國立中央大學 National Central University

水文與海洋科學研究所 Institute of Hydrological and Oceanic Sciences

ASGC TWGrid

A New Moving-Solid Algorithm for Landslide Tsunami and Boulder Movement

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Tsunami Science Laboratory

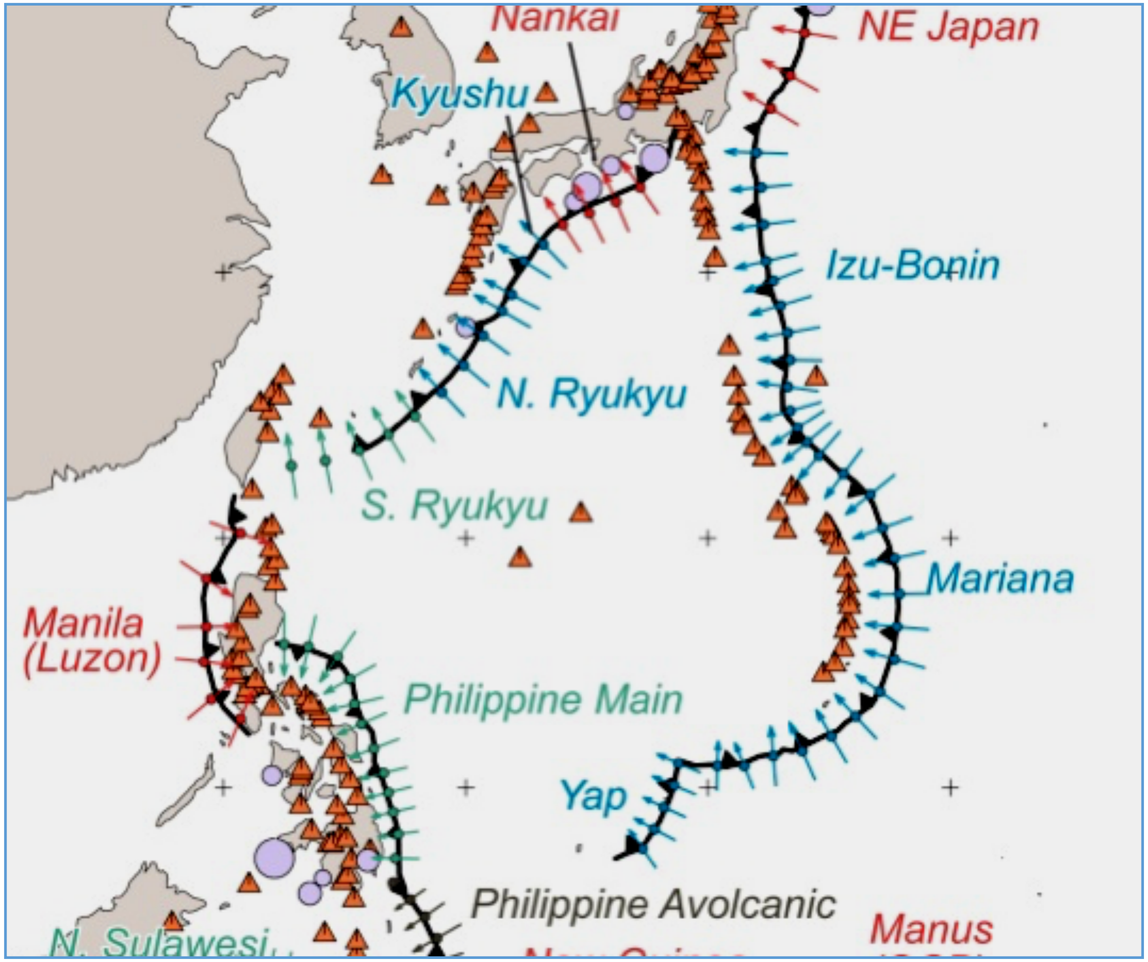
海 嘯 科 學 研 究 室

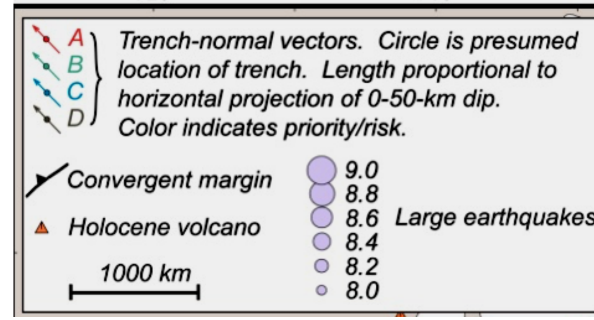
TSUNAMI SCIENCE LABORATORY

ABSTRACT

In this presentation, we will present our recent research results on the potential tsunami hazard in the South China Sea and the Philippine Sea. The methodology in determining the fault parameters, such as the fault plane area, length, width, dislocation, and asperity, along the Manila subduction zone is first discussed. Numerical simulations of tsunami generation, propagation and inundation, based on several scenario earthquakes, are conducted to assess potential tsunami hazard in the region. Our results show that the potential tsunamis, generated along the Manila Trench, would mainly affect the west coast of Luzon Island, the East coast of Vietnam, the South of Taiwan, Hong Kong, and the south coast of Mainland China.

For the purpose of establishing a tsunami warning system in the region, a numerical algorithm is also developed to determine the most effective locations for deploying deep ocean pressure sensors. Finally, a newly developed Impact Intensity Analysis (IIA) method will be presented. This method is used to identify the locations of tsunami source that could generate tsunamis affecting the study site. One of the important applications of the IIA method is for mitigating tsunami hazard affecting coastal nuclear power plants. It is also a useful tool for locating the tsunami source of historical and paleo tsunamis. Validation and demonstration of the IIA method will be presented for the 1867 Keelung tsunami event in Taiwan, since 3 nuclear power plants are located nearby.



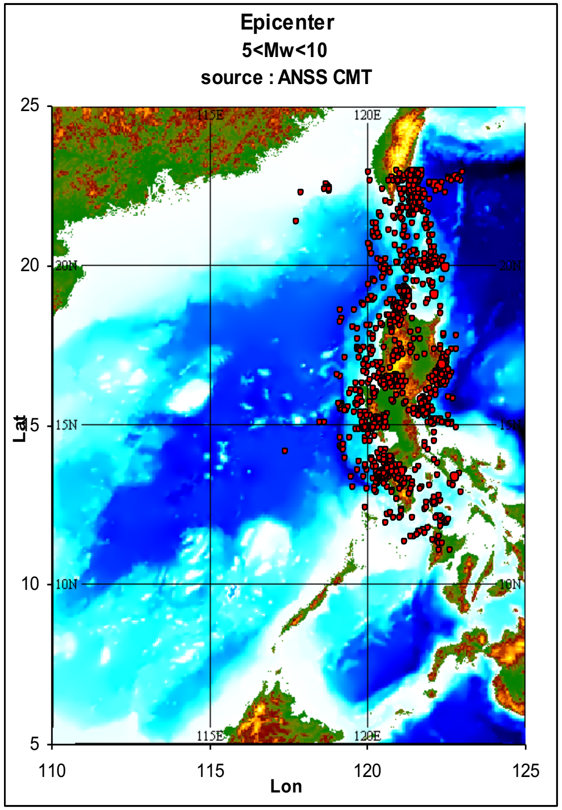


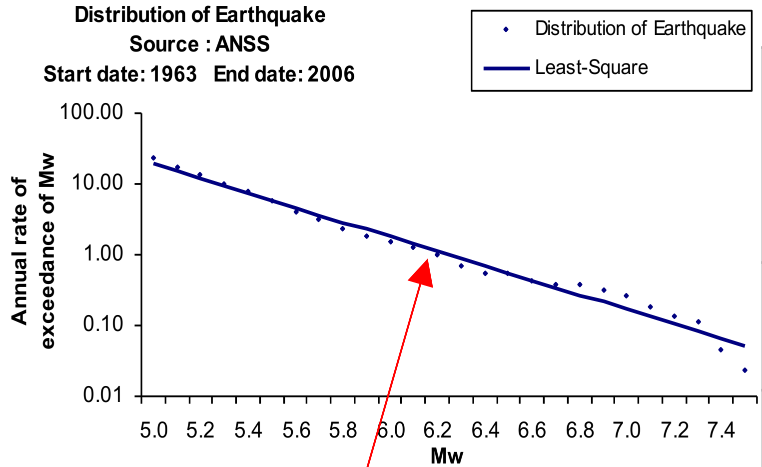
Tsunami Source Characterization for Western Pacific Subduction Zones: A Preliminary Report
USGS1 Tsunami Subduction Source Working Group

BOTTOM LINE
Hazard appraisal key:
A: High
B: Intermediate
C: Low
D: Not classified

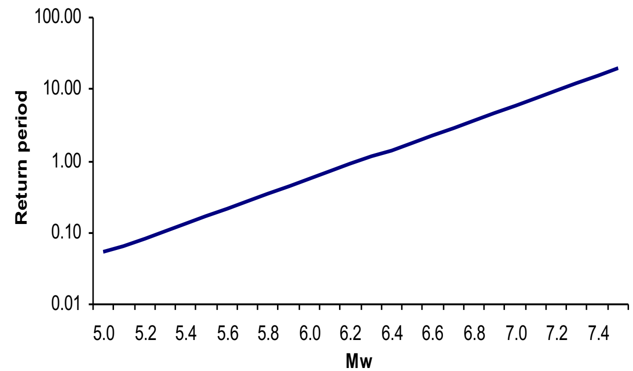
Recently the USGS issued a report assessing the potential risk as a tsunami source along the entire Pacific seduction zones. One highly risk zone is identified along the Manila (Luzon) trench, where the Eurasian plate is actively subducting eastward underneath the Luzon volcanic arc on the Philippine Sea plate.

Estimation of Return period





$$\log N = 6.410 - 1.026M$$

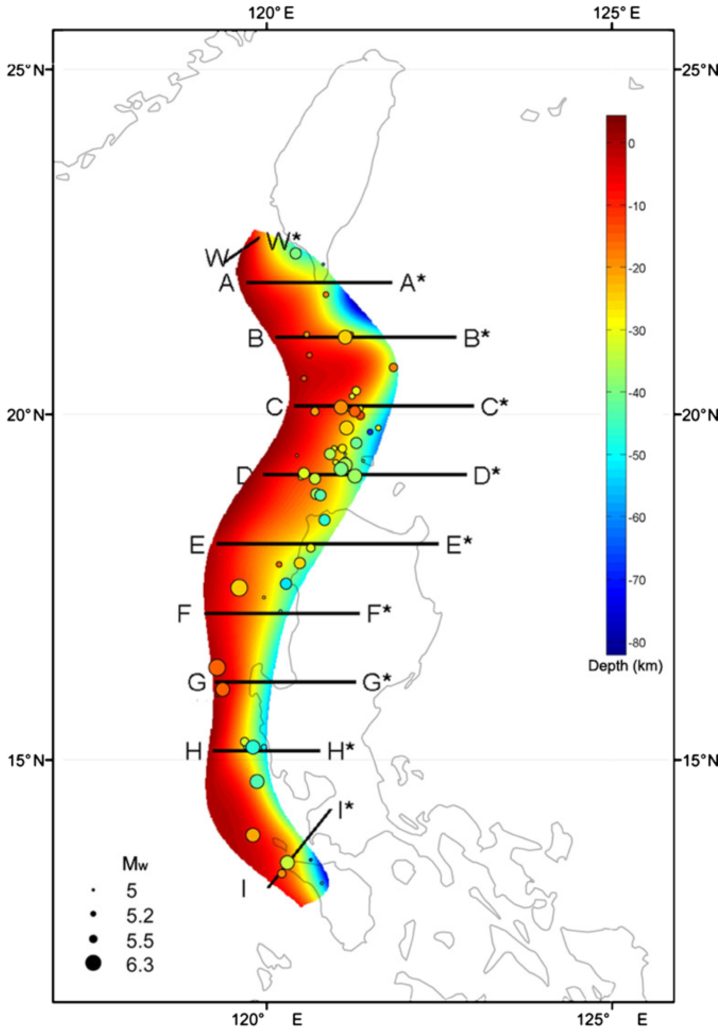


Mw	Return Period (year)
7.0	6
7.5	19
8.0	63
8.5	205
9.0	667

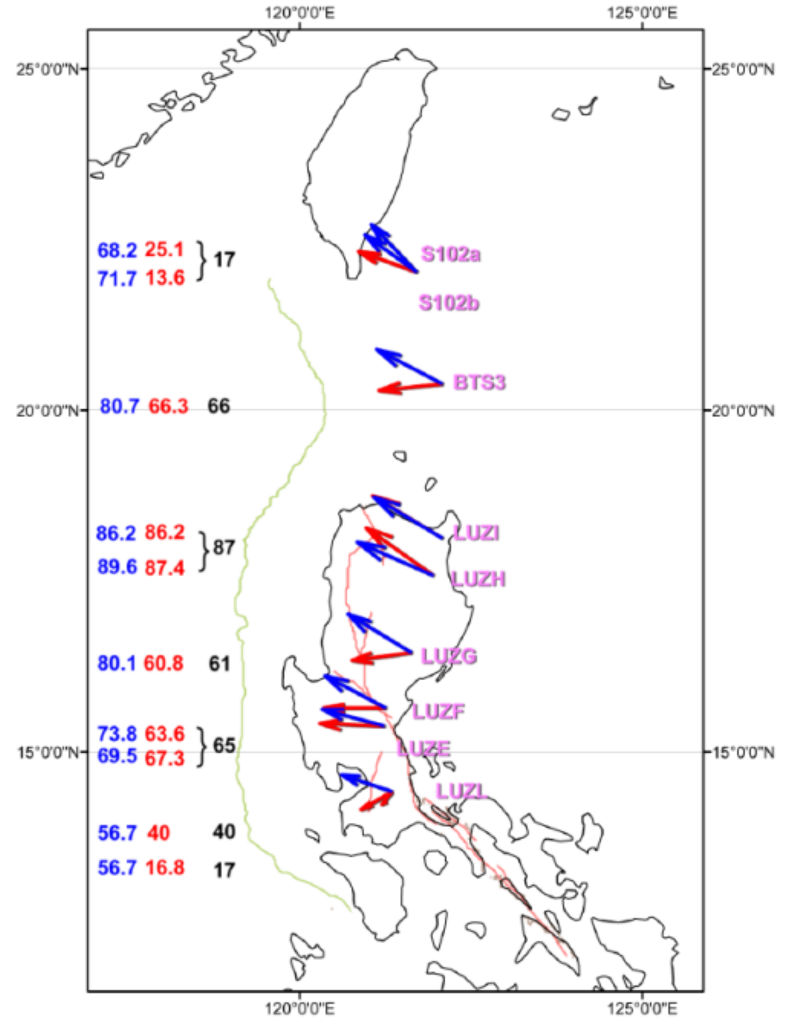
Source:ANSS 1963-2006

It is significant that since the Spanish colonization of Luzon in the 1560s, no earthquake exceeding magnitude 7.8 has been observed (Repetti, 1946). Conservatively, it can be postulated that very large events on this Megathrust have a recurrence interval exceeding 440 years. Taking a trench-normal convergence velocity of 87 mm/yr, strain of ~38 m would range of plausible scenarios. It is comparable to the 1960 Mw 9.5 Chilean earthquake, in which coseismic slip reached 40 m (Barrientos and Ward, 1990), and larger than 2004 Aceh-Andaman event, which produced 20 m of coseismic slip (Chlieh et al., 2007).

Anat Ruangrassamee (2007)

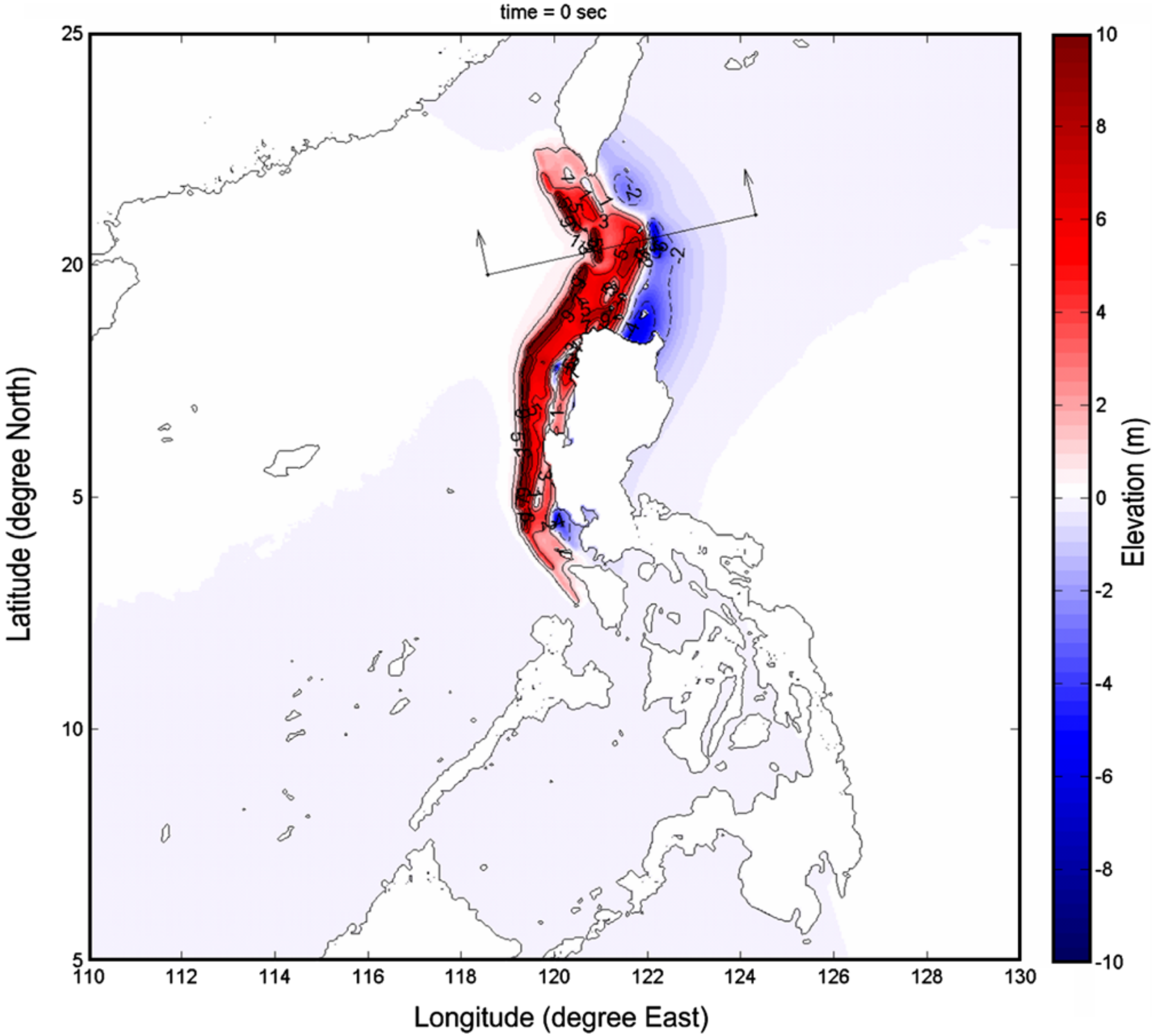


The sinuous rupture interface of the South China Sea megathrust, together with ten seismic cross sections between latitude 12.5N and 23.5N from the studies by Bautista et al. (2001) and Wu et al. (2007). Epicenters of thrust-faulting earthquakes are plotted to mark the downdip boundary of the rupture interface.



GPS data (Yu et al., 1999) indicating motion of the converging Eurasian Plate and the Philippines Sea Plate, where the blue arrows and numbers show raw velocity values (mm/yr) taken from Yu et al. (1999), the red arrow and numbers indicate velocity values (mm/yr) resolved in the direction perpendicular to the trench front, and the black numbers give the rounded values (mm/yr) used for slip estimation.

(Megawati et at., 2009)


time = 0 sec
Latitude (degree North)
Longitude (degree East)
Elevation (m)
110
112
114
116
118
120
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8
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-2
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-6
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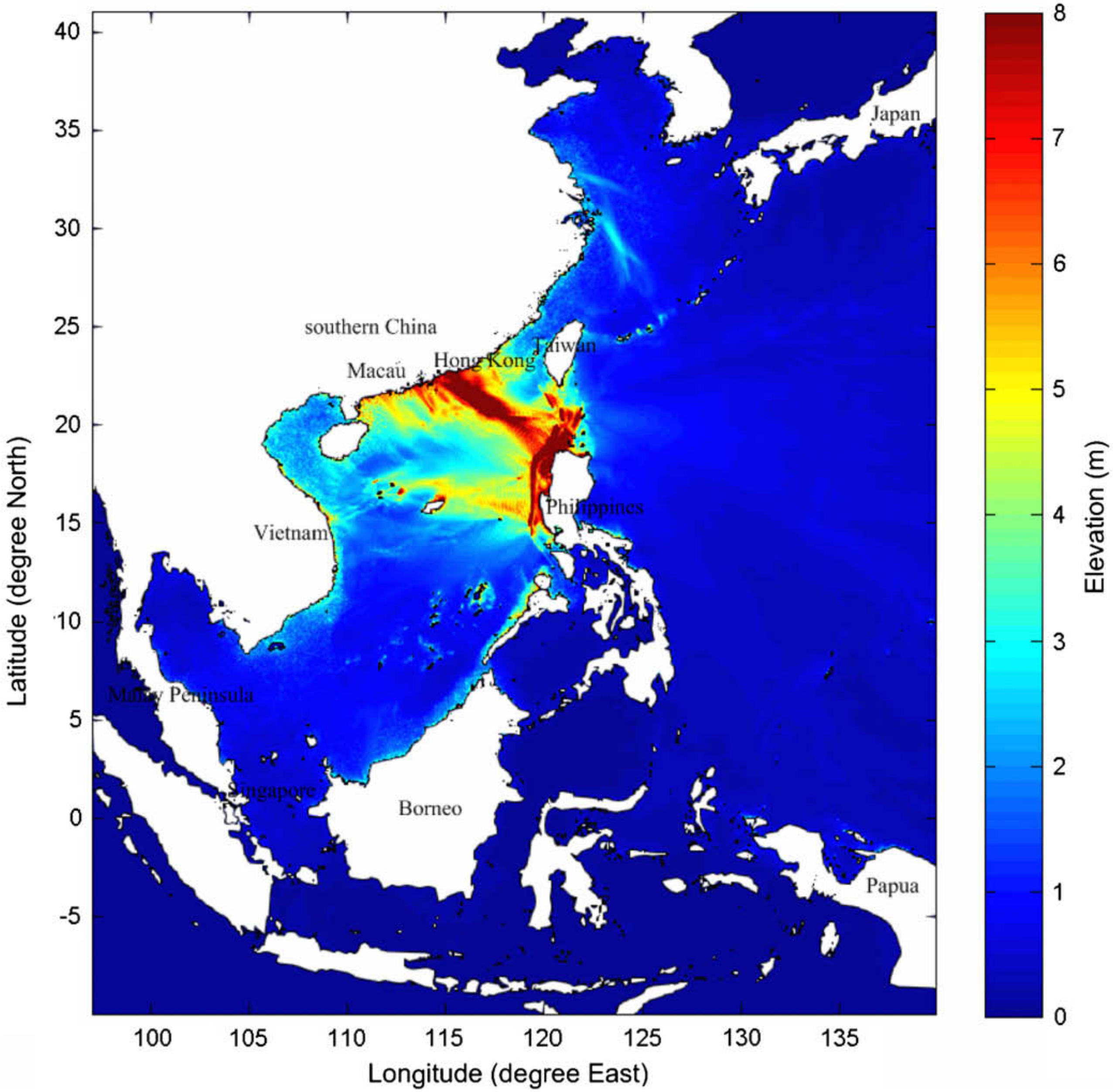
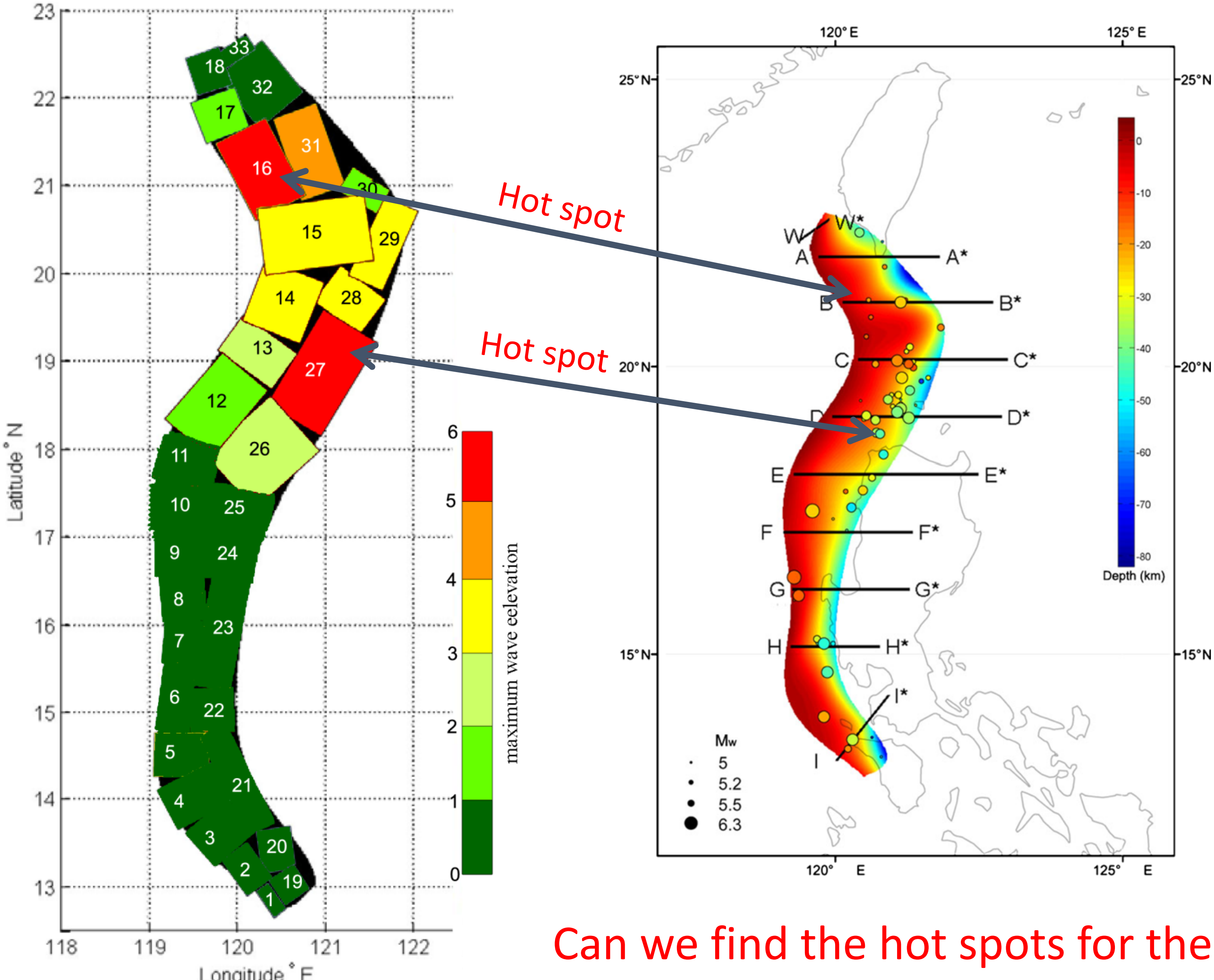
-10

