# Numerical Simulation of Tsunami-Borne Debris Impact Loads on Bridges

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# Project description

## Funding Agency

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## Participant

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# Project objectives

- Understand the two-fold effect of debris: (a) **impact** and (b) **damming** on bridges.
- Decipher (a) **debris-wave interaction during tsunami propagation inland** and (b) **debris-wave-bridge interaction and associated loads**, for different debris orientations.
- Explore and calibrate novel **particle-based** (SPH) and/or coupled mesh-particle methods (**SPH-FEM**) and hybrid particle-mesh based (**PFEM,** to be undertaken by OSU)
- Decipher the role of **non-structural** mass.
- Develop **prescriptive load equations** for debris impact forces for inclusion in the *Tsunami Design Guidelines for Coastal Bridges* developed by PEER and recently adopted by the AASHTO Committee on Bridges and Structures.

# Why debris?


Debris-related issues (from left to right): (a) Shipping containers after the 2010 Tsunami in Talcahuano, Chile (Garcia, 2010), (b) Remaining boat debris after the 2011 Japan tsunami (courtesy: Dr. Unjoh, Public Works Research Institute, Japan)


Span removed due to shipping container collision during the 2011 Japan tsunami. (Source: Hoshikuma, PWRI, OSU Tsunami modeling workshop, 2014)

# Methodology

**Particle-Based; Smoothed Particle Hydrodynamics (SPH)**

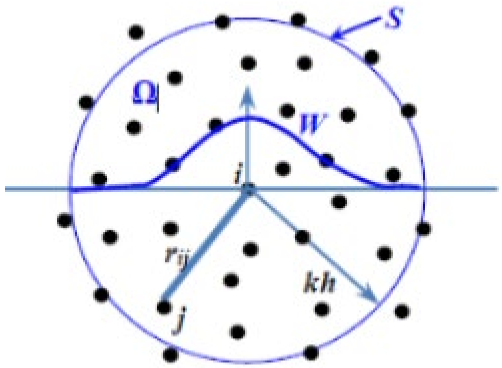
- **Originally** invented for solving astrophysical problems in open space.
- **Applied** to general fluid dynamic problems in early 1990s.

➢ SPH- Numerical Approximation

- **Weight function** (or **smoothing function**), ***W***, centered on particles and describe continuous or discrete field function,

Kernel approximation: $< f(x) >= \int_0^{\kappa h} f(x')W(x-x',h)dx'$

Particle approximation: $< f(x_i) >= \sum_{j=1}^{n} \frac{m_j}{\rho_j} f(x_i)\, W(x_i - x_j, h) = \sum_{j=1}^{n} \frac{m_j}{\rho_j} f\left(x_j\right) W_{ij}$



SPH approximation in 2D space

# Methodology (cont.)

- SPH- Equation of Motions for Fluid - Implemented in **LS-DYNA**

**Density**

$$\frac{d\rho_i}{dt} = \sum_{j=1}^{n} m_j \ (x_i^\beta - x_j^\beta) \ \frac{\partial W_{ij}}{\partial x_i^\beta}$$

**Momentum**

$$\frac{dv_i^\alpha}{dt} = \sum_{j=1}^{n} m_j \ \left(\frac{\sigma_i^{\alpha\beta}}{\rho_i^2} + \frac{\sigma_j^{\alpha\beta}}{\rho_j^2}\right) \frac{\partial W_{ij}}{\partial x_i^\beta}$$

**Energy**

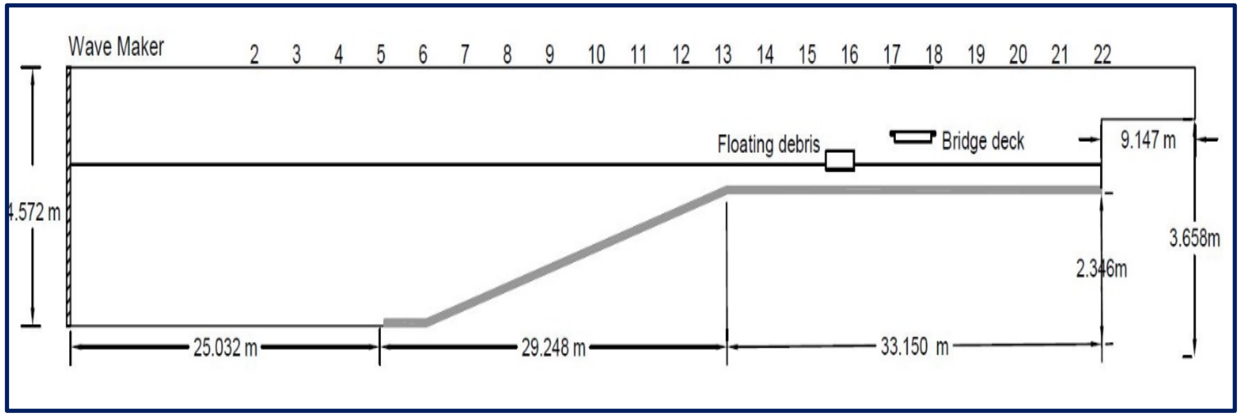
$$\frac{de_i}{dt} = -\frac{p_i + \Pi_{ij}}{\rho_i^2} \sum_{j=1}^{n} m_j \ (v_i - v_j) \ \frac{\partial W_{ij}}{\partial x_i^\beta}$$

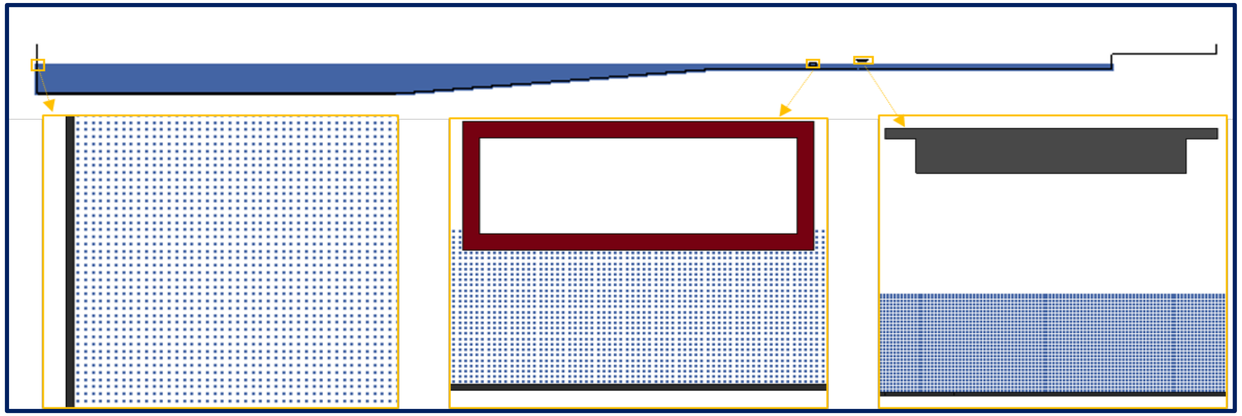
**Strain**

$$\frac{dx_i^\alpha}{dt} = v_i + \varepsilon \sum_{j=1}^{n} \frac{m_j}{\rho_j} (v_i - v_j) \, W_{ij}$$

# Multi-physics modeling of tsunami debris impact on bridge decks

- Wave maker, flume, debris and bridge: **Finite Element**, Mesh size=1cm
- Fluid: **SPH**, Particle size= 1cm
- Interaction between SPH and FE parts: Node-to-solid contact
- Interaction between the FE parts: Two-way segment-based contact
- Final numerical model consisted of 17,077 shell elements and **1,328,633** SPH particles.
- Using up to 80 cores per analysis, the run-time for each model was **19hrs**.

