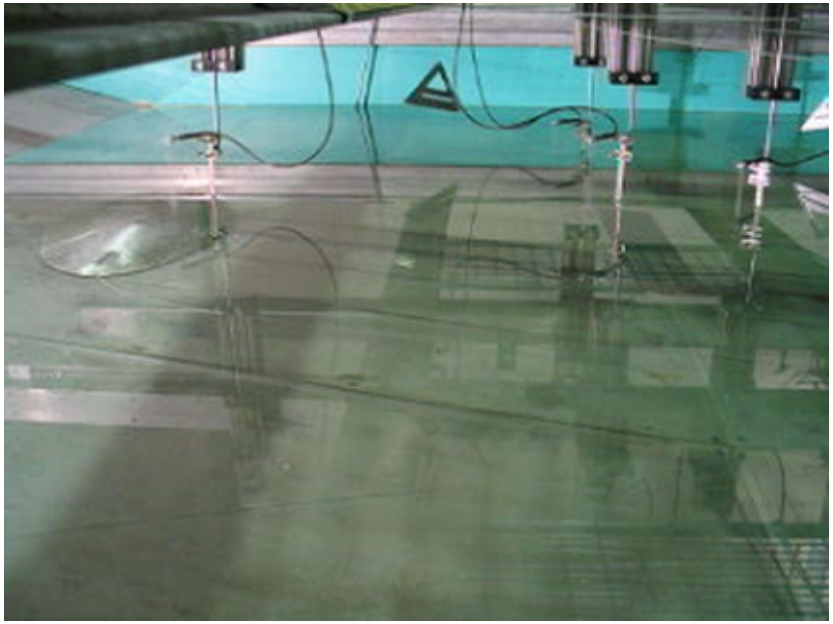
Benchmark Problems

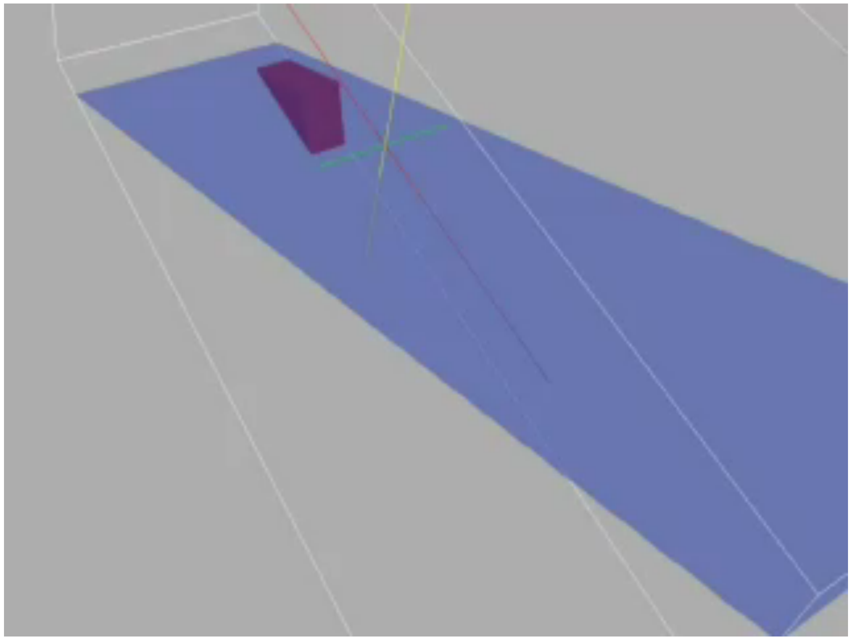
Data Availability: What are possible benchmark tests?

- Submarine slides:
  - Solid block movement
  - Granular slides (initiated by pulling a vertical gate)
  - Experiments on mud deposits/cohesive bed failures
  - Possible field cases (Papua New Guinea, Grand Banks, Port Valdez, …)
- Subaerial slides:
  - Good field observations (Lituya Bay, other events in fjords)
  - Good experimental data sets for granular cases

Solid submarine slides (2D and 3D)



Enet and Grilli (2007)



Liu et al, 2005

Granular-flow, submarine slide (2D)

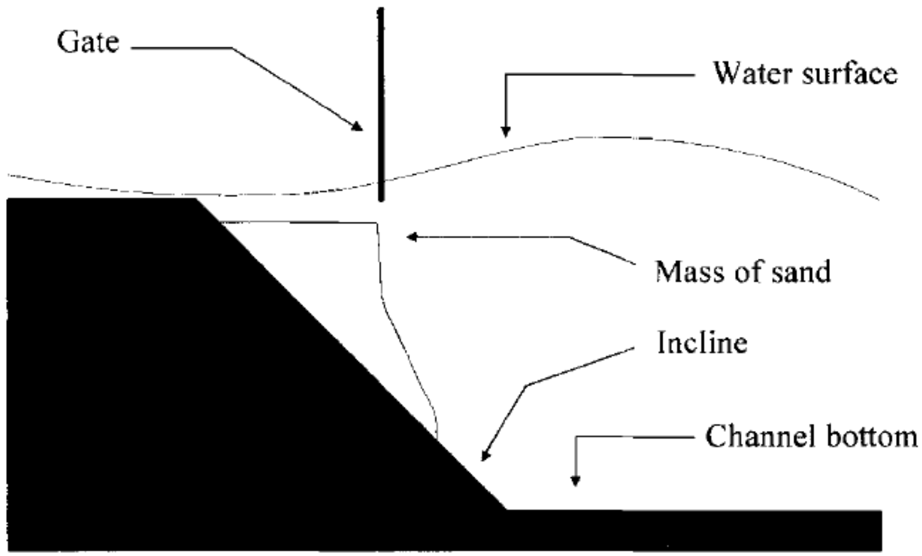


FIG. 6. Experimental Setup

Assier-Rzadkiewicz and Heinrich (1997)

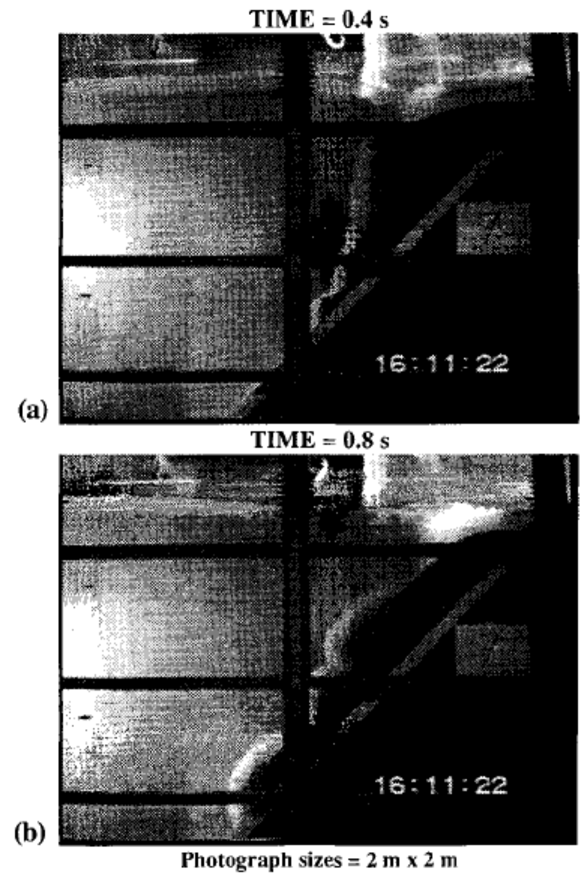
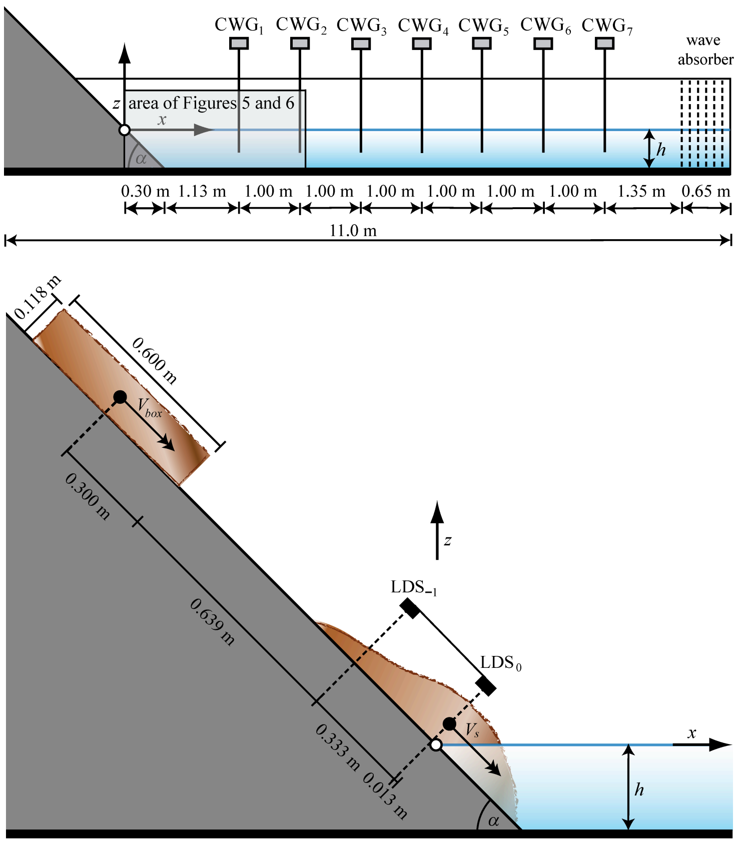
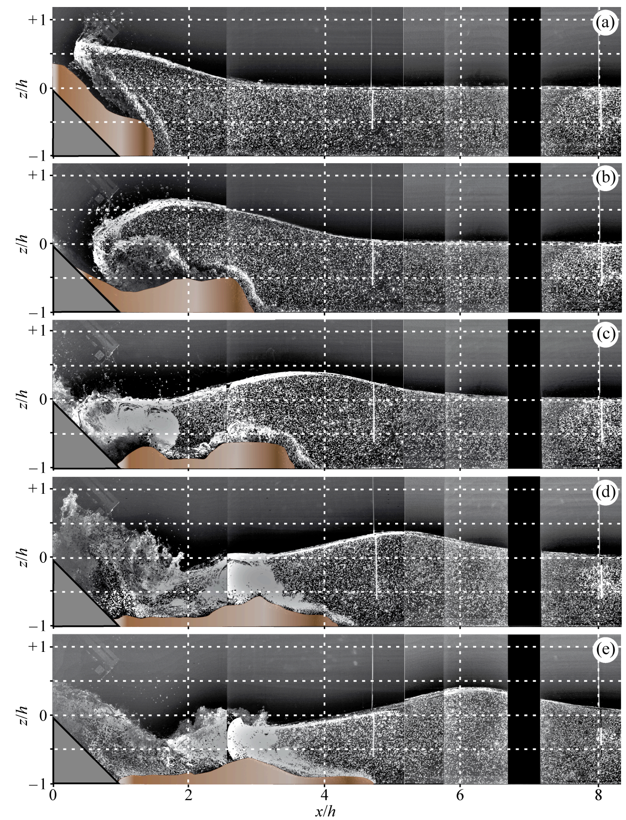


FIG. 7. Experimental Results at t = 0.4 s and t = 0.8 s for Coarse Sand Sliding Down 45° Slope