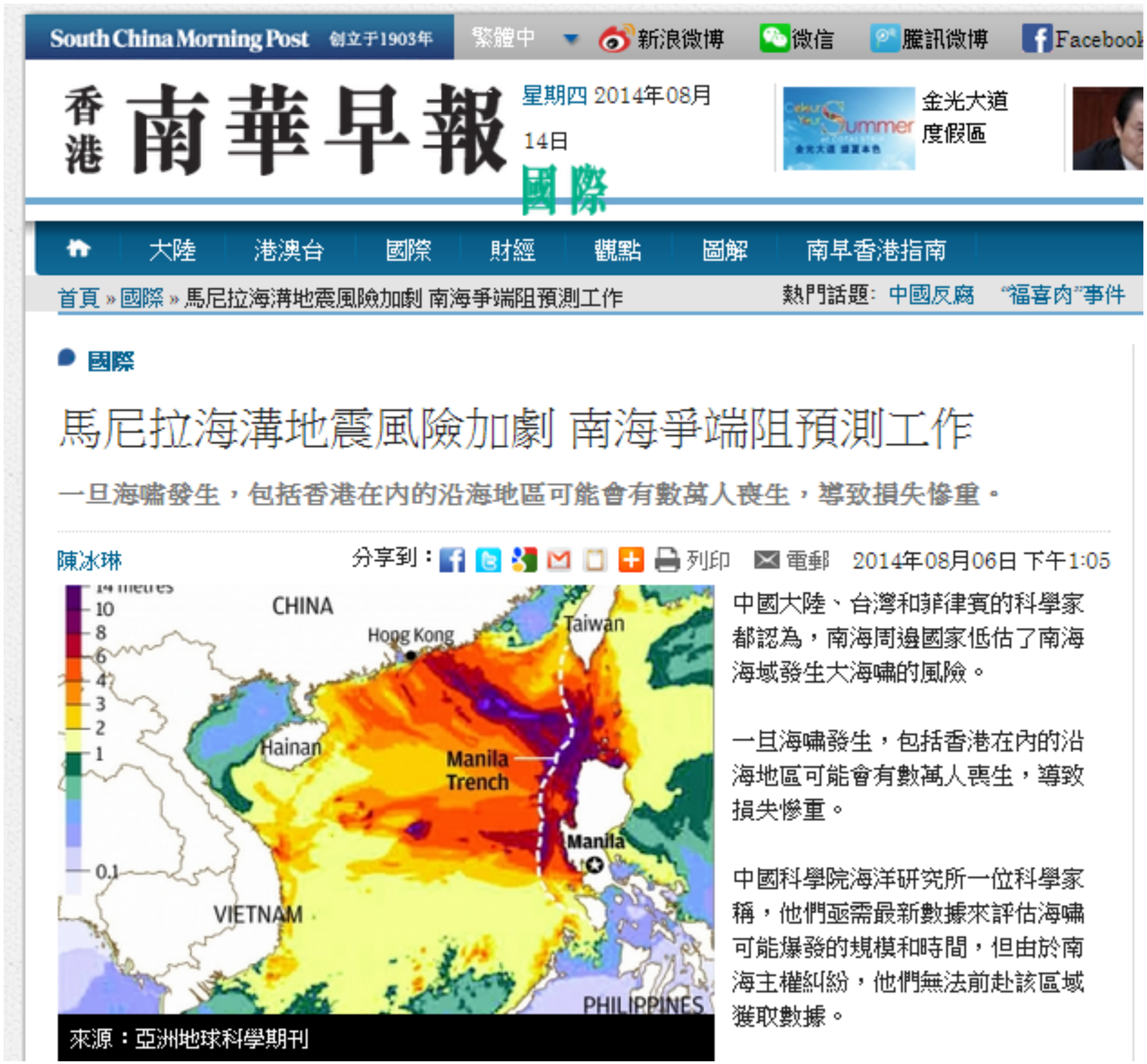


Japan
southern China
Taiwan
Hong Kong
Macau
Philippines
Vietnam
Malay Peninsula
Singapore
Borneo
Papua
Latitude (degree North)
Longitude (degree East)
Elevation (m)



Can we find the hot spots for the study site systematically?

News Report:



South China Morning Post 创立于1903年 繁體中 新浪微博 微信 騰訊微博 Facebook

香港 南華早報 星期四 2014年08月14日 國際

金光大道度假區

大陸 港澳台 國際 財經 觀點 圖解 南早香港指南

首頁 » 國際 » 馬尼拉海溝地震風險加劇 南海爭端阻預測工作　熱門話題: 中國反腐 "福喜肉"事件

國際

馬尼拉海溝地震風險加劇 南海爭端阻預測工作

一旦海嘯發生，包括香港在內的沿海地區可能會有數萬人喪生，導致損失慘重。

陳冰琳　分享到： 列印 電郵 2014年08月06日 下午1:05

來源：亞洲地球科學期刊

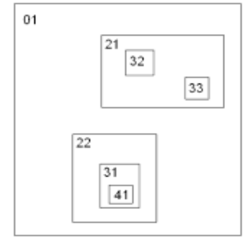
中國大陸、台灣和菲律賓的科學家都認為，南海周邊國家低估了南海海域發生大海嘯的風險。

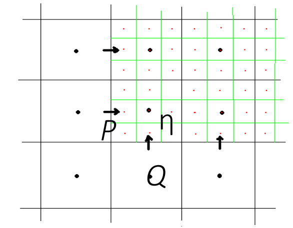
一旦海嘯發生，包括香港在內的沿海地區可能會有數萬人喪生，導致損失慘重。

中國科學院海洋研究所一位科學家稱，他們亟需最新數據來評估海嘯可能爆發的規模和時間，但由於南海主權糾紛，他們無法前赴該區域獲取數據。

Tsunami Model: COMCOT

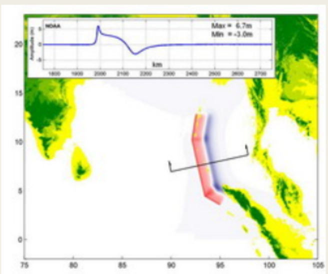
(Cornell Multi-grid Coupled Tsunami Model)



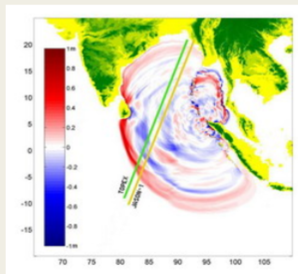


- Capable of simulating the entire lifespan of a tsunami, from its generation, propagation and runup/rundown on coastal regions
- A numerical model which solves nonlinear shallow water equation (SWE).
- On both/either Spherical or Cartesian coordinate system.
- Using nested grid to solve multi-scale problems.
- **Moving-boundary for inundation calculation**
- Parallelized
- THANKS, Dr. Xiaoming WANG

COMCOT: A Tsunami Modeling Package



Tsunami Generation



Tsunami Propagation

COMCOT (Cornell Multi-grid Coupled Tsunami Model) is a tsunami modeling package, capable of simulating the entire lifespan of a tsunami, from its generation, propagation and runup/rundown in coastal regions.

- **Governing Equations**

COMCOT was developed based on Shallow Water Equations (SWE) in Spherical Coordinates (*Eq.01*) and Cartesian Coordinates (*Eq.02*). In the equations, ζ denotes free surface elevation; P and Q are volume flux in x and y direction ($P=hu$, $Q=hv$); φ and ψ stand for longitude and latitude, respectively.

$$\frac{\partial \zeta}{\partial t}+\frac{1}{R\cos\varphi}\left[\frac{\partial P}{\partial \psi}+\frac{\partial}{\partial \varphi}(\cos\varphi Q)\right]=0$$

$$\frac{\partial P}{\partial t}+\frac{gh}{R\cos\varphi}\frac{\partial \zeta}{\partial \psi}-fQ=0$$

$$\frac{\partial Q}{\partial t}+\frac{gh}{R}\frac{\partial \zeta}{\partial \varphi}+fP=0$$

$$\frac{\partial \zeta}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}=0$$

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{H}\right)+\frac{\partial}{\partial y}\left(\frac{PQ}{H}\right)+gH\frac{\partial \zeta}{\partial x}+\frac{\tau_x H}{\rho}=0$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{PQ}{H}\right)+\frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right)+gH\frac{\partial \zeta}{\partial y}+\frac{\tau_y H}{\rho}=0$$

Eq.01 SWE in Spherical Coord. *Eq.02 SWE in Cartesian Coord.*

- **Moving Boundary Scheme**

Moving boundary scheme was also introduced in COMCOT to model the run-up and run-down. The instant "shoreline" is defined as the interface between a dry grid and wet grid and volume flux normal to the interface is assigned to zero.

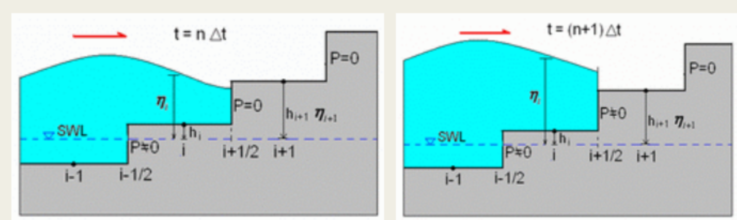
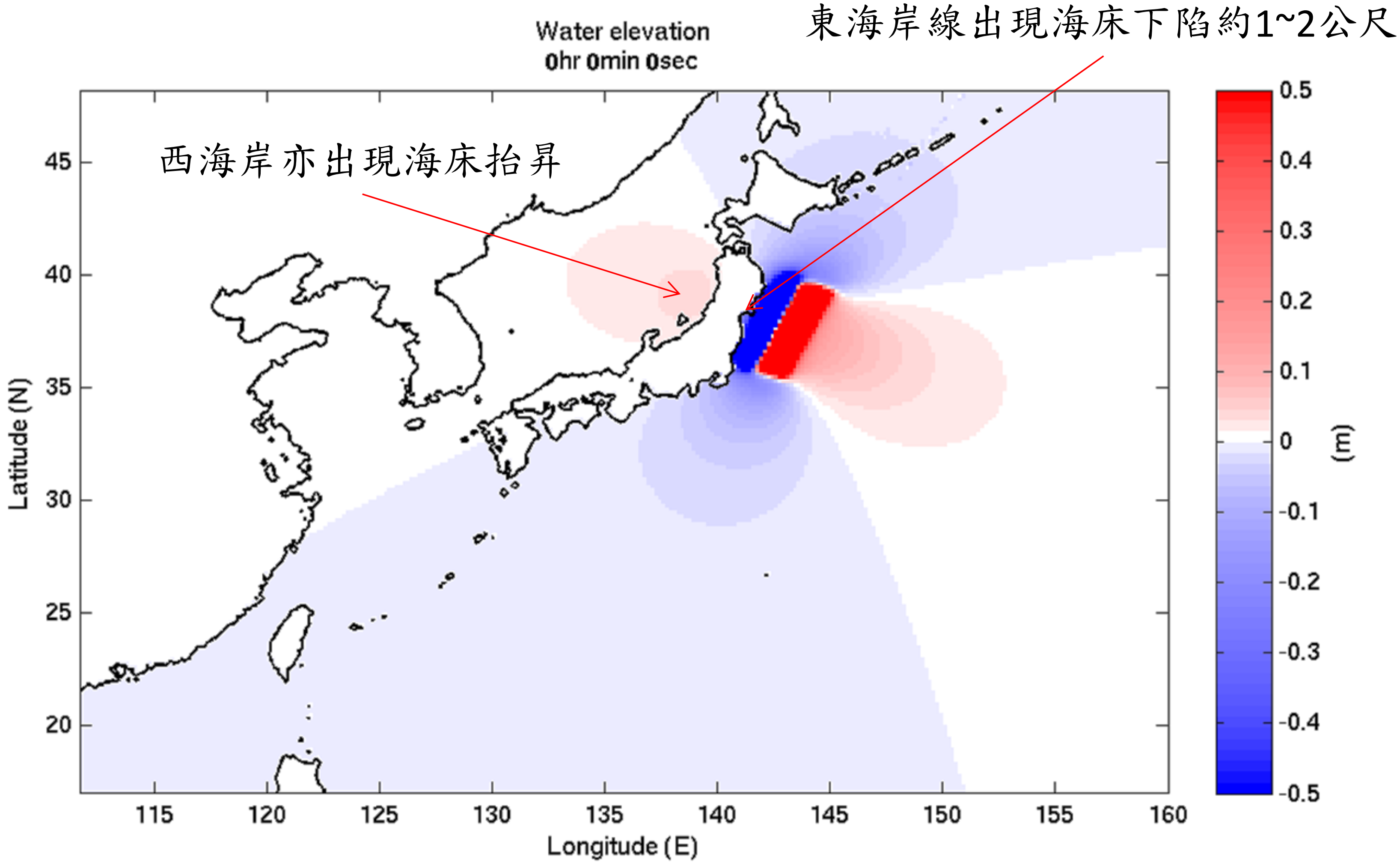


Fig.02 Moving Boundary Scheme

2011 Tōhoku earthquake and tsunami

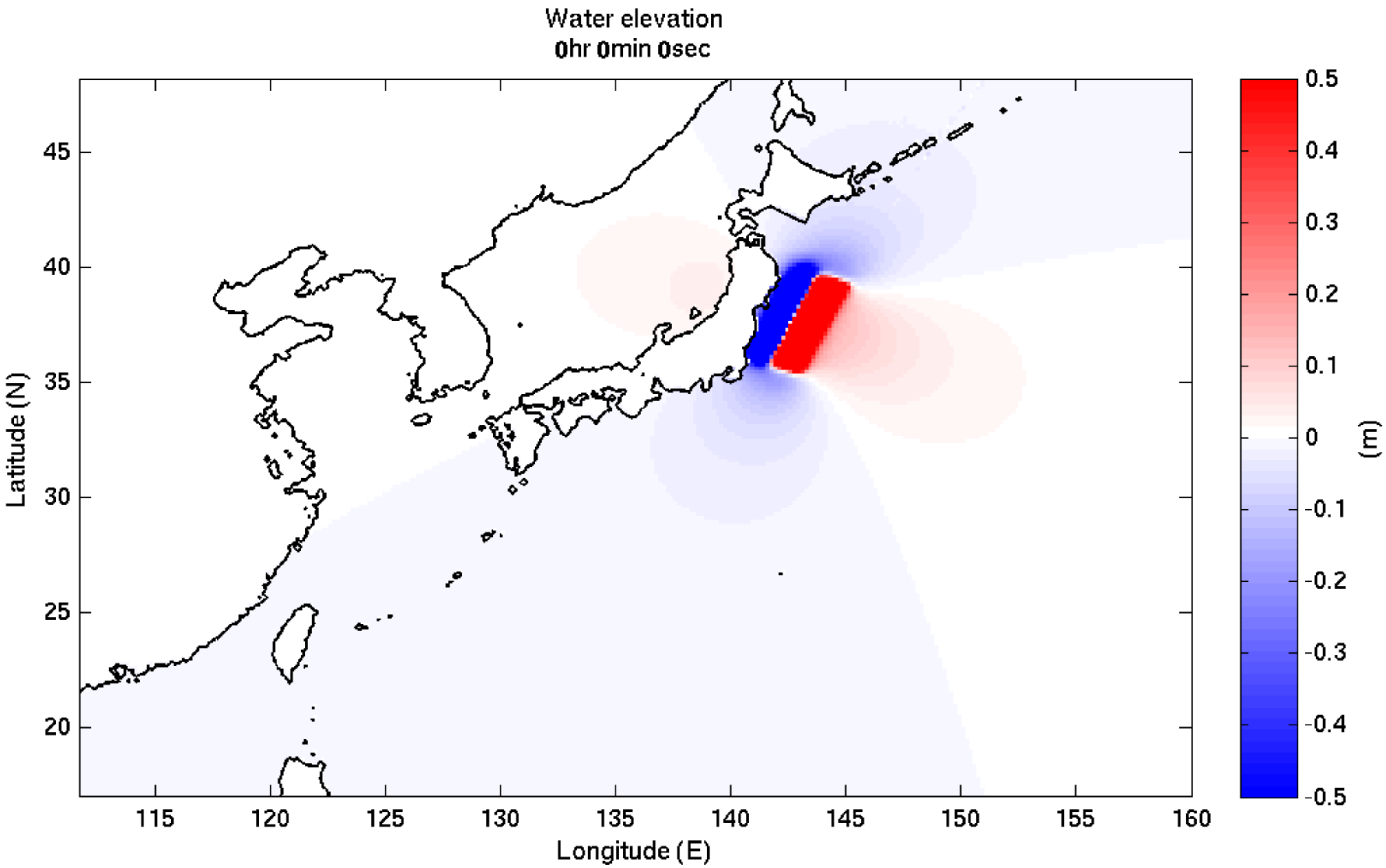
- We spent about 20 minutes to prepare, or wait for, the fault parameters
- COMCOT spent about 1 min to finish the tsunami simulation from Japan to Taiwan.
- It is about real-time simulation
- COMCOT predicted that the tsunami wave height was about 12 cm offshore Taiwan.
- Field data also showed 12 cm.

Initial Free-Surface of 311 Japan Tsunami Event

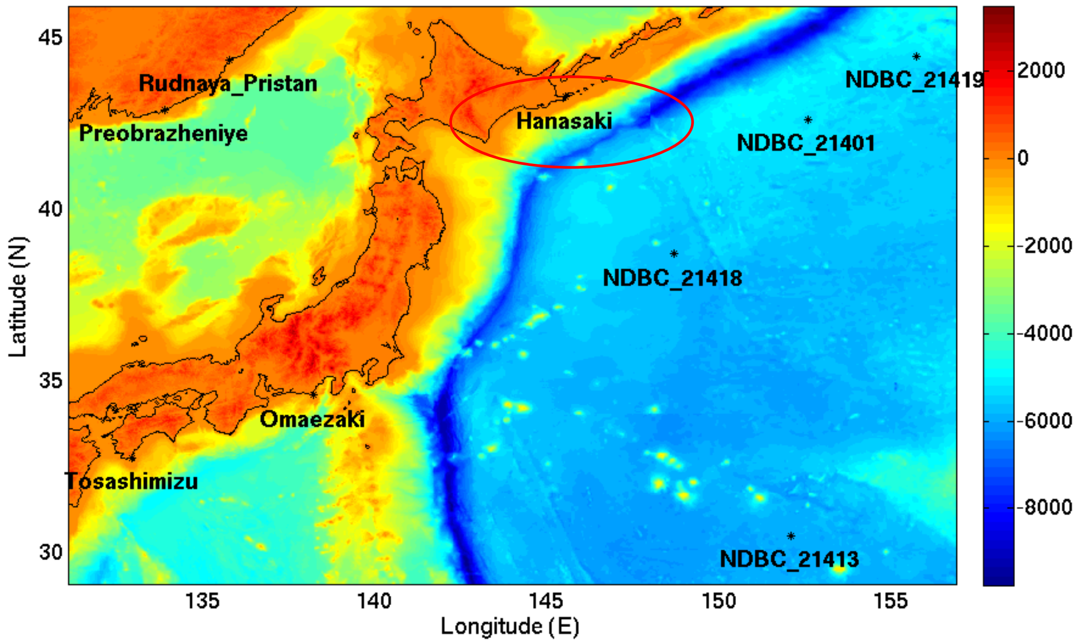


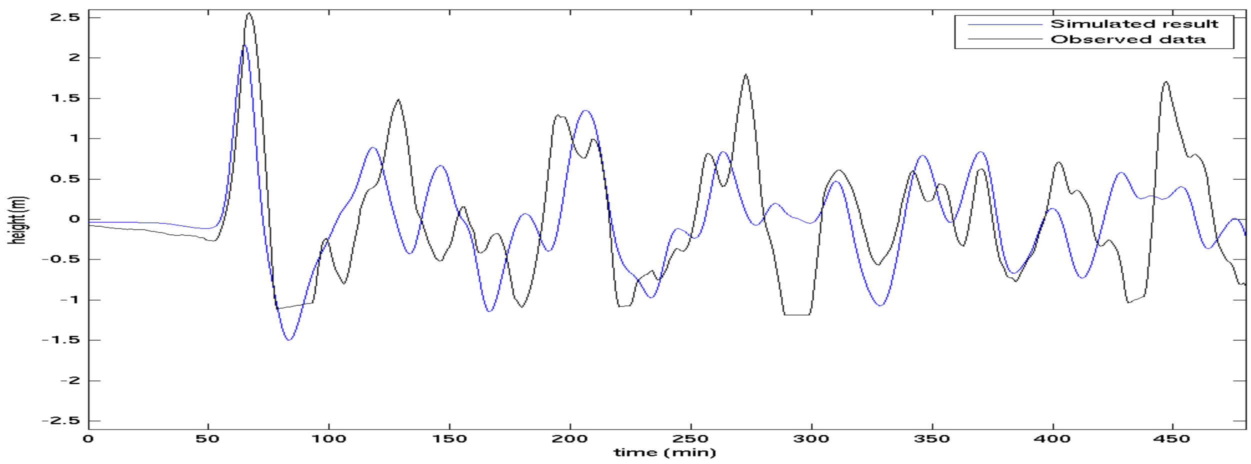
模式預測海床抬昇量為4.5公尺，與實際觀測之5公尺相當接近。

Animation of Tsunami Propagation



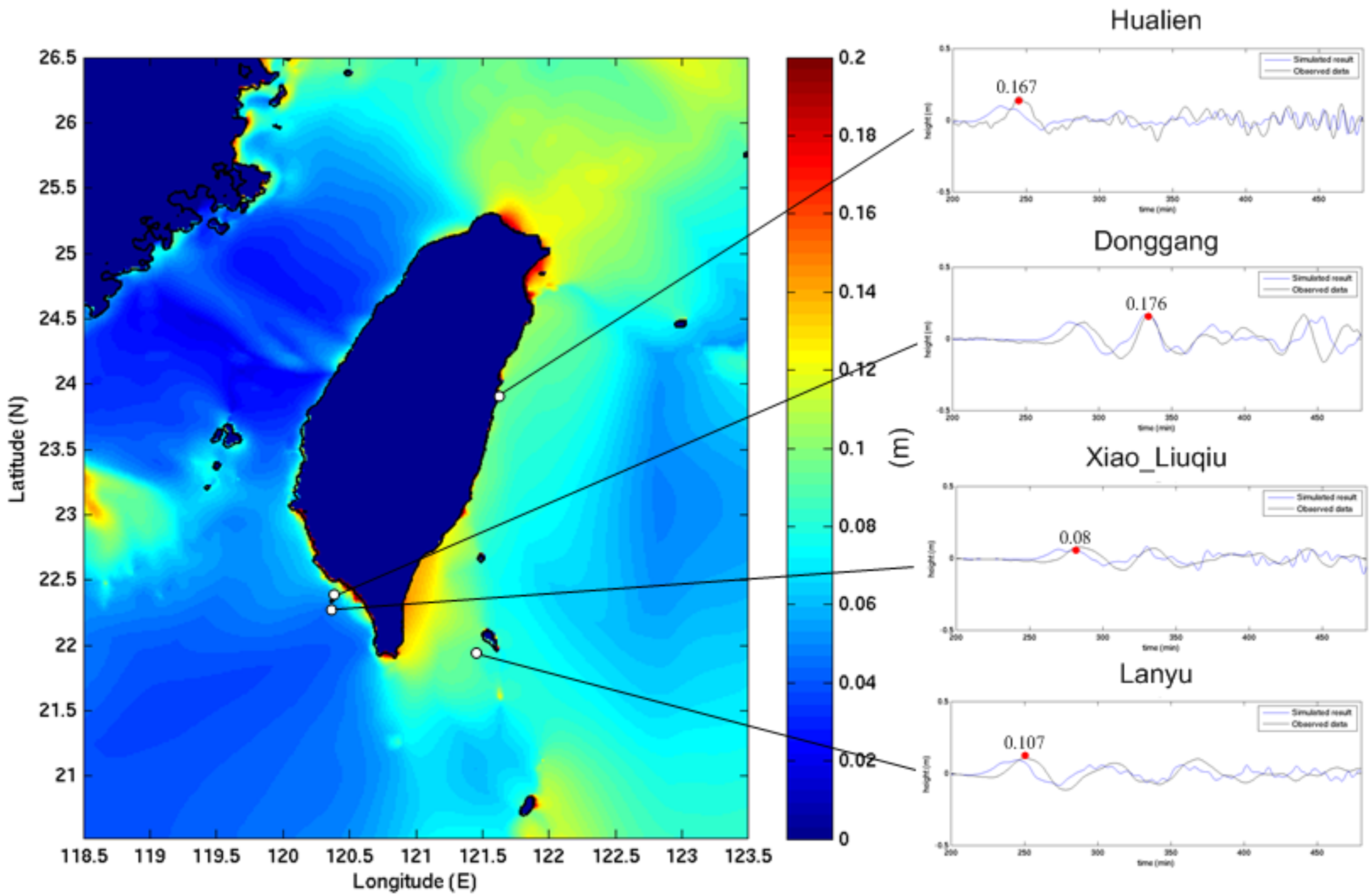
模式預測之海嘯波高與日本潮位站實測比對：Hanasaki





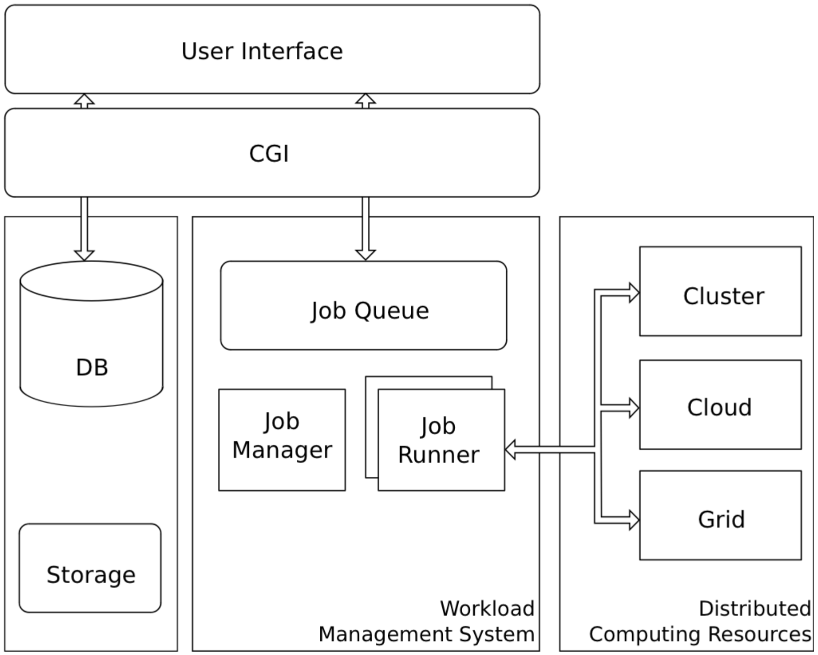
Hanasaki 潮位站比對，藍線為模擬結果，黑線為實測資料。該站位於斜坡部分，模擬結果與實測比對相當一致。