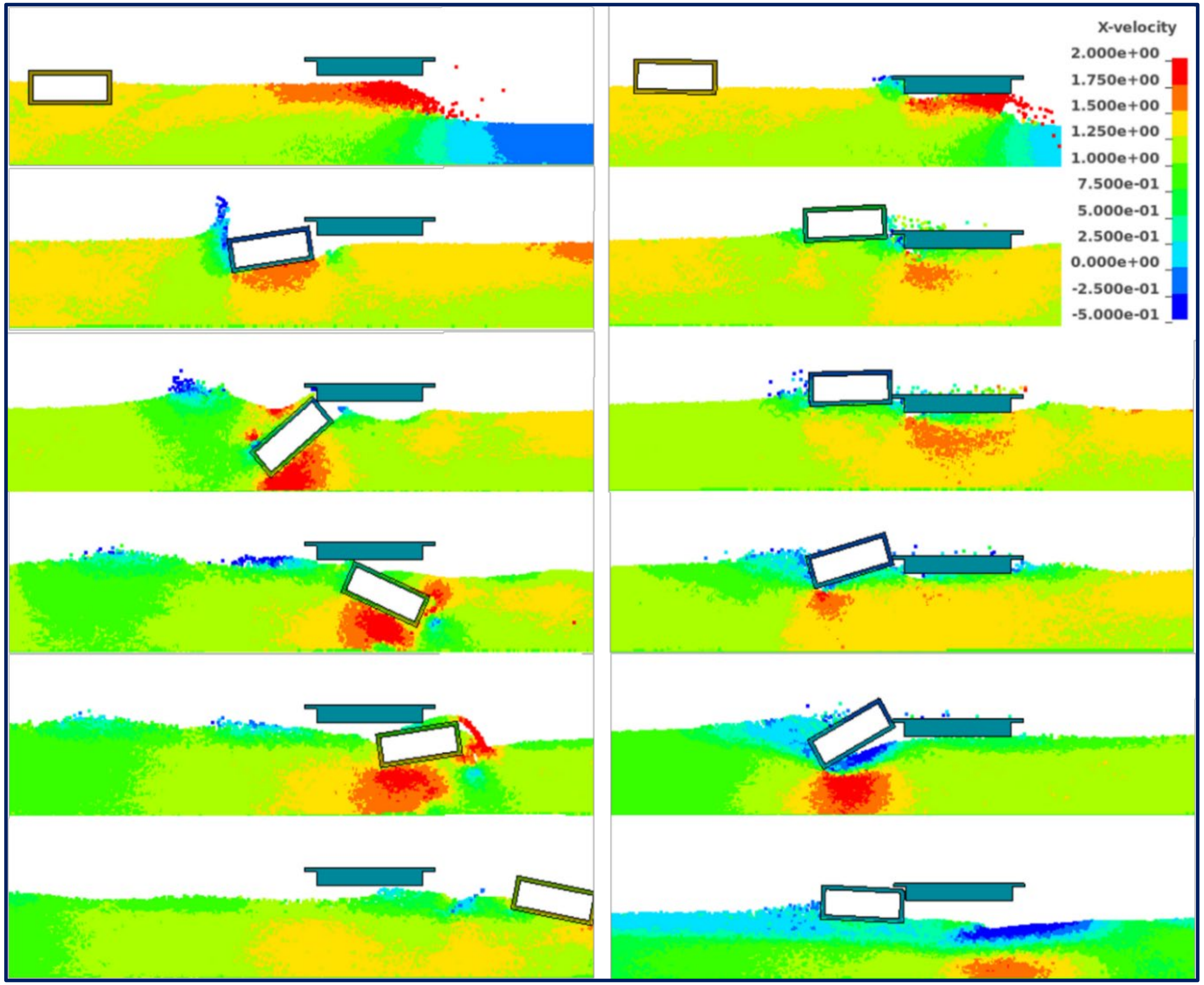


Hasanpour, A., Istrati, D., & Buckle, I. (2021). Multi-physics Modeling of Tsunami Debris Impact on Bridge Deck. *3rd International Conference on Natural Hazards & Infrastructure.*

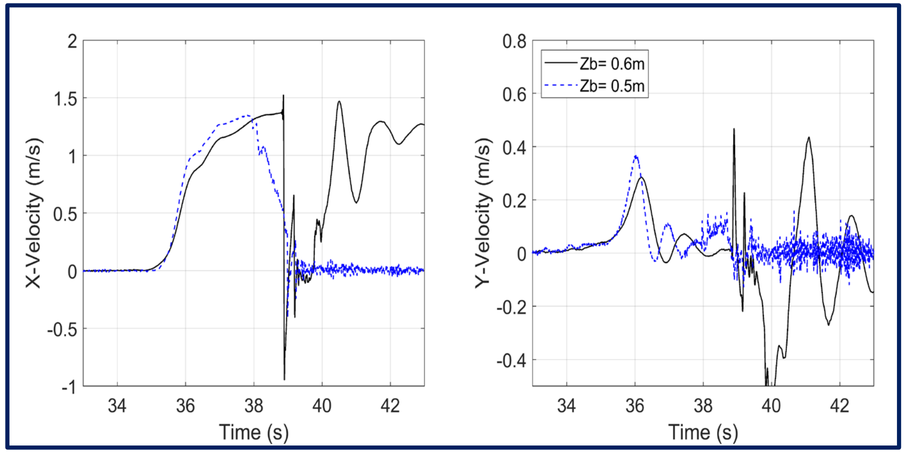
# Multi-physics modeling of tsunami debris impact on bridge decks

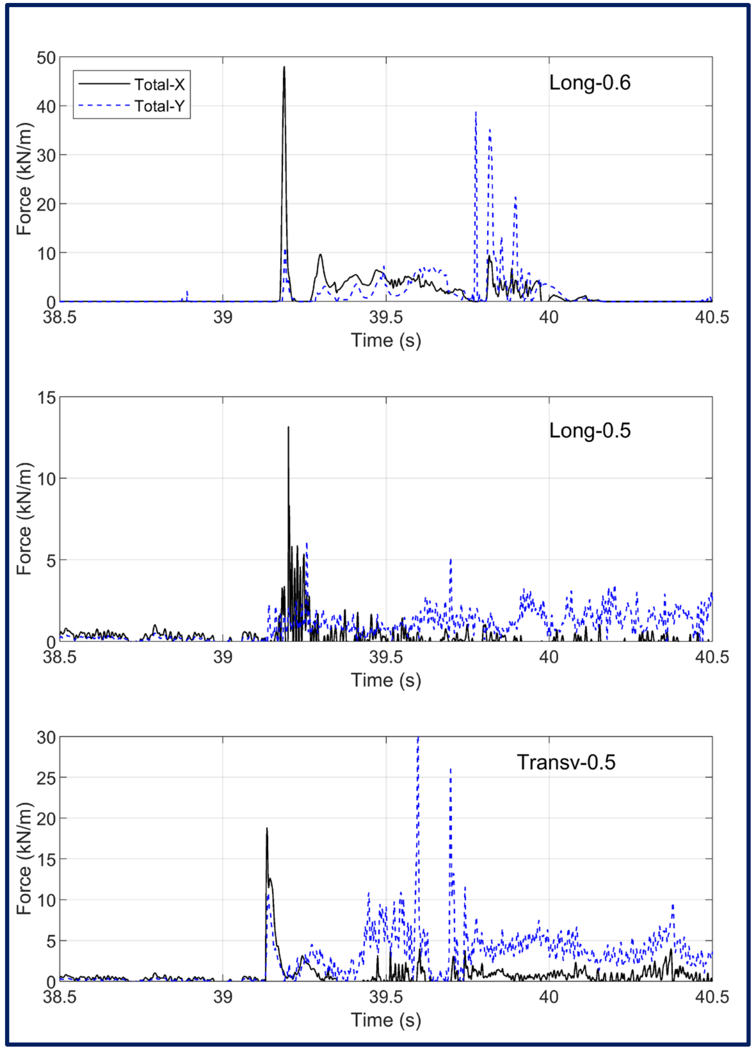
- Debris can either **move below the deck** or **become trapped below the overhang**.
- Complex debris flow pattern is function of the deck elevation and the bore properties.
- Is it **possible to predict in advance the debris motion**? Such information would be essential for future risk assessment frameworks.



