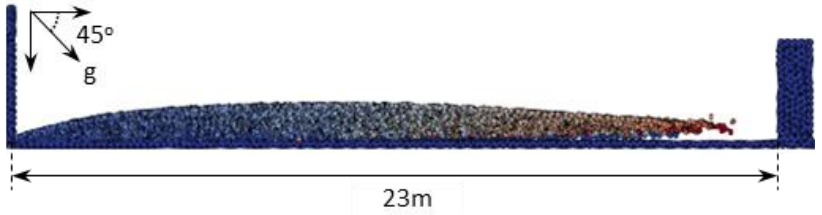


Geometric scaling

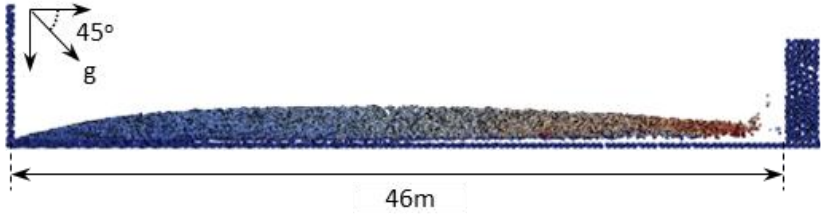
- λ=1

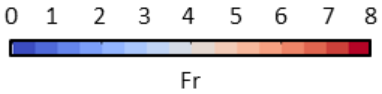


- λ=10



- λ=20



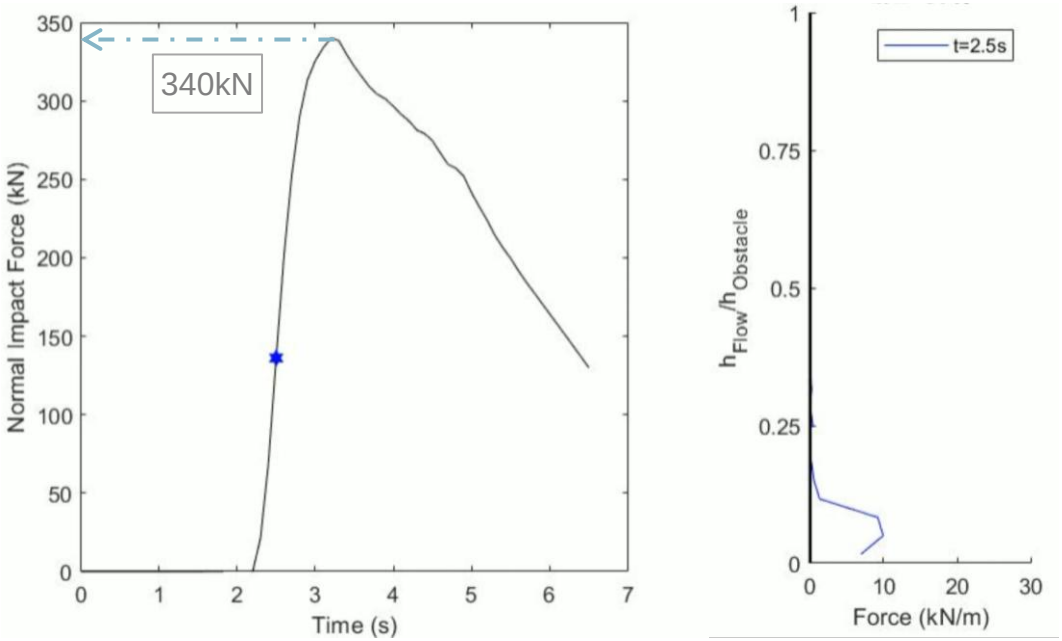


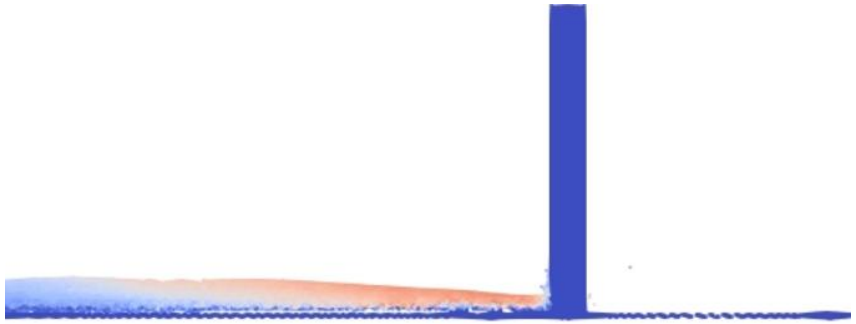
Froude similarity

Variable	Symbol	Factor	Iai et al. (2005)
Length (m)	l^*, h^*, w^*	λ	μ
Density (kg/m3)	ρ^*	1	μ_ρ
Mass (kg)	m^*	λ^3	-
Displacement (m)	x^*	λ	$\mu\mu_\varepsilon$
Pressure (N/m²)	p^*	λ	$\mu\mu_\rho$
Impact Force (N)	F^*	λ^3	$\mu^3\mu_\rho$
Flow Height (m)	$h_f{}^*$	λ	-
Strain	ε^*	1	μ_ε
Velocity (m/s)	v^*	$\sqrt{\lambda}$	$\sqrt{\mu\mu_\varepsilon}$
Time (s)	t^*	$\sqrt{\lambda}$	$\sqrt{\mu\mu_\varepsilon}$
Stiffness (N/m)	K^*	λ	$\mu\mu_\rho/\mu_\varepsilon$
Acceleration (m/s)	a^*	1	1