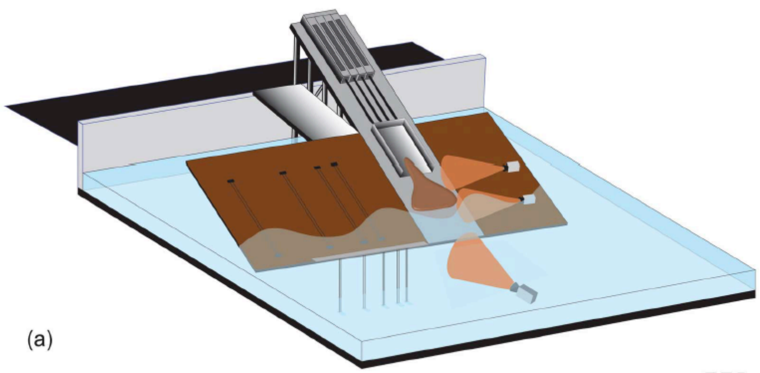
Granular-flow, subaerial slide (2D)

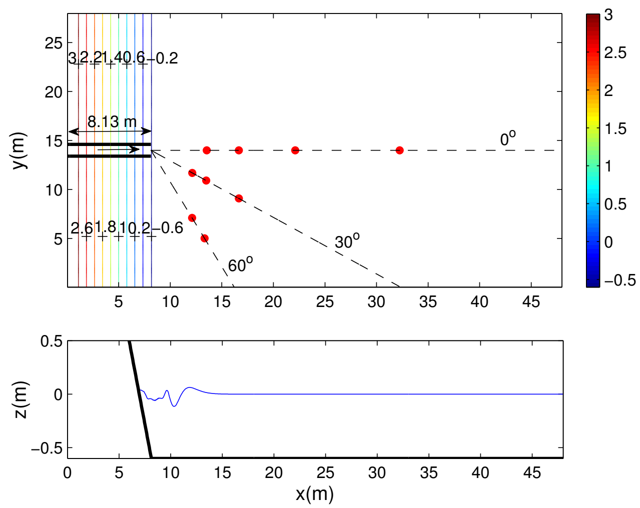


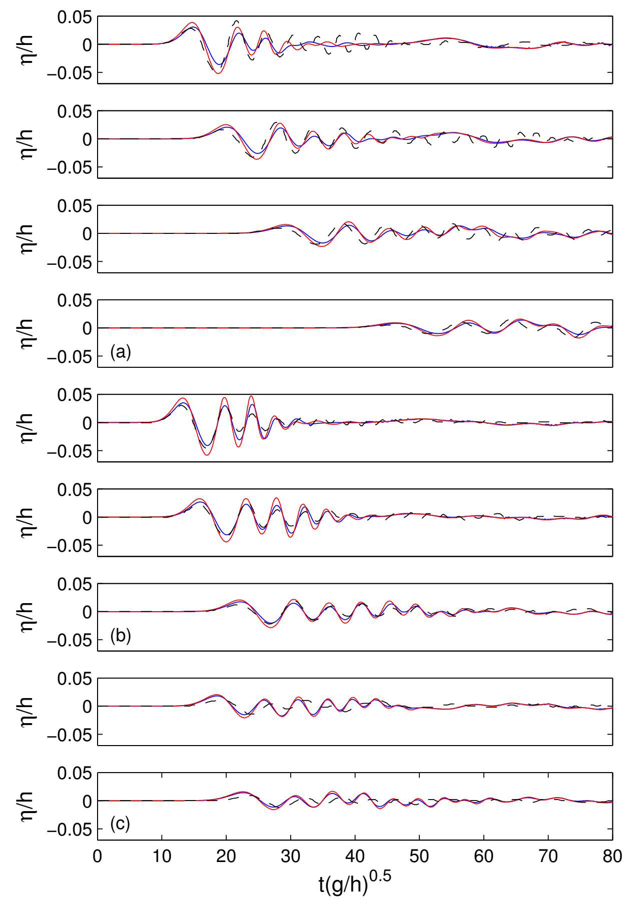


Heller, 2007; Heller and Hager 2010

Granular-flow slide (3D)







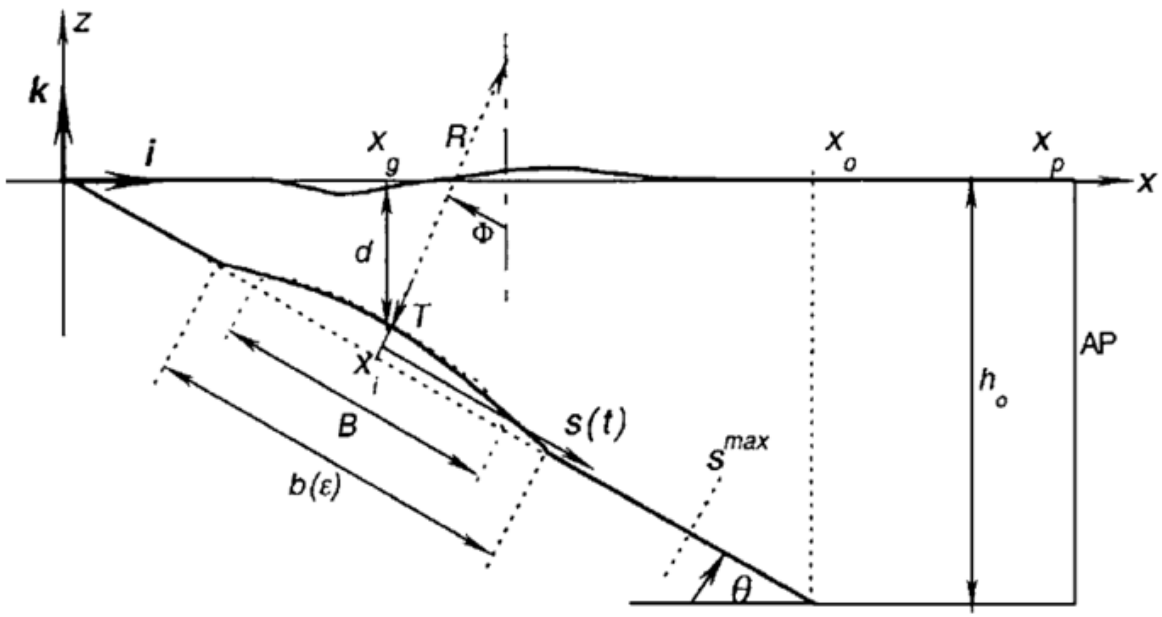
Mohammad and Fritz (JGR 2012)

Choosing benchmark tests for NTHMP-related modeling

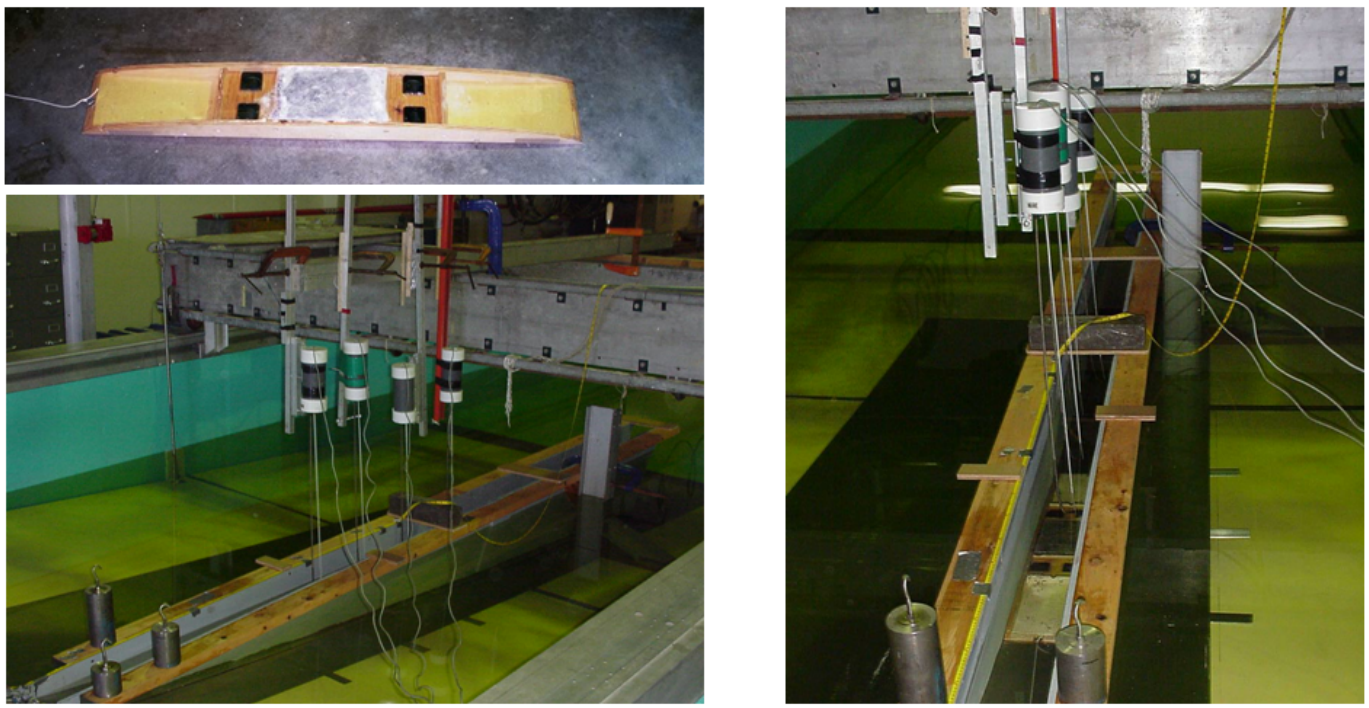
- Most ongoing or envisioned work is related to submarine slides and slumps
  - East Coast:
    - Upper East Coast silicate deposits – Currituck-like slide events
    - Southern limit of coast – carbonate shelf deposits – Bahama Banks
  - Gulf Coast: similar
  - Historical events rare – difficult to establish the sort of return period analysis that emergency managers desire
- Modeling subaerial events has unquestioned importance in understanding hazards to communities near fjords, reservoirs, other areas flanked by steep topography. (NTHMP involvement?)