# Multi-physics modeling of tsunami debris impact on bridge decks

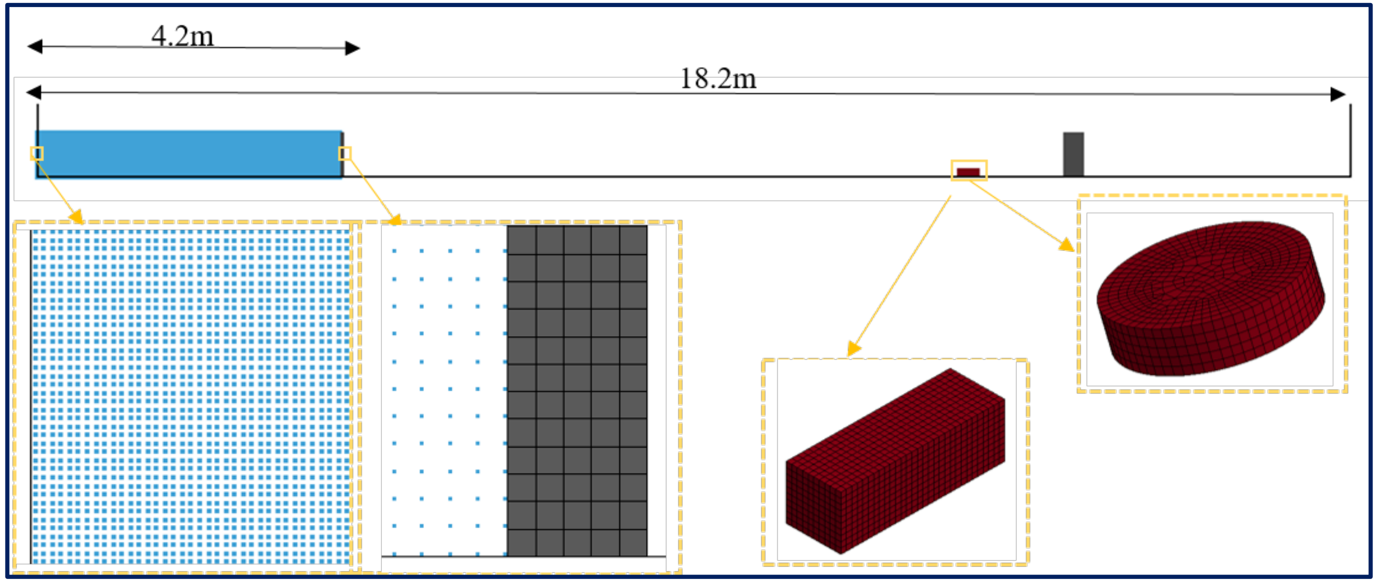
- The debris has **vertical impact velocity** with a magnitude in the range of (20-27)% of the horizontal velocity.
- There are **several vertical impact loads** on the superstructure after the primary impact, with magnitudes up to **4 times larger** than the initial impact.
- **Horizontal and vertical** debris loads are **maximized at different** instants. Consider **multiple load cases** to identify the critical case.



# Three-dimensional large debris transport and impact

- Source (Shafiei 2016)
- The experiment was conducted in a 14m long, 1.2m wide and 0.8m deep wave flume at the University of Auckland.
- The coastal structure was represented by a square prism.
- Rigid acrylic box and disk with dimensions of 0.1*0.1*0.3m and 0.2 (diameter)* 0.05 (thickness) m were used as the debris.
- To measure the free-surface and fluid velocity, five wave gages were installed along the flume.

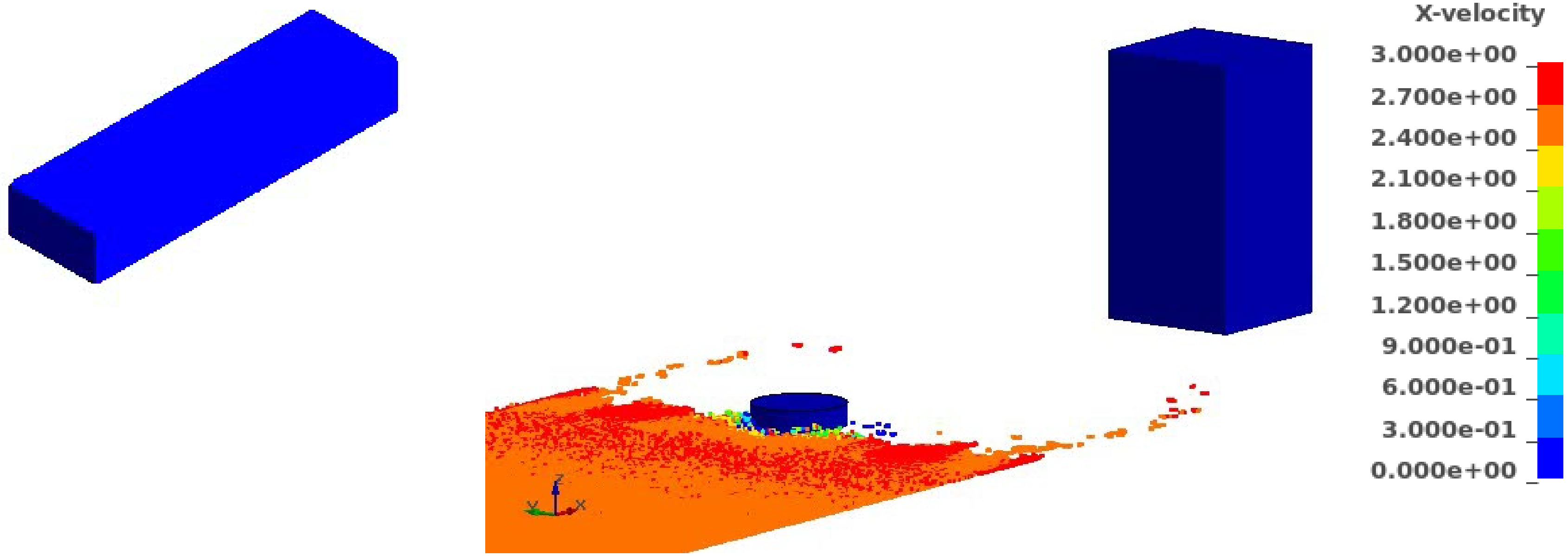


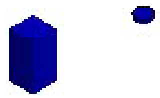

Shafiei (2016). *Tsunami Inland Structures Interaction and Impact of Floating Debris* (Doctoral dissertation, University of Auckland).