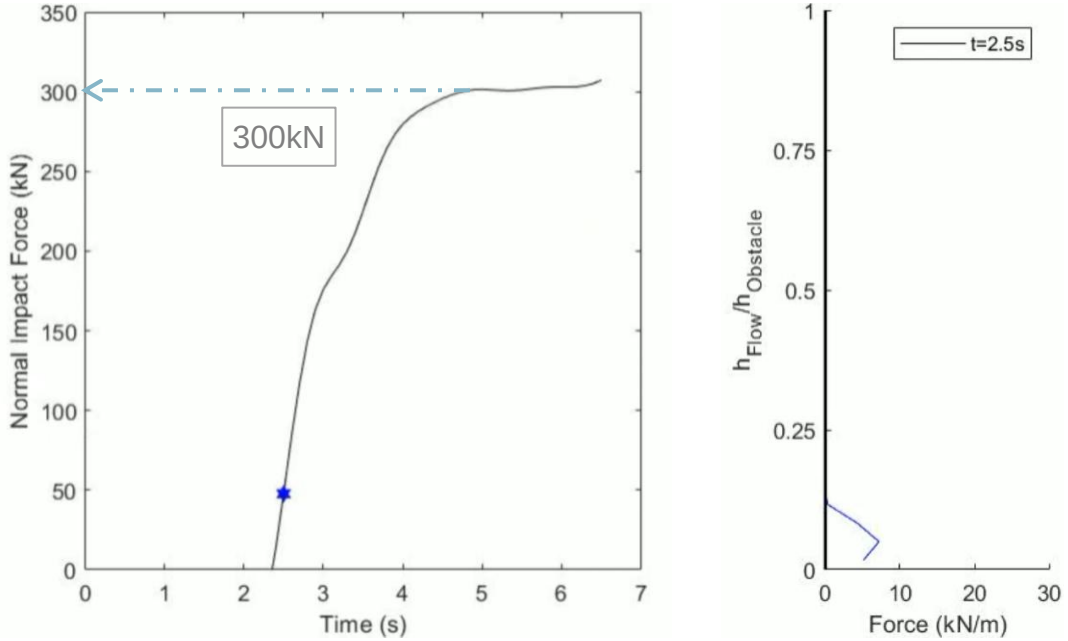
Normal Impact Force

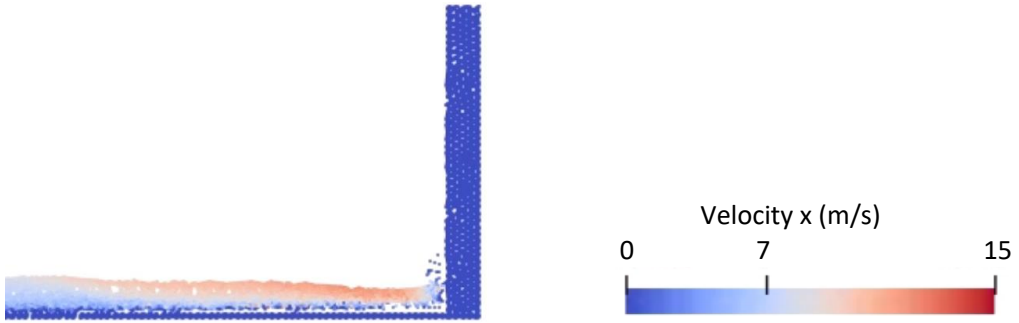