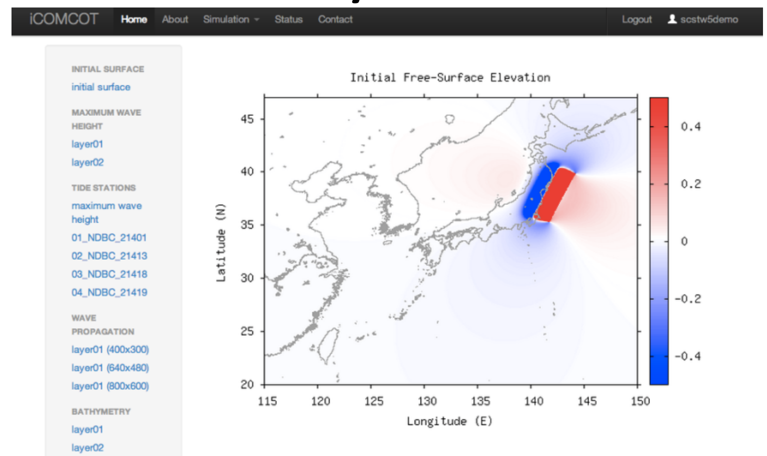
模式預測之海嘯波高中央氣象局潮位站資料比對

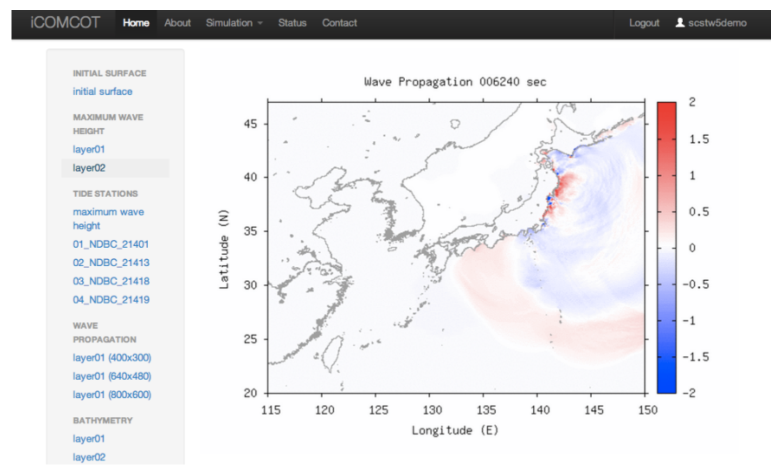


台灣測站比對。比對花蓮、東港、小琉球、蘭嶼四個測站，結果相當理想。（藍線為模擬結果，黑線為實測資料，資料提供：中央氣象局）

iCOMCOT:
a grid/cloud-based Tsunami system







在中研院網格中心協助下，將COMCOT模式提昇為雲端系統，以利其他國家之海嘯災防

(1) 2012 Invited Speech at UNESCO
(2) Interviewed by isgtw, London, UK

http://www.isgtw.org/feature/forecasting-wrath-tsunami

isgtw international science grid this week

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Forecasting the wrath of a tsunami

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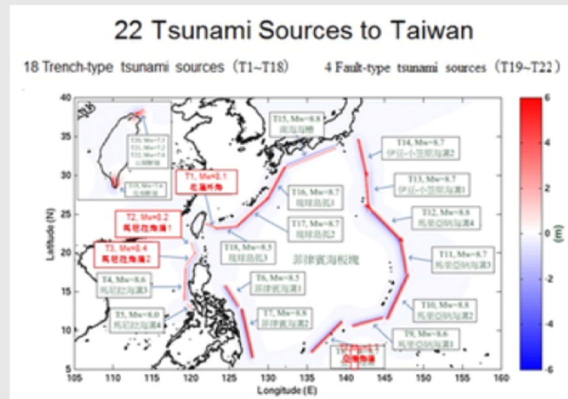
FEATURE | APRIL 24, 2013 | BY ZARA QADIR

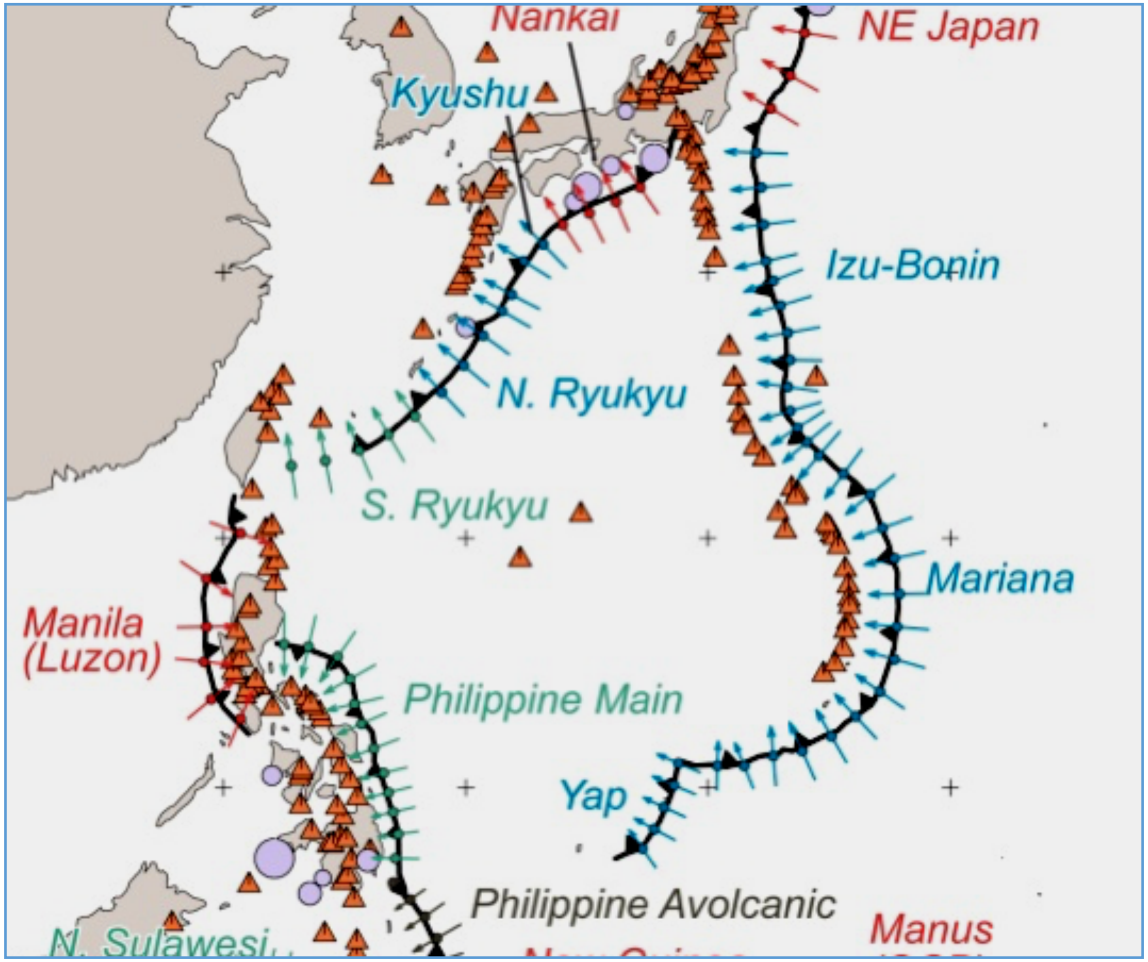
mmediately to the south-west of Taiwan, is the South China Sea and the deep oceanic Manila trench. Roughly every 10 years, the area experiences a moderate earthquake (under 6.9 on the Richter scale). However, there has not been a major earthquake since the 1570s. GPS data and global historical records show that every 700 years an earthquake of magnitude 9.0 is likely to strike the area. The region, therefore, is due one relatively soon (in terms of geological time frames) and if (or *when*) a mega-sized one does strike, people living in the

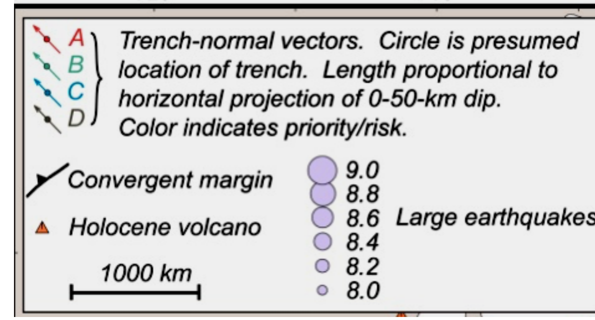


The spatial distribution of 18 trench-typed tsunami sources (T1-T-18) and 4 fault-typed tsunami sources (T19-T-22). The color bar indicates the seafloor displacement of each tsunami source.Click for large version. Image courtesy Simon Lin, ASGC, from Tso-Ren Wu's paper.

COMCOT (Cornell Multi-grid Coupled Tsunami Model) is a numerical model that allows both simulation and visualization of the whole lifespan of a tsunami. It shows how a wave will travel on the earth and gives an estimate of its arrival time and the level of run up on to dry land. "The original research model focuses on accuracy and not speed; it took between 12 to 24 hours to generate a result. But for the system to be operational, COMCOT needed to simulate a tsunami as fast as real time propagation, from hours to minutes," says Wu.

Usually an operational system sacrifices some level of accuracy, but COMCOT allows both linear and non-linear equations. "A linear system speeds up the operation and is accurate for the deep ocean, but is not precise enough for the near-shore region. When the wave approaches the shoreline its speed diminishes, and it becomes thinner and taller so the curve can no longer be represented linearly. Most tsunami systems ignore this part of the simulation but it is the most important to impact on human life," explains Wu. COMCOT integrates the spherical with a Cartesian coordinate system, which is more accurate for near shore simulations.





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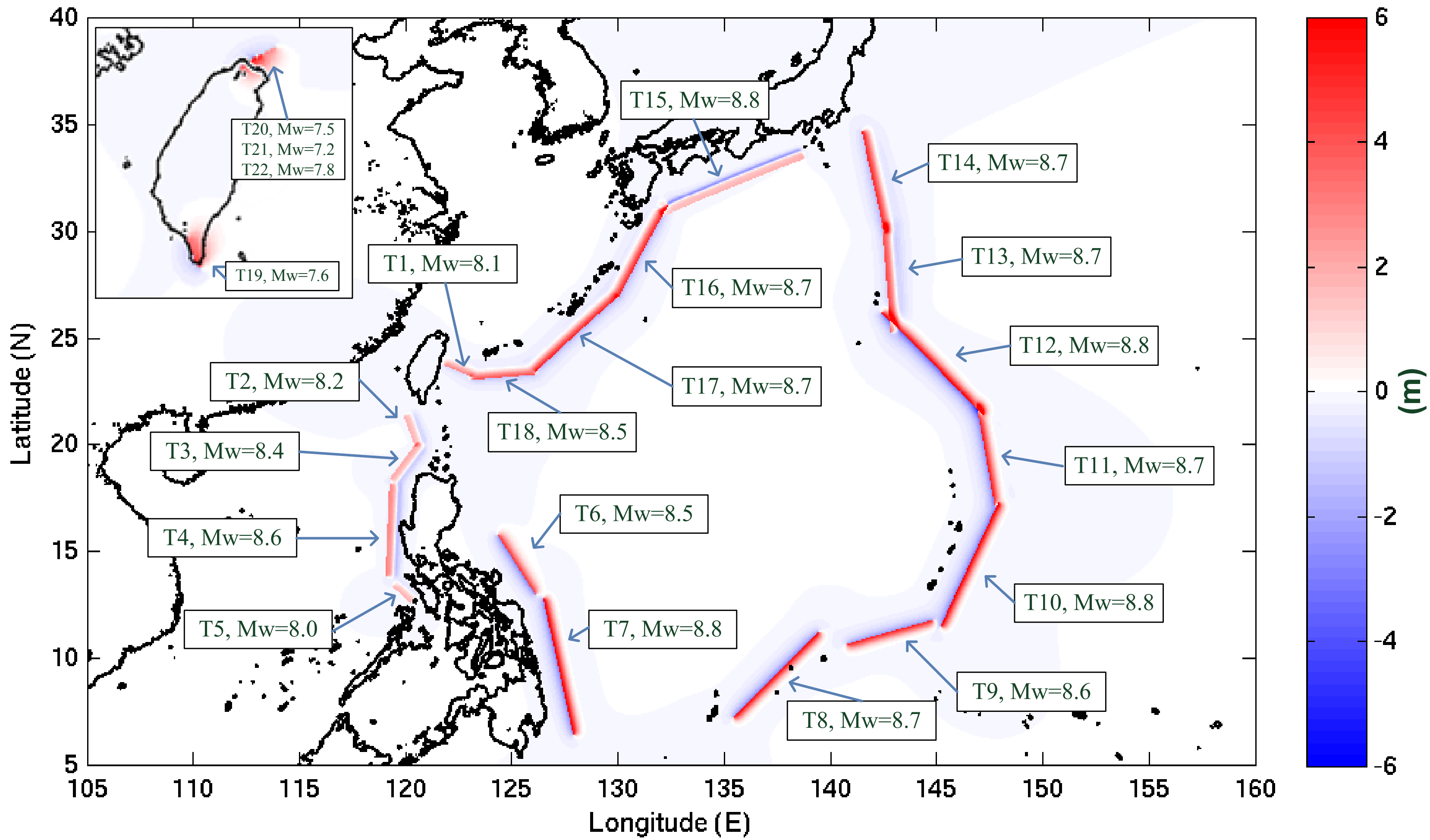
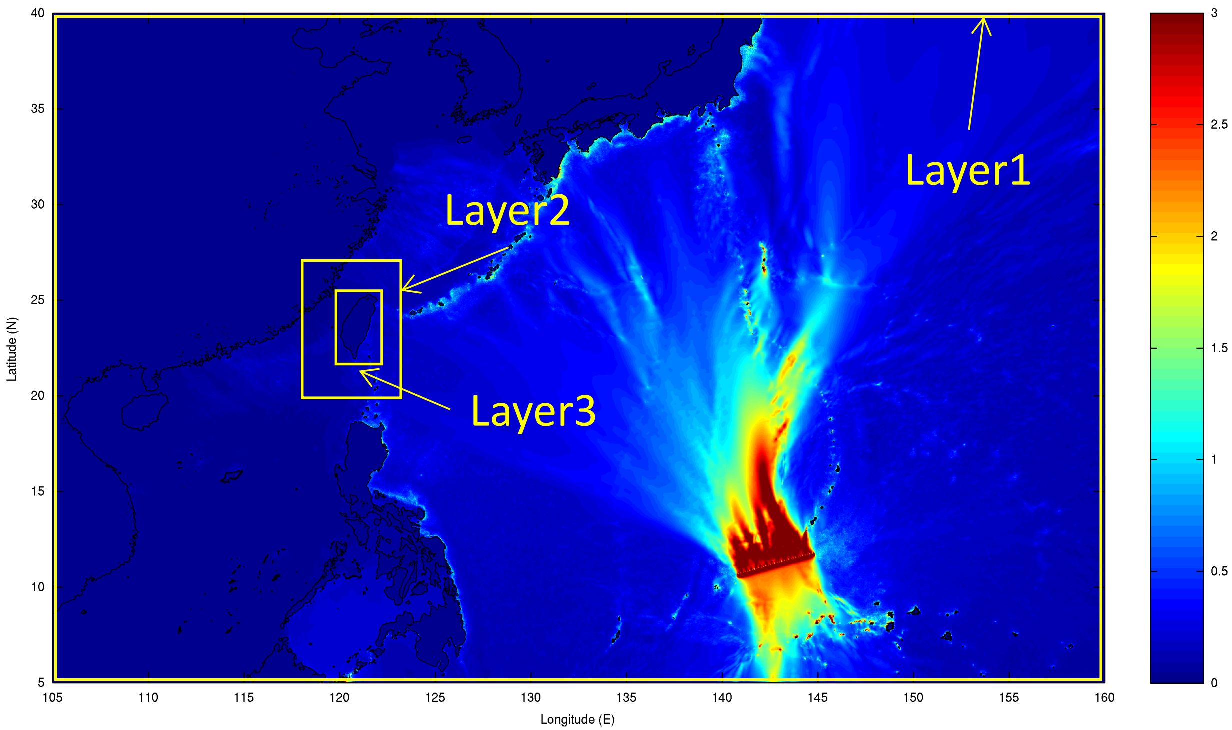
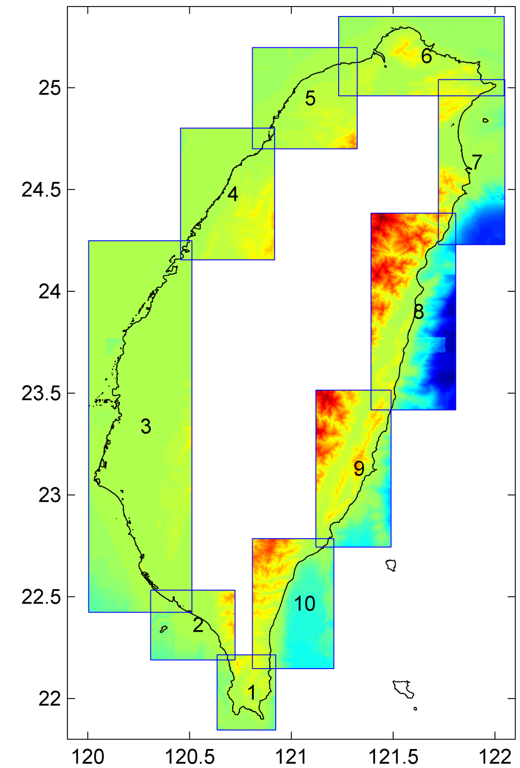
Tsunami Sources of 18 Trench and 4 Fault Segments

18 Trench-type tsunami sources（T1~T18） 4 Fault-type tsunami sources（T19~T22）



Nested Grids





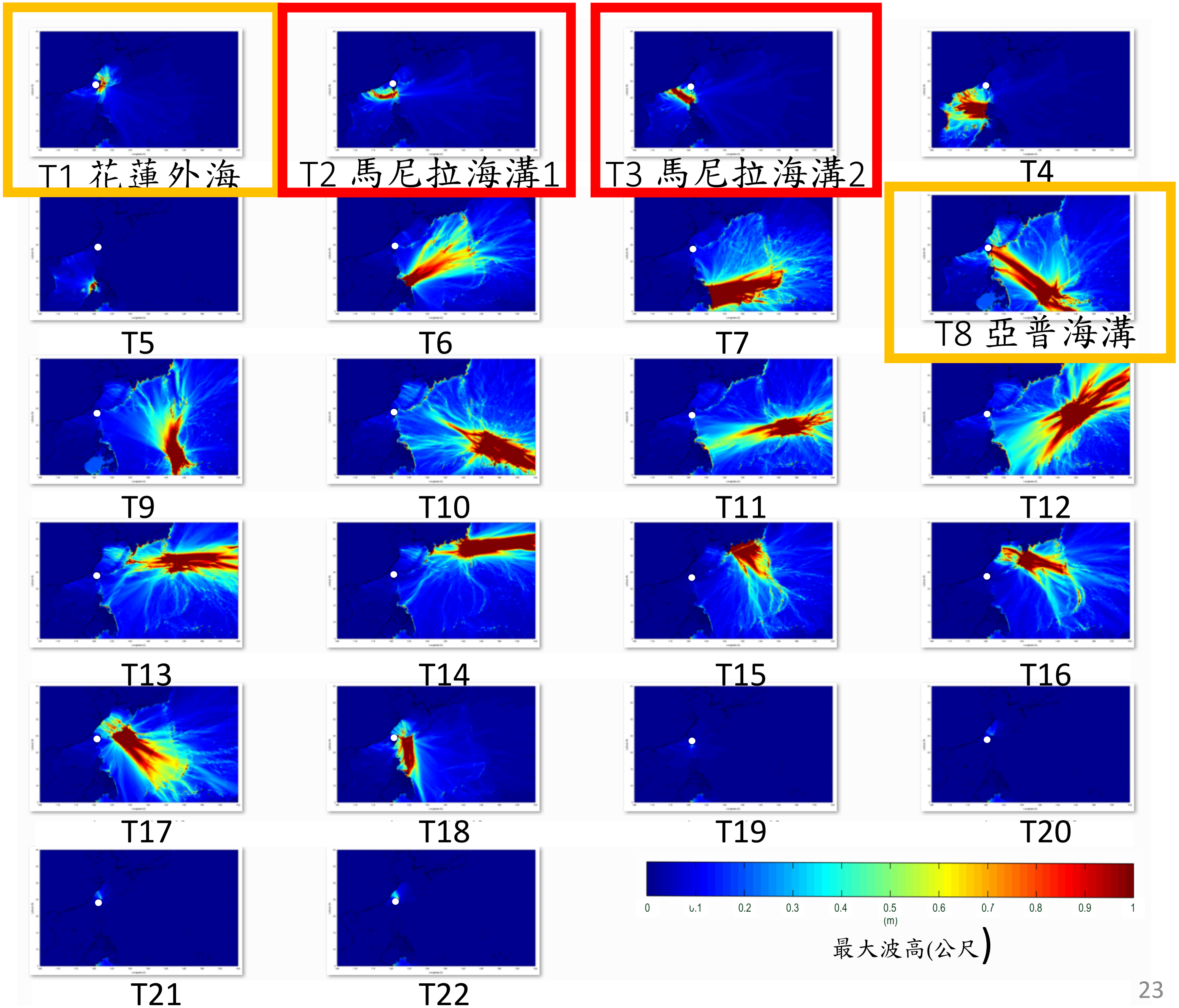
Layer 1: 2 min (~3500m);
Layer 2: ½ min (~900m);
Layer 3: 1/8 min (~200m);
Layer 4: 1/128 min (~50m);
Layer 5: 1/512 min (~10m);
Layer 6: 1/2048 min (~2m);

Source of Bathymetry

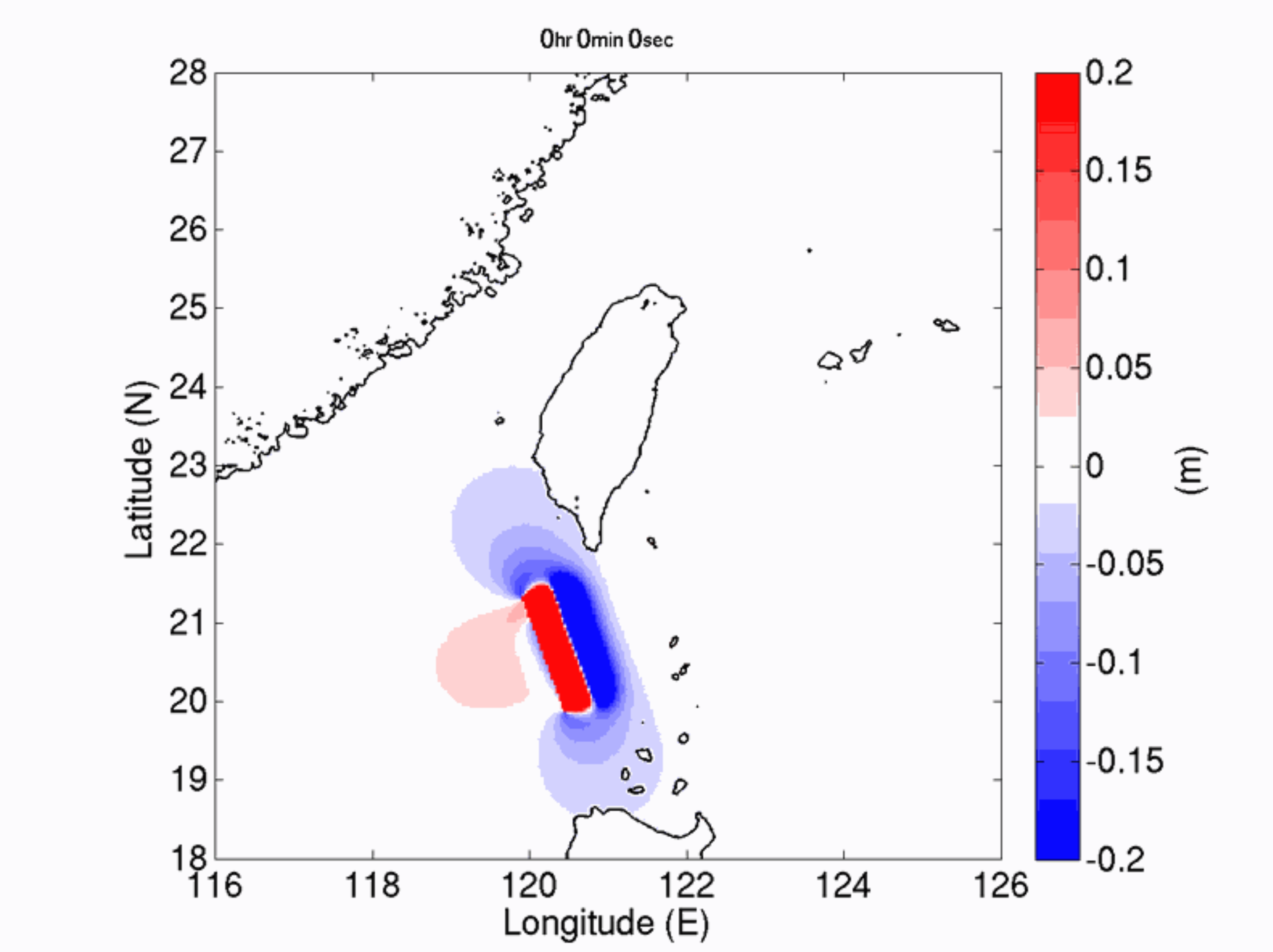
- **ETOTO2:** (2 arc min)
- http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html，
- **GEBCO:** (0.5 arc min)
- http://www.gebco.net/data_and_products/gridded_bathymetry_data/。
- **NAVY**
- **NCU:** 40m DEM。
- **National Land Surveying and Mapping Center: 10m DEM**
- **Tai Power: 1m DEM**