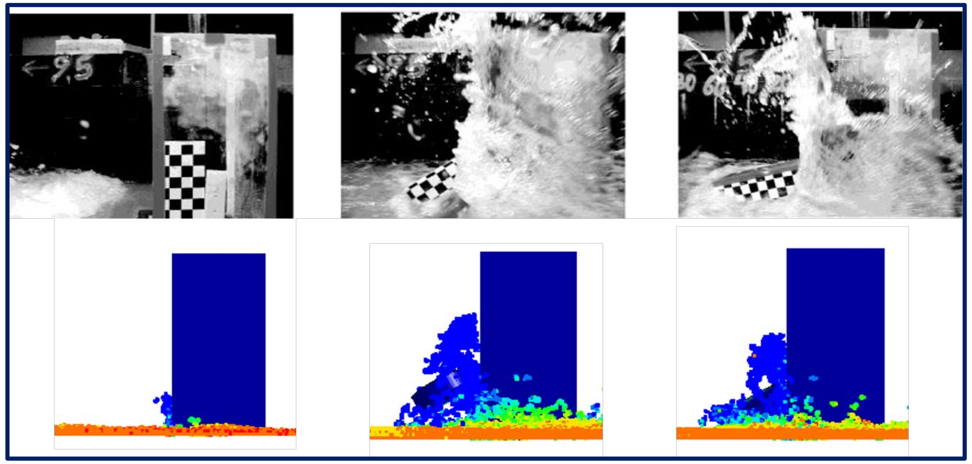
# Three-dimensional large debris transport and impact

- Gate, flume, debris and structure: **Finite Element**, Mesh size=1cm
- Fluid: **SPH**, Particle size= 1cm
- Interaction between SPH and FE parts : NODES_TO_SURFACE
- Interaction between FE parts : SURFACE _TO_SURFACE
- Three different bores named weak (**B1**) with velocity of 1.98m/s and height of 140mm, moderate (**B2**) with velocity of 2.2m/s and height of 170mm and strong (**B3**) with velocity of 2.48m/s and height of 210mm were generated.
- Final numerical model consisted of 632,848 shell elements and **3,049,163** SPH particles.
- Using up to 80 cores per analysis, the run-time for each model ranged between 27 and **43hrs**, depending on the hydrodynamic characteristics.

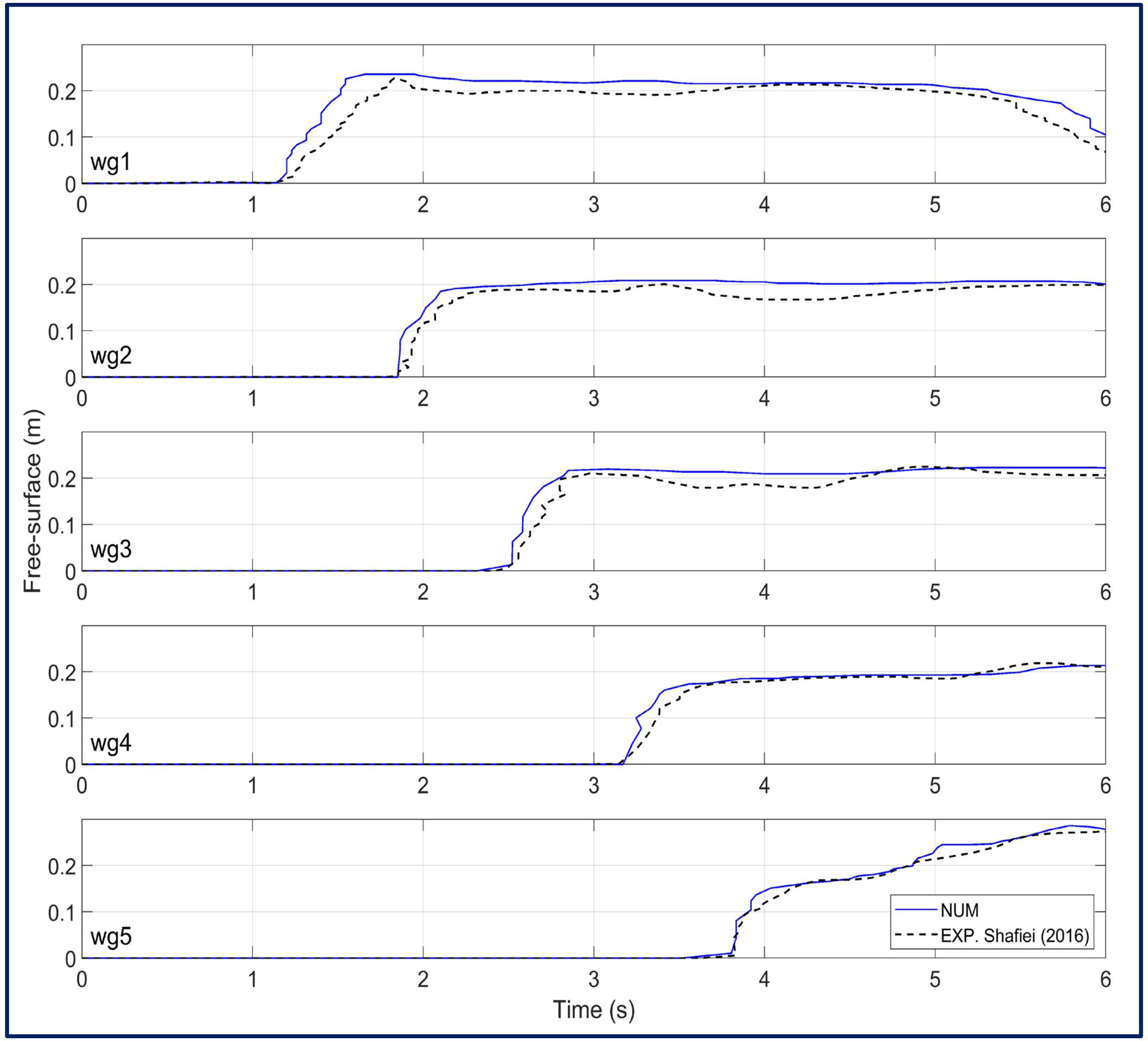
# Three-dimensional large debris transport and impact