- Passable obstacle (b/w=0.5)





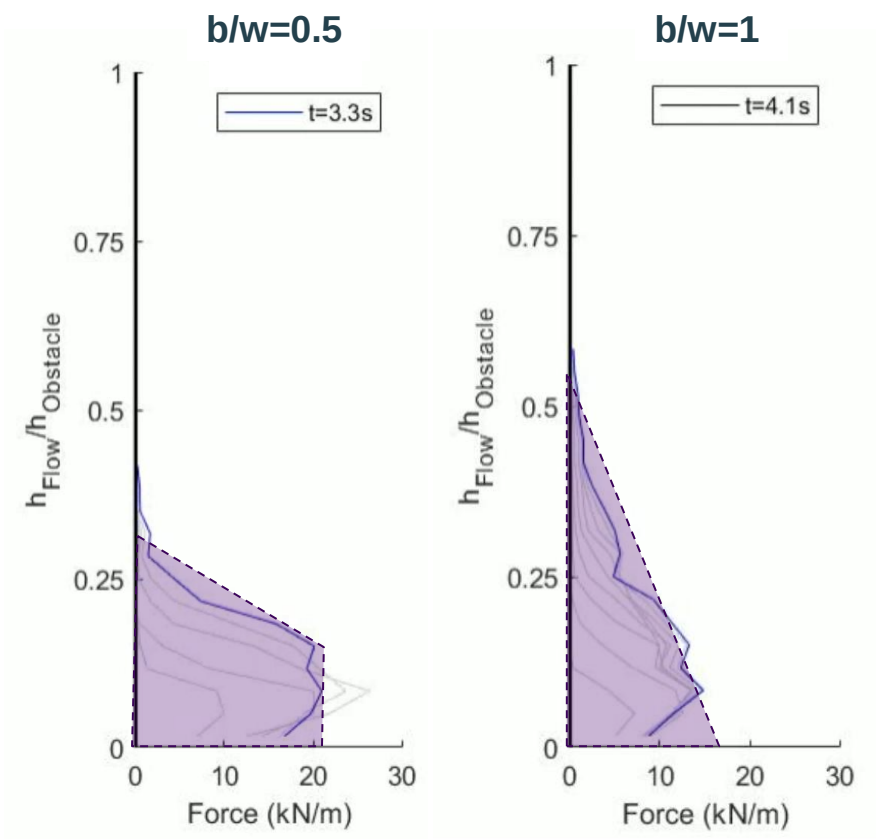
- Full-width obstacle (b/w=1)



