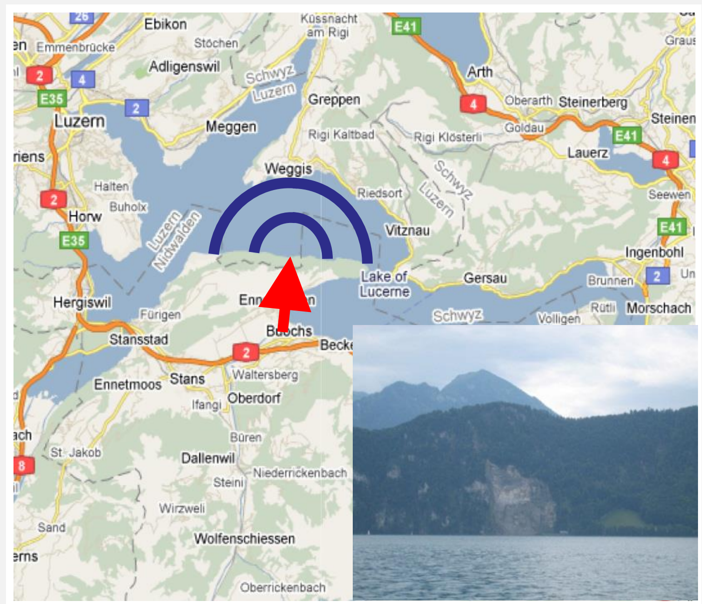
# A laboratory-DualSPHysics modelling approach to support landslide-tsunami hazard assessment




Lake Lucerne case, Switzerland, 2007

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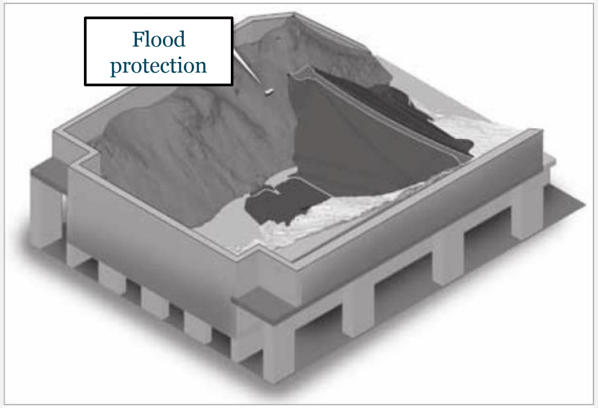
# Introduction

## 3 main methods to predict landslide-tsunamis (impulse waves)

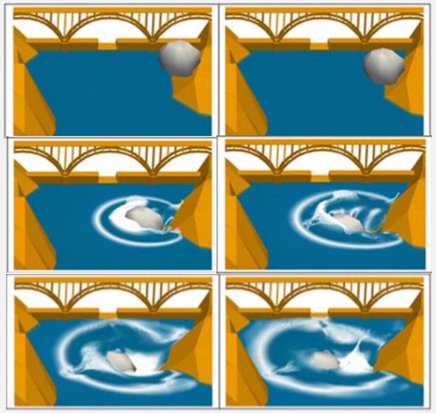
### (i) Case-specific physical modelling




Küthai reservoir at 1:130 (Fuchs et al. 2011)

+ Most accurate
– Time consuming and expensive (> 1 year)

### (ii) Case-specific numerical modelling



SPH model (Gomez-Gesteira et al. 2012)

+/– Reasonable accurate
+/– Time consuming/expensive (weeks - months)

### (iii) Generic empirical equations based on idealised conditions

Tests of present study in wave basin

E.g. $a_{M,2D} = (4/9)\mathsf{P}^{4/5}h$ (Heller & Hager 2010)