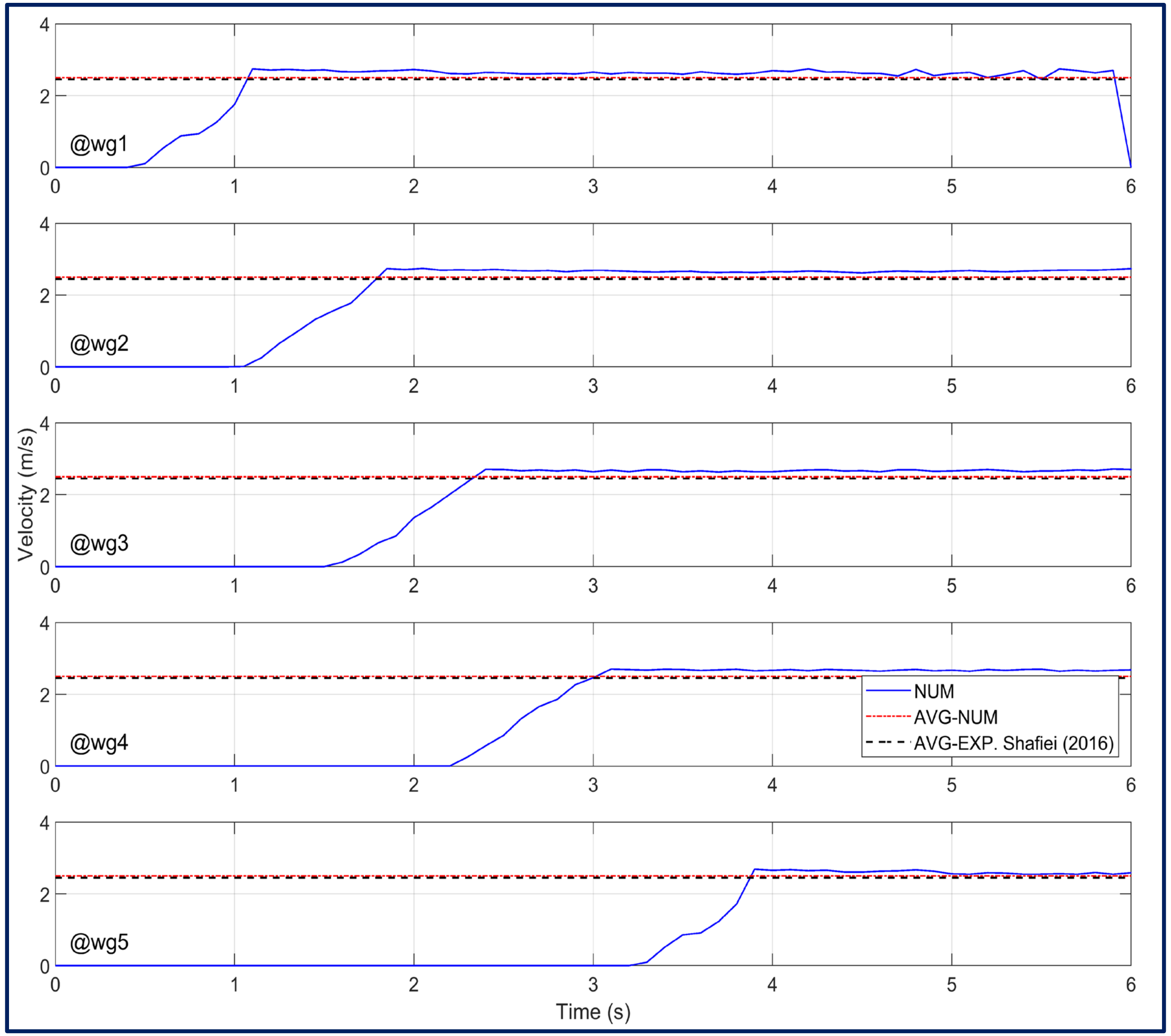




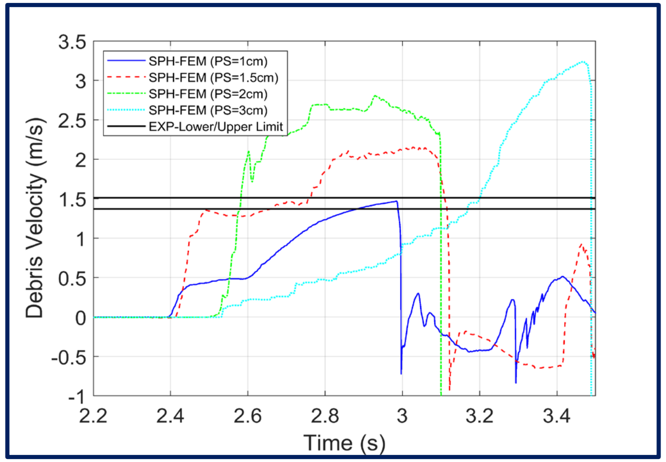
# Three-dimensional large debris transport and impact

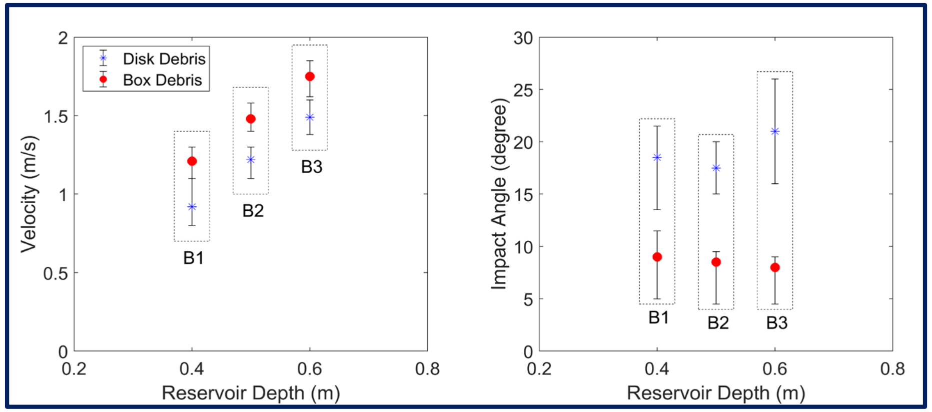


# Three-dimensional large debris transport and impact

## Disk velocity and impact angle

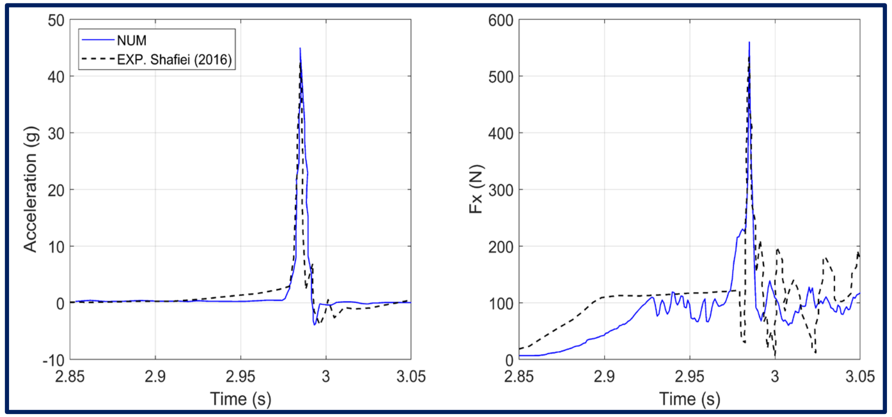


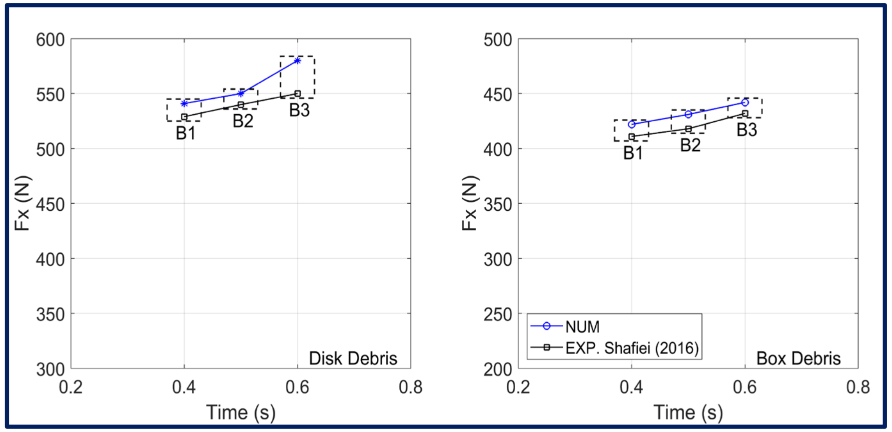




•Velocity: Maximum deviation ranged between (1.5-3)% for the disk and (1-1.5) % for the box.

• Impact angle: Maximum deviation ranged between (3-5)% for the disk and (2-6) % for the box.

## Debris acceleration and force in the pier




•Impact force: Maximum deviation ranged between (1.8-5.5)% for the disk and (2.5-3.11) % for the box.

# 3D Parametric investigation of single container impact

The **validated 3D numerical tank** was used for the parametric investigation, with some additional modifications:

- The coastal structure was replaced by a bridge deck which follows the dimensions of the deck used in previous large-scale hydrodynamic test (Istrati 2017).
- The floating debris was represented by a standard shipping container .
- The length of the reservoir for the numerical investigation was increased from 4.2m to 10m.
- The outlet was moved 2m further upstream of the bridge and an artificial beach with slope of 1:12 with end reservoir were added to the numerical model.