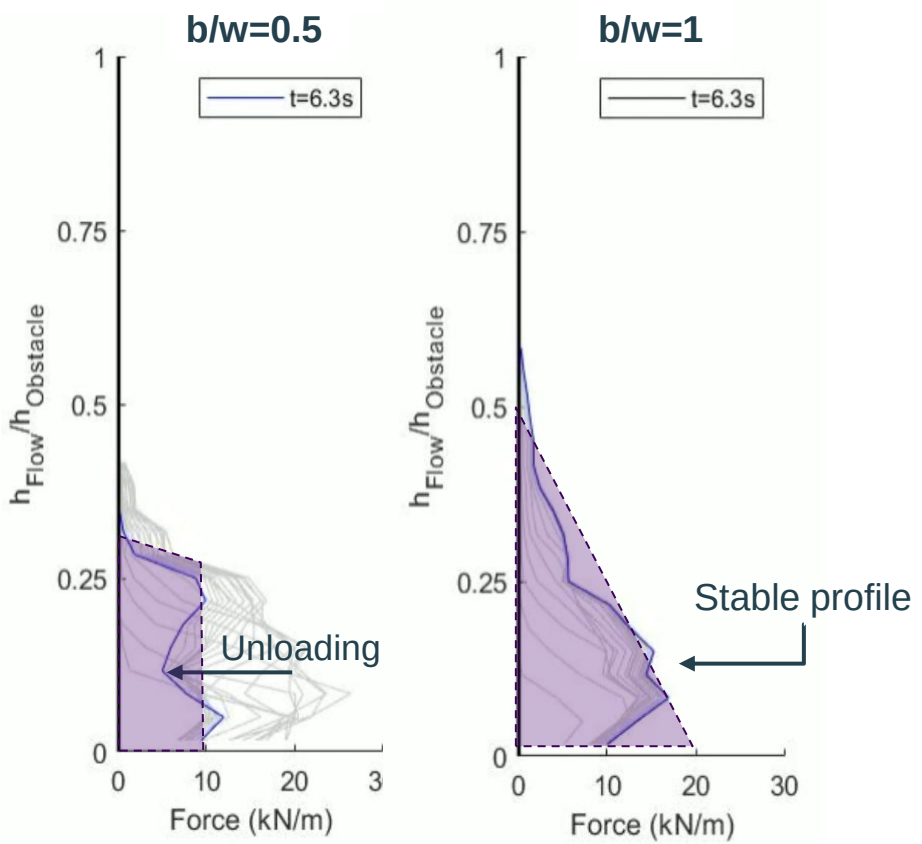


Normal Force Distribution

❑ Peak Impact

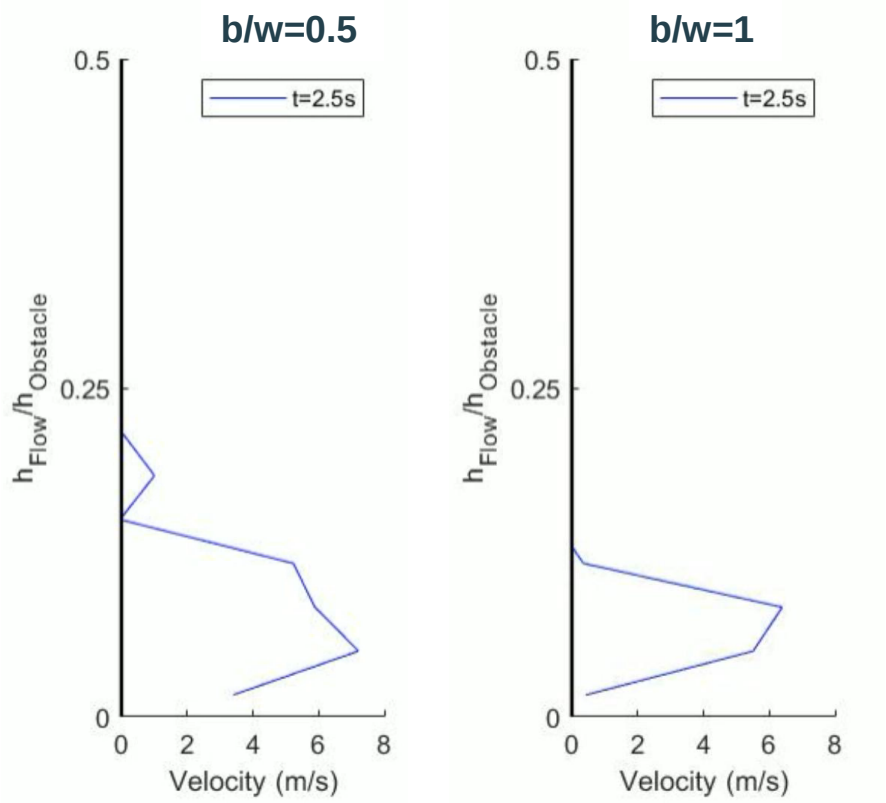


❑ End of the analyses