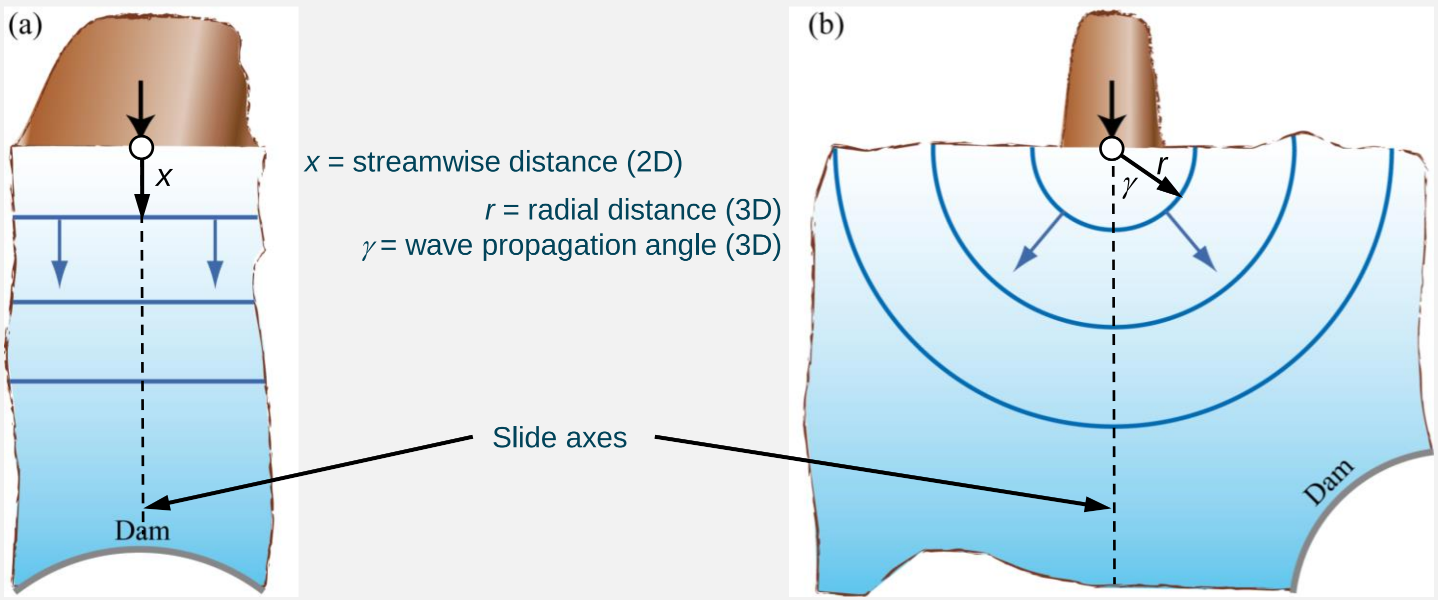
– Delivers estimates only
+ Efficient, inexpensive and fast (days)