# 3D Parametric investigation of single container impact

- Gate, flume, debris and structure: **Finite Element**, Mesh size=1cm
- Fluid: **SPH**, Particle size =1cm
- Scale: 1/20
- Interaction between fluid and solid body: NODES_TO_SURFACE
- Interaction between the solid bodies: SURFACE _TO_SURFACE
- Final numerical model consisted of 969,908 shell elements and **4,203,331** SPH particles.
- Using up to 80 cores per analysis, the run-time for each model ranged between 78 and **110**hrs, depending on the hydrodynamic characteristics.

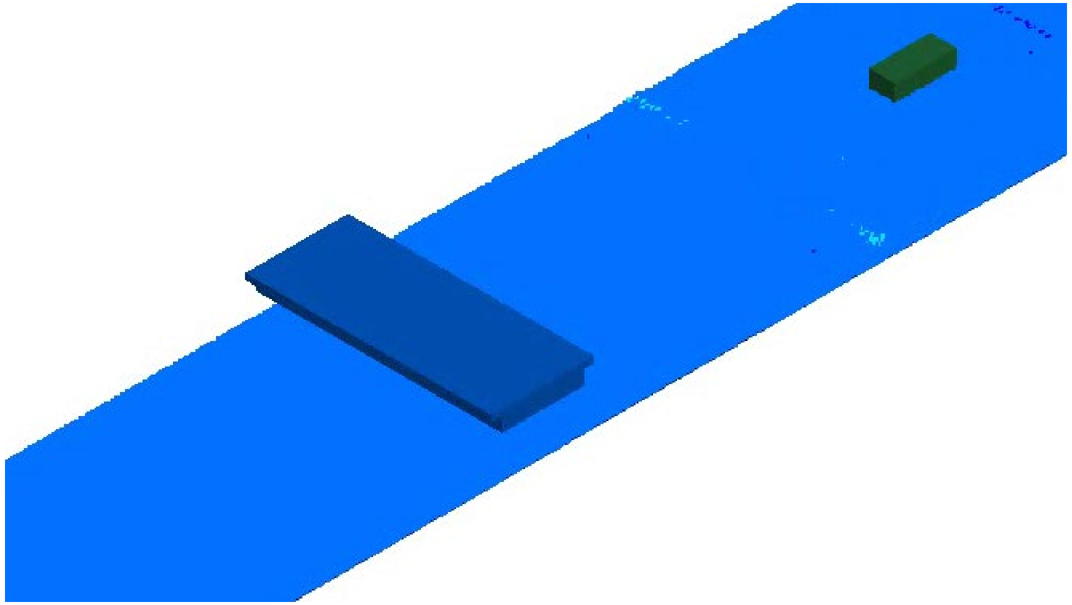
Investigate the effect of:

- **Bridge elevation** (0.20, 0.30 and 0.35m)
- **Debris orientation** (longitudinal and transverse)
- **Debris mass**
- **Hydrodynamic conditions** ($H_{res}$= Reservoir depth, d= Still-water depth)

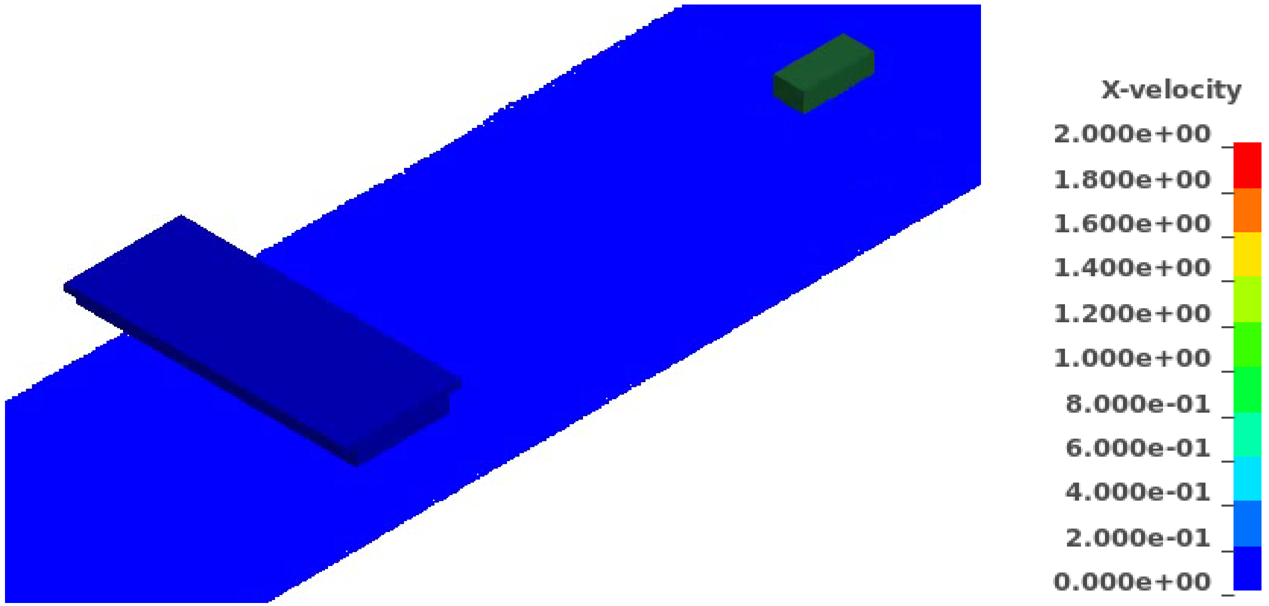
| Hydrodynamic Conditions | | |
|---|---|---|
| **Bore Cases** | **Hres (m)** | **d (m)** |
| **B1** | 0.40 | 0.10 |
| **B2** | | 0.15 |
| **B3** | 0.60 | 0.075 |
| **B4** | | 0.10 |
| **B5** | | 0.15 |
| **B6** | | 0.20 |
| **B7** | | 0.25 |

# 3D Parametric investigation of single container impact

Role of **deck elevation**: B4: $H_{res}$ = 0.60m, d = 0.10m, deck elevation ($Z_b$) : 0.20 and 0.30m