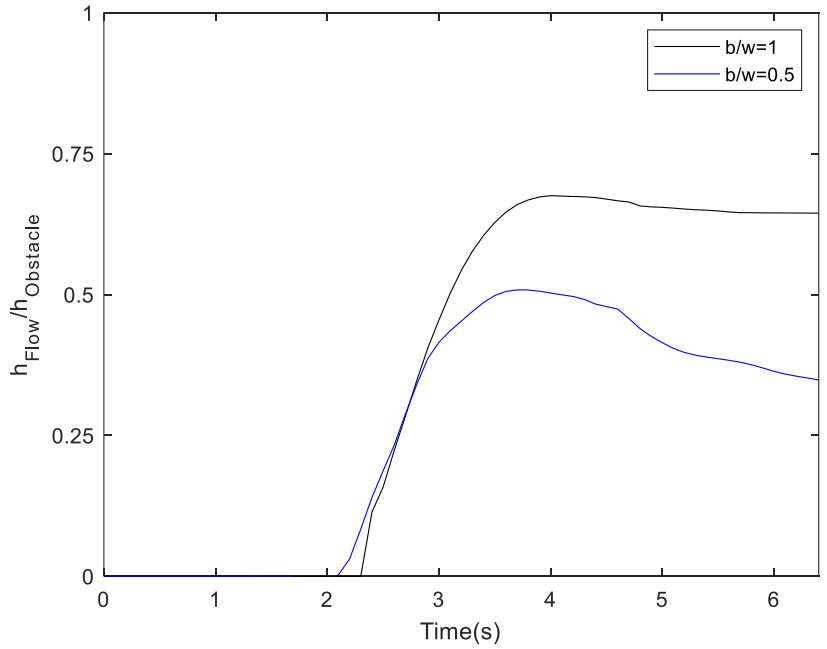


Flow response

❑ Flow velocity



❑ Flow height/ Sediment

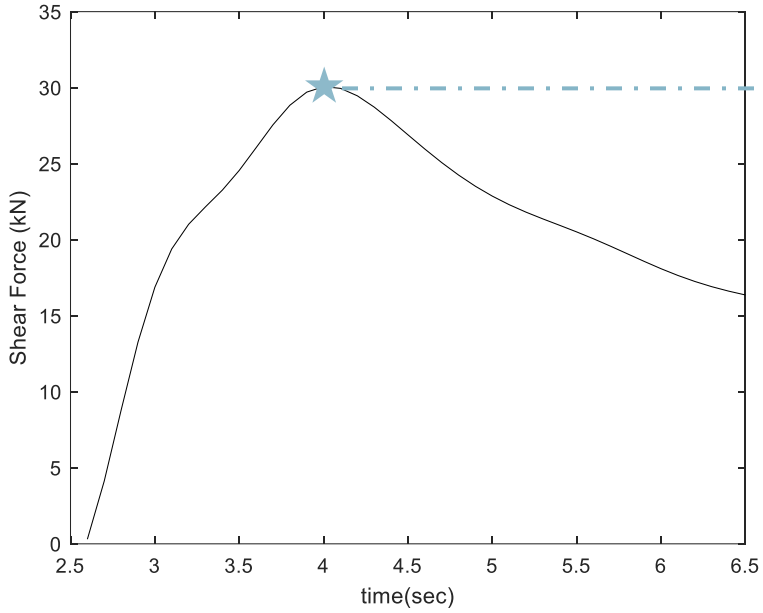


Reduction in b/w :