# Introduction

## Idealisation of the water body geometry: 2D versus 3D

2D: Wave flume geometry

3D: Wave basin geometry

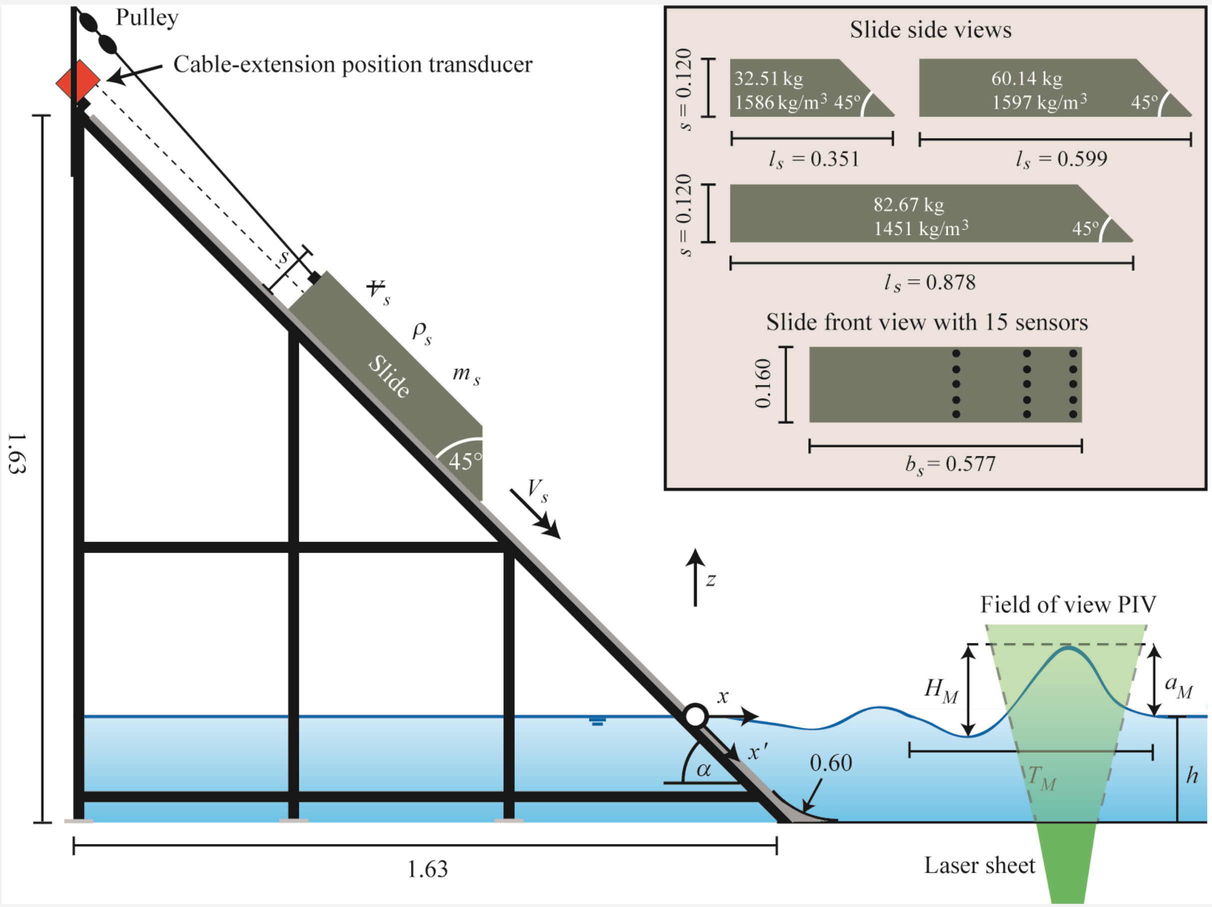



- Longitudinally slide impact
- Slide width ≥ reservoir width (line source)
- Confined wave propagation along *x*

- Slide impact at any possible location
- Slide width < reservoir width (point source)
- Free wave propagation on semi-circles along *r* and $\gamma$

**Aims:** Method to transform parameters from 2D to 3D and intermediate geometries

# Models (physical)




## Unknown parameters

Maximum wave amplitude $a_M$
Maximum wave height $H_M$
Maximum wave period $T_M$

## Known parameters

Still water depth $h$ (0.24 - 0.48 m)
Slide mass $m_s$
Slide impact velocity $V_s$ (0.94 - 3.79 m/s)
Slide volume $\forall_s$
Slide thickness $s$
Slide density $\rho_s$
Slide impact angle $\alpha$ (45º)

# Models (physical)

Test in wave flume (unobstructed 21.0 m × 0.6 m)

Video wave flume (2D)

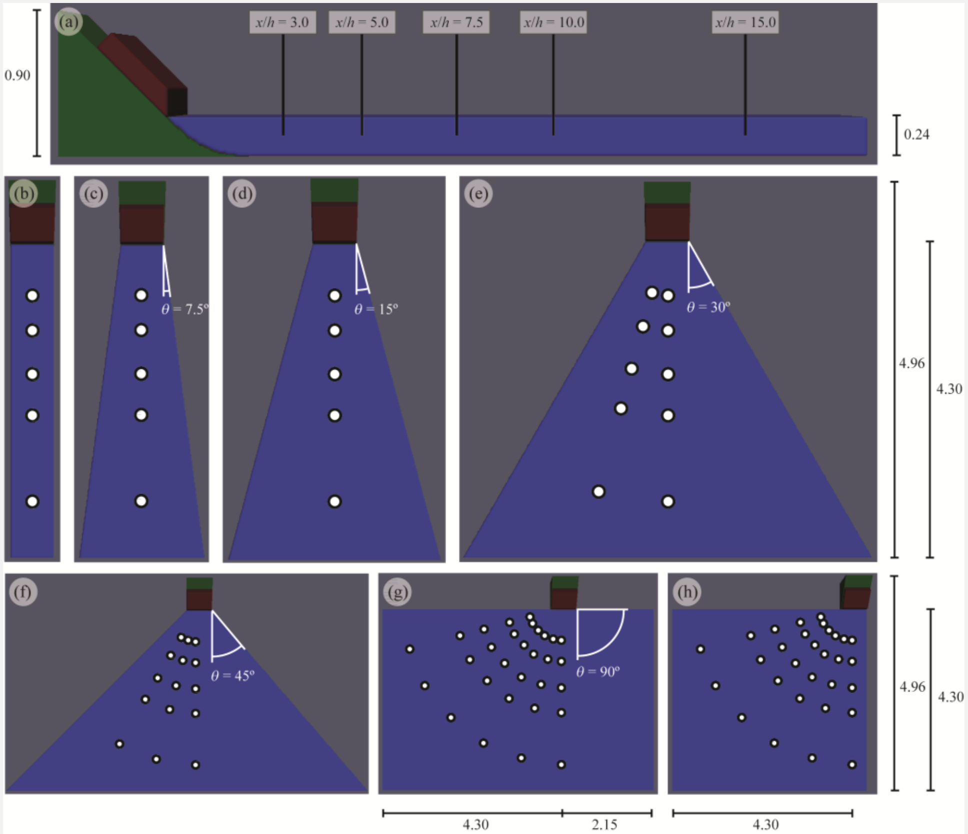
Test in wave basin (unobstructed 7.4 m × 20 m)