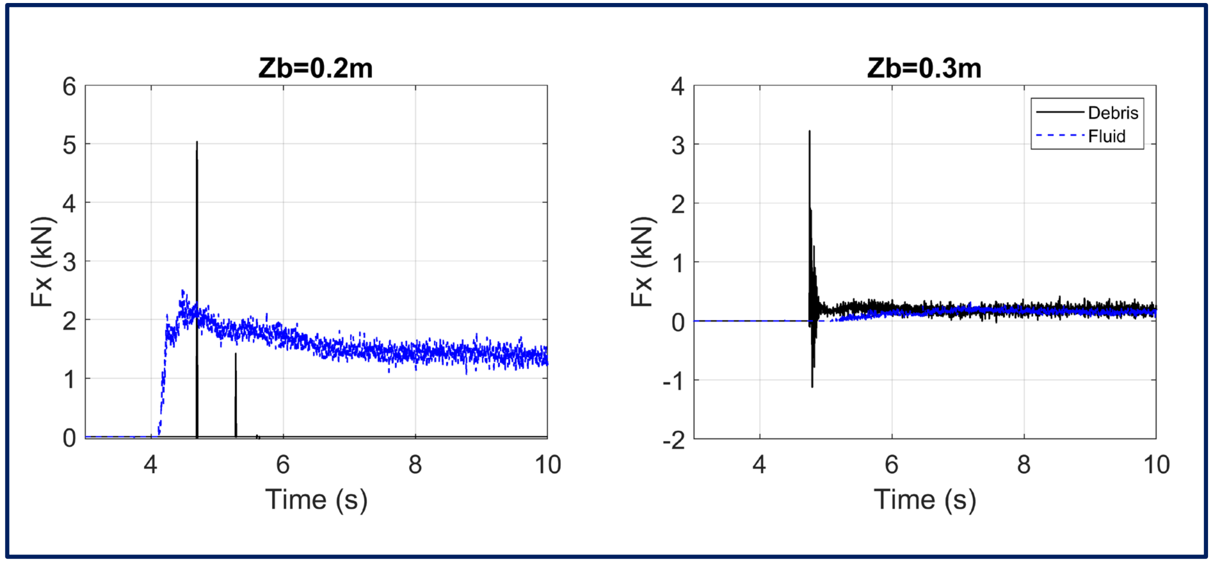
B4- Deck Elevation: 0.20m

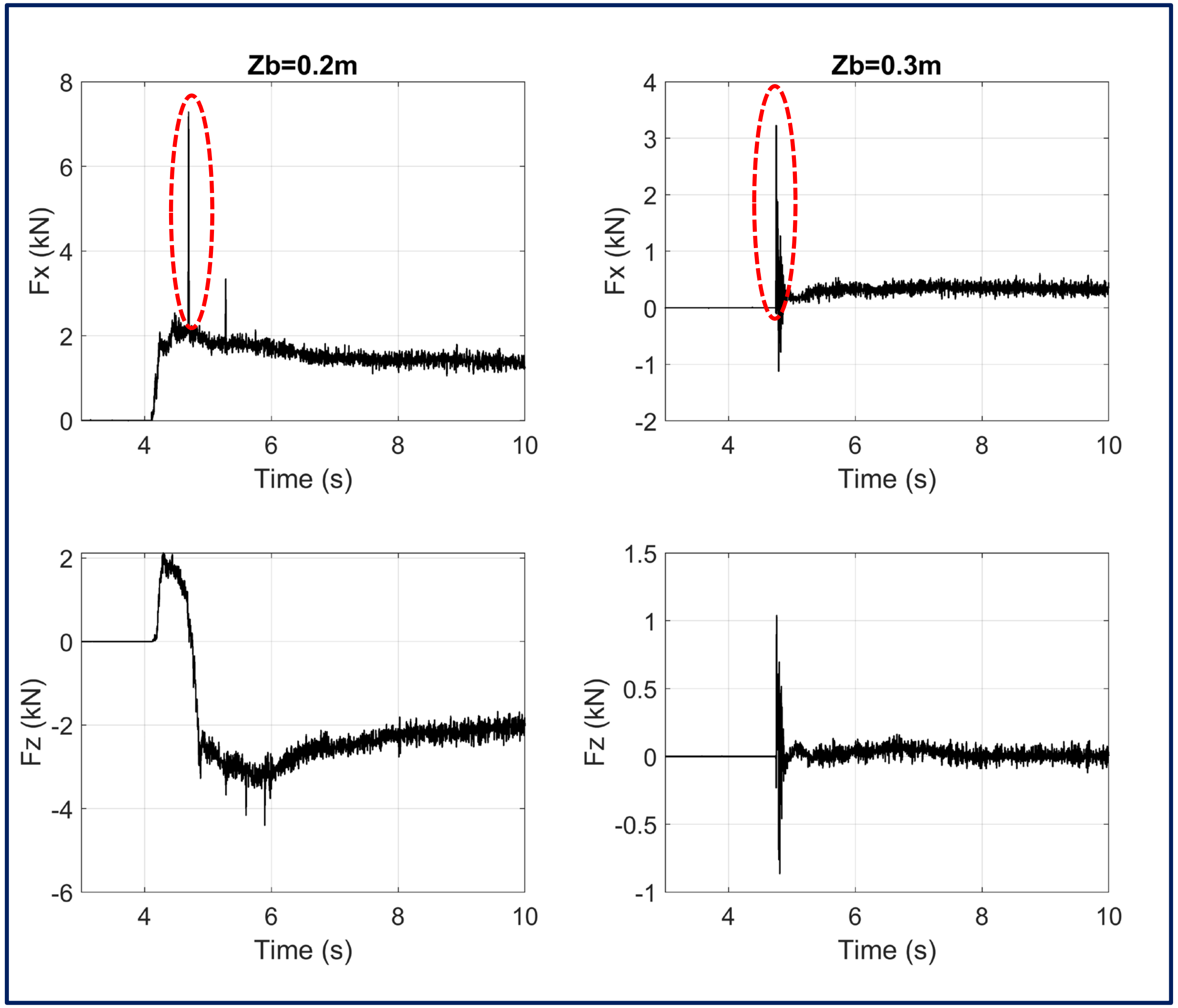



B4- Deck Elevation: 0.30m

# 3D Parametric investigation of single container impact

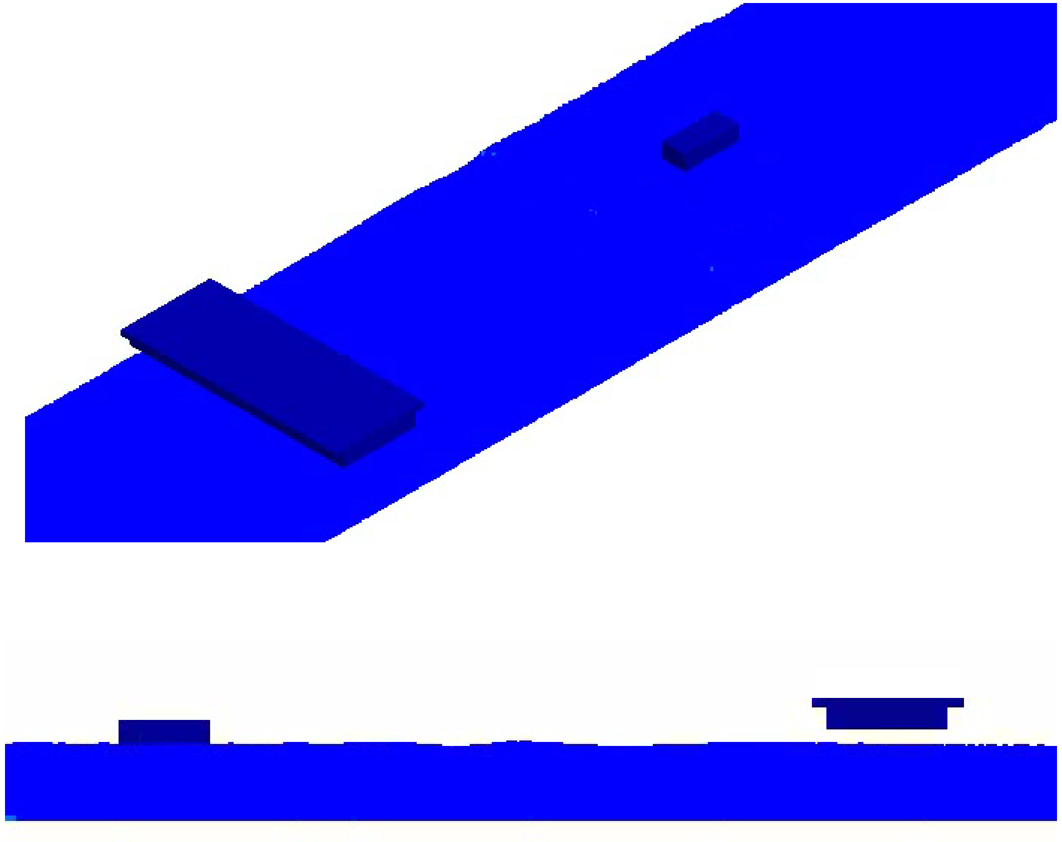
- Depending on the deck elevation, ratio of the maximum **debris/fluid** force ranged between **2.5 up to 10**.
- Debris impact vertical load depends on the deck elevation. For higher deck elevations (e.g. $Z_b$ =0.3m) the **uplift load comes only from the debris**.



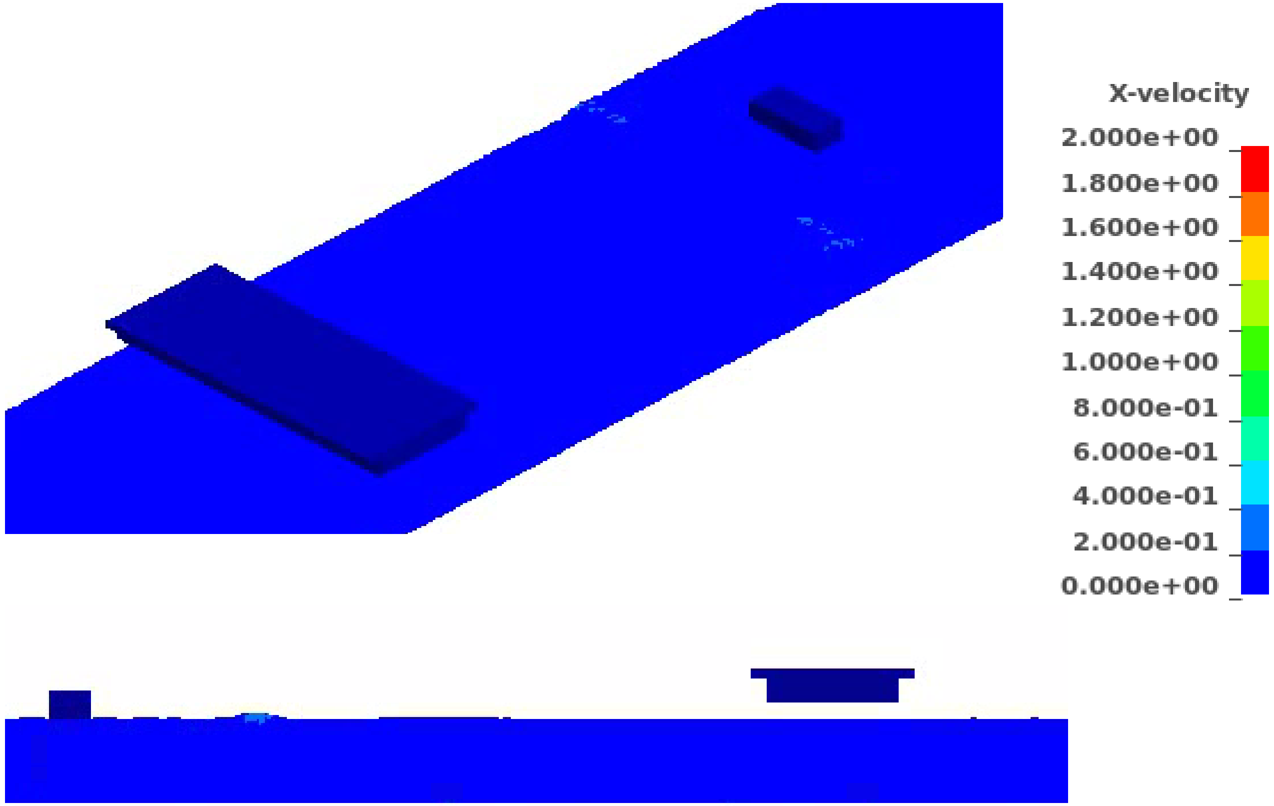



# 3D Parametric investigation of single container impact

Role of **debris orientation**: B7: $H_{res}$ =0.60m, d=0.25m, deck elevation ($Z_b$) : 0.30m



B7- Longitudinal Debris



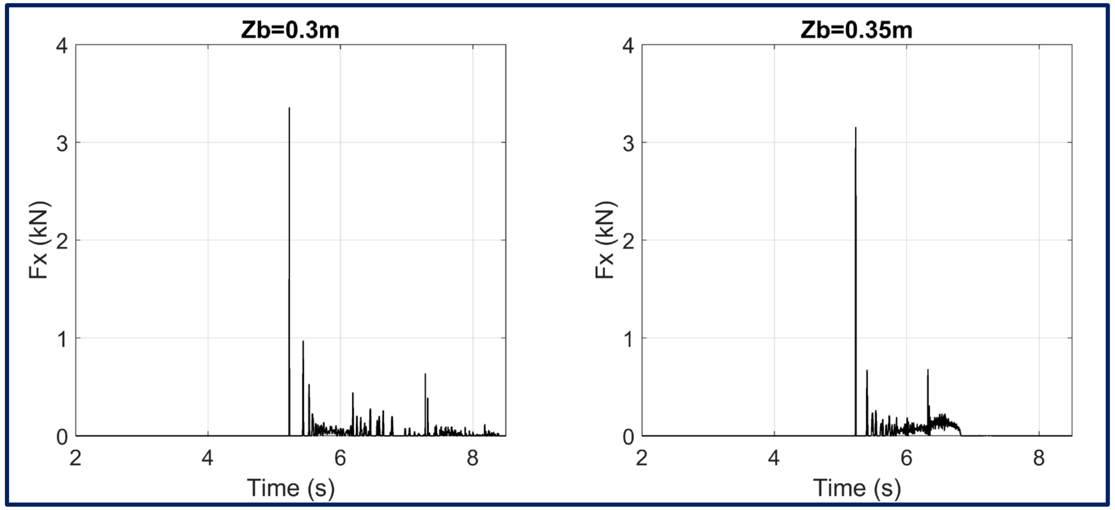

B7- Transverse Debris

# 3D Parametric investigation of single container impact

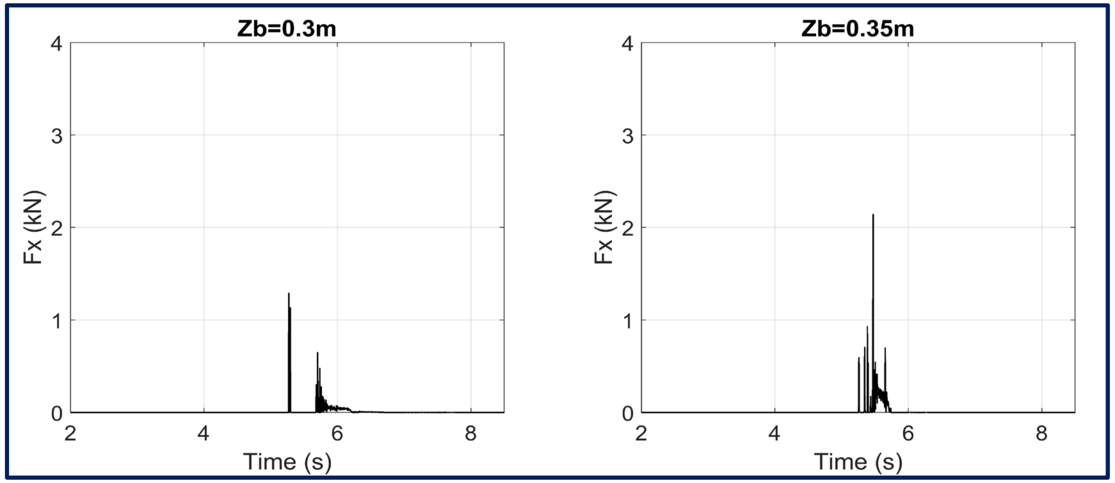
Role of debris orientation: B7: $H_{res}$ =0.60m, d=0.25m, Deck elevation ($Z_b$) : 0.30m

- Preliminary data shows **debris orientation** has **significant** effect on (a) the **debris motion** around the bridge (e.g. if it will move above or below the superstructure), and (b) the **peak applied load** (Fx).
- The ratio of the **Fx_longitudinal/Fx_transverse** ranged between **1.47 to 2.7** (actual ratio is dependent on deck elevation and bore properties).

B7- Longitudinal Debris




B7- Transverse Debris



# Thank you!