- Limits the peak flow height
- Downward post-peak branch

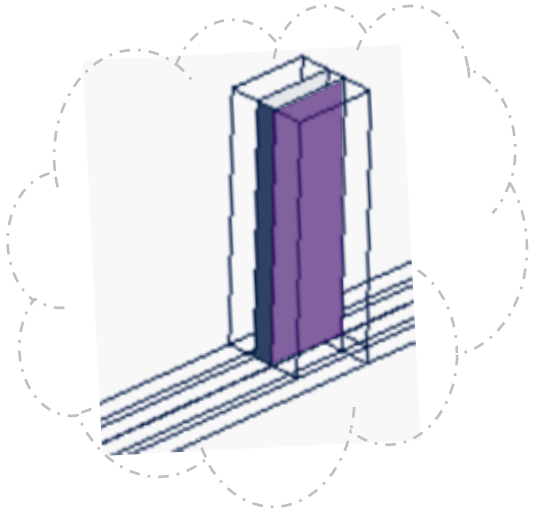
Shear Force

- Passable obstacle (b/w=0.5)



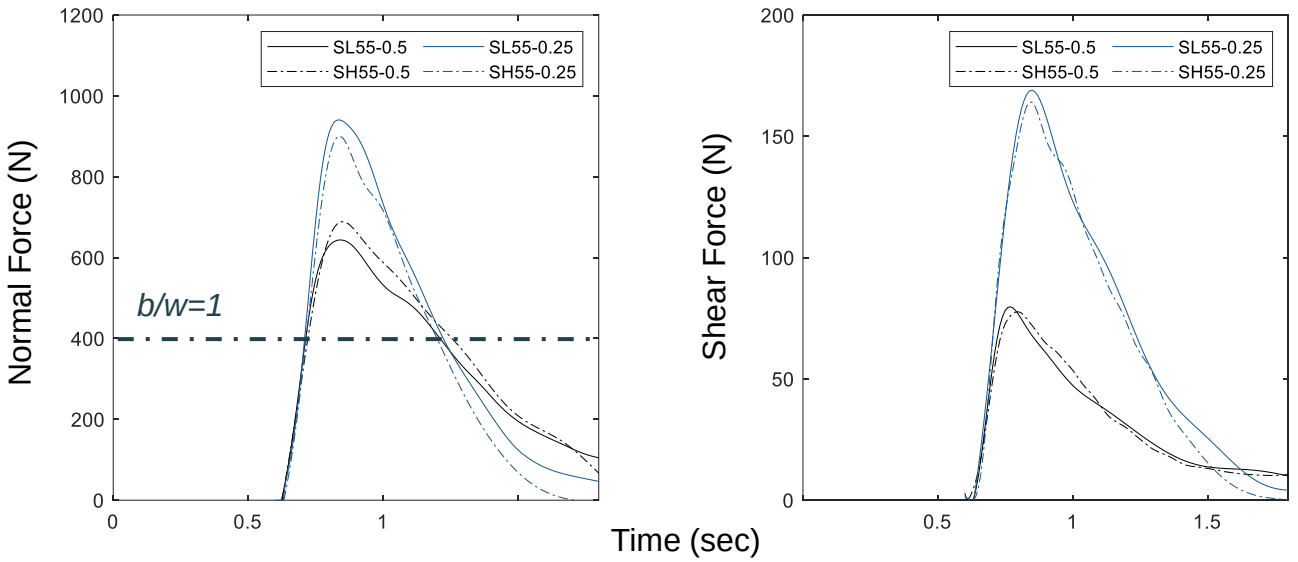
Total peak shear force: 60kN
(20% of normal force)