Video wave basin (3D)

- All conditions, apart from the water body geometry, are identical between 2D and 3D
- A total of 18 2D-3D test pairs were investigated involving different slide masses, release positions and wave types

# Models (DualSPHysics)

- The **beta executable v3.1** was used
- v3.1 includes a **discrete element method** (**DEM**) formulation such that solid-solid and solid-fluid interaction may be simulated with contact law theory (Canelas et al. 2013)
- **DEM is essential** for the present work to model the slide as a floating object moving along a rigid-beach boundary
- A **bed friction coefficient**, Young's modulus and Poisson ratio can be specified in DEM
- **Formulations:** cubic spline kernel, artificial viscosity formulation, Verlet time-stepping algorithm, Delta-SPH density filter
- A **HPC clusters** was accessed (**12 core** Westmere nodes Intel® Xeon® CPU X5650 at 2.67 GHz with DDR3 memory running at 1333 MHz)
- Most expensive case herein (*dp* = 10 mm, 8 Mio particles) took **13 h per second** real time



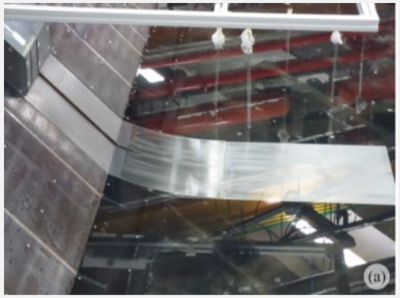

All geometries: (a,b) side and plane view of 2D case, (c) basin side angle $\theta$ = 7.5º, (d) 15º, (e) 30º, (f) 45º, (g) 90º (3D) and (h) 3D corner case 3Dc

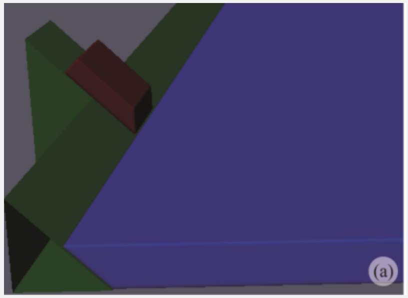
# Models (DualSPHysics)

## Validation and calibration of DualSPHysics

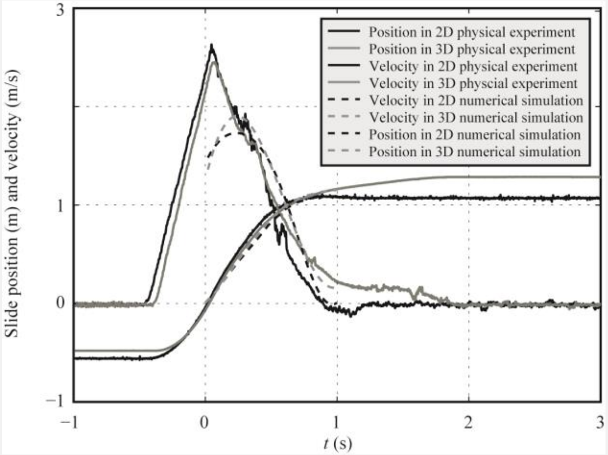
**Numerical strategy**:

- Everything is identical to physical tests except that slide starts with slide nose at water surface
- The front impact velocity $V_{sf}$ was adjusted to minimise the difference between $a_{M,Num}$ and $a_{M,Phys}$ ($V_{sf,Num}$ = 1.72 m/s < $V_{sf,Phys}$ = 2.43 m/s)