Benchmark 1: Solid slide, 2D (x,z)

- Data source: Grilli and Watts (2005)
- Slide with semi-elliptical cross-section, effective density of 1850 kg/m^3
- Slide geometry:



Slide geometry and wave gauge positions



Wave generation by 2D slide ([Figure 1.1]). Experimental set-up, with views of sidewalls, capacitance wave gages, and lead-loaded rolling semi-elliptical slide model

- Slide released from rest position. Trajectory observed to agree well with theoretical prediction of position

$$\frac{S}{S_0} = \log\left\{\cosh\left(\frac{t}{t_0}\right)\right\} \tag{1}$$

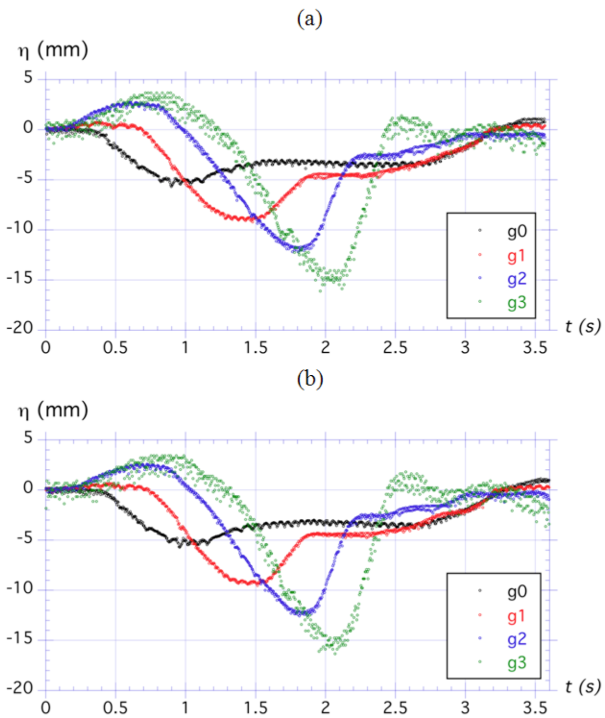
with

$$t_0 = \frac{u_t}{a_0} \quad \text{and} \quad S_0 = \frac{u_t^2}{a_0} \tag{2}$$

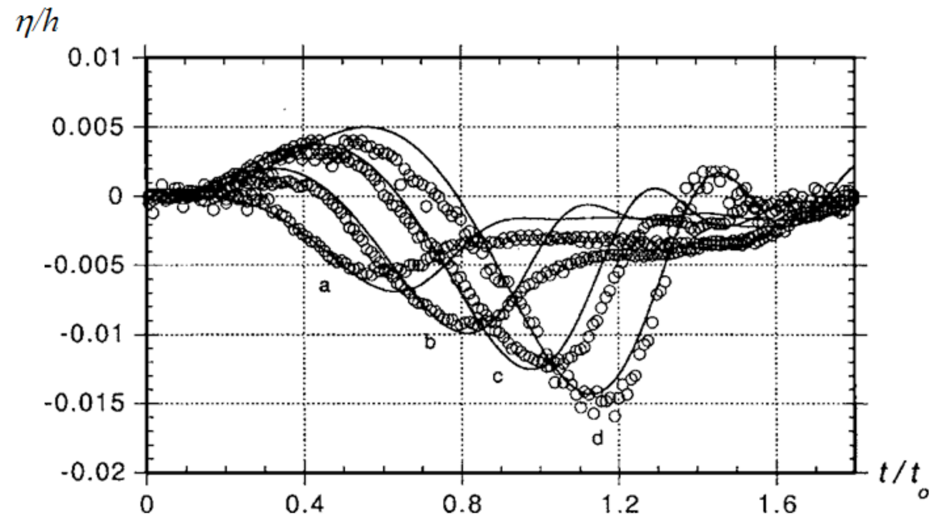
where u_t and a_0 are the terminal velocity and initial acceleration of the slide on a planar slope.

- Surface elevation as a function of time measured at 4 wave gages

Repeatability



Comparison to potential flow solution using Boundary Element Method



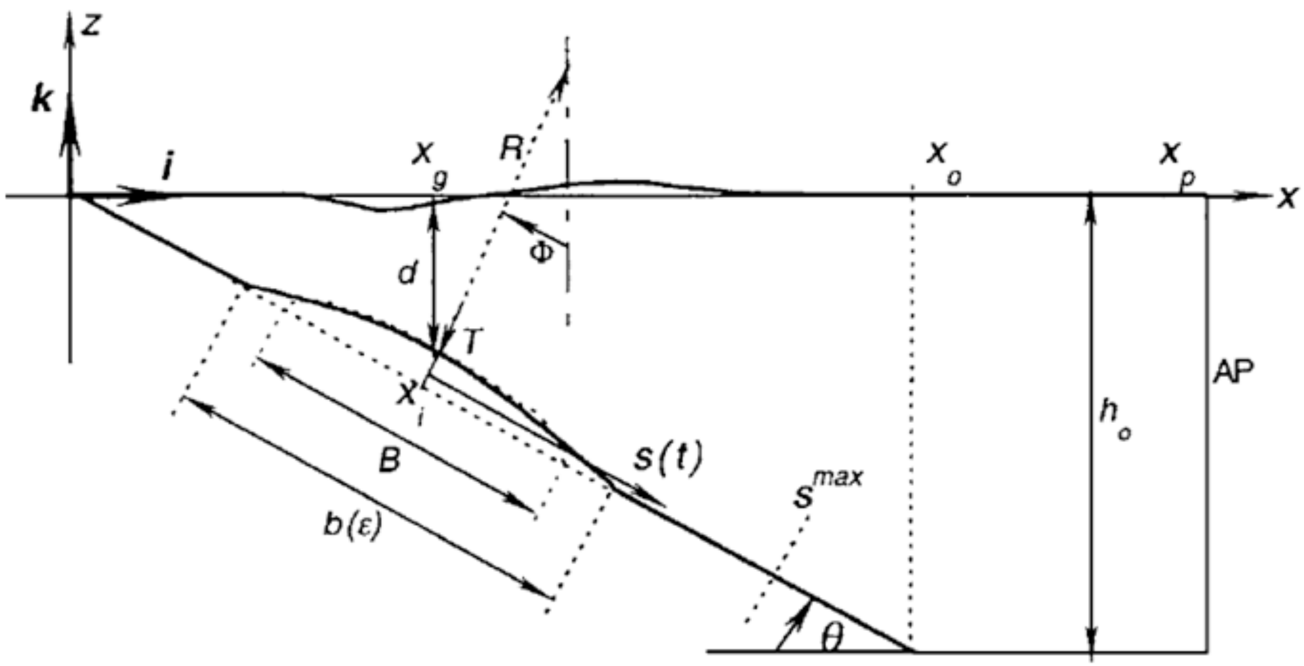
Wave generation by 2D slide. Two sets of experimental results (a: trial 4 and b: trial 5) from Grilli and Watts' (2005) 2D slide experiments, for d = d_{ref} = 0.259 m. Labels g0 to g3 denote measurements of surface elevation at gages located at x (m) = 1.234, 1.549, 1.864, 2.179.

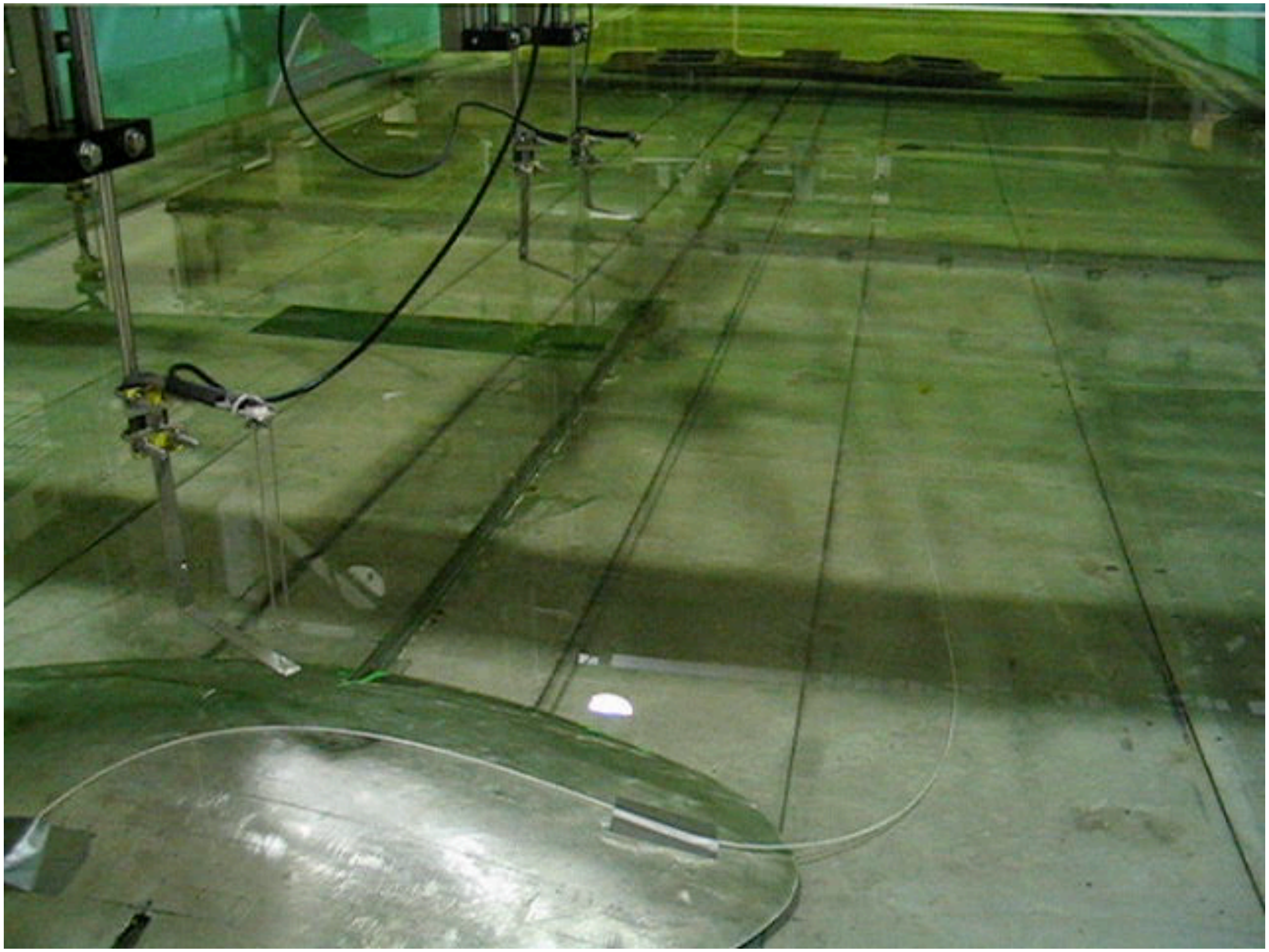
For this workshop:

- **Data:**
  - Time series of raw data from Figure 1.4 are provided in Matlab formatted mat files bench1_trial4.mat and bench1_trial5.mat and in excel format as Bench1_trial4.xlsx and Bench1_trial5.xlsx.
- **Problem:**
  - The benchmark here consists of using the above information on slide shape, density, submergence and kinematics, together with reproducing the experimental set-up to simulate surface elevations measured at the 4 wave gages.
- **Reference:**
  - http://www.udel.edu/kirby/landslide/problems/benchmark_1.html

Benchmark problem 2: Solid slide-3D

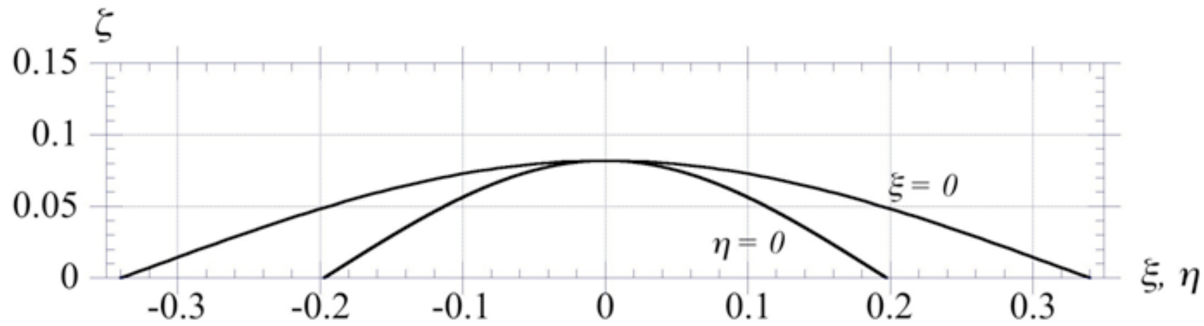
Semi-elliptic geometry also used in *y* direction (Flying saucer)





Slide geometry:

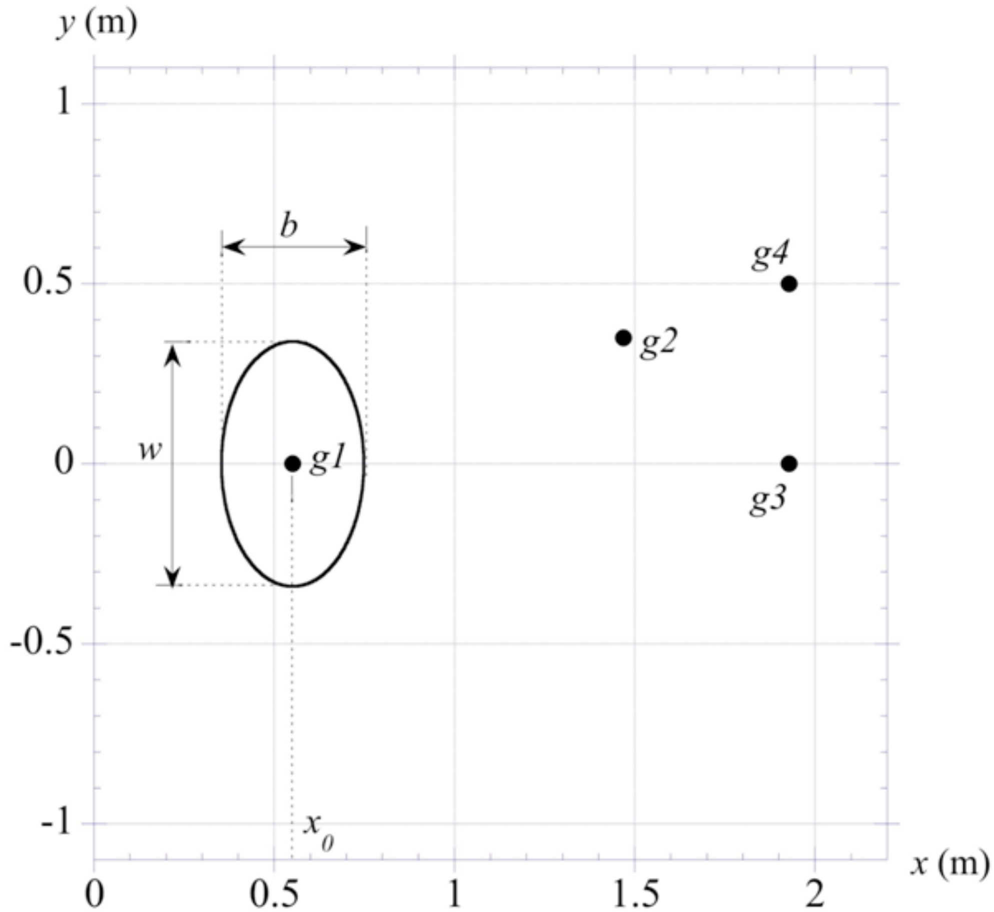
$$\zeta(\xi,\chi)=\frac{T}{1-\varepsilon}\max\left[0,\ \operatorname{sech}(k_b\xi)\operatorname{sech}(k_w\chi)-\varepsilon\right]$$
$$k_b=\frac{2}{b}\operatorname{acosh}\frac{1}{\varepsilon}\qquad(1)$$
$$k_w=\frac{2}{w}\operatorname{acosh}\frac{1}{\varepsilon}$$



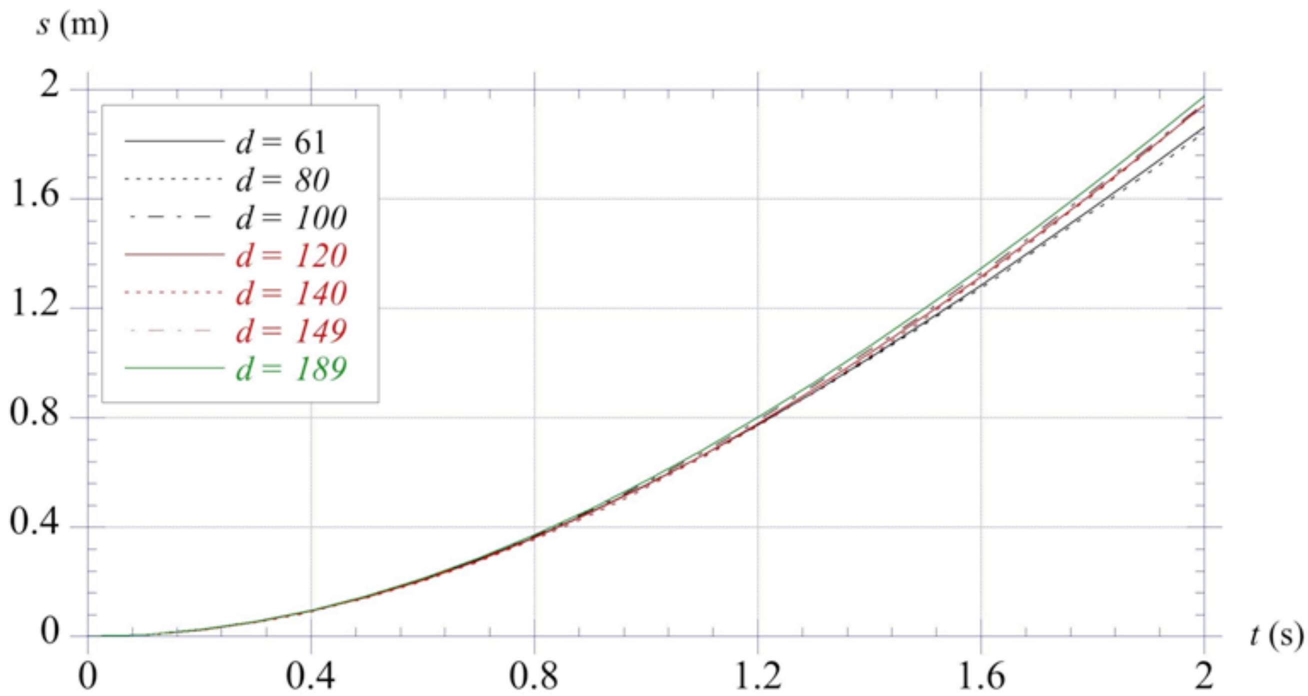
(It has been noted during this workshop exercise that the expression for slide volume given is incorrect)

Measurements:

- Slide kinematics
- Water surface elevation at 4 wave gauge locations
- Shoreline runup on centerline axis

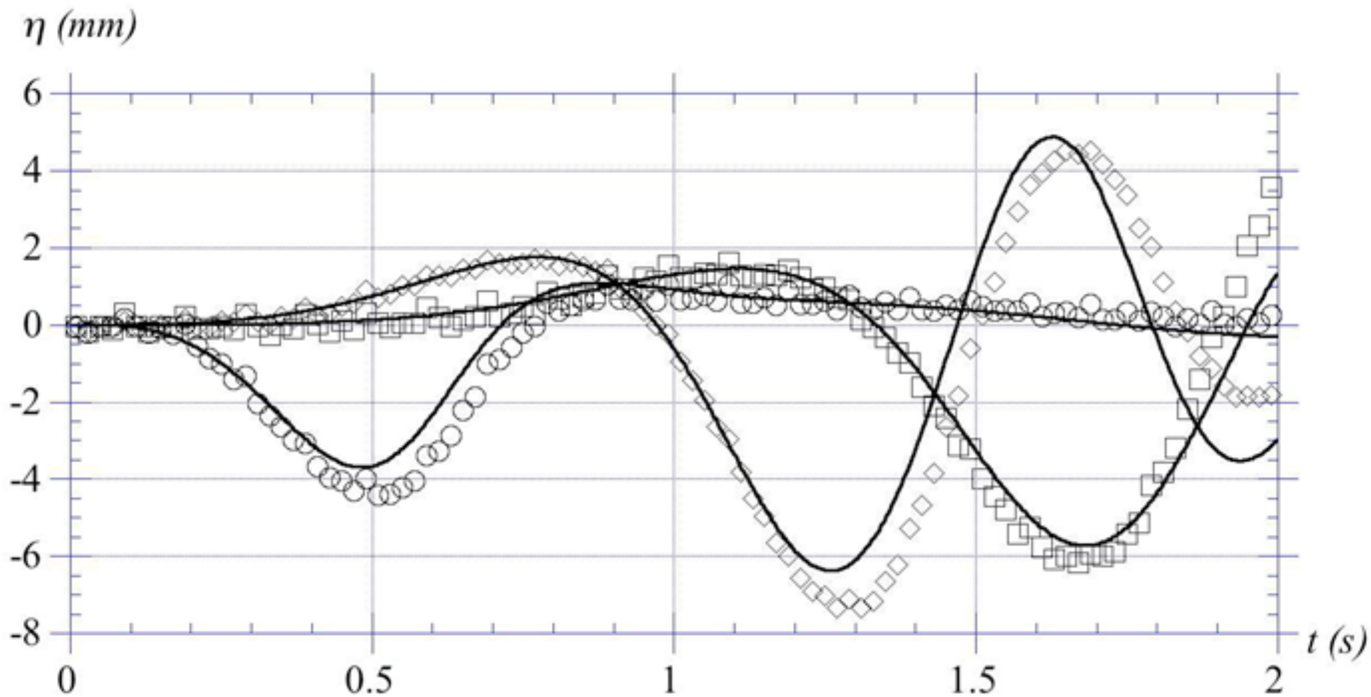


Slide kinematics (based on curve fit to measurements)



Wave generation by underwater 3D slide. Experimental slide kinematics, as a function of initial submergence depth d , calculated with Eqs. (1-2 for Benchmark #1, 4) using average experimentally fitted values of S_0 and t_0 . Agreement with theoretical predicted kinematics also good, as in Benchmark 1.

Example model/data comparison



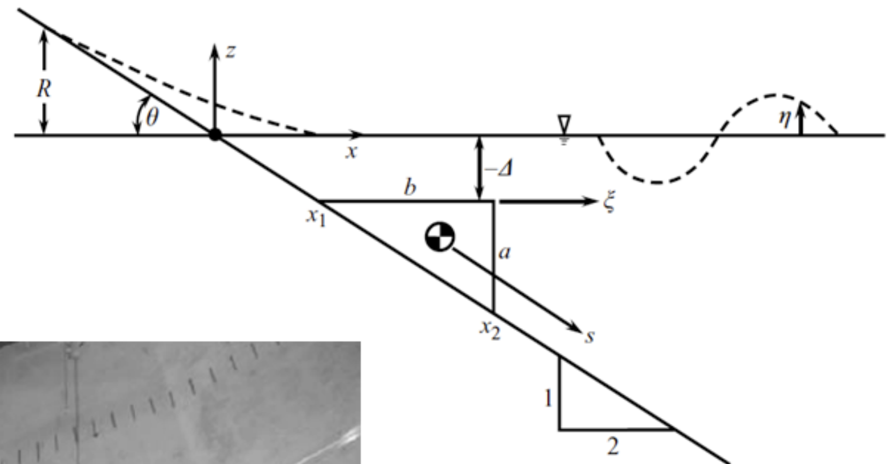
- *Comparison of FNPF model results (-) with 3D submarine slide experiments of Enet and Grilli (2007) (symbols) for d = 0.140 m, at gage g1 (◇) and g2 (□) (only 10% of experimental data points are shown). [from Grilli et al., 2010].*