Significant load to be considered in the assessment framework

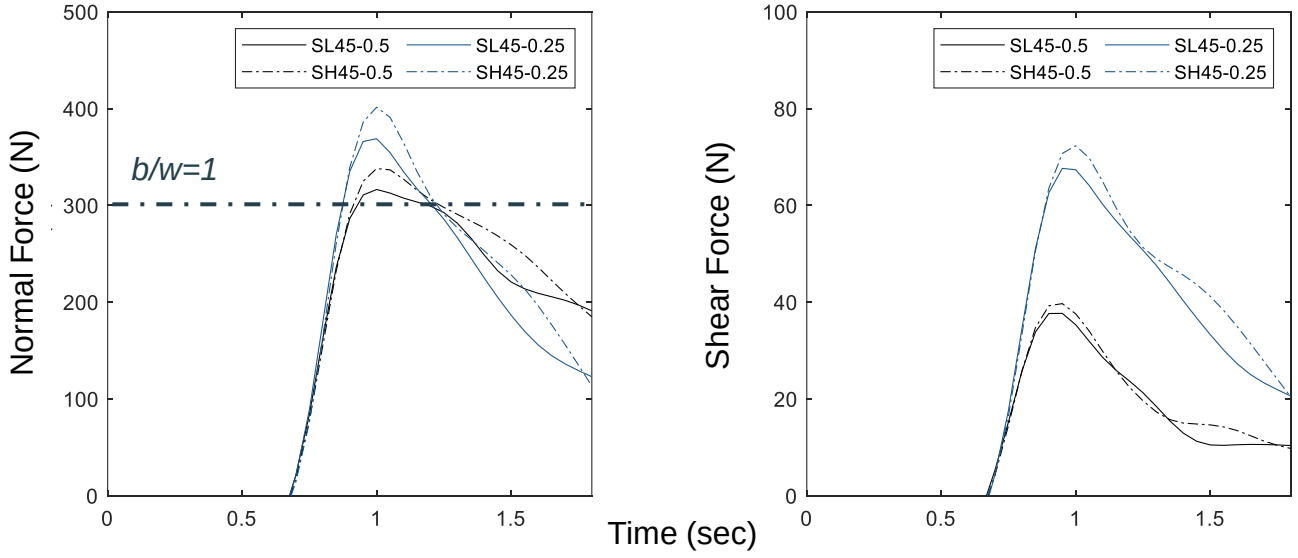


Soil-Structure Interaction

❑ Flume inclination 55º:

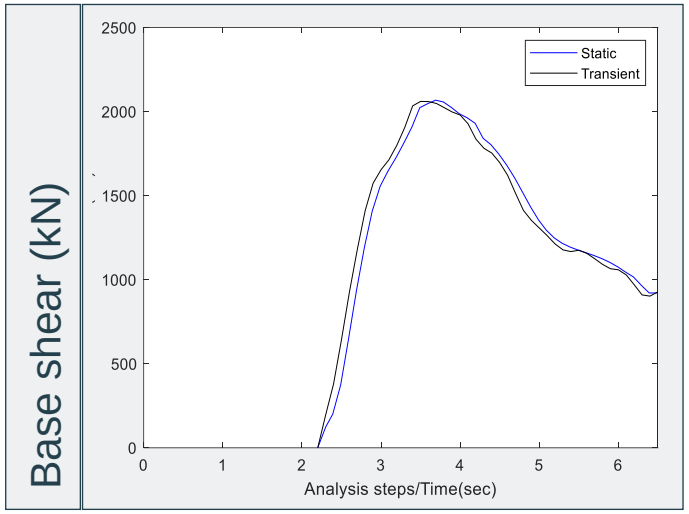


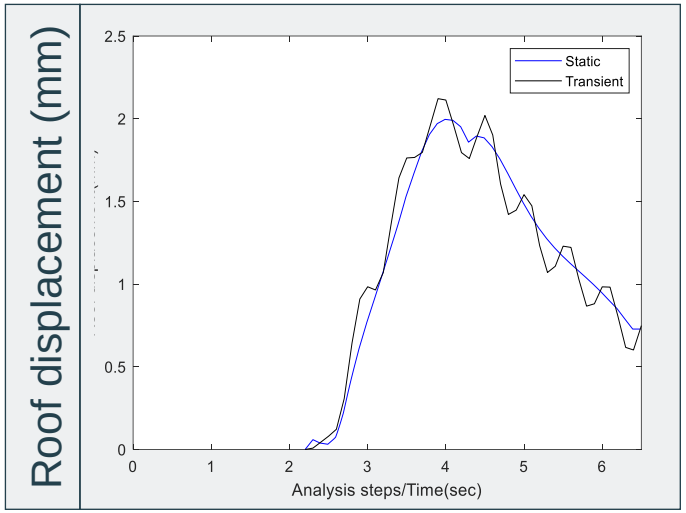
❑ Flume inclination 45º:

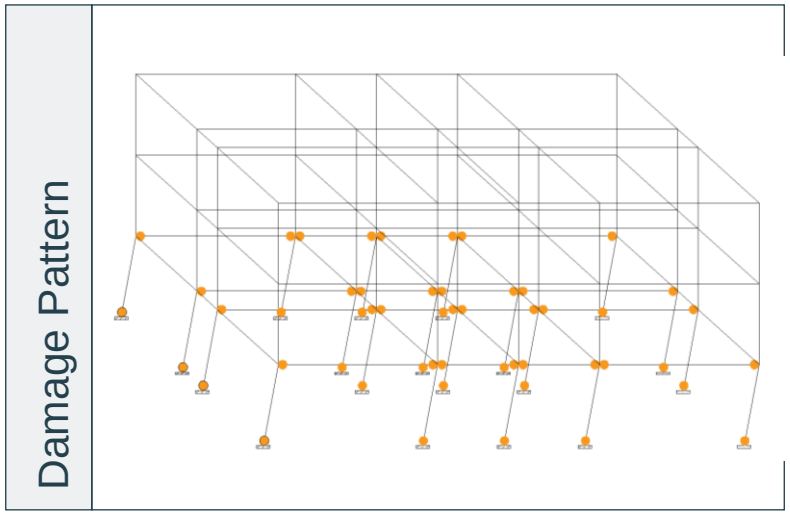


$h_{obstacle}$	b/w	Legend
3m	0.5	SL φ _0.5
10m	0.5	SH φ _0.5
3m	0.25	SL φ _0.25
10m	0.25	SH φ _0.25

Dynamic vs Static Analysis

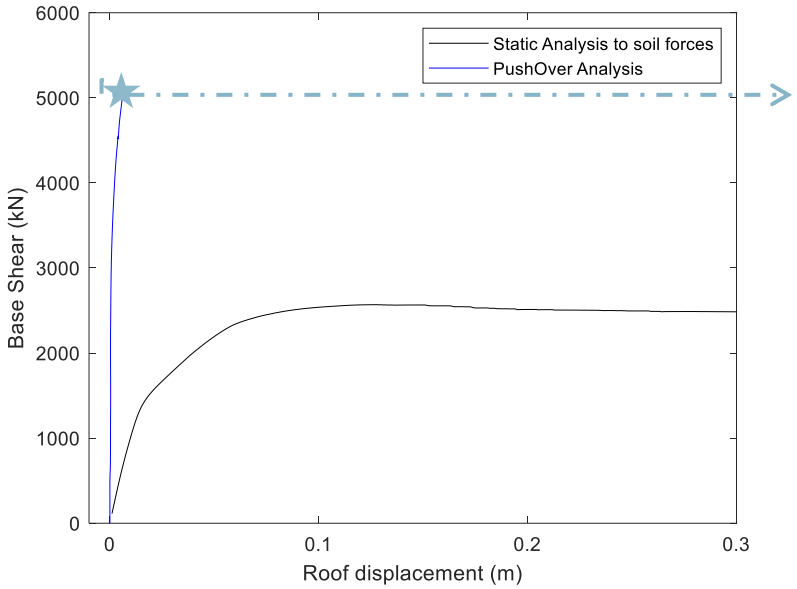






Validity of static approach to address landslide impact on structures

Push Over vs Static analysis under soil forces



Post-capping response is not captured

Load-controlled analysis method

Increased stiffness and strength of structure when subject to soil forces

Progressive loading from the base of the structure upwards

Conclusions

SSI with Passable Obstacles

- Normal Impact increases with reducing b/w.
- Normal Force Distribution: Trapezoidal
- Significant Shear component, that has been overlooked.

Structural Performance to soil-flow impact

- Static method is valid for addressing buildings' response
- Increased strength and stiffness compared to Pushover analysis.

Assessment Method

- Equations for estimating the flow response based on the b/w
- Analytical approach for determining impact loads
- Simplified load pattern

Improve Resilience in Landslide prone regions

THANK YOU FOR YOUR INTEREST!

uceskon@ucl.ac.uk

https://www.linkedin.com/in/maria-kontoe-00226a133/

University College London, Gower Street
London, WC1E 6BT