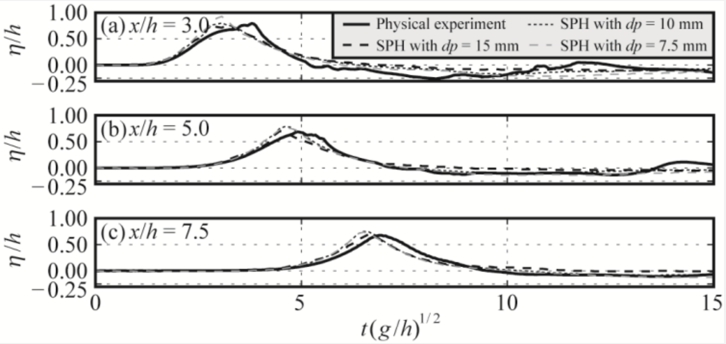



Slide positions and velocities




Convergence tests in 2D (*dp* = 7.5, 10 and 15 mm)



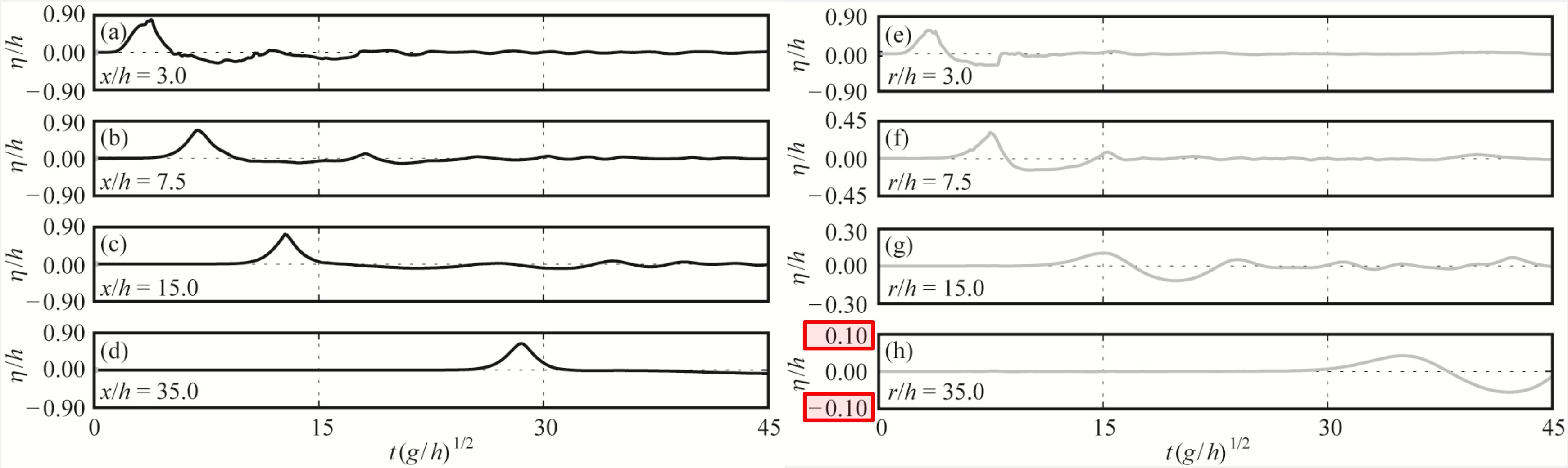

Convergence at $x/h$ = 5.0 and 7.5, unclear at $x/h$ = 3.0 (non-linearities, multi-phase effects due to slide impact); $dp$ = 10 mm seems an appropriate compromise between simulation time and accuracy