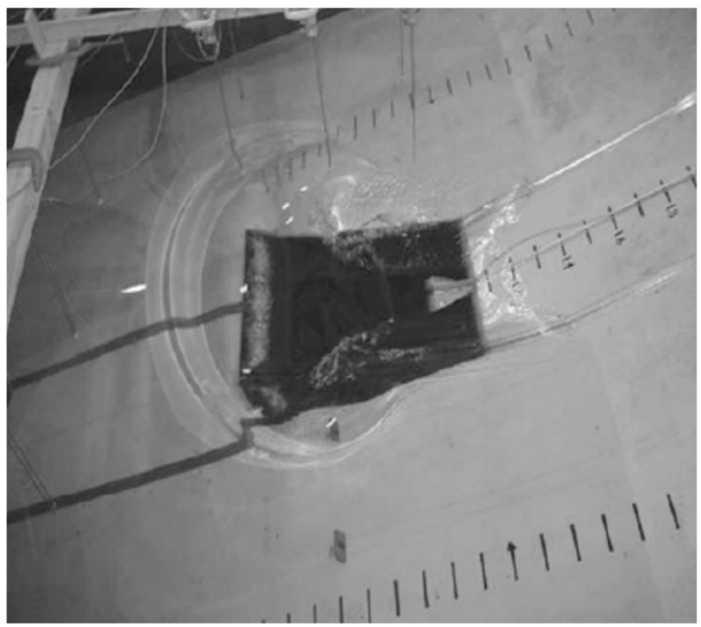
For this workshop:

- **Data:**
  - Seven data files are provided (in both .txt and .xls format), which contain, for each of the 7 initial submergence depths (d = 61, 80, 100, 120, 140, 149, 189 mm), the time series of surface elevation measured at up to the 4 gages (in mm) listed g1, g2, g3, g4.
- **Benchmark Problem:**
  - The benchmark test here consists of using the information on slide shape, density, submergence and kinematics to simulate surface elevations measured at the 4 wave gages. **We request that participants provide results for the cases with initial depth of submergence d=61mm and d=120mm**.
- **Reference:**
  - http://www.udel.edu/kirby/landslide/problems/benchmark_2.html

Benchmark 3: Solid slide, 3D

Liu et al (2005)
Wu (2004)

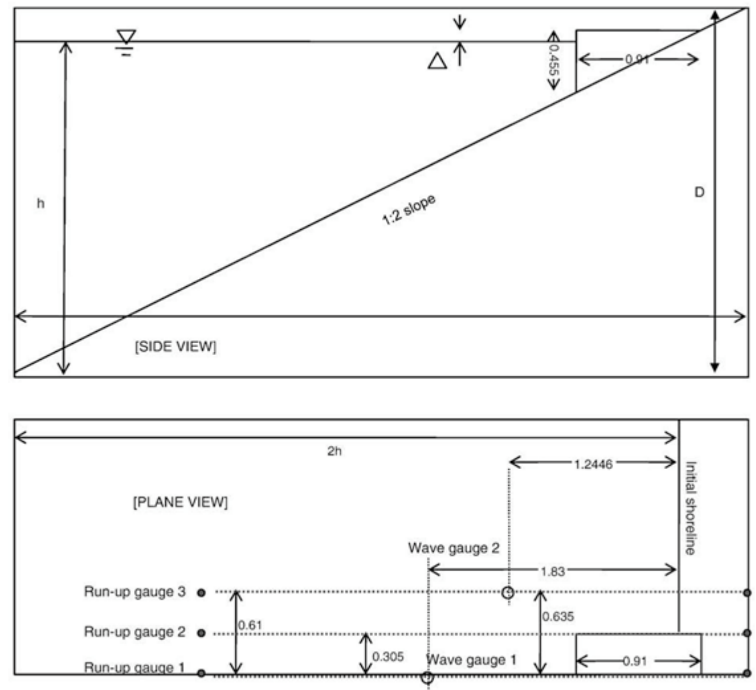


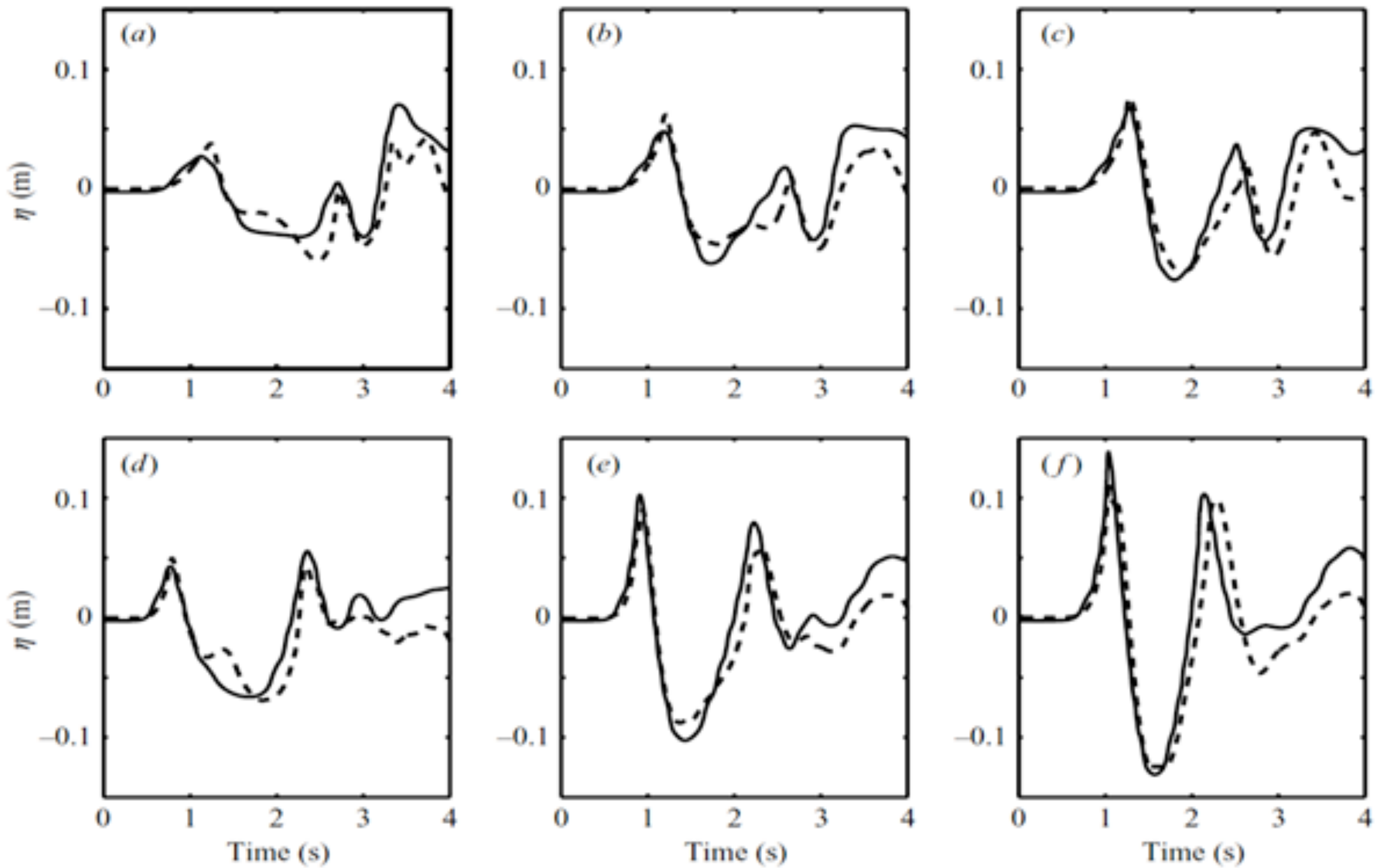


Tests conducted with a range of block geometries and effective densities ranging from 1512 to 3765 kg/m^3. Starting slide positions were both submarine and subaerial.

Data collected during experiments included slide motion, water surface elevation at 2 positions, and shoreline runup at two positions.

Liu et al (2005) show model results from a 3D LES/VOF model: sample results are shown next.





Solid triangular block experiments for Δ = 0.454 m (subaerial) and γ =3.43. Computed (-) and measured (- - -) surface elevations at wave gauges located at (x, y) in m: (a) 0.4826, 1.092; (b) 0.8636, 1.092; (c) 1.2446, 1.092; (d) 0.4826, 0.635; (e) 0.8636, 0.635; (f) 1.2446, 0.635.

For this benchmark:

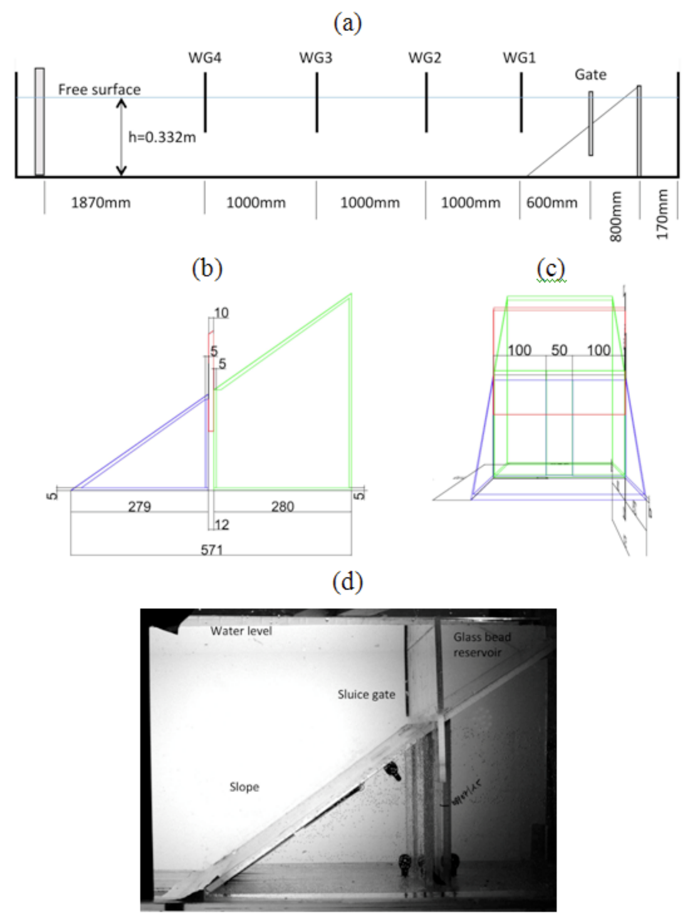
- **Data:**
  - Data for recorded block motion, wave gage and runup measurements are provided for the two different initial elevations of the wedge on the beach; a submarine case referred to as Case 30, and a subaerial case referred to as Case 32. Measured free surface elevations are given for 2 wave gages placed at (x,y) = (1.83, 0) and (x,y) = (1.2446, 0.635) m, where x = distance to the initial shoreline, y = distance to the central axis. Measured runup is given at runup gages 2 and 3 lying on the slope at distances of 0.305 and 0.61 m from the central axis.
- **Problem:**
  - The benchmark proble is to simulate surface elevations measured at the wave gages and runup/rundown measured on the beach for two initial locations of the block, with: Δ = 0.1 m (subaerial); and Δ = -0.025 m (submerged). As a minimum results should be provided for the same experiment as in Abadie et al. (2010) with Δ = 0.1 m.
- **Reference:**
  - http://www.udel.edu/kirby/landslide/problems/benchmark_3.html