Tsunami Sources of 18 Trench Segments

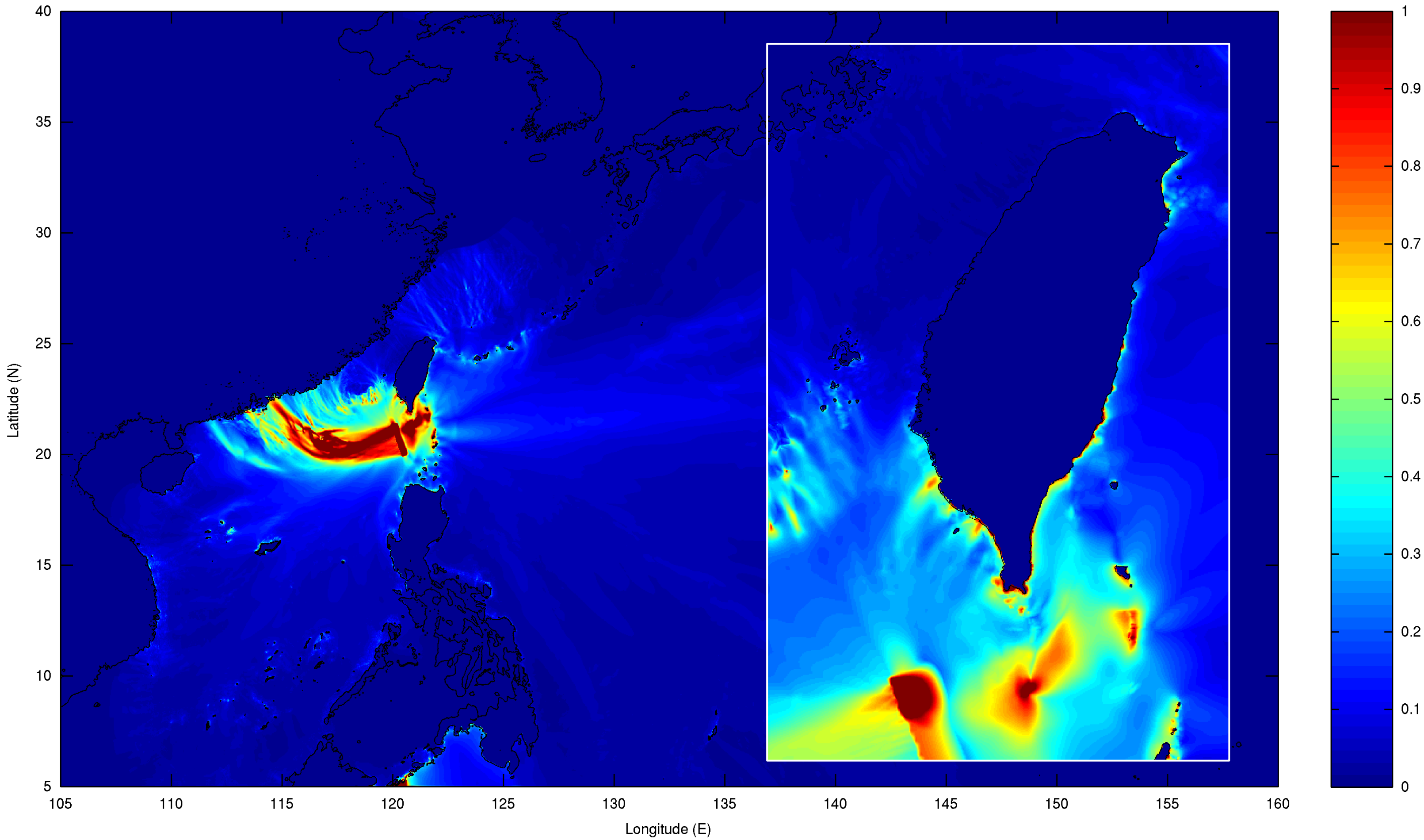
Taiwan has to be aware of the tsunamis from T1, T2, T3, and T8



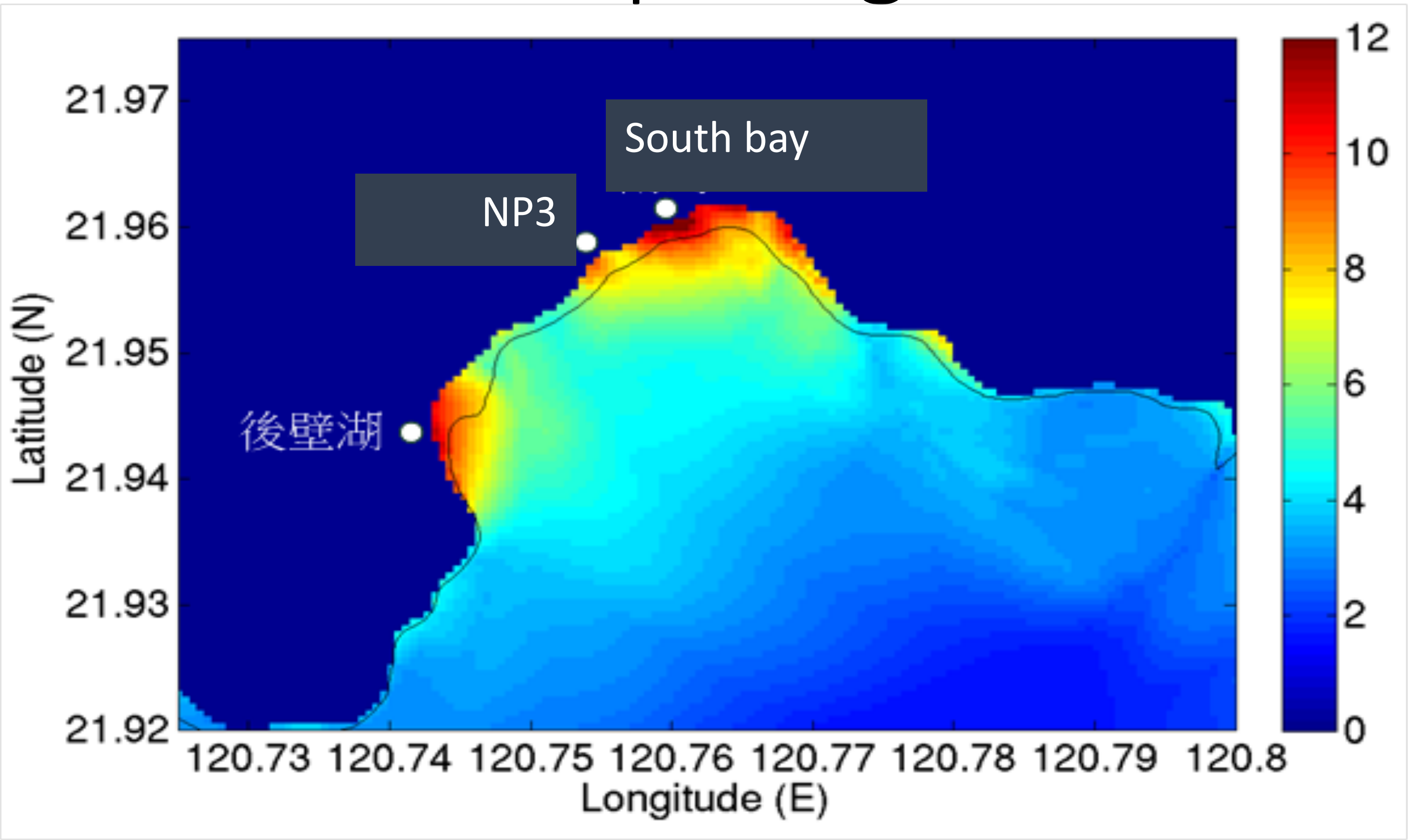
T2 (Manila Trench 1) (Animation)



T02, Inundation and Maximum Runup Height



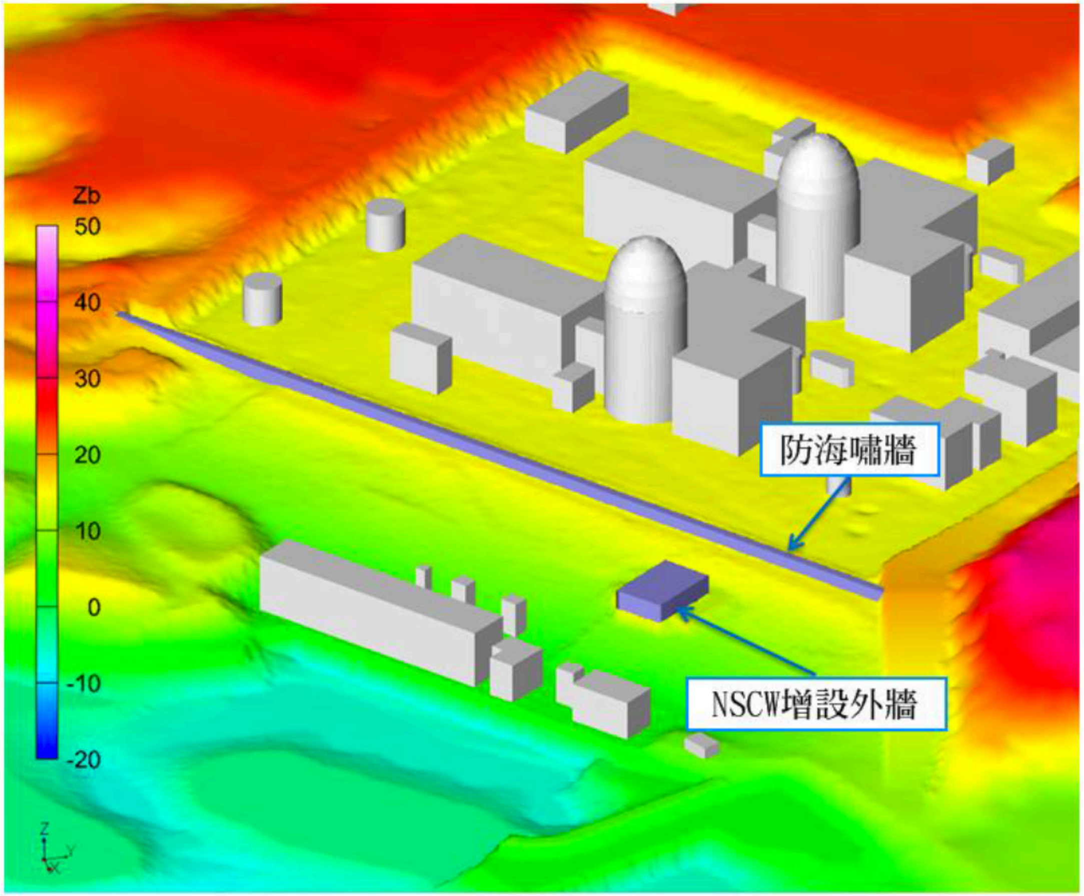
T02, Nearshore Inundation and Maximum Runup Height



Runup height: NP3: 10~12m; South Bay: 18m

The First National-wide Tsunami Drill in Taiwan in 2014/9/19

核一、二及三廠增設防海嘯牆規劃設計



1. 震央經度
2. 震央緯度
3. 震源深度
4. 地震規模

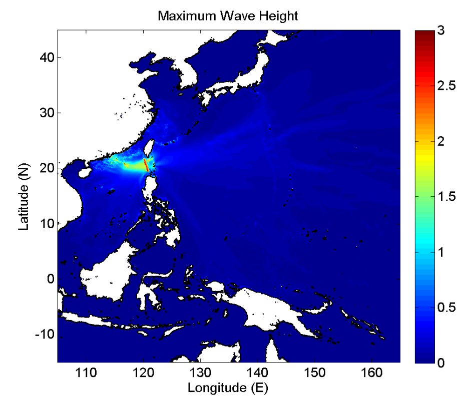
Tsunami Fast Calculation System for CWB in Taiwan.

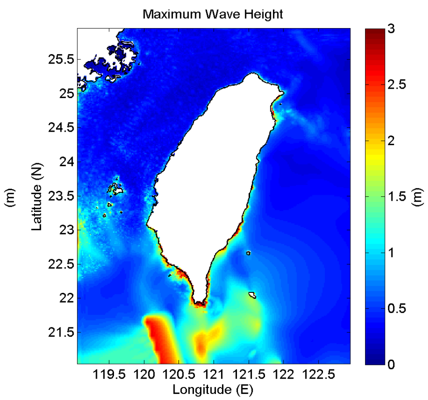
Fully automatic. One-click to finish them all.

Simulation with the region covers the PS and SCS can be done in 1.5 mins.

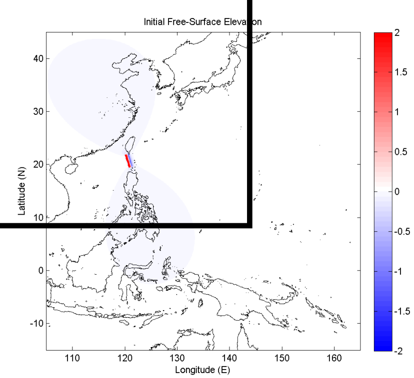
1. 震央經度
2. 震央緯度
3. 震源深度
4. 地震規模
5. Strike
6. Dip
7. Slip

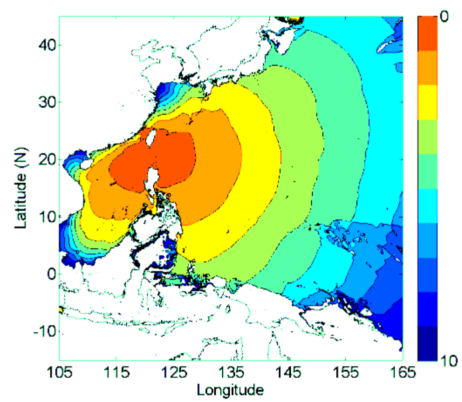
COMCOT
計算&繪圖

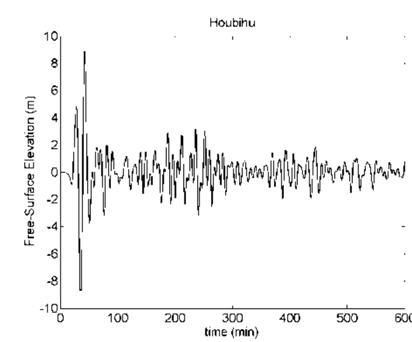




1. 震央經度
2. 震央緯度
3. 震源深度
4. 地震規模
5. Strike
6. Dip
7. Slip
8. 斷層破裂長寬
9. 錯動量
10.其他模擬設定

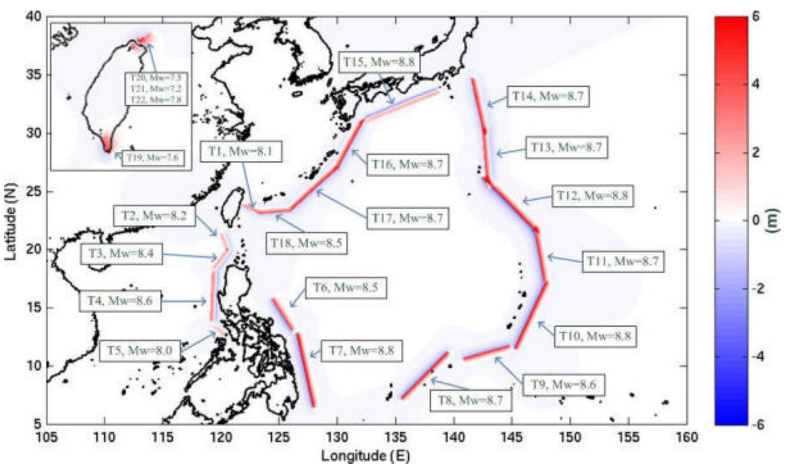






Database for earthquake parameters
海溝走向資料庫—提升準確性

資料庫參考過去學者針對台灣具有潛在海嘯威脅之海溝所訂定之參數(Wu,2012)所設計。若地震位於資料庫外，則走向平行於台灣海岸線，判斷方式為，以南投虎子山一等三角點代表台灣中心，走向垂直於震源和虎仔山連線方向。



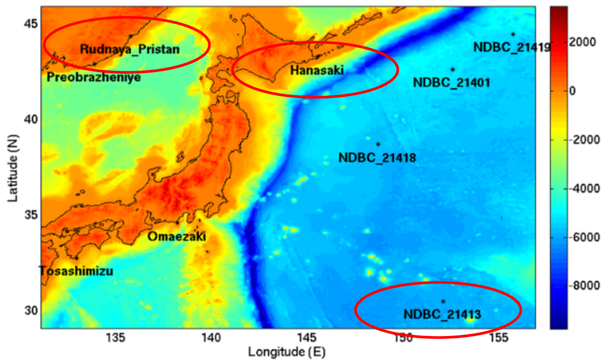
海溝之空間分布(吳祚任，2011)

海溝名稱	走向(度)	適用經度範圍 (°E)	適用緯度範圍 (°N)
T1花蓮外海	-66.2422	121.9 ~123.5	23.8~24.5
T2馬尼拉海溝1	340.7619	119.25~120.75	19.5~22.0
T3馬尼拉海溝2	35.3532	119.0~121.0	17.5~20.0
T4馬尼拉海溝3	2.403	118.5~120.5	13.5~19.0
T5馬尼拉海溝4	313.0466	119.0~121.0	12.5~14.0
T6菲律賓海溝1	328.3928	123.5~125.5	13.5~15.5
T7菲律賓海溝2	347.6032	125.5~127.5	5.5~13.5
T8亞普海溝	44.9191	135.0~140.0	6.0~12.0
T9馬里亞納海溝1	74.3247	141.0~145.5	10.5~13.5
T10馬里亞納海溝2	24.4308	145.5~150.5	12.5~17.5
T11馬里亞納海溝3	-9.6795	146.0~149.0	16.5~22.5
T12馬里亞納海溝4	-42.1025	143.0~149.0	22.5~25.0
T13伊豆-小栗原海溝1	-4.1057	141.0~144.0	26.0~30.0
T14伊豆-小栗原海溝2	-10.9672	140.0~144.0	30.0~35.0
T15南海海溝	-115.806	132.5~140.0	31.0~35.0
T16琉球島弧1	-154.62	130.0~132.5	27.5~31.0
T17琉球島弧2	-134.981	126.0~130.0	23.0~27.5
T18琉球島弧3	-95.1302	123.5~126.0	23.0~24.75

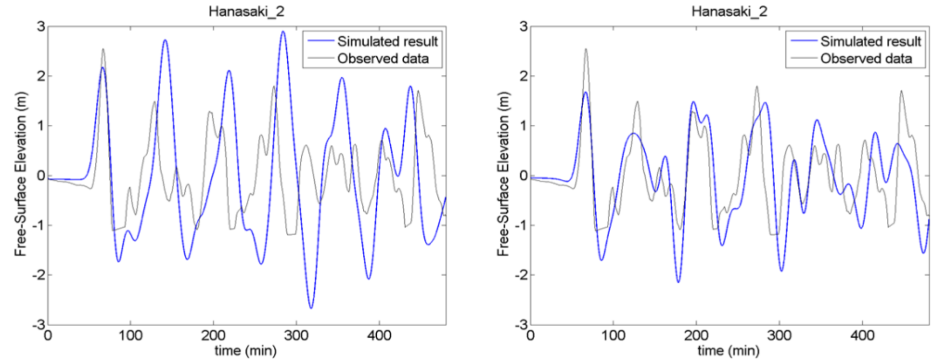
海溝之參數與範圍分布

Validation

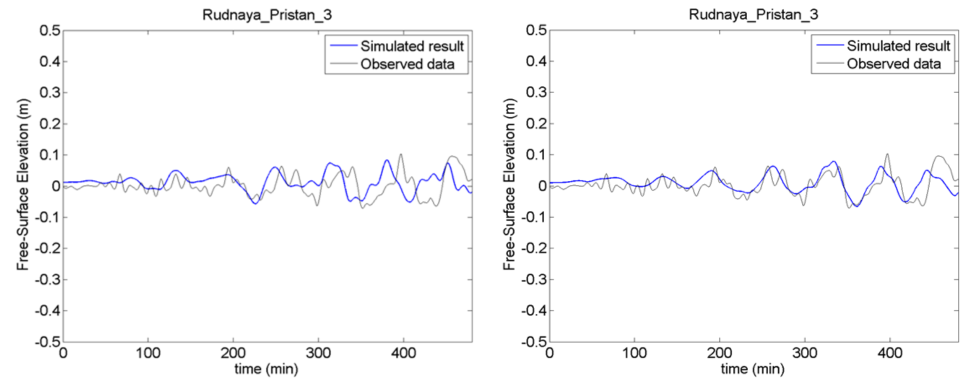
By assuming that only four parameters were known in the early stage.



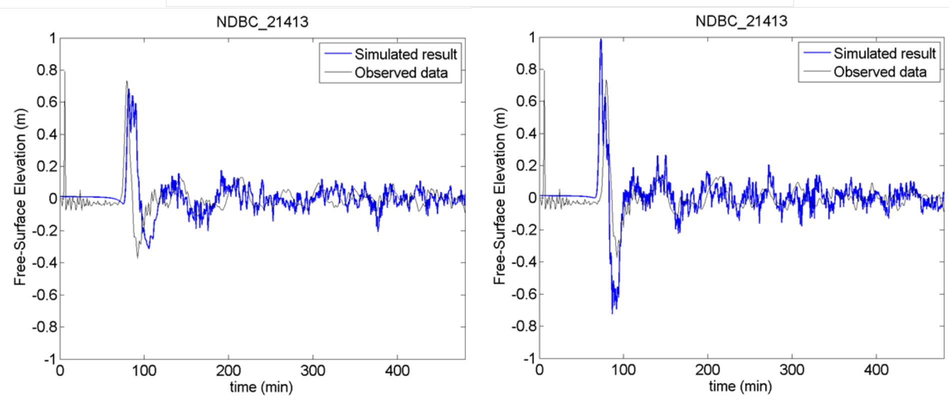
Japan 日本



Russia 俄羅斯

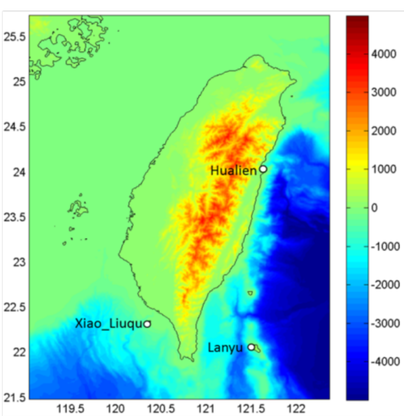


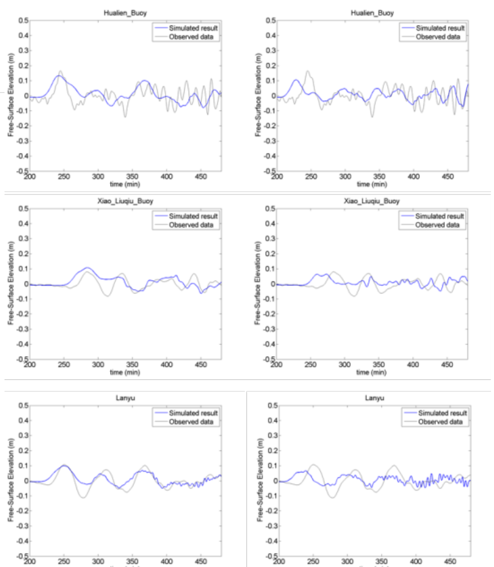
USA 美國



初步參數(present)　較詳細參數(GCMT)

Taiwan 台灣

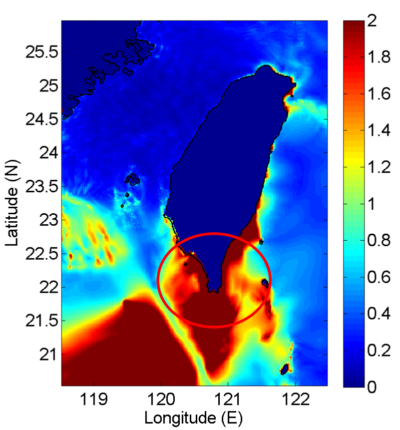


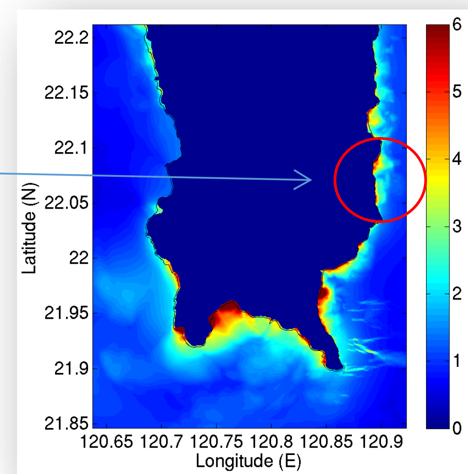


初步參數(present)　較詳細參數(GCMT)

Landslide and Local Scour

Motivation
Tsunami Boulders were found in the Southern Taiwan

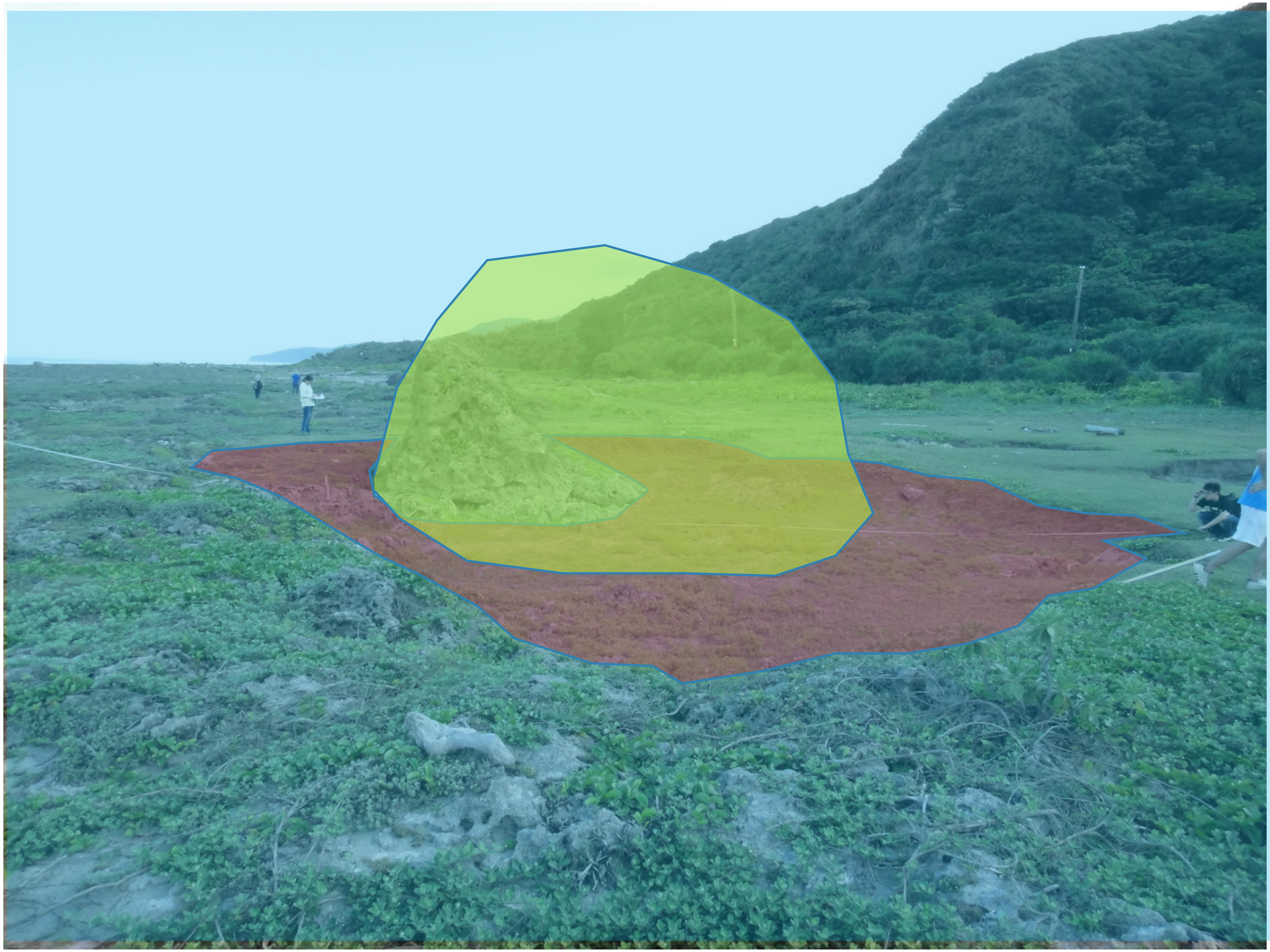




Motivation

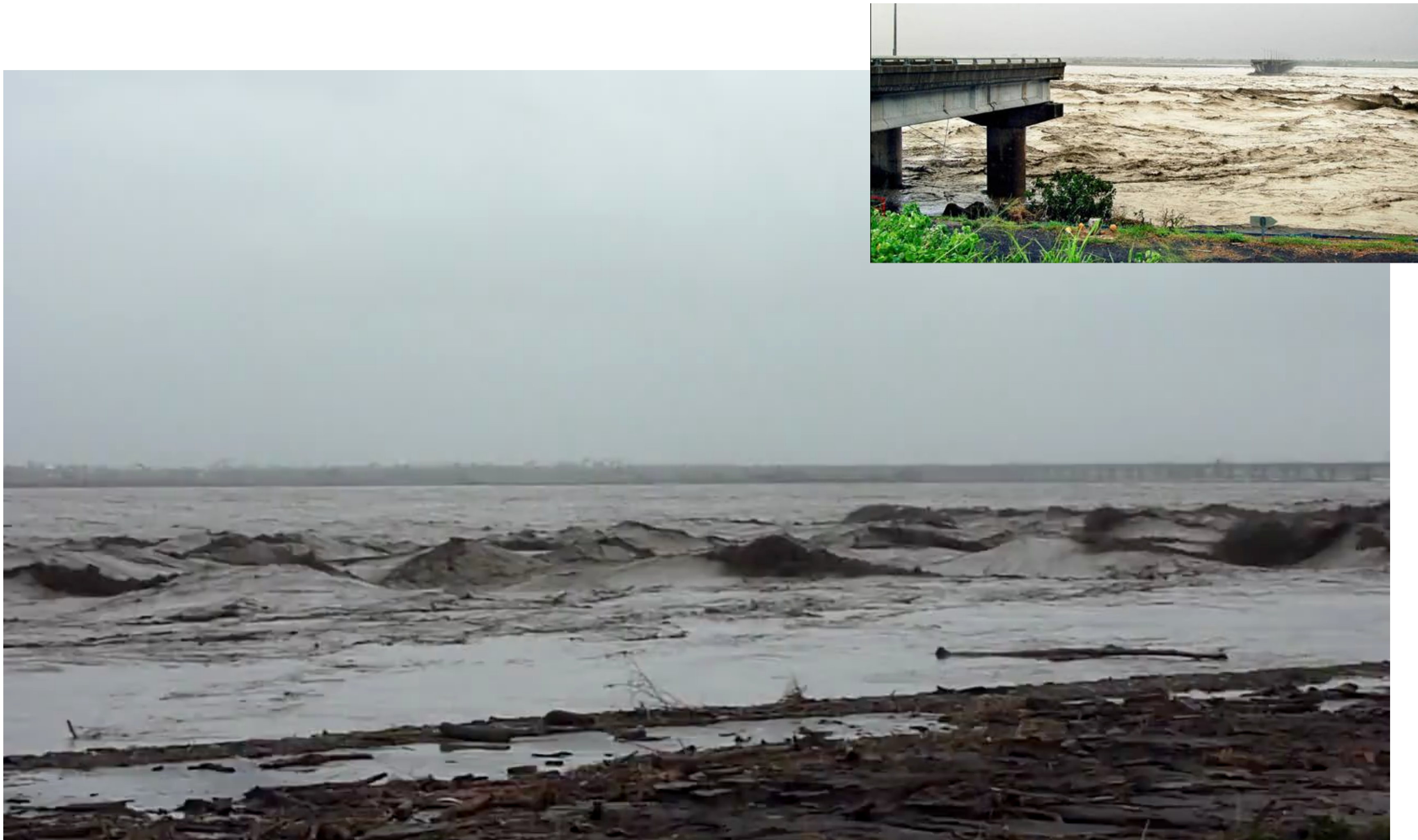
One of the boulders is in a huge scour hole

The broken coral boulder implies an originally much bigger size and higher tsunami wave height



The failure of Shuang-Yuan Bridge in the event of 2009 Typhoon Morakot.

The undular waves indicate the soft reverbed and sever local scour around the bridge piles.
2009 莫拉克颱風強烈水流導致雙園橋斷裂
波狀水躍暗示床質鬆軟及橋墩周圍沖刷



Breaking wave modeling, Splash3D (史百力士3D)

We adopted the Splash3D numerical model to solve for the breaking wave problems (Wu, 2004; Liu et al., 2005). This model solves 3-dimensional incompressible flow with Navier-Stokes equations. The free-surface is tracked by Volume-of-Fluid (VOF) method. The domain is discretized by finite volume method (FVM). The turbulent effect is closed by large eddy simulation (LES) with Smagorinsky model.

Incompressible continuity equation:

$$\nabla \cdot \boldsymbol{u} = 0$$

Navier-Stokes Equation

$$\frac{\partial(\boldsymbol{u})}{\partial t} + \nabla \cdot (\boldsymbol{uu}) = -\frac{1}{\rho}\nabla P + \frac{1}{\rho}\nabla \cdot \tau + \boldsymbol{g} + \boldsymbol{F}_0$$

Disney Splash Mountain
迪士尼 史百力士山

Splash: 飛濺

Volume of Fluid (VOF) method

The fluid density is presented in fluid fraction, and the transport equation is used to describe the fluid movement.

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (\rho_m \boldsymbol{u}) = \frac{\partial \rho_m}{\partial t} + \boldsymbol{u}\frac{\partial \rho_m}{\partial x} + \boldsymbol{v}\frac{\partial \rho_m}{\partial y} + \boldsymbol{w}\frac{\partial \rho_m}{\partial z} = 0$$

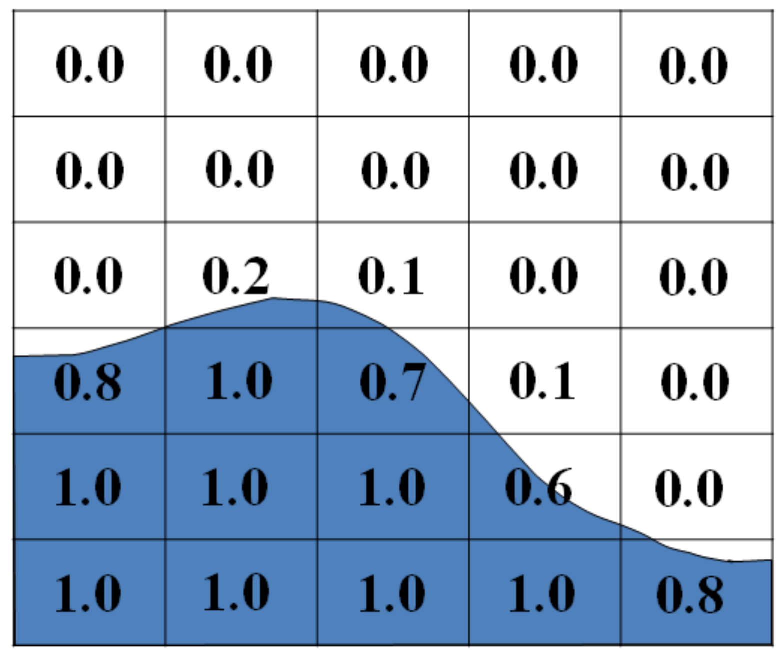
$$\rho = \sum_m f_m \rho_m^0$$

$$\frac{\partial f_m}{\partial t} + \nabla(\boldsymbol{u}_i f_m) = 0$$

Piecewise linear interface calculation (PLIC)

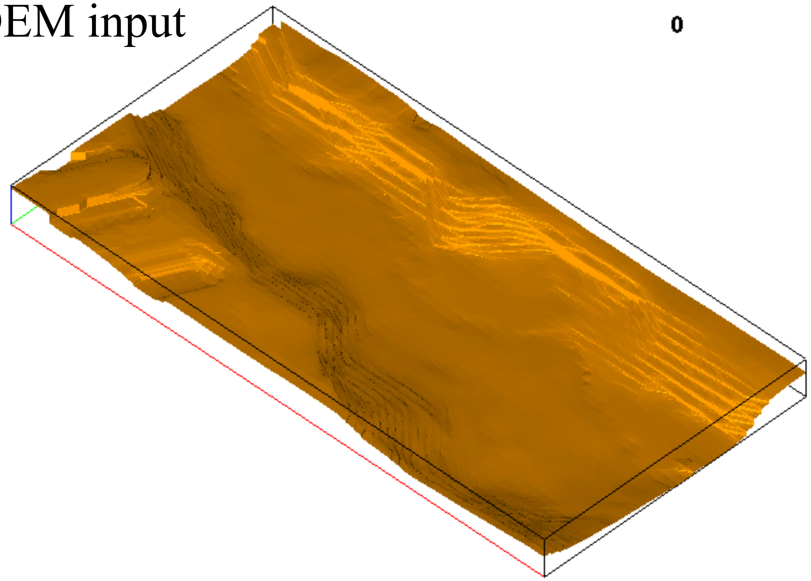
$$\vec{N} \cdot \vec{x}_p - C_p = 0$$

$$F(C_p) = V_{tr}(C_p) - f_m * \forall \approx 0$$



DEM and LiDAR topography input module and COMCOT boundary coupling module

DEM input



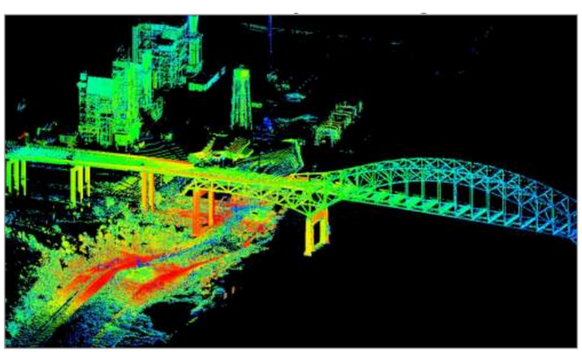
Partial-Cell treatment

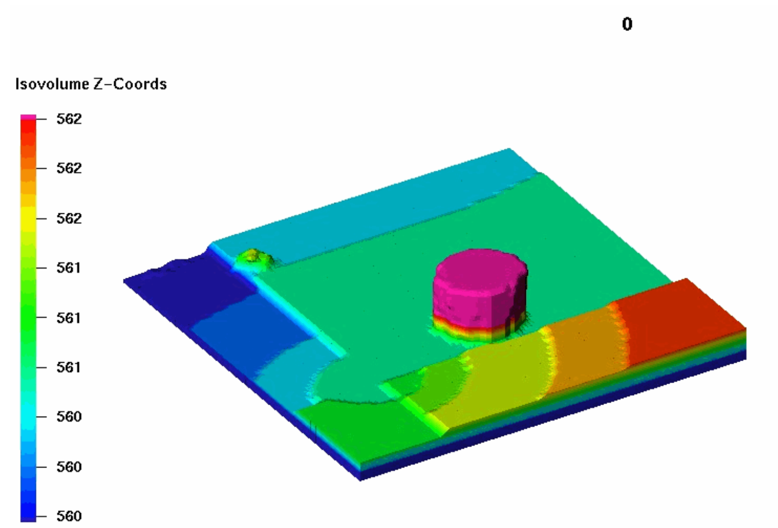
$$\forall_{eff} = (1 - f_{solid})\forall = \theta\forall$$

$$\partial \frac{(\theta f_m)}{\partial t} + \nabla \cdot (\theta f_m V) = 0$$

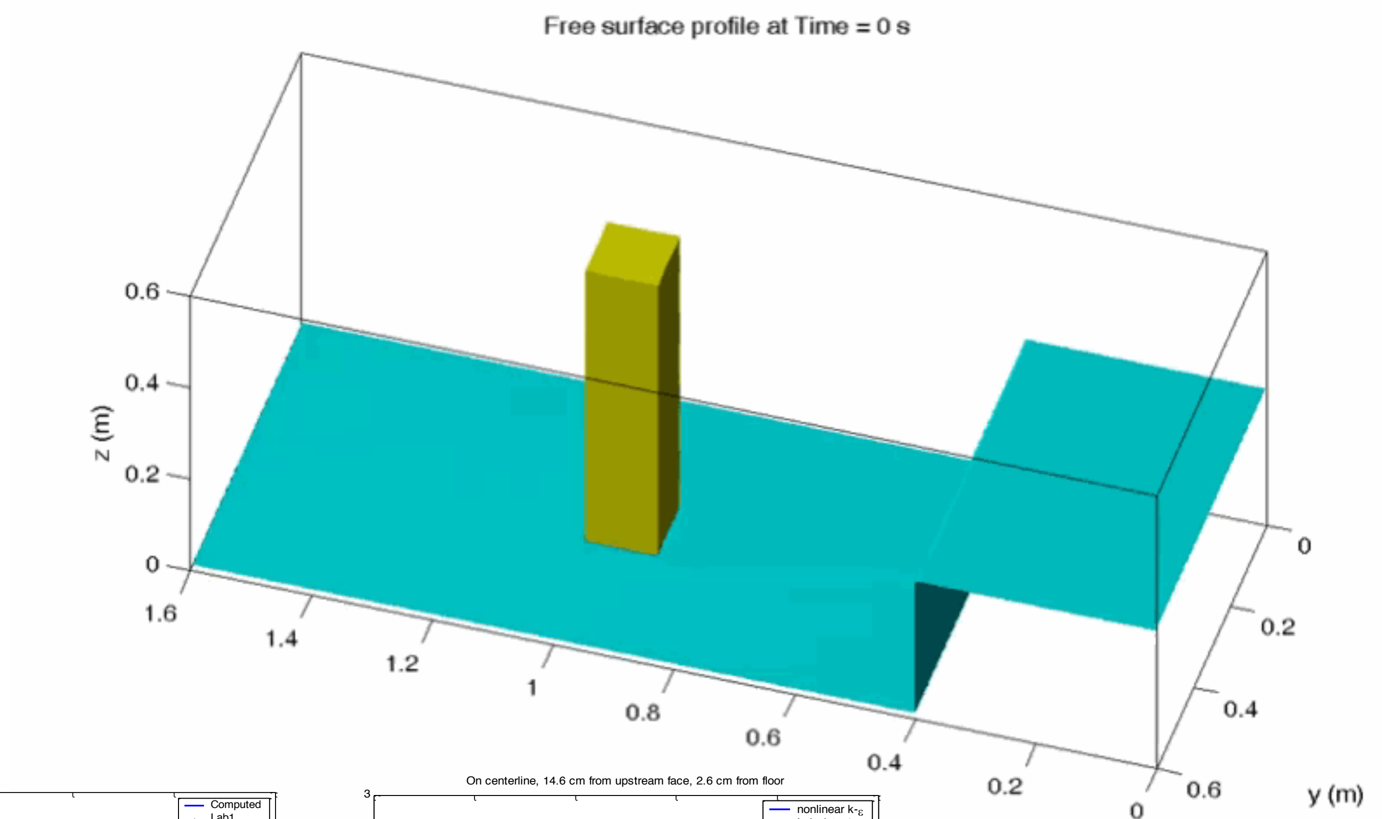
Topography of Toce River Valle

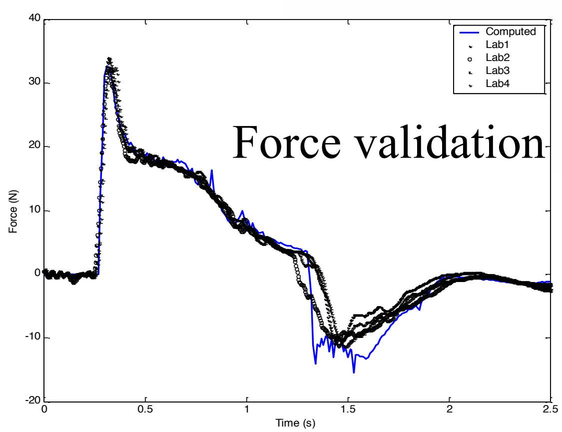
LiDAR input

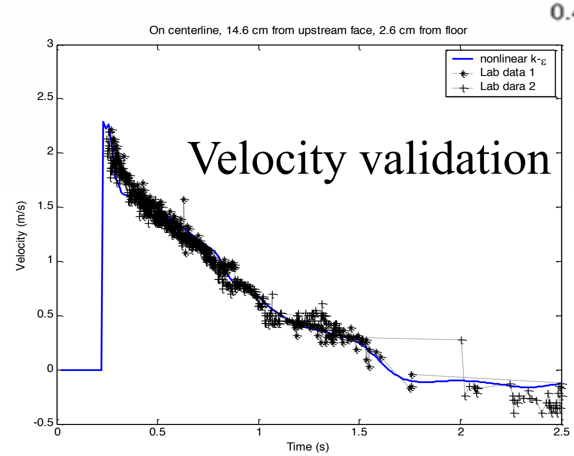




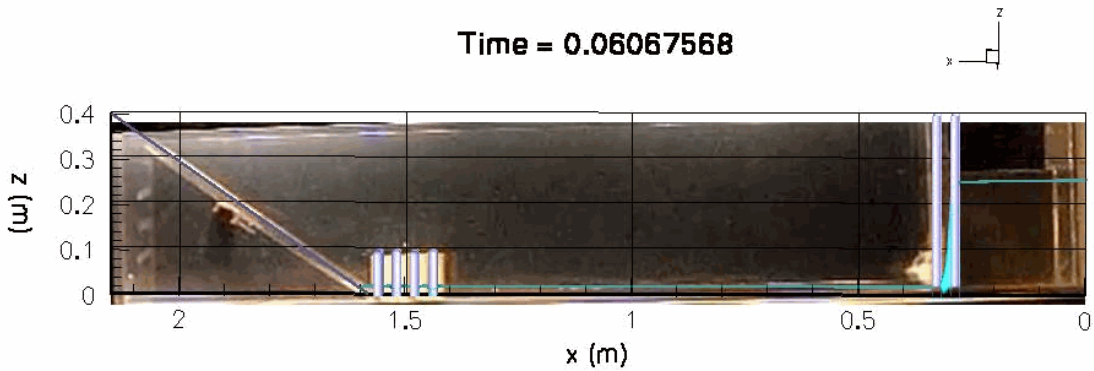
Model Validation 1: Dam-break bore impinging a square cylinder



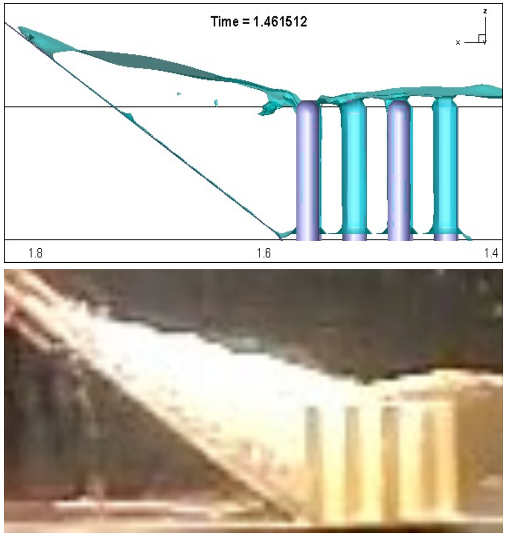


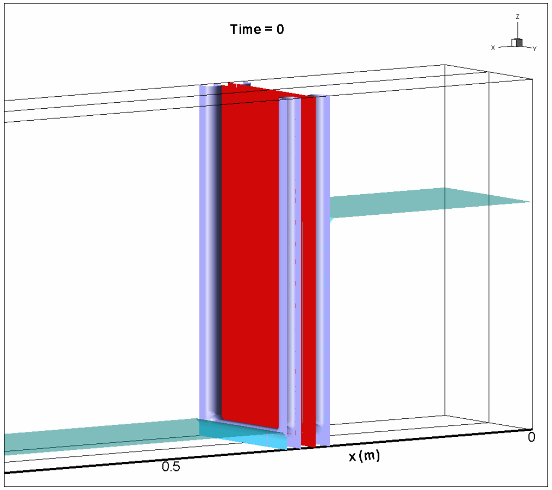


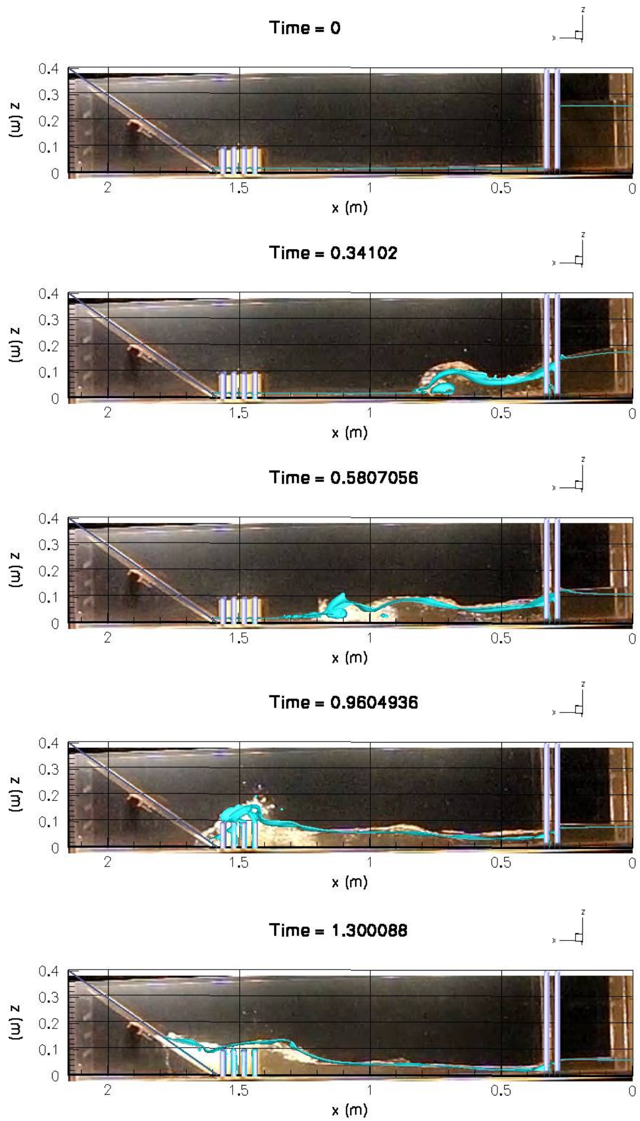
Model Validation: Free-surface



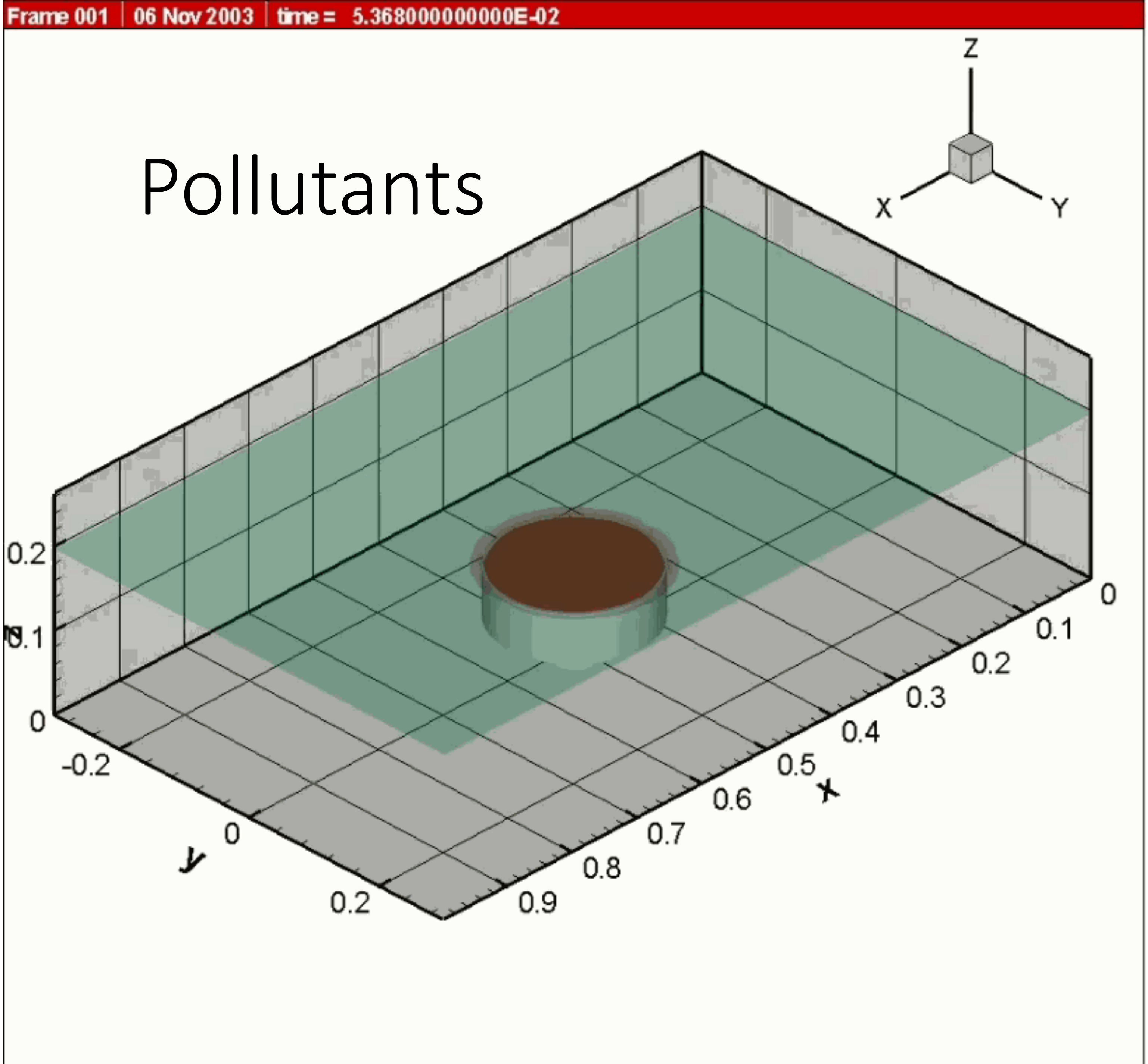
Moving-Solid Algorithm was adopted for Gate Lifting.



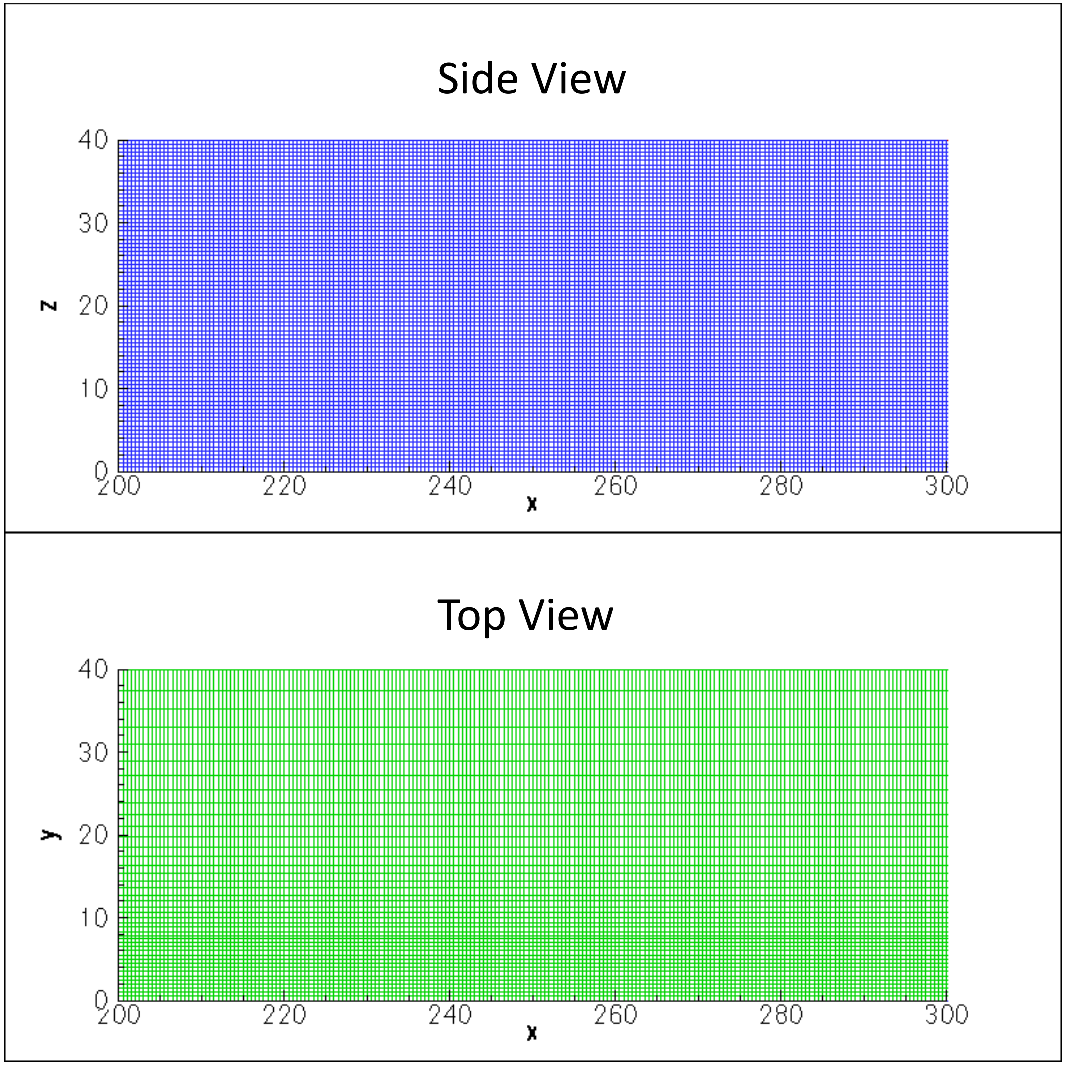


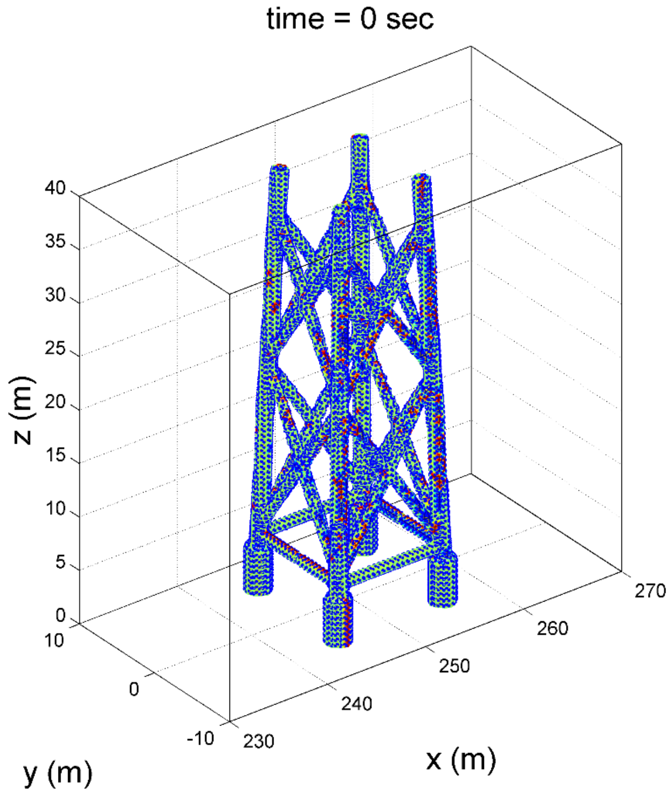


Pollutants

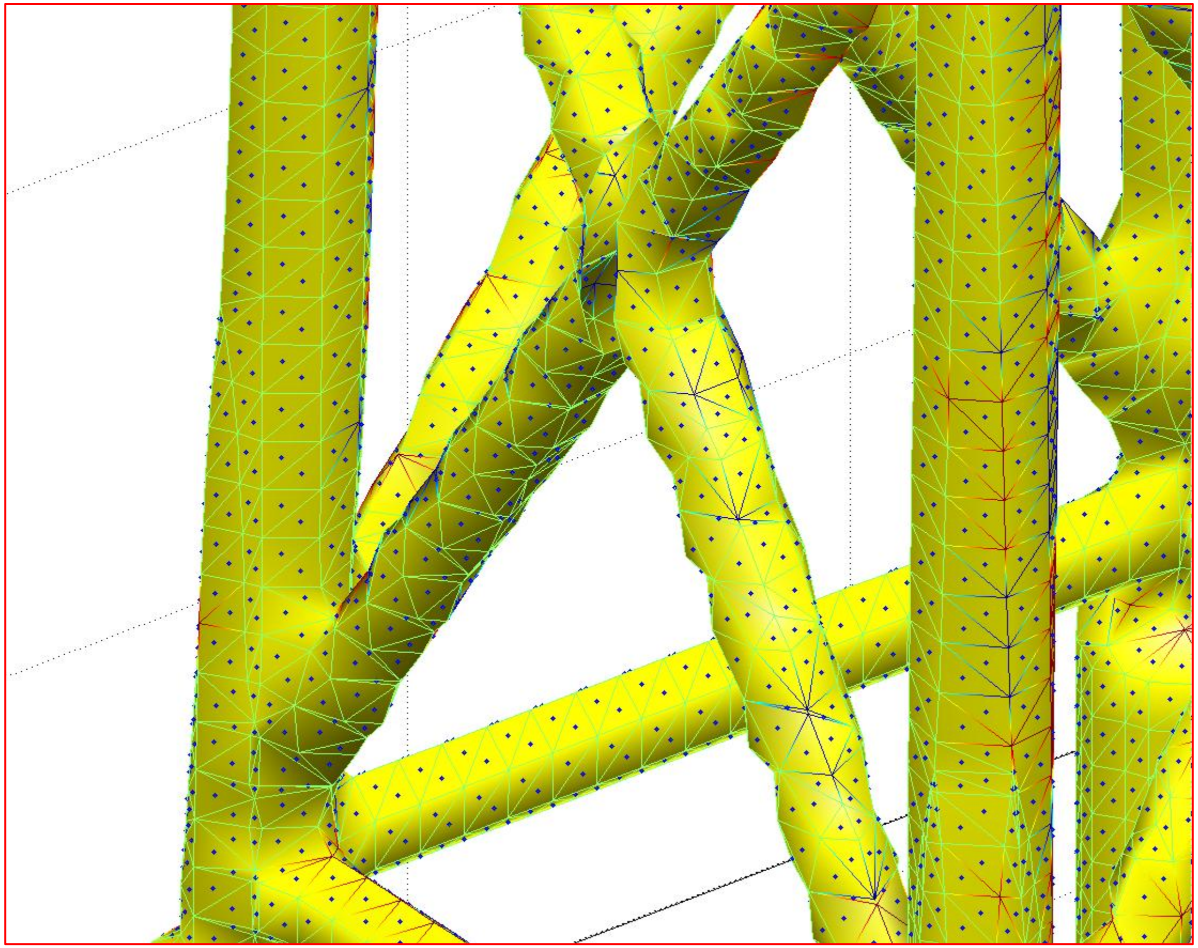

Frame 001
06 Nov 2003
time = 5.368000000000E-02
Z
X
Y
0.2
0.1
0
-0.2
0
y
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x

Grid Setup: Non-uniform in the spam-wise direction

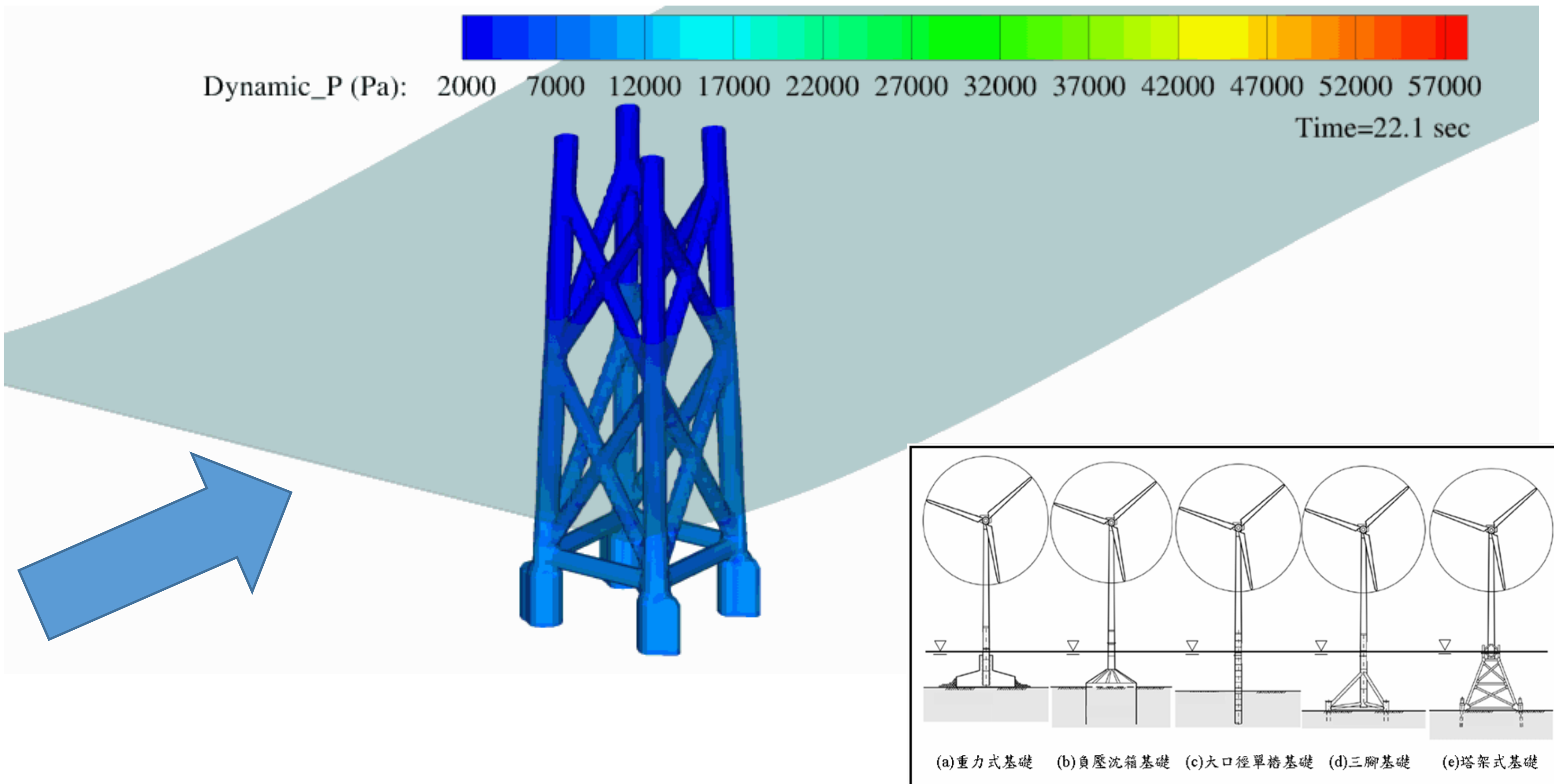




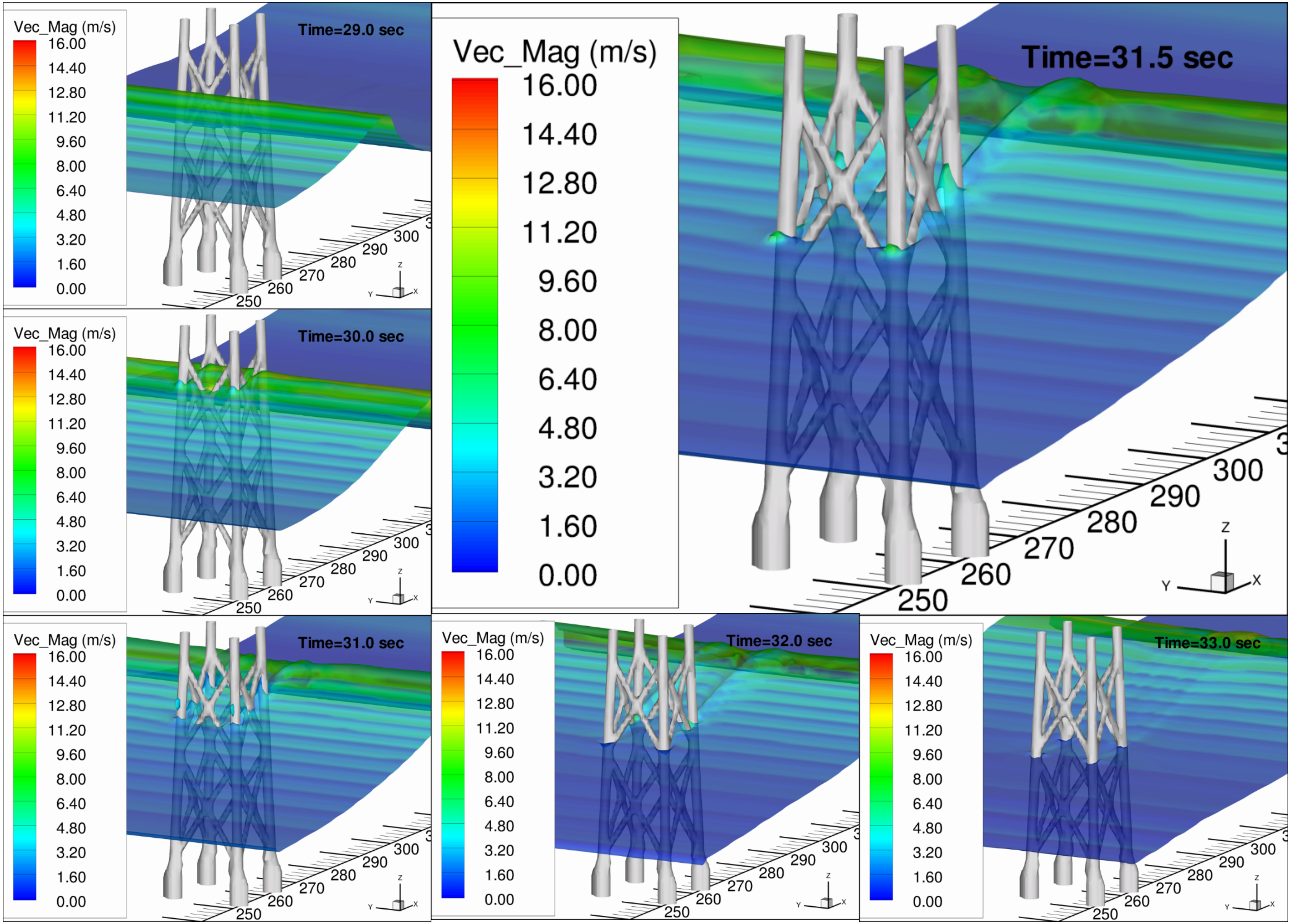
The Detail of the Truss, and the Surface-Force integration cells with normal vectors.



Wave + Current + Truss
Surface Elevation and Dynamic Pressure

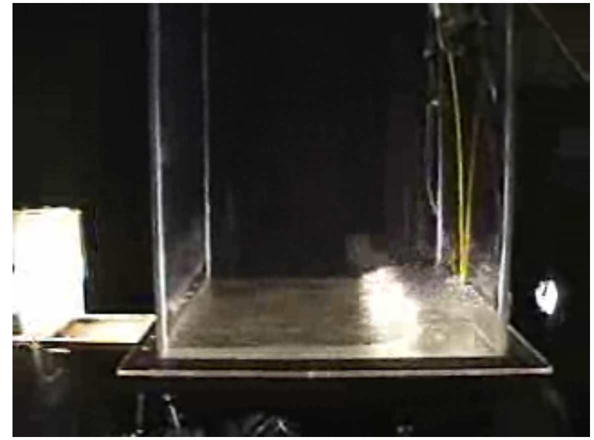


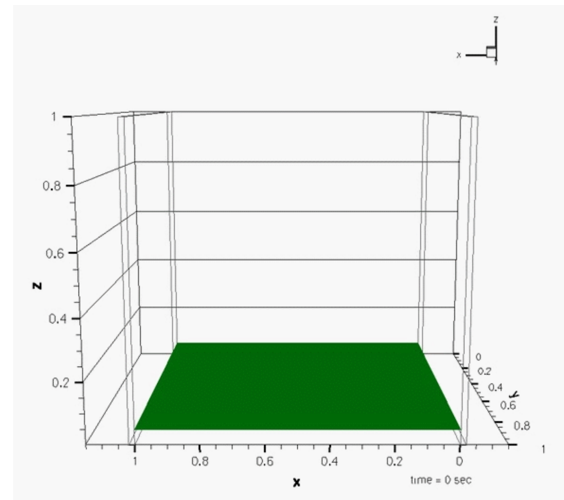
Surface Velocity Magnitude

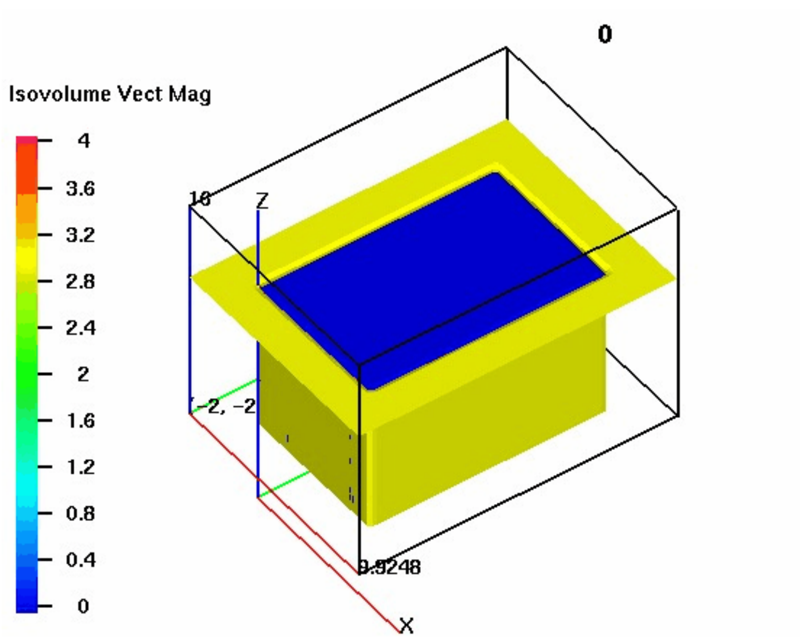


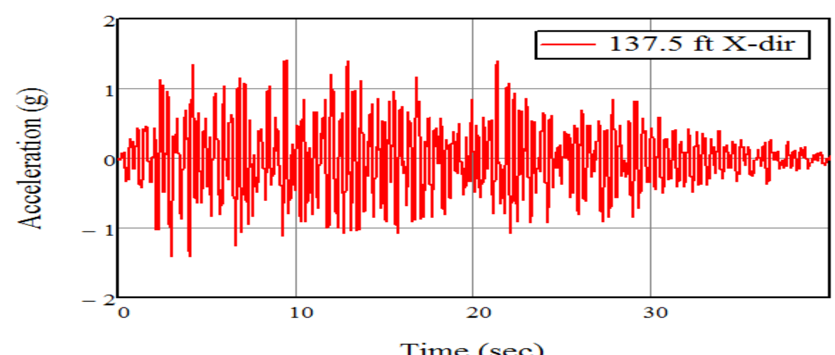
Sloshing Problem

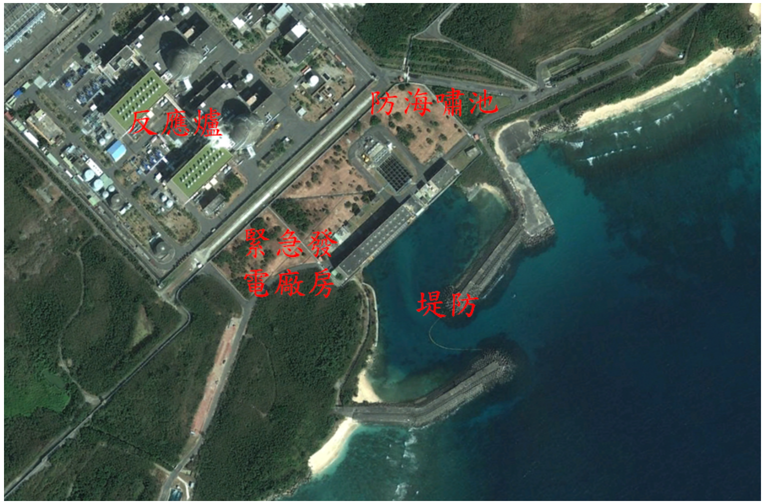
2015 Nepal Earthquake, Swimming pool.





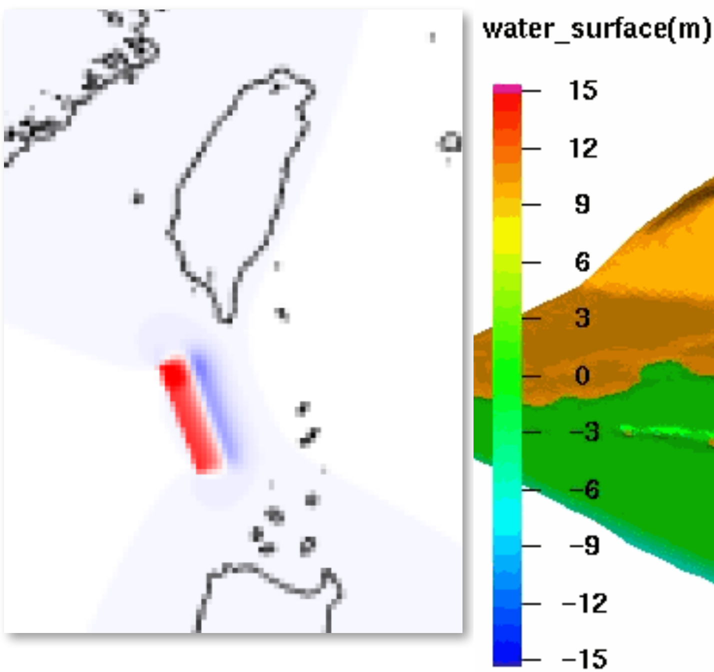




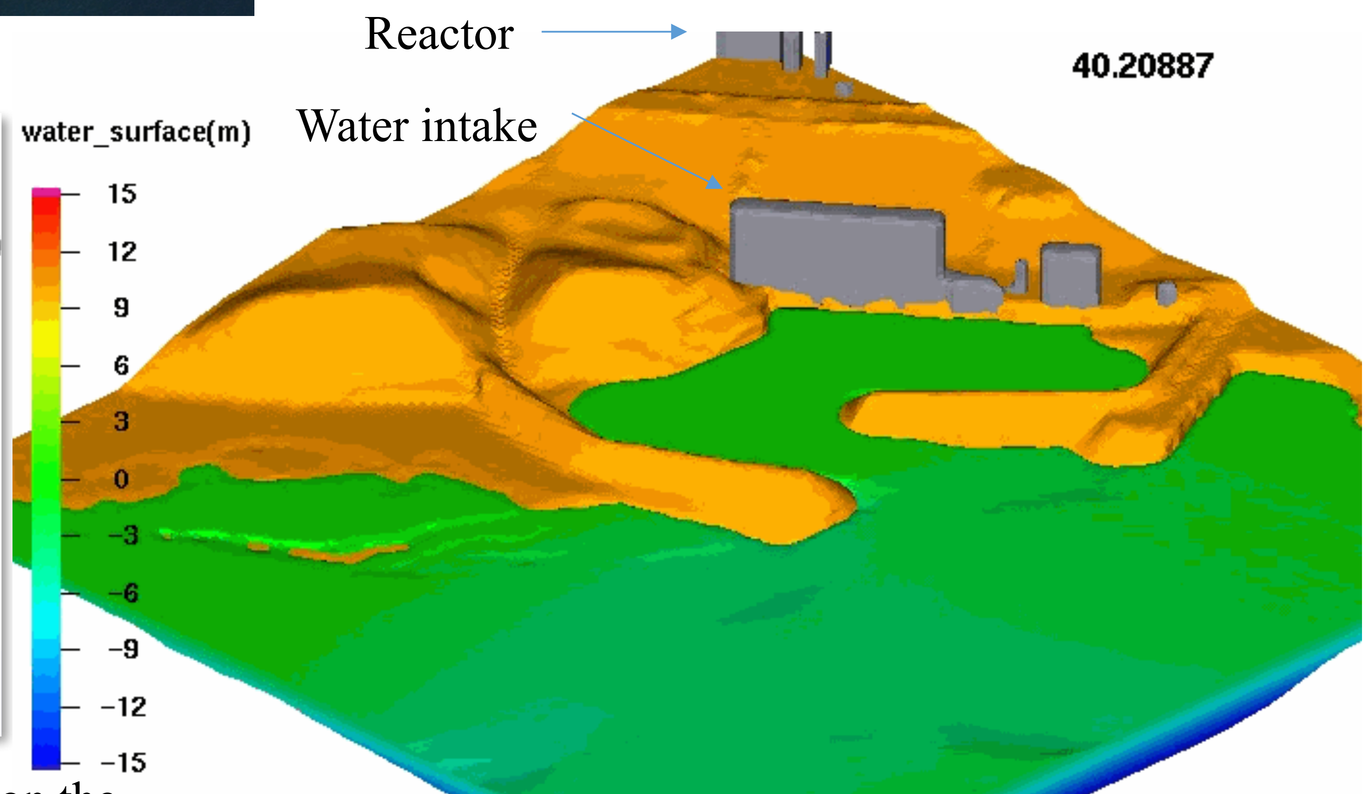


Potential tsunami impact on the Nuclear Power Plant (NPP) No.3 in Taiwan.

Splash3D Coupled with the result of 2D COMCOT tsunami model



Scenario tsunami source on the northern Manila Trench



Dynamic Two-Way Coupling
Implicit Velocity Correction Method (IVCM)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) = -\nabla P + \nabla \cdot \tilde{\tau} + \mathbf{f}_B$$

$$\frac{\rho^{n+1}\mathbf{u}^* - \rho^{n+1}\mathbf{u}^*}{\Delta t} = -\nabla \cdot (\rho \mathbf{u}\mathbf{u})^n - \nabla P^n + \nabla \cdot \left(\mu^{n+1} \left(\nabla \mathbf{u} + \nabla^{\mathrm{T}} \mathbf{u} \right) \right) + \mathbf{f}_B^n$$

$$\frac{\rho^{n+1}\mathbf{u}^{**} - \rho^{n+1}\mathbf{u}^*}{\Delta t} = -\nabla \delta P^{**} + \mathbf{f}_B^{n+1} - \mathbf{f}_B^n$$

$$\nabla \cdot \frac{\nabla \delta P^{**}}{\rho^{n+1}} = \nabla \cdot \left(\frac{\mathbf{u}^*}{\Delta t} + \frac{\mathbf{f}_B^{n+1}}{\rho^{n+1}} - \frac{\mathbf{f}_B^n}{\rho^{n+1}} \right)$$

$$\mathbf{u}^{**} = \mathbf{u}^* - \Delta t \left(\frac{\nabla \delta P^{**} - \mathbf{f}_B^{n+1} + \mathbf{f}_B^n}{\rho^{n+1}} \right)$$

Loop until $\left(\mathrm{abs}\left(\mathbf{u}^{n+1} - \mathbf{u}_s \right) < \mathrm{tolerance} \right)$

$$\mathbf{f}_s^{n+1} = \rho^{n+1} \left(\frac{\mathbf{u}_s^{n+1} - \mathbf{u}^{**}}{\Delta t} \right)$$

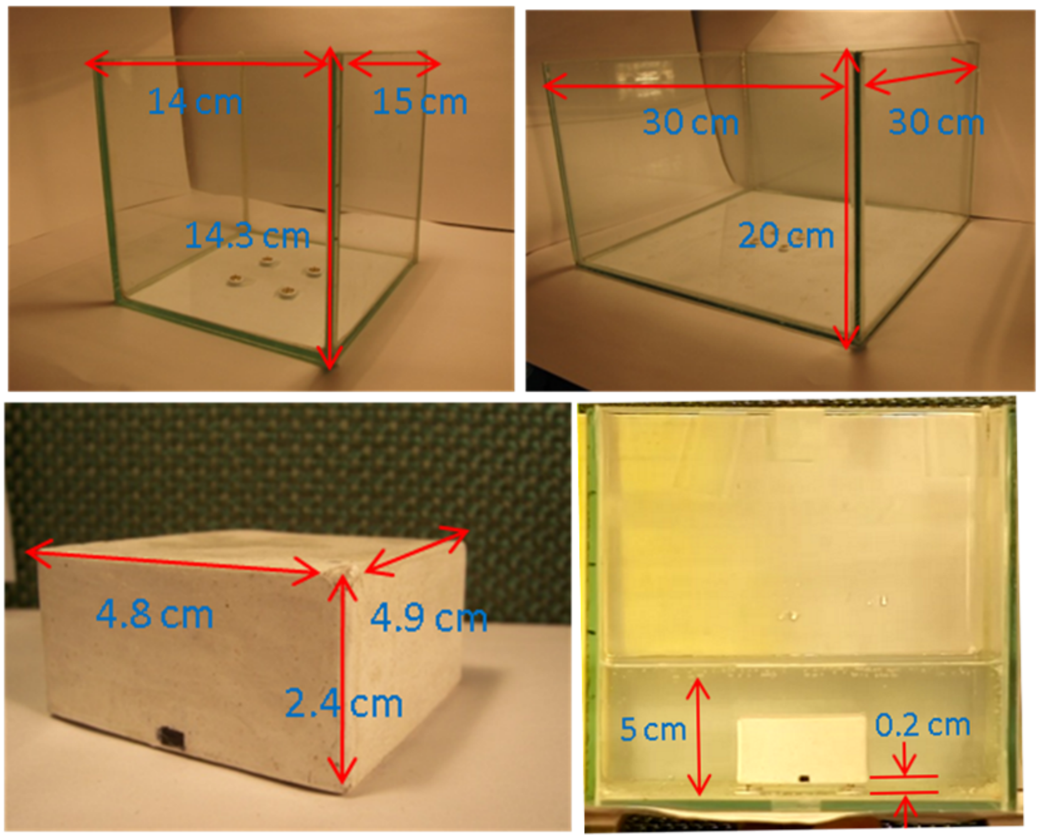
$$\frac{\rho^{n+1}\mathbf{u}^{n+1} - \rho^{n+1}\mathbf{u}^{**}}{\Delta t} = -\nabla \delta P^{n+1} + \mathbf{f}_B^{n+1} - \mathbf{f}_B^n + \mathbf{f}_s^{n+1}$$

$$\nabla \cdot \frac{\nabla \delta P^{n+1}}{\rho^{n+1}} = \nabla \cdot \left(\frac{\mathbf{u}^{**}}{\Delta t} + \frac{\mathbf{f}_B^{n+1}}{\rho^{n+1}} - \frac{\mathbf{f}_B^n}{\rho^{n+1}} + \frac{\mathbf{f}_s^{n+1}}{\rho^{n+1}} \right)$$

$$\mathbf{u}^{n+1} = \mathbf{u}^{**} - \Delta t \left(\frac{\nabla \delta P^{n+1} - \mathbf{f}_B^{n+1} + \mathbf{f}_B^n - \mathbf{f}_s^{n+1}}{\rho^{n+1}} \right)$$

End Loop

Floating Obstacle

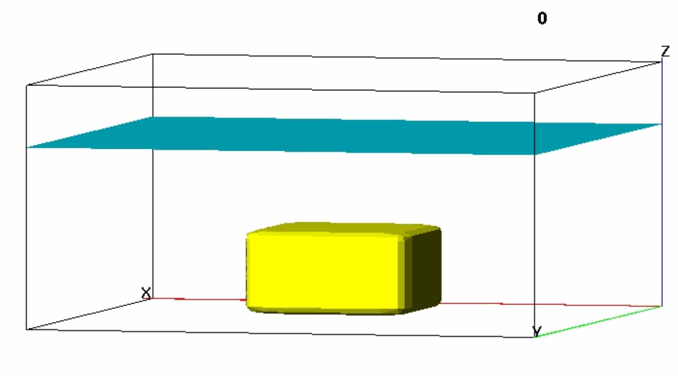


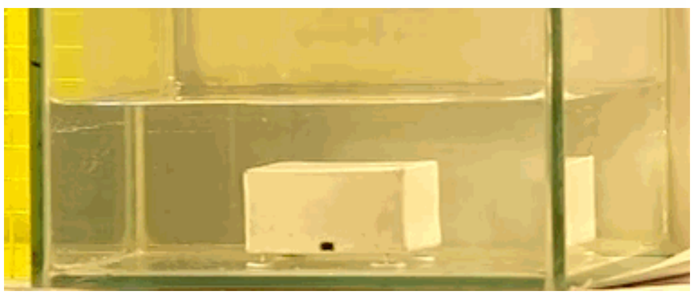
Numerical setup of the floating bodies.

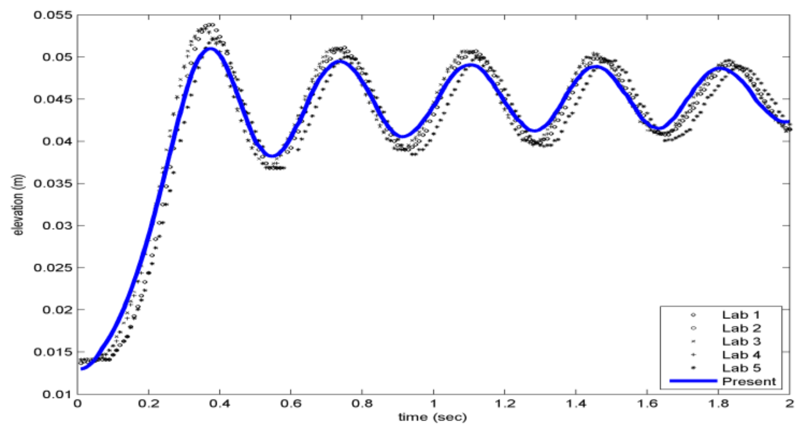
tank size (cm)	14 x 15	30 x 30
cell	45 x 42 x 28	55 x 55 x 28
coordinate (cm)	X (0.0, 15.0) Y (0.0, 14.0) Z (0.0, 7.0)	X (0.0, 30.0) Y (0.0, 30.0) Z (0.0, 7.0)
Simulation time	1.2 sec	
Calculation time (CPU time)	0.17 hours	1.5 hours

The photos with dimension of the small tank (upper left) and the large tank (upper right). The floating box is made of wood (lower right). A small black dot is painted on it to trace the floating trajectory. The still water depth is 5 cm. The box is initially elevated 0.2 cm by four pins. (Lower left).

Simulation on a Floating Obstacle



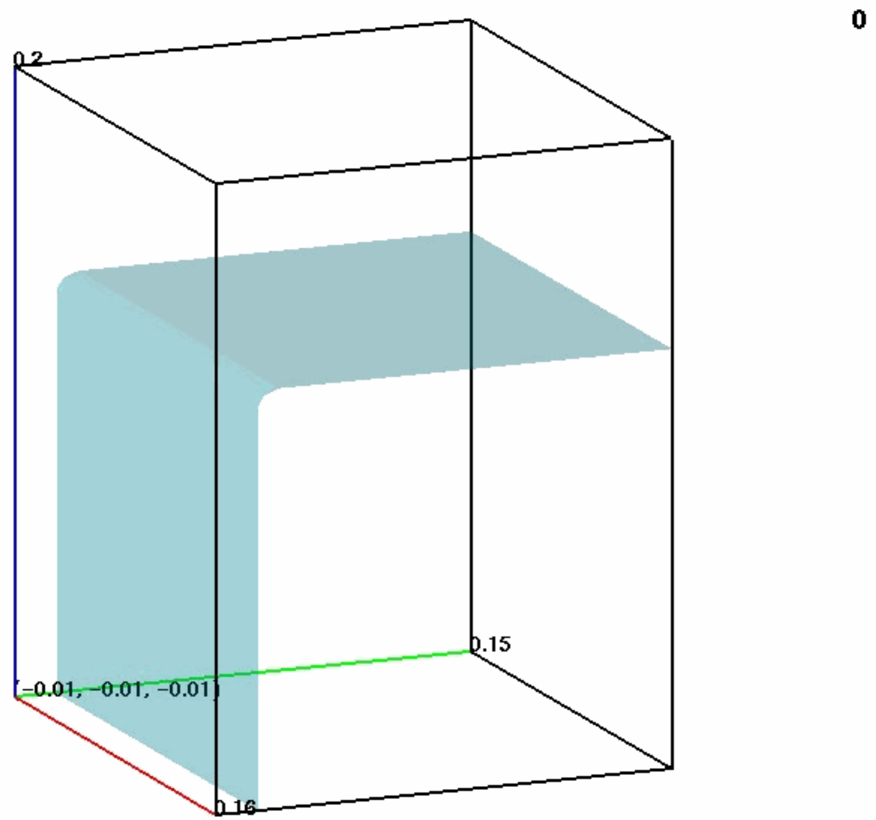




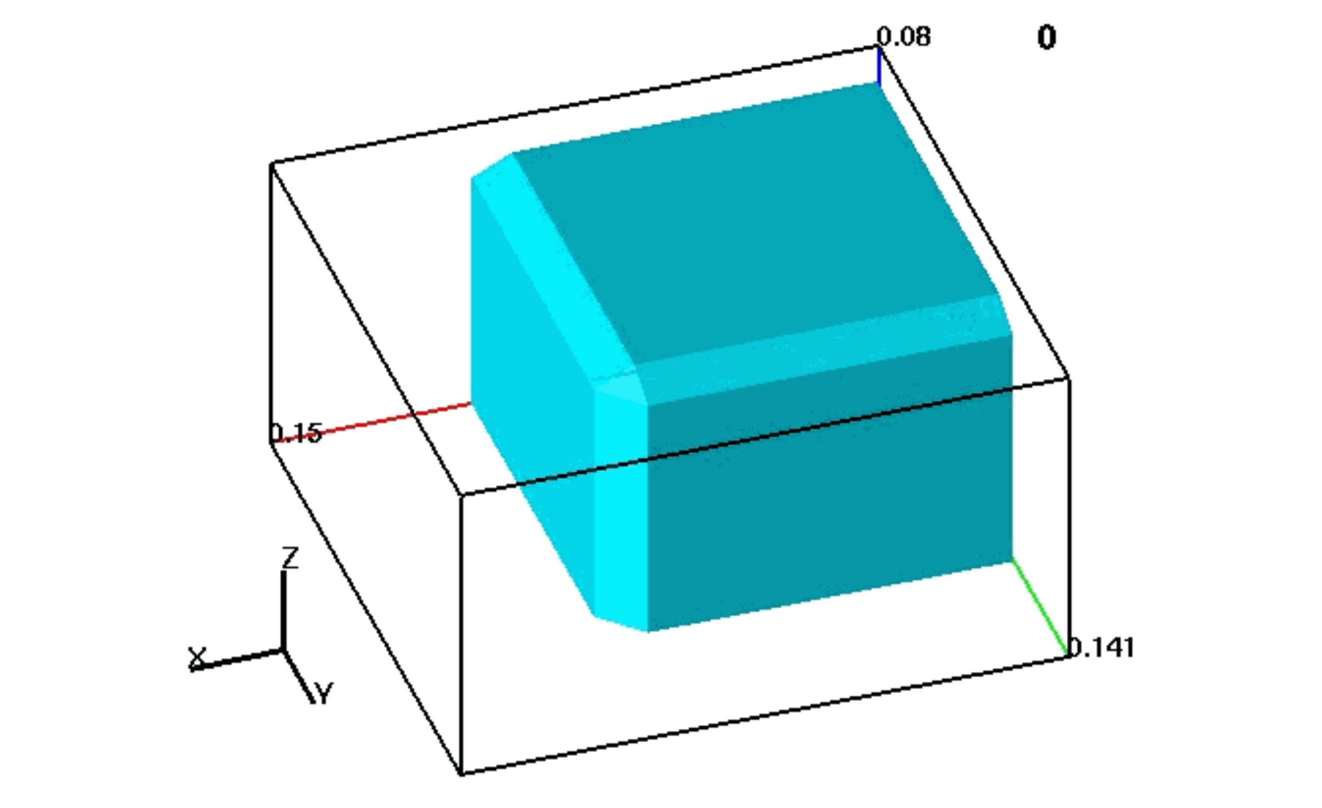
（莊美惠製）

- 渠槽大小：15 ╳ 14 cm、30 ╳ 30 cm
- 網格大小：0.33 ╳ 0.33 ╳ 0.25 cm
- 楔形體：4.8 ╳ 4.9 ╳ 2.4 cm
- 變動條件：渠槽大小

Floating and sinking balls



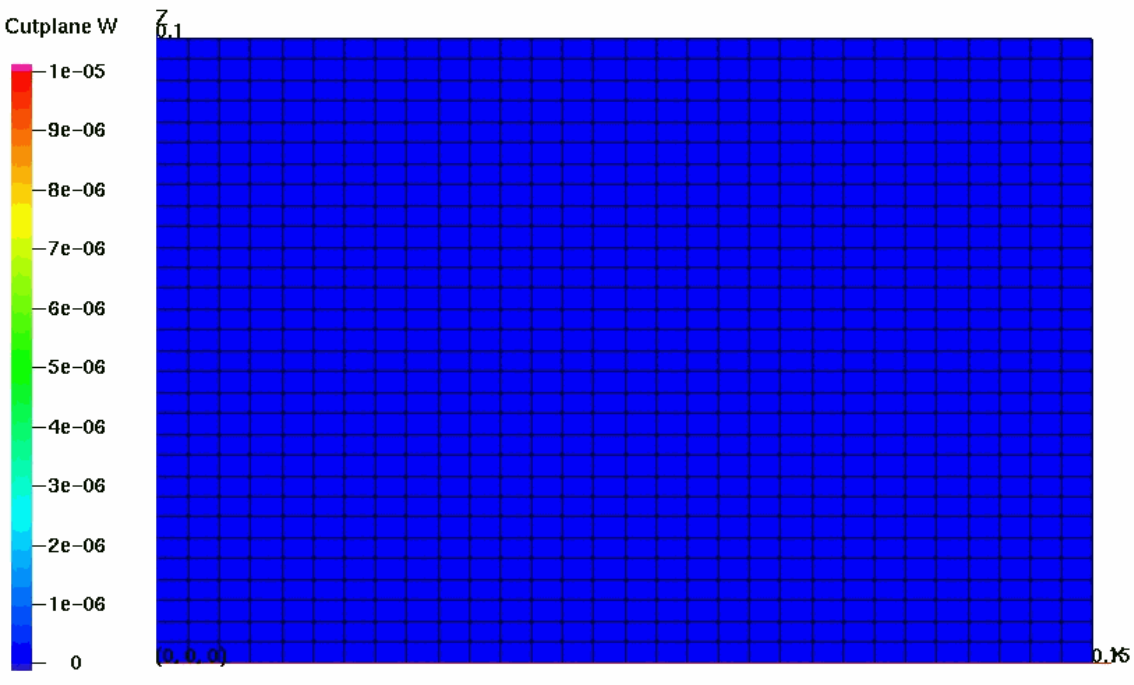
Fast moving ball with collapsing water

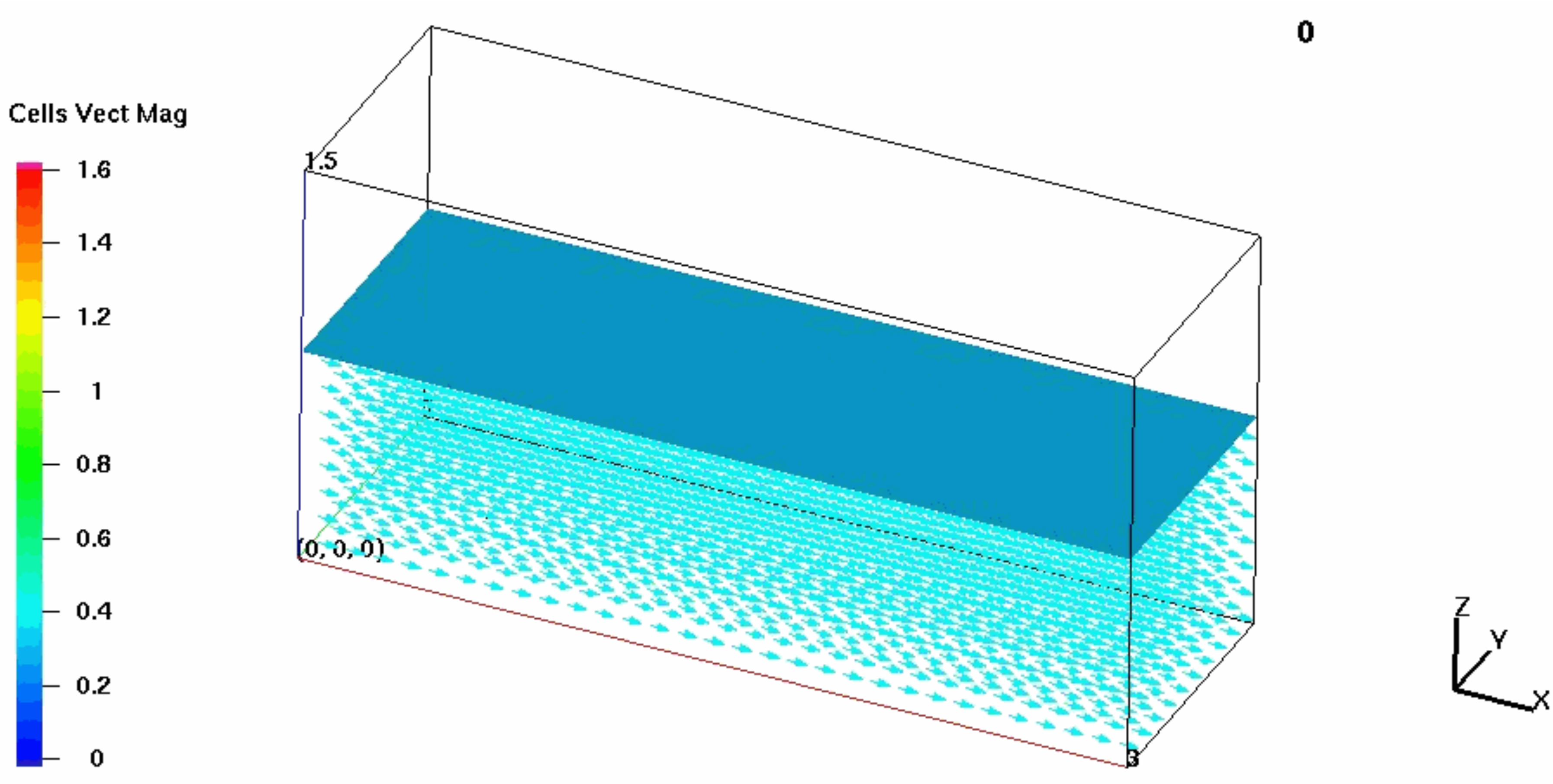


Rotation

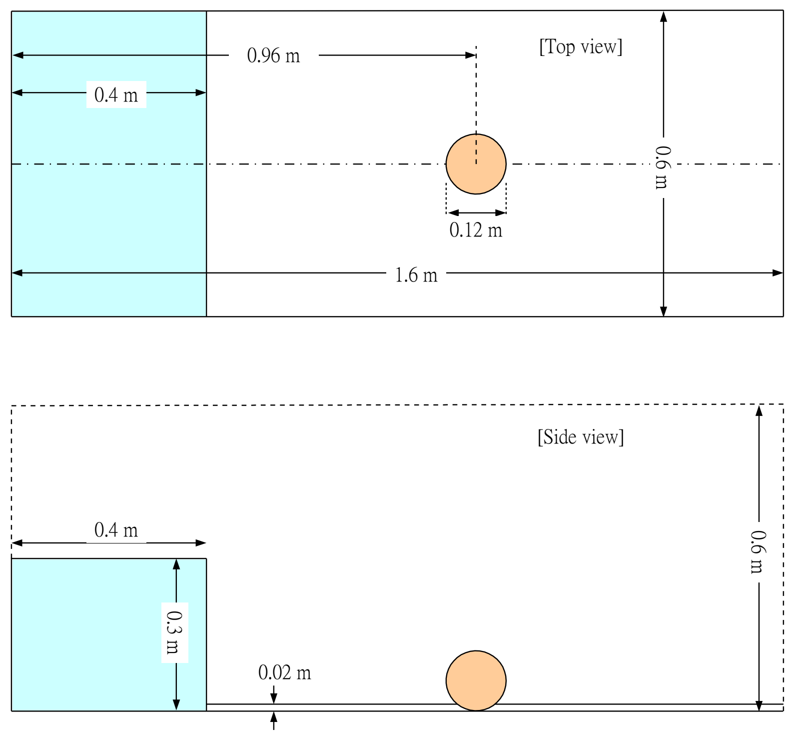
$$\omega_y = 100\ (rad/s)$$

0




Cells Vect Mag
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1.5
(0, 0, 0)
3
Z
Y
X

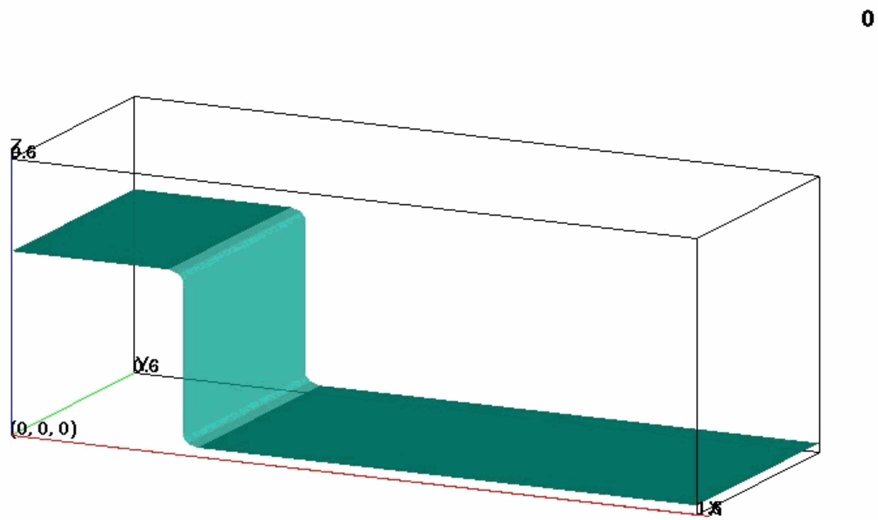
Dam-break bore interacting with a movable ball

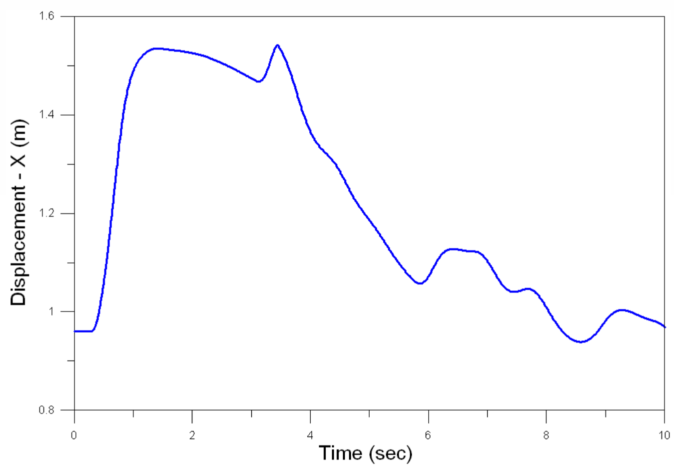


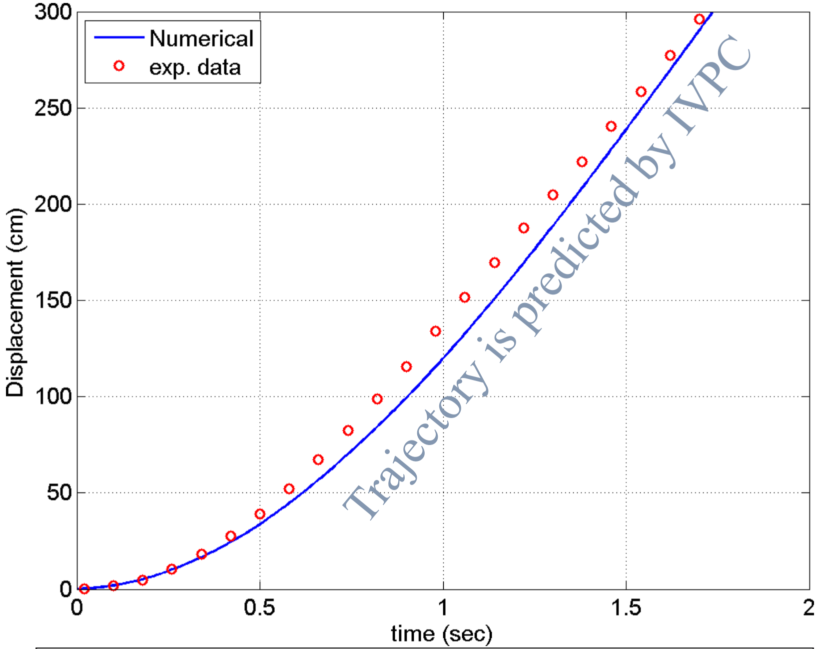
Water density 1000 kg/m^3

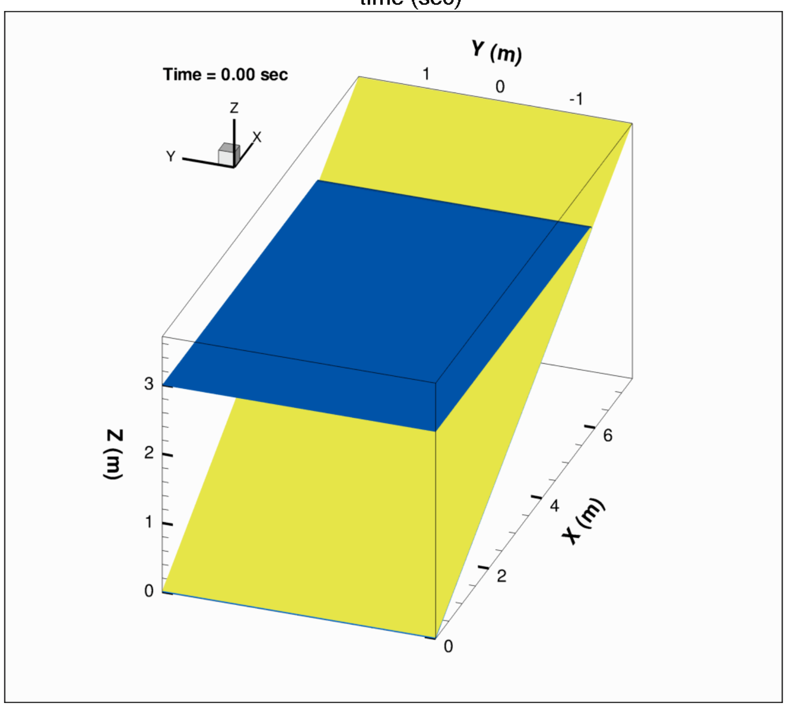
Ball density 1200 kg/m^3

Resolution 70 X 30 X 30; Computational time: 3hrs 19min;
CPU:i5-2500 CPU @ 3.30GHZ


0
Z
0.6
Y
0.6
(0, 0, 0)
X

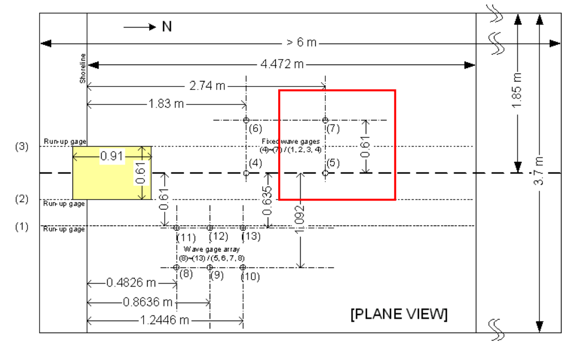

Displacement - X (m)
Time (sec)
1.6
1.4
1.2
1
0.8
0
2
4
6
8
10





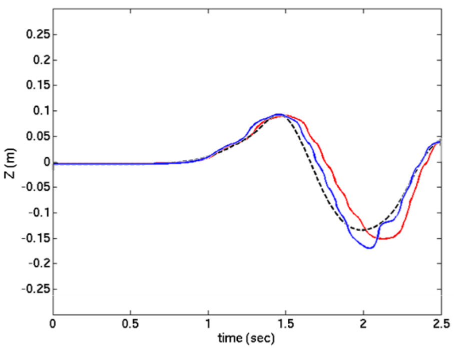
Two-way Coupled Moving Solid Method

Implicit Velocity-Pressure Coupling (IVPC)

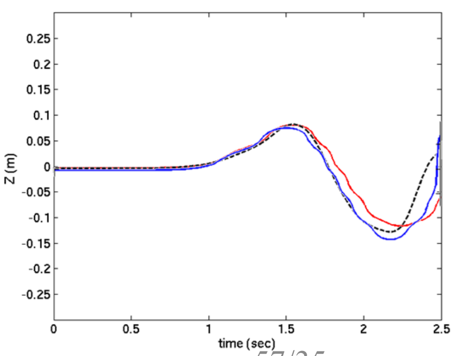


-- exp. Data
— two-way couple

#05



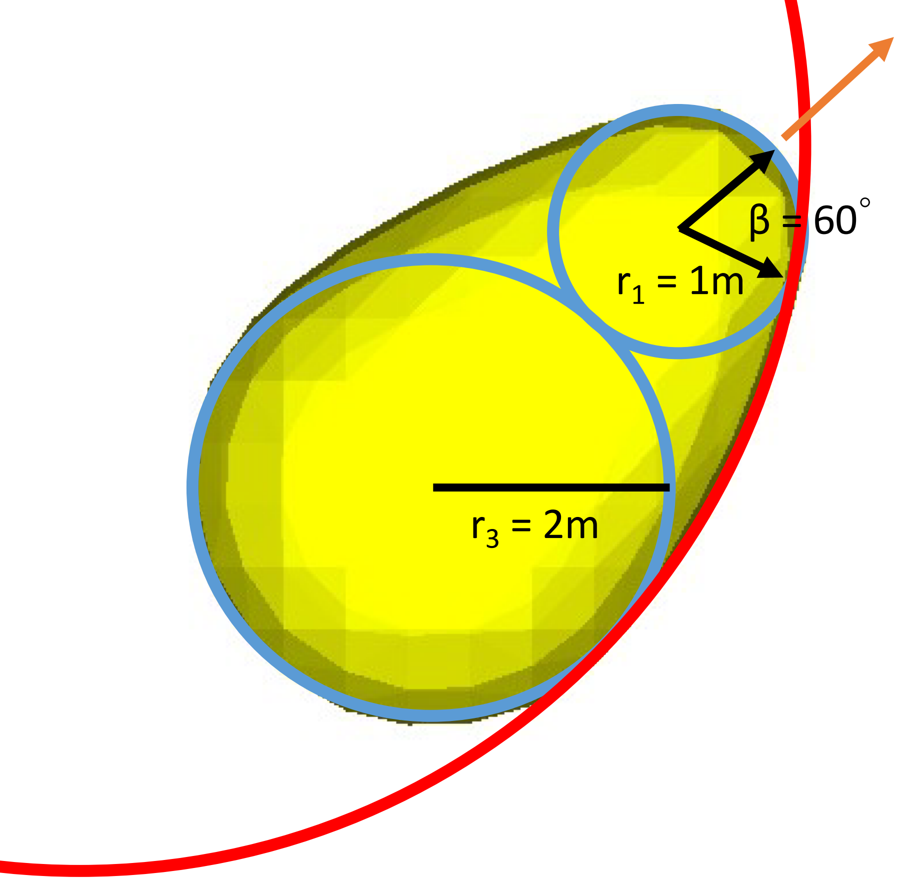
#07

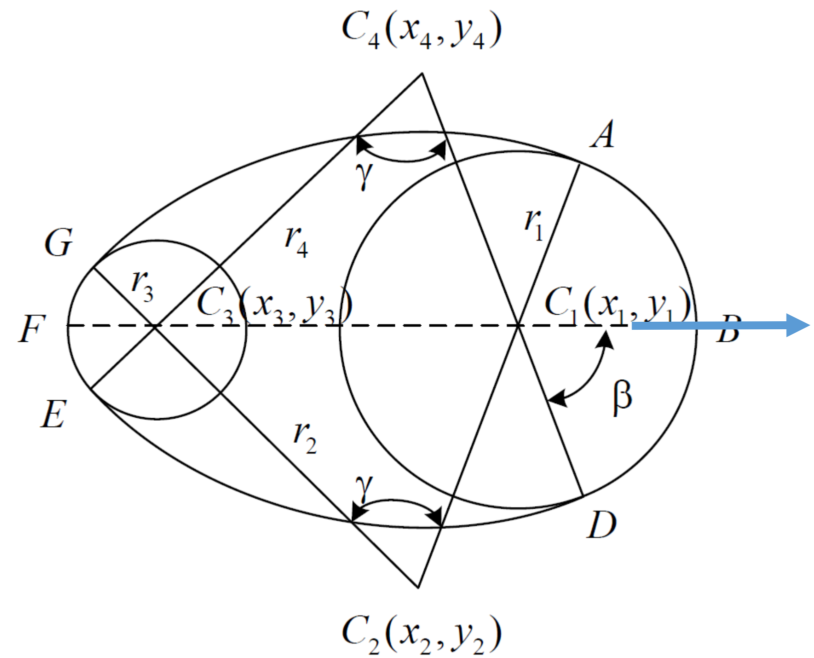


(OSU's O.H. Hinsdale Wave Research Lab之Large Wave Flume)

Model Description

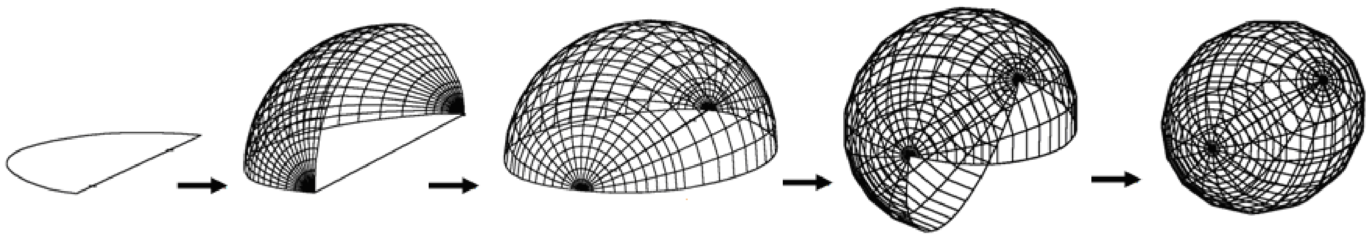
Shape Description of An Egg-Shaped Particles





Model Description

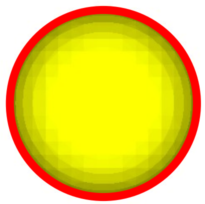
Shape Description of An Egg-Shaped Particles

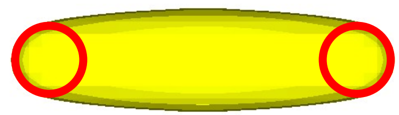


Model Description

Four Kinds of Shape

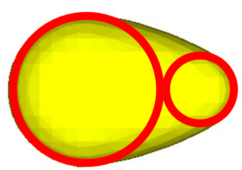
L1 = 0.0
R1 = 0.25
L3 = 0.0
R3 = 0.25
β = 60°

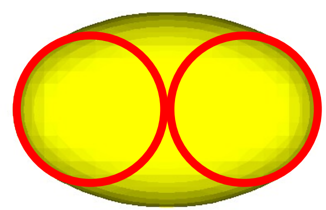




L1 = 0.4
R1 = 0.1
L3 = 0.4
R3 = 0.1
β = 80°

L1 = 0.1
R1 = 0.1
L3 = 0.2
R3 = 0.22
β = 60°



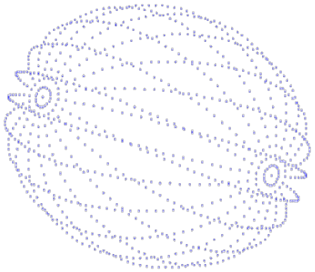


L1 = 0.2
R1 = 0.2
L3 = 0.2
R3 = 0.2
β = 60°

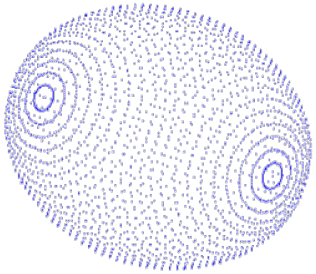
Model Description

Fluid-Structure Interaction Method

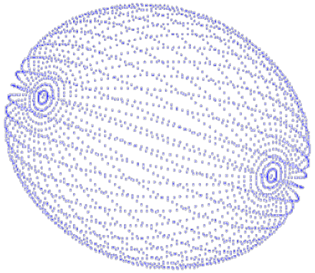
- Discrete Element Method (DEM)



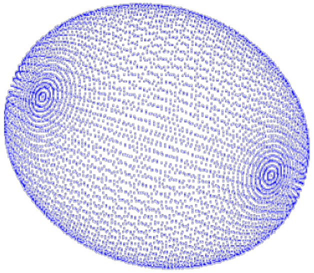
$N_d = 20, N_c = 50$



$N_d = 75, N_c = 40$



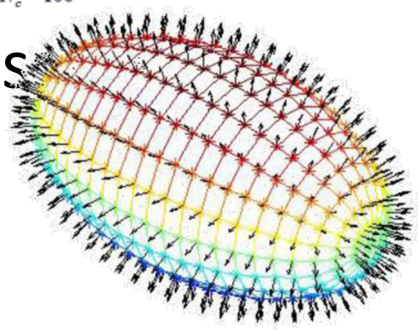
$N_d = 40, N_c = 75$



$N_d = 75, N_c = 100$

Surface Force = (Normal Stress p + Shear Stres τ

Area

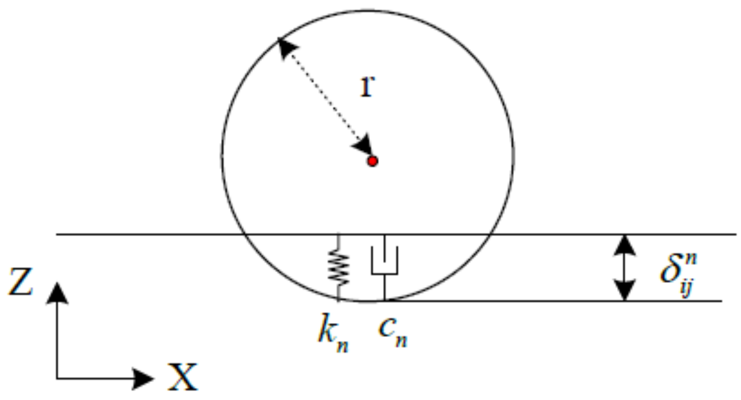


$$\tau = \mu \frac{\partial u}{\partial x}$$

Model Description

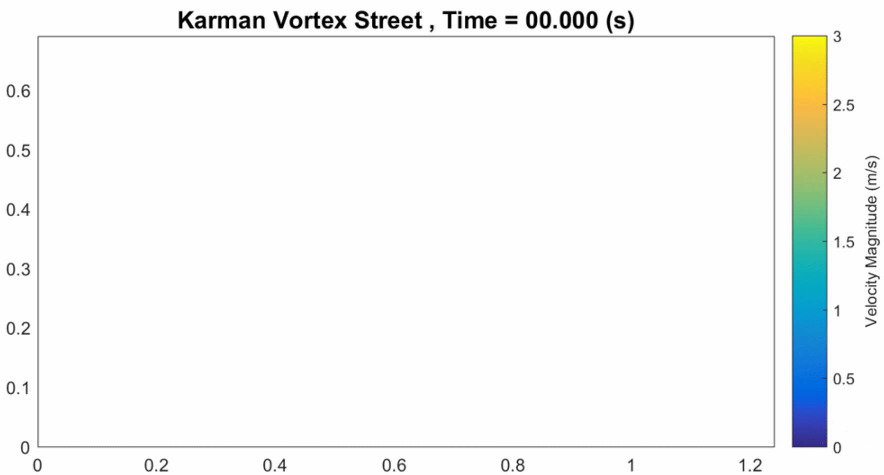
Fluid-Structure Interaction Method

Calculation model of normal contact force

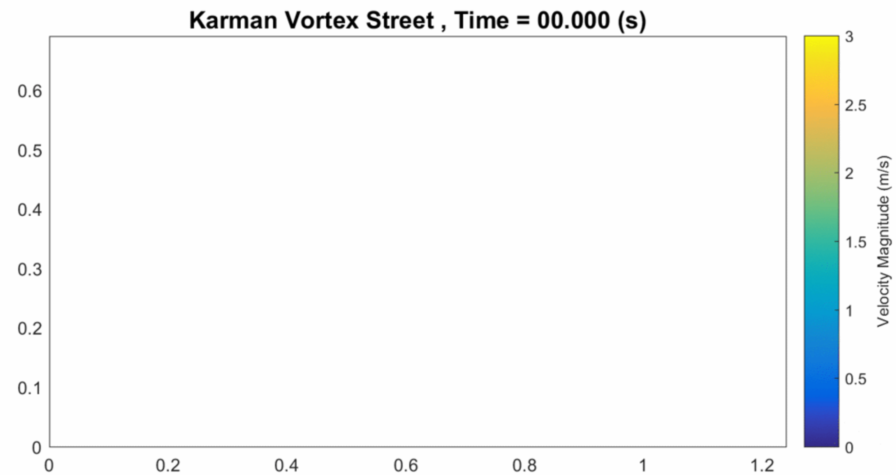


$$F_{total} = F_{surface} + F_{contact} + F_{Body}$$

Model Validation
Kármán Vortex Street Case

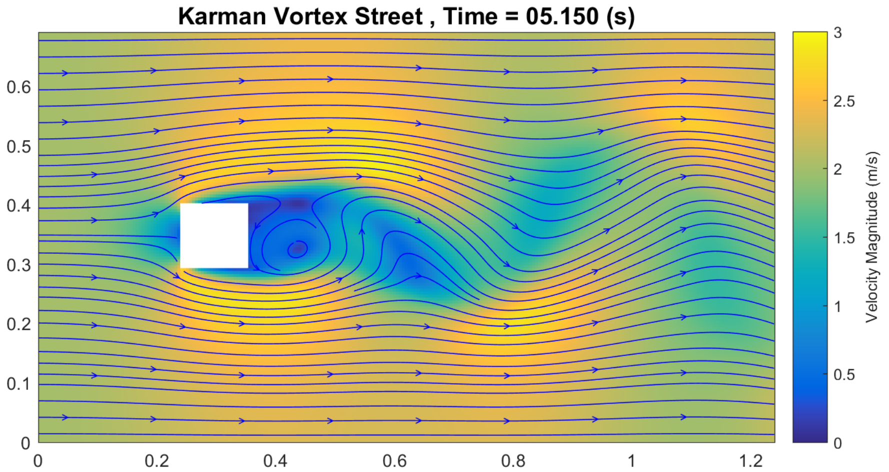


Moving Solid Algorithm

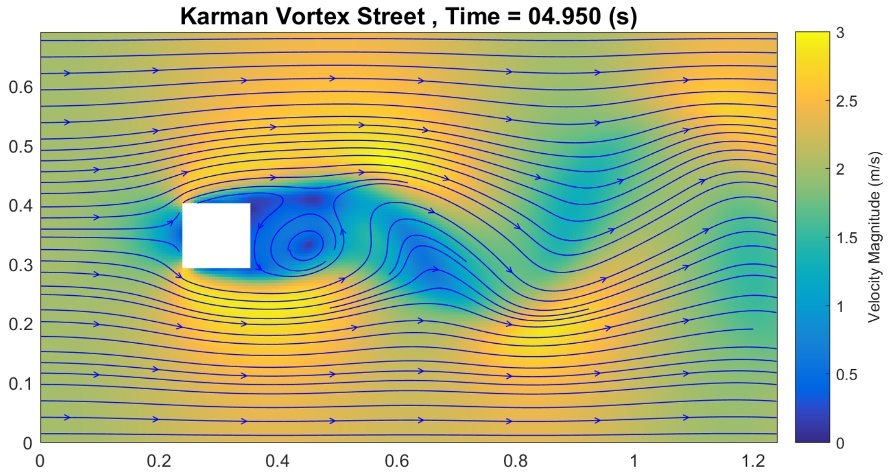


Partial Cell Treatment

Model Validation
Kármán Vortex Street Case

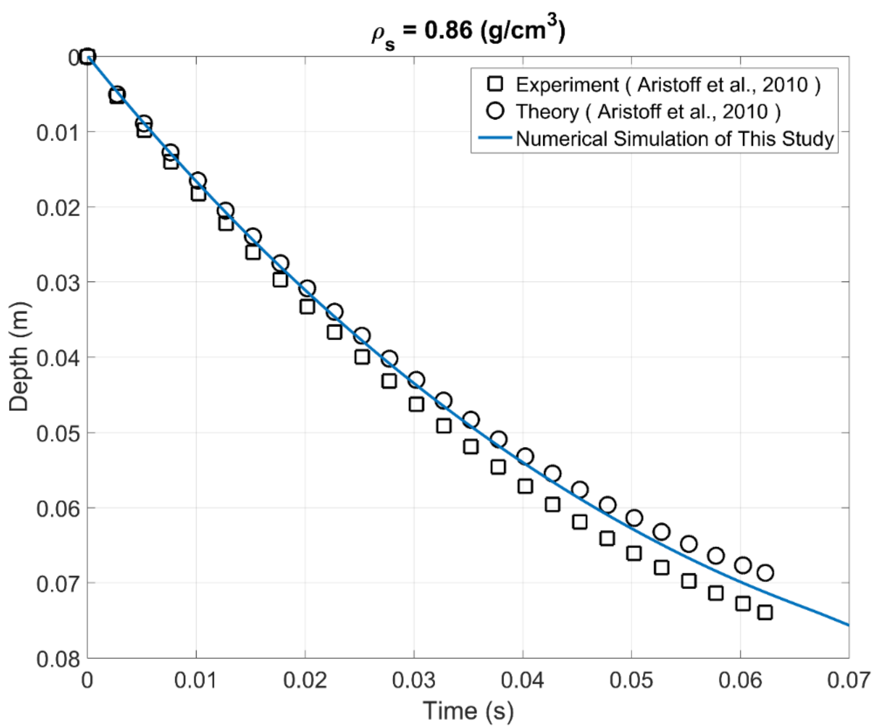


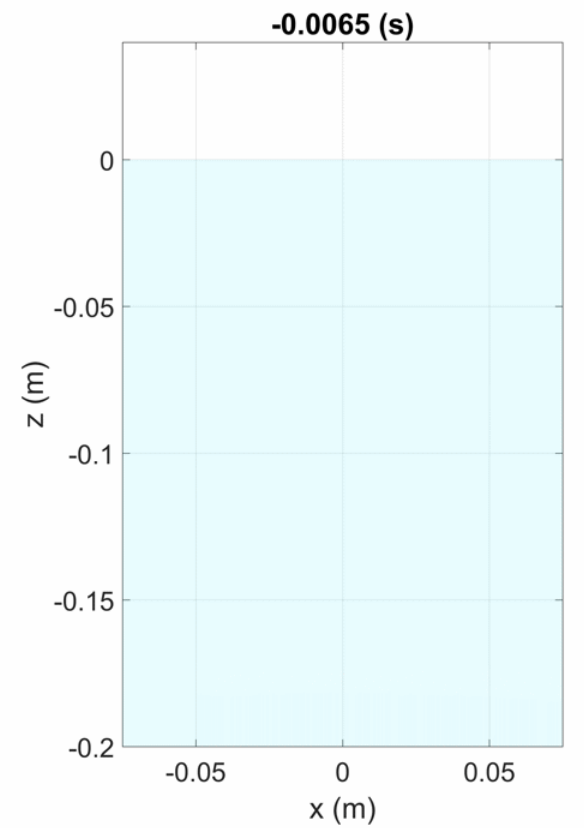
Moving Solid Algorithm