# Results (physical)

## Test conducted in 2D and 3D under otherwise identical BCs

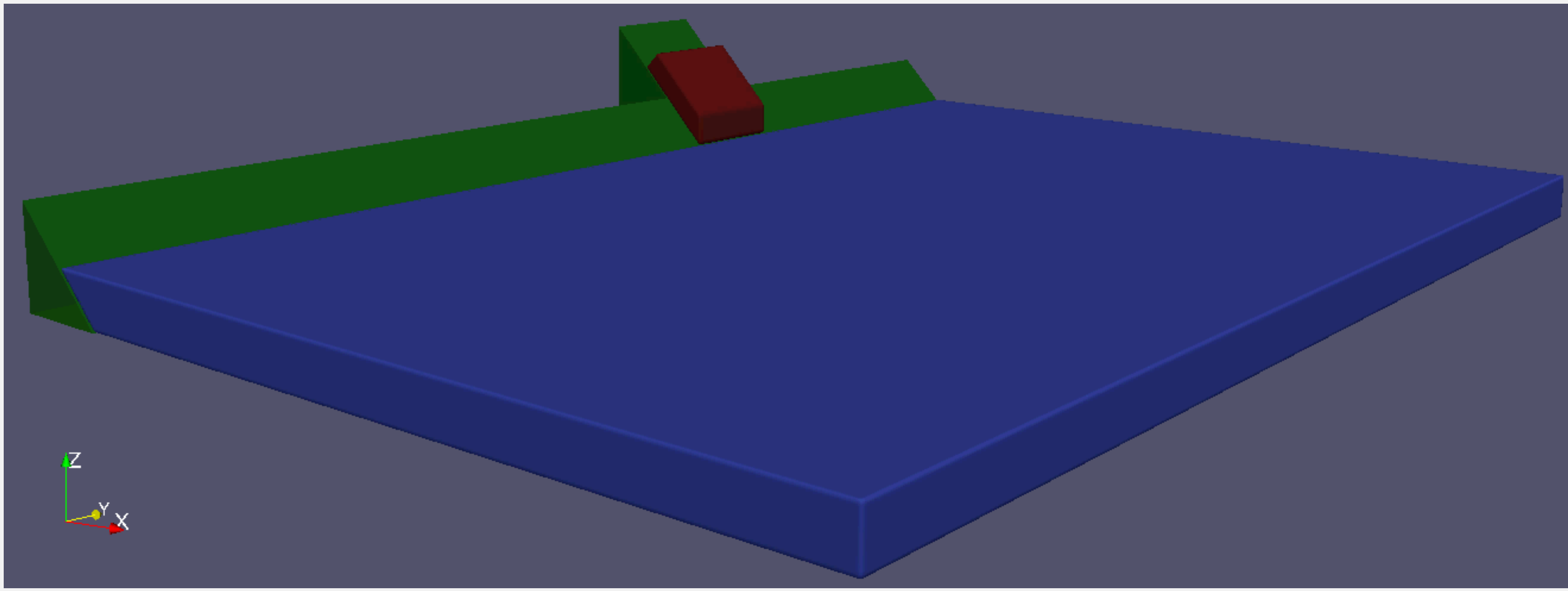
2D: Wave flume geometry

3D: Wave basin geometry




- In this case, the waves are only 30% different between 2D and 3D close to the slide impact zone
- Tsunami decays much faster in 3D, mainly due to spatial wave energy spread
- The wave amplitude in 3D is 16 times smaller than in 2D at $x/h = r/h = 35$

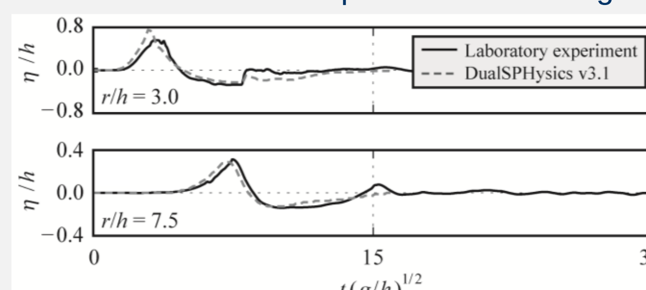
# Results (DualSPHysics)




**Numerical strategy:**

- The 2D test (treated as a 3D problem) was used to calibrate DualSPHysics via $V_{sf}$
- The same value for $V_{sf}$ as in 2D was then used for 3D
- The validation in 3D is shown on the right resulting in a good agreement with data from physical tests