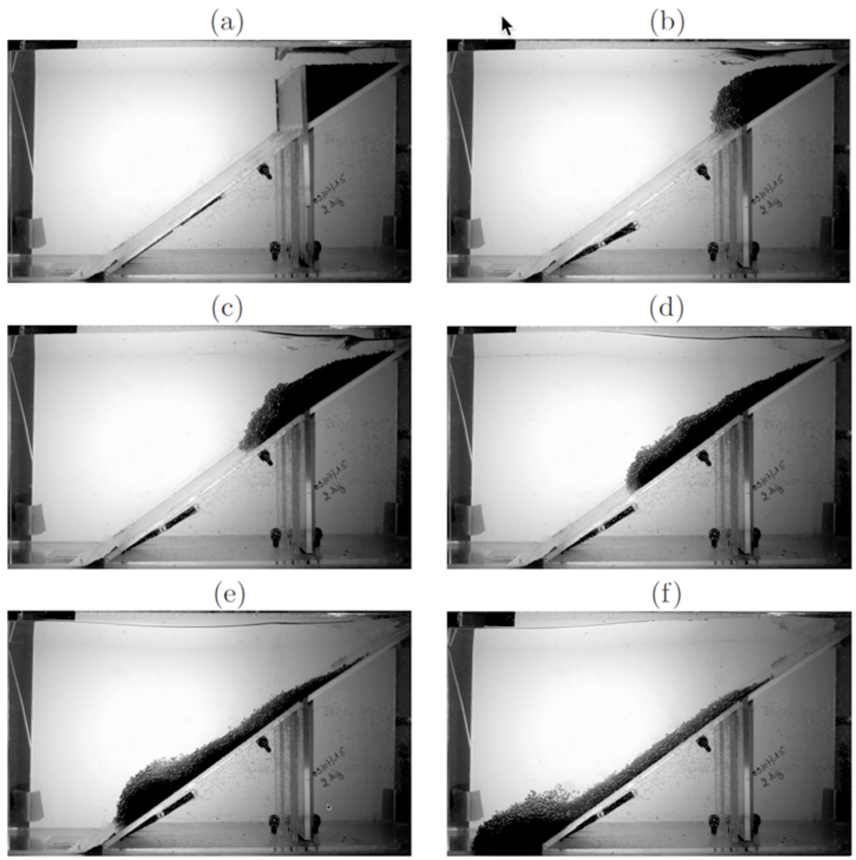
Benchmark 4: Submarine granular slide, 2D

In this study, a fully submerged volume of glass beads is retained behind a vertical gate which is dropped at the experiment start, allowing the volume to slide down a 35° slope.

58 experiments were conducted at Ecole Centrale de Marseille's (IRPHE) precision tank (Marseille, France), with a small subset reported by Grilli et al (2016).

Data consists of time series of water surface displacement at 4 gauges (top frame in figure) and 1000 fps video of moving slide geometry.



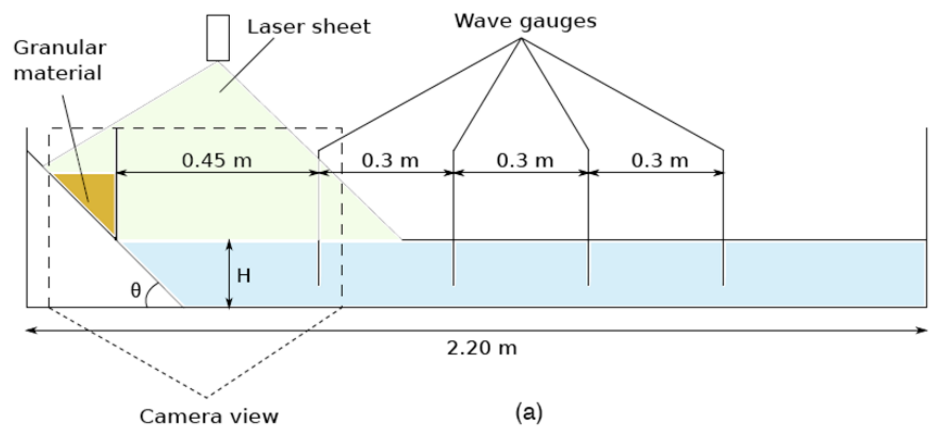


Snapshots of laboratory experiments of tsunami generation by underwater slide made of glass beads, for h = 0.330 m; db = 4 mm, Wb = 2 kg, at times t = (a) -0.105; (b) 0.02; (c) 0.17; (d) 0.32; (e) 0.47; and (f) 0.62 sec. Note, glass beads are initially stored within the glass bead reservoir with the sluice gate up; at later times, after the gate is withdrawn, the deforming slide moves down the 35 deg. slope while the free surface is deformed. The starting time of experiments t = 0 is defined when the gate has just withdrawn into its cavity.

For this benchmark:

- **Data:**
  - Recorded water surface displacements are provided for the 4 wave gauges for the test denoted Test 17. (Data for all 58 tests is also accessible). The high speed video for test 17 is also provided. Matlab code for extracting and plotting the data for each test case is included. This code also calculates the various dimensions of the slide itself, plus necessary parameters for computations.
- **Problem:**
  - The benchmark problem is to calculate (at a minimum) the surface elevation at the four wave gauges for the configuration of Test 17. Model reproduction of slide geometry would also be of interest.
- **Reference:**
  - http://www.udel.edu/kirby/landslide/problems/benchmark_4.html

Benchmark 5: Subaerial granular slide, 2D

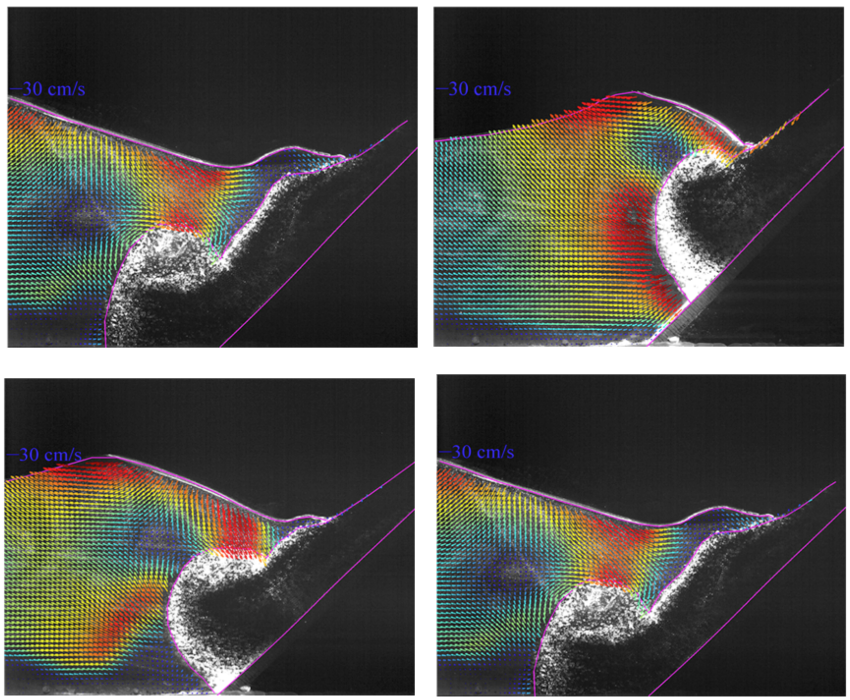


This benchmark problem is based on the 2D laboratory experiments of Viroulet et al. (2014) in a small tank at Ecole Centrale de Marseille's (IRPHE; Marseille, France), for a series of triangular subaerial cavities filled with dry glass beads of diameter D and density ρ_s = 2,500 kg/m3, released by lifting a sluice gate and moving down a plane 45 deg. slope into water. The benchmark is similar to #4 except for the subaerial position of the initial slide material.

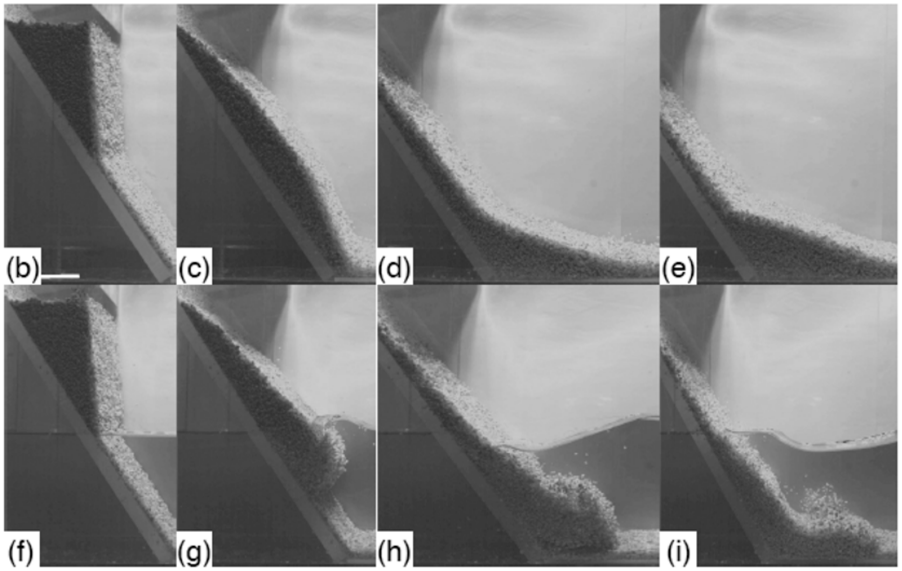
Data collected for these tests included wave gauge measurements, high speed video and PIV measurements of water velocities near the moving slide.

Subaerial granular slide

PIV of fluid motion



Video of slide motion

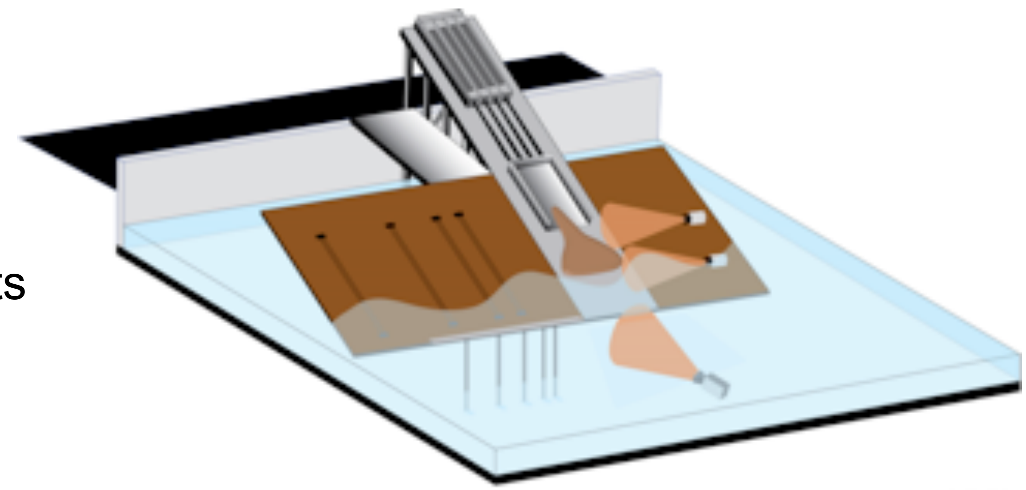


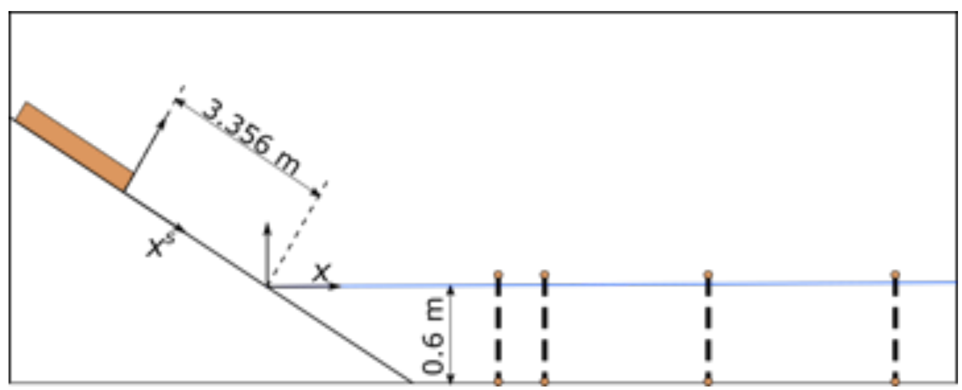
For this benchmark:

- **Data:**
  - Two test cases are considered in this benchmark, which are referred to as Case 1 and Case 2 in the result files names. The initial conditions for each case are
  - **Case 1 : *D* = 1.5 mm, *H* = 14.8 cm, *L* = 11cm**
    Case 2 : *D* = 10 mm, *H* = 15 cm, *L* = 13.5 cm
  - The volume fraction of the granular media for the 2 cases was estimated to be 0.6 ± 0.05.
- **Problem:**
  - The benchmark here will consist in simulating the time series of free surface elevations at the 4 wave gages for the 2 test cases listed above.
- **Reference:**
  - http://www.udel.edu/kirby/landslide/problems/benchmark_5.html

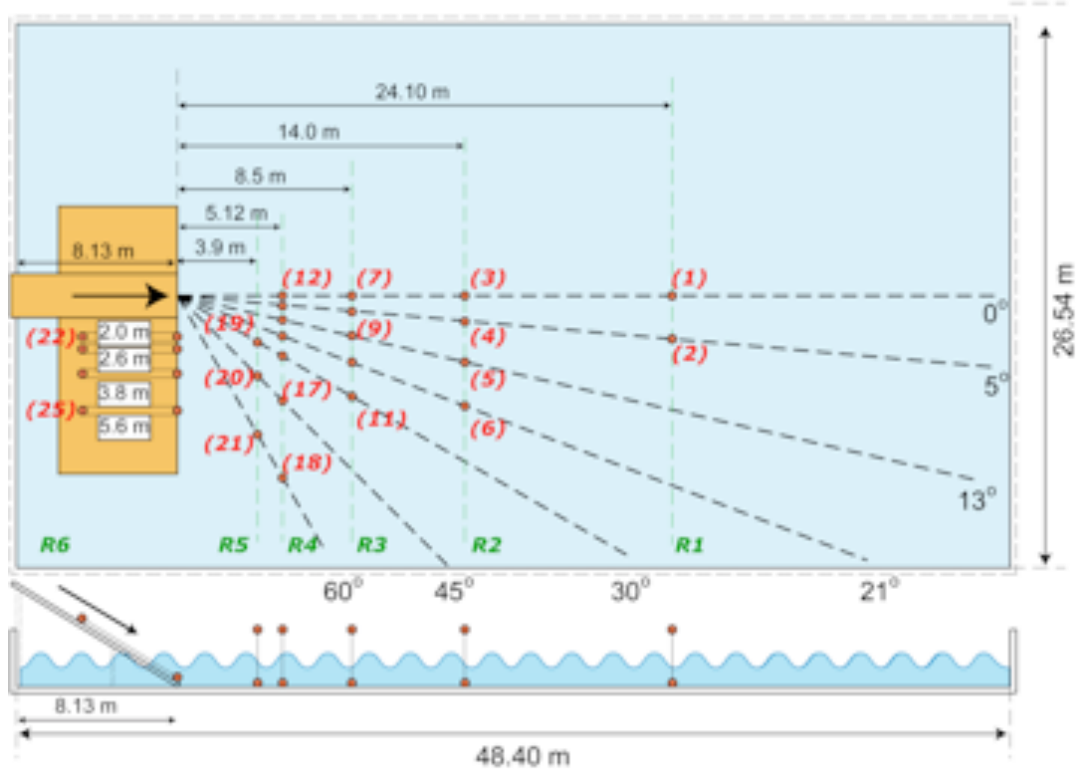
Benchmark 6: Subaerial granular slide, 3D

This benchmark problem is based on the 3D laboratory experiments of Mohammed and Fritz (2012). The landslide tsunami experiments were conducted in the tsunami wave basin at Oregon State University in Corvallis. The landslides are deployed off a plane slope built on one end of the wave basin. In contrast to the previous benchmark, the generated slide and wave evolve in 3D, and the slide is generated with an initial momentum.





Measurements include water surface displacements at 21 wave gauges and 4 runup gauges labeled at right. Data are also provided for slide deposit configuration and slide velocity and shape at initial water impact.

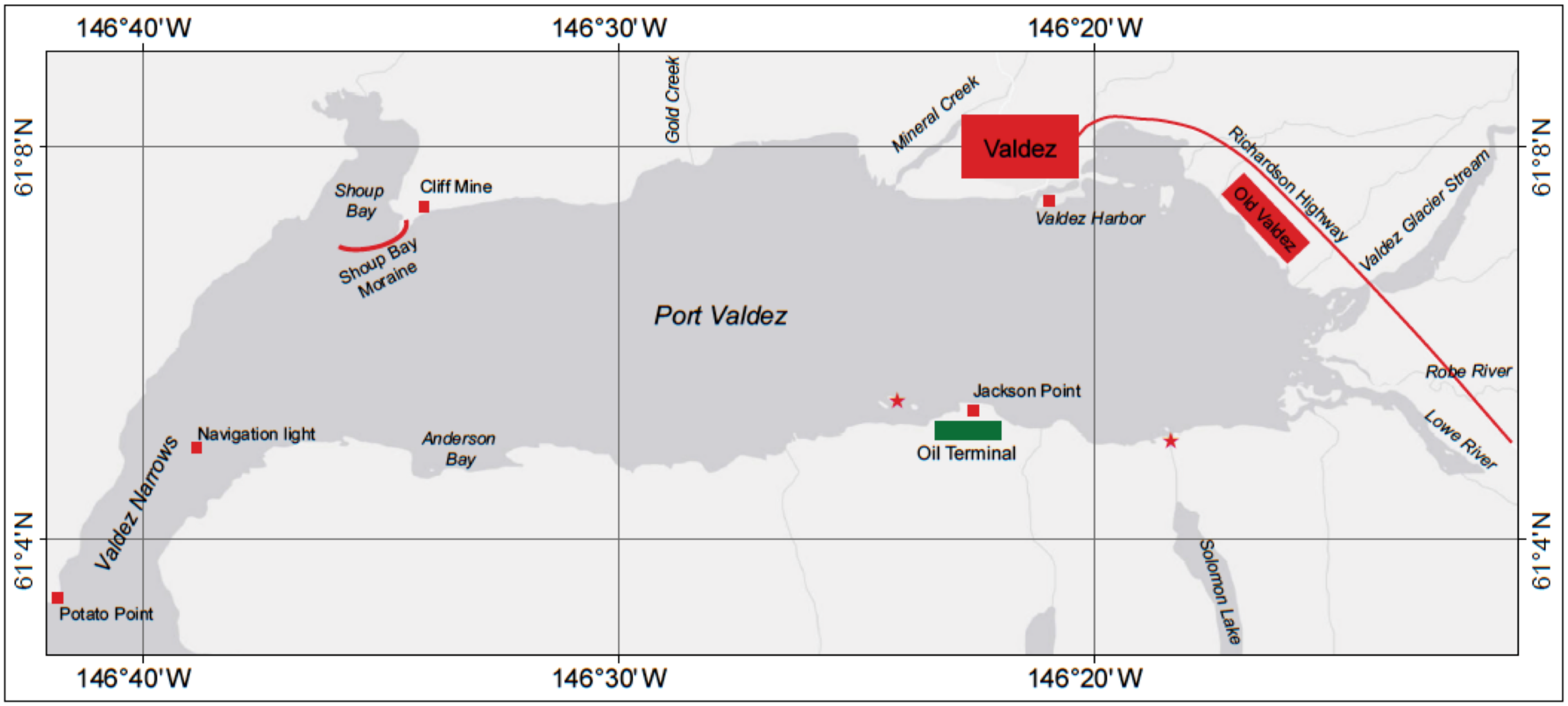


Wave gauge location in the wave basin relative to the wave basin.

For this benchmark:

- **Data:**
  - Data for slide configuration and gauge measurements are provided for all 12 tests.
- **Problem:**
  - The benchmark here will consist in simulating the time series of free surface elevations at the 21 labeled wave gauge and 4 runup gauge locations, along with details of slide geometry and motion.
- **Reference:**
  - http://www.udel.edu/kirby/landslide/problems/benchmark_6.html

Benchmark 7: Field Case
Landslides near Port Valdez, AK, during 1964 Alaska Earthquake



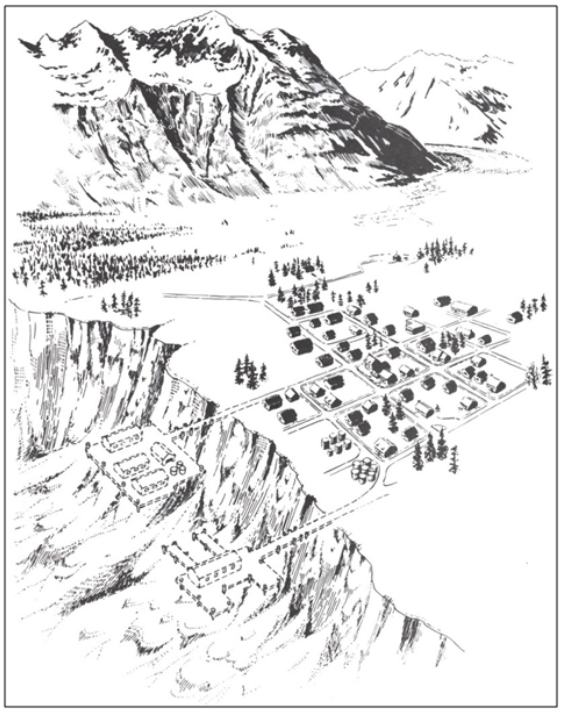
- This benchmark problem is based on the historical event which occurred at Port Valdez, AK during the Alaska Earthquake of March 27, 1964. The event has previously been in recent studies by Parsons et al. (2014) and Nicolsky et al. (2013). The second document provides an overview of the historical background and geology for the site, and is the principal source for the problem described below. Other background documents include Coulter and Migliaccio (1966), Plafker et al. (1969), and Wilson and Tørum, (1972).

- Two principal slide events occurred, labeled here as
  - HPV, occurring along the shoreline in front of and to the south of Old Valdez
  - SBM, occurring in the area of Shoup Bay moraine

HPV Slide

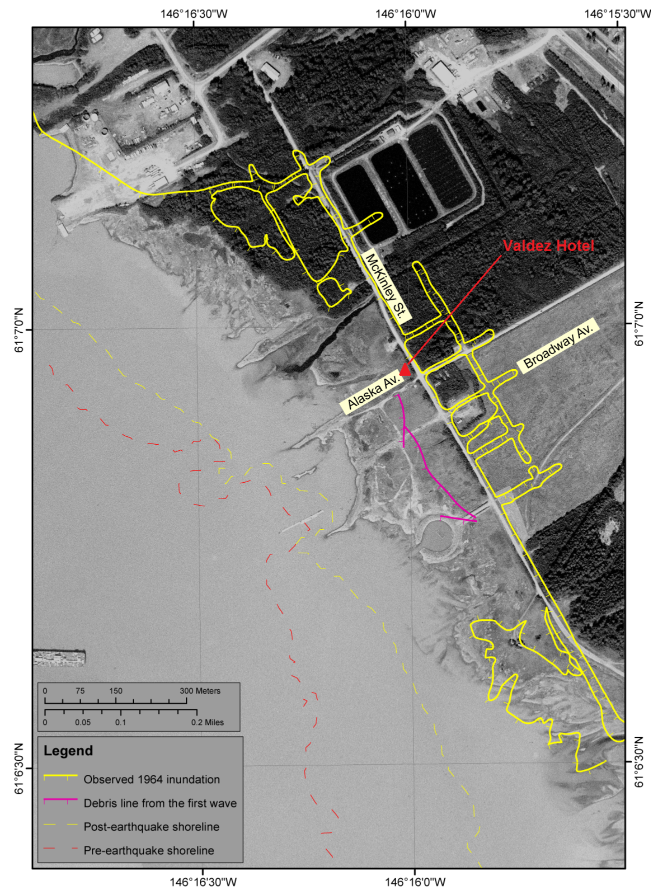
- The great disaster during the M_w9.2 Alaska Earthquake happened in the dock and harbor area, where a massive submarine landslide generated a tsunami, inundating the waterfront up to two blocks inland. The pre- and post-earthquake bathymetry profiles near the site are shown in (Coulter and Migliaccio, Appendix 2, 1966). To the south of Valdez, depth changes exceeding 90 m occurred, which exceeds the depth change off Valdez itself. Thus the major part of the slide took place off the Lowe River delta. It is estimated that approximately 75 million m^3 of unconsolidated deposits were transferred from the waterfront into the bay (Coulter and Migliaccio, 1966). A sequence of the waves following the landslide are reconstructed from eyewitness reports and observations.

HPV slide



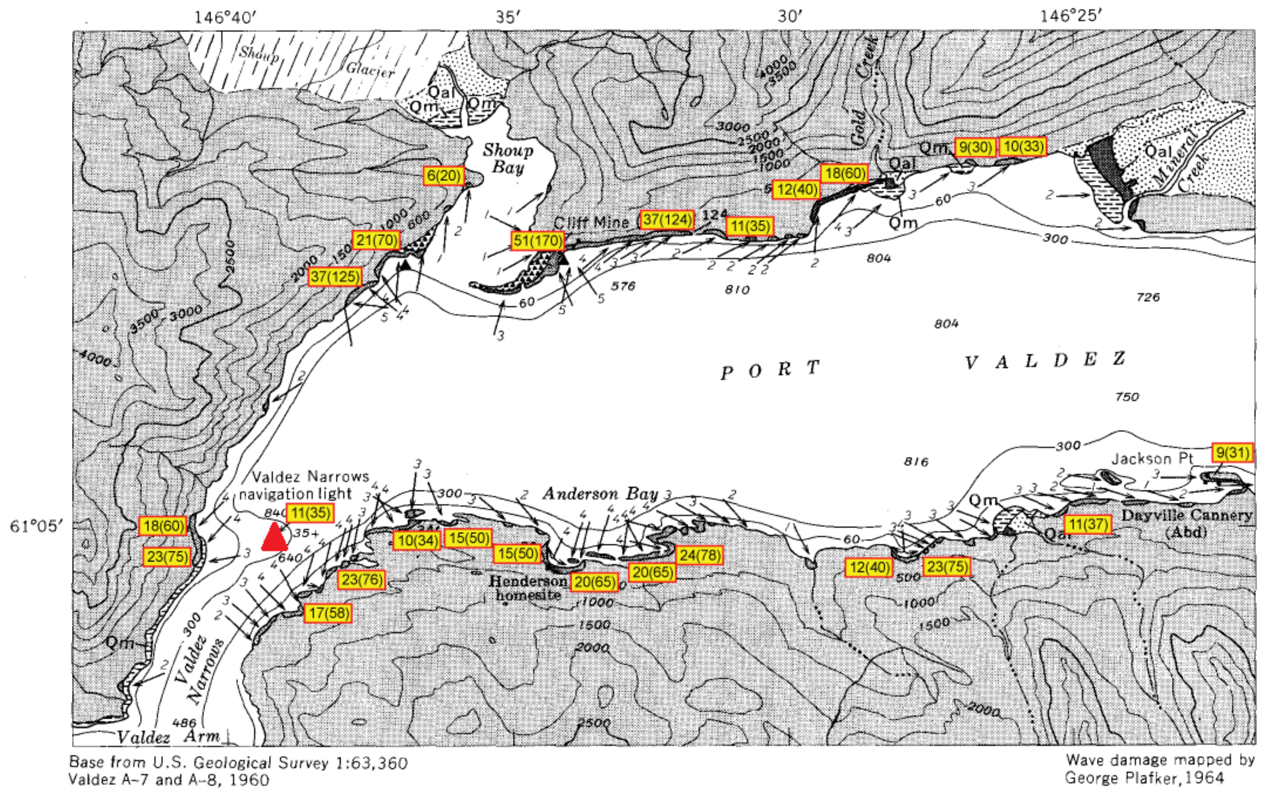

Before


After


146°16'30"W
146°16'0"W
146°15'30"W
61°7'0"N
61°6'30"N
McKinley St.
Valdez Hotel
Broadway Av.
Alaska Av.
0 75 150 300 Meters
0 0.05 0.1 0.2 Miles
Legend
Observed 1964 inundation
Debris line from the first wave
Post-earthquake shoreline
Pre-earthquake shoreline

SBM slide

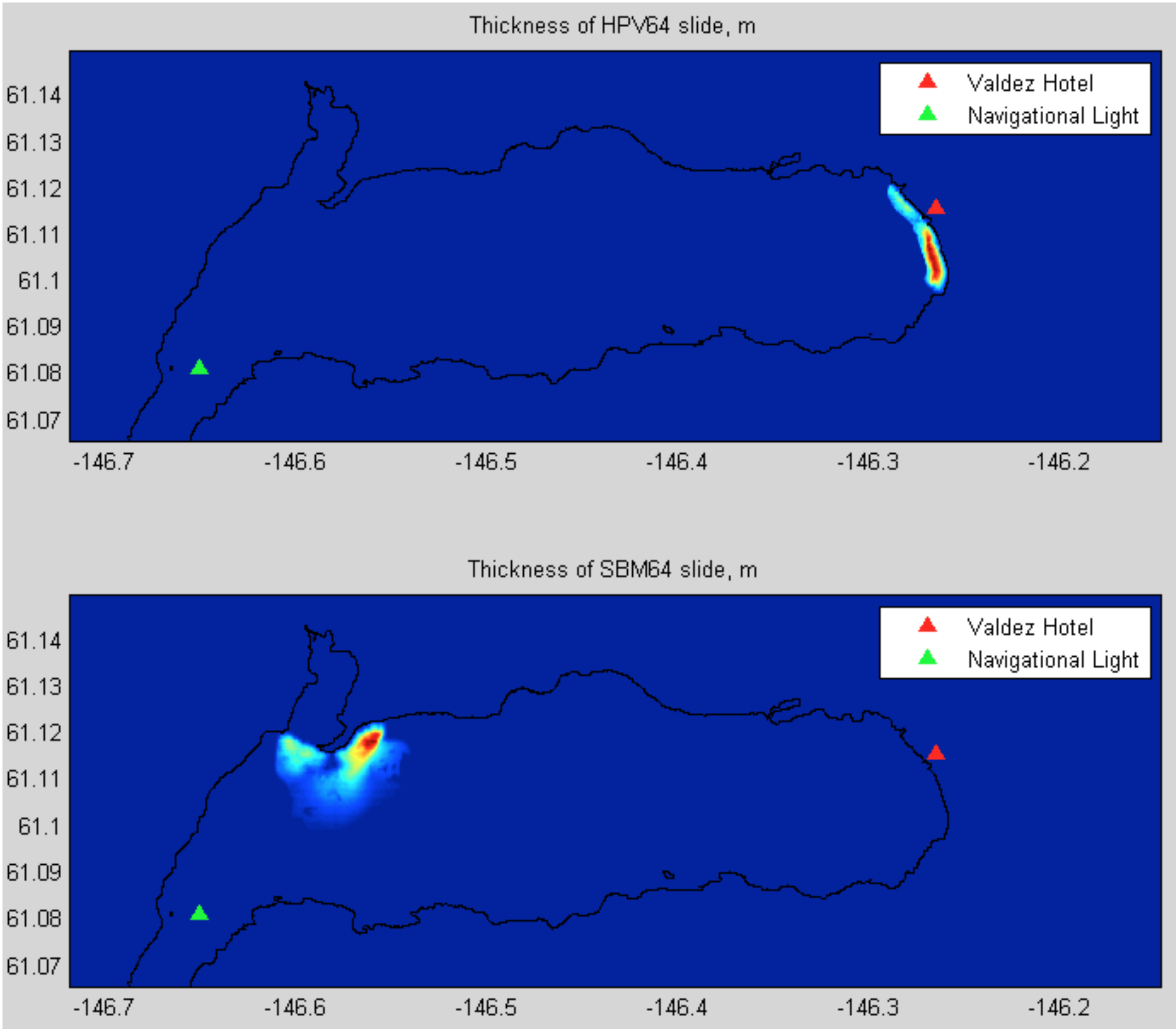
- There were no eyewitnesses to waves that struck the shore at other locations along Port Valdez. However, the inundation line was evident from scattered debris and marks on fresh snow. Figure 7.5 shows the observed runup around Port Valdez. The highest location obliterated by waves was near the large, abandoned Cliff Mine. According to Plafker and others (1969), the waves deposited driftwood at points 52 m (170 ft) above sea level and splashed silt and sand up to an elevation of 67 m (220 ft). Directly across from the Cliff Mine in Anderson Bay at the south shore of Port Valdez, the waves ran up to 24 m (78 ft) above the water level and destroyed a small fishing camp. All structures of the camp were swept away, leaving only the driven piling foundations. Its sole inhabitant, Harry Henderson, was missing and presumably drowned in the violent local waves that struck Anderson Bay.



- *Distribution and intensity of wave damage in Port Valdez after the 1964 earthquake, mapped by L. Mayo and G. Plafker. Inferred direction of the wave arrival is shown by arrows. Relative magnitude of damage is indicated by a numeral at the base of an arrow, based on the scale: 1-runup about 1-2 m (0-6 ft); 2-runup 8 m (25 ft) on steep shores; 3-maximum runup 17 m (55 ft); 4-maximum runup 21 m (70 ft); 5-maximum runup 52 m (170 ft). Yellow boxed numerals onshore next to shaded areas at edge of water provide runup height in meters (and feet) above sea level at time of the earthquake. The base map and description of the damage are from Plafker and others (1969).*

For this benchmark:

- **Data:**
  - Pre-earthquake bathymetry for the Port Valdez basin
  - Estimates of slide thicknesses for the HPV and SBM slides, based on comparison of before and after bathymetry.
  - Shape files for
    - Observed inundation line in Old Valdez
    - Observed debris line from first wave in Old Valdez
    - Location of McKinley Street
    - Estimates of maximum runup reported at a locations


Thickness of HPV64 slide, m
Valdez Hotel
Navigational Light
61.14
61.13
61.12
61.11
61.1
61.09
61.08
61.07
-146.7
-146.6
-146.5
-146.4
-146.3
-146.2
Thickness of SBM64 slide, m
Valdez Hotel
Navigational Light
61.14
61.13
61.12
61.11
61.1
61.09
61.08
61.07
-146.7
-146.6
-146.5
-146.4
-146.3
-146.2

- **Benchmark problem:**

The benchmark here will consist in simulating the extent of inundation for two slide events (at the head of the bay and at the Shoup Bay moraine), based on before and after bathymetry data, eye-witness observations of the event, and observed runup distribution.

<u>For the slide at the head of Port Valdez (HPV)</u>, it is recommended to reproduce two waves that struck the Valdez waterfront to simulate an extent of inundation reaching at least McKinley Street.

<u>For the slide at the Shoup Bay moraine (SBM)</u>, it is recommended

- to simulate an extent of inundation around Port Valdez and reproduce 20+ m runup at the Anderson Bay
- to simulate 10+ m wave inundating the navigation light.
- to simulate 0.5m wave in the Valdez Hotel.