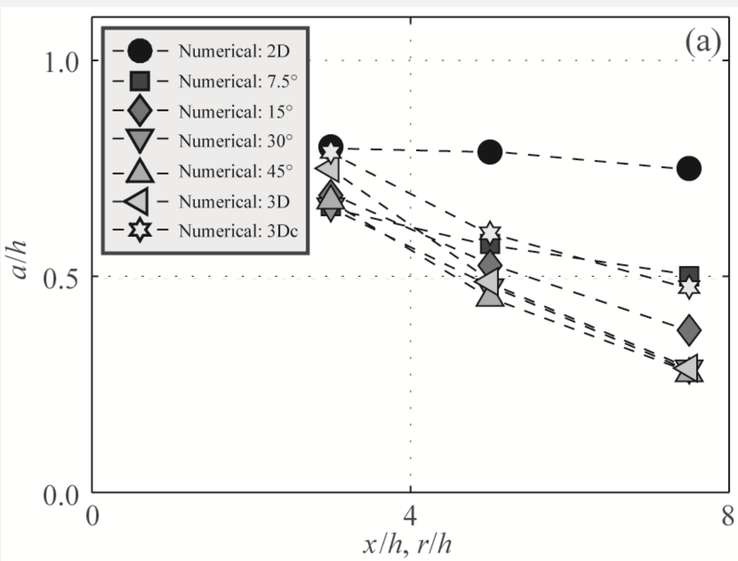
Physical and numerical wave profiles in 3D along slide axis



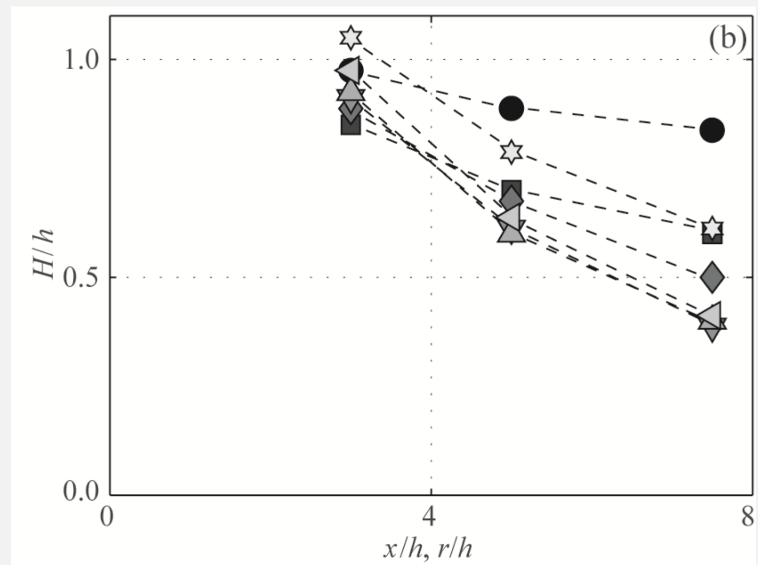
# Results (DualSPHysics)

## Investigation of intermediate geometries

Wave amplitude decay



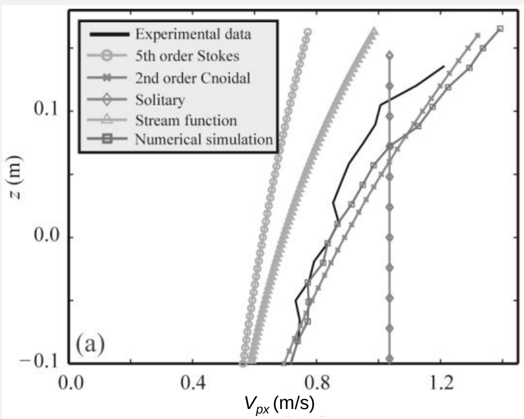

Wave height decay




- The wave parameters in the geometry with $\theta = 7.5^o$ lie approximately halfway between the values observed in 2D and 3D
- The wave parameters for $\theta \geq 30^o$ may be approximated with the 3D values

# Results (physical, DualSPHysics and analytical kinematics)

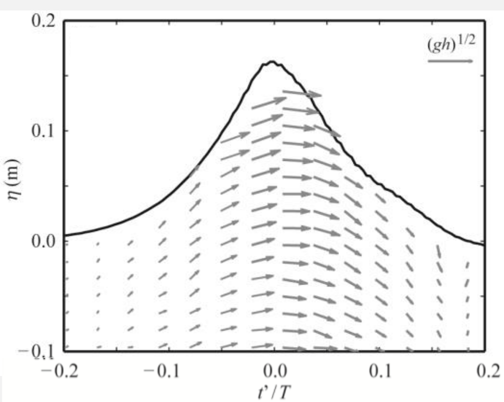
## Wave crest kinematics (from SWL to crest) in 2D at $x/h$ = 7.5



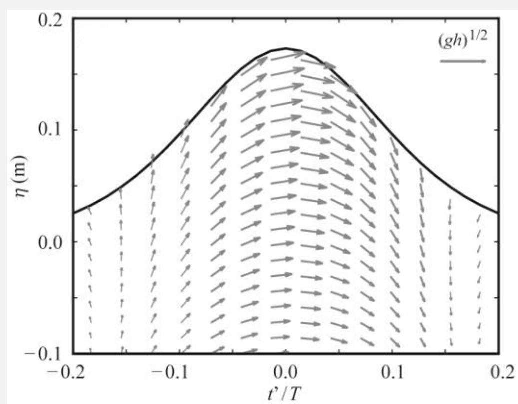

| Method | Maximum $v_{px}$ (m/s) | Mean $v_{px}$ (m/s) |
|---|---|---|
| Measured | **1.21** | **0.97** |
| 5th order Stokes | 0.77 | 0.69 |
| 2nd order cnoidal | **1.32** | **1.09** |
| Solitary | 1.04 | 1.04 |
| Stream function | 0.99 | 0.83 |
| DualSPHysics | **1.39** | **1.12** |

$v_{px}$ = horizontal water particle velocity component

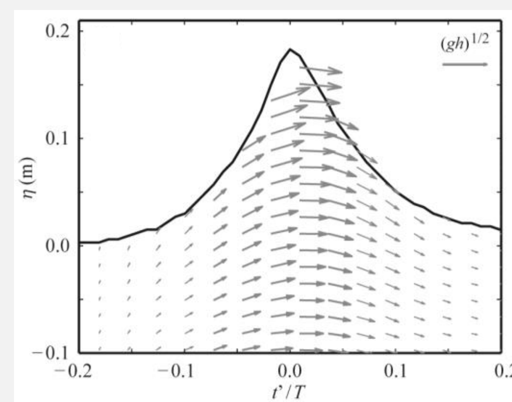
Measured (PIV)




Theoretical (cnoidal wave theory)




DualSPHysics



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# Conclusions

- The **effect of the water body geometry** on subaerial landslide-tsunamis (impulse waves) was investigated
- **Physical model tests** were conducted in a wave flume (2D) and basin (3D) and **numerical simulations** were carried out with DualSPHysics
- The geometrical effect is significant and deviations of **up to a factor of 16** between wave parameters in 2D and 3D were observed
- An overall **good agreement** between numerical and experimental results was achieved; DualSPHysics semms an **excellent option**
  (i) to further investigate the effect of the water body geometry and
  (ii) for case-specific landslide-tsunami hazard assessment (potential to be *the* leading code for such applications)
- Improvements in DEM (slide kinematics) and implementation of the Riemann solver would make DualSPHysics **even more promising** in this regard

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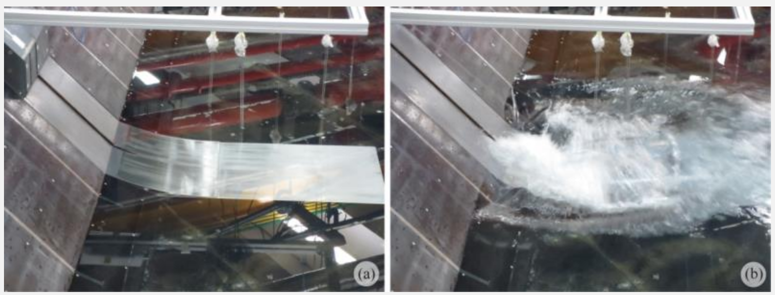
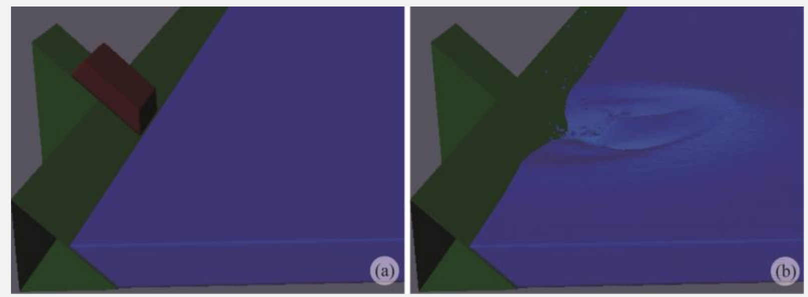
# Outlook

- Fully-funded PhD project to continue this research (get in touch)
- Ongoing and future tests are run with the GPU version of DualSPHysics
- Simulations of pressure on slide surface (physical model data available on SPHERIC website (validation test 11) and/or in Heller et al., 2015)





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## Thank you for your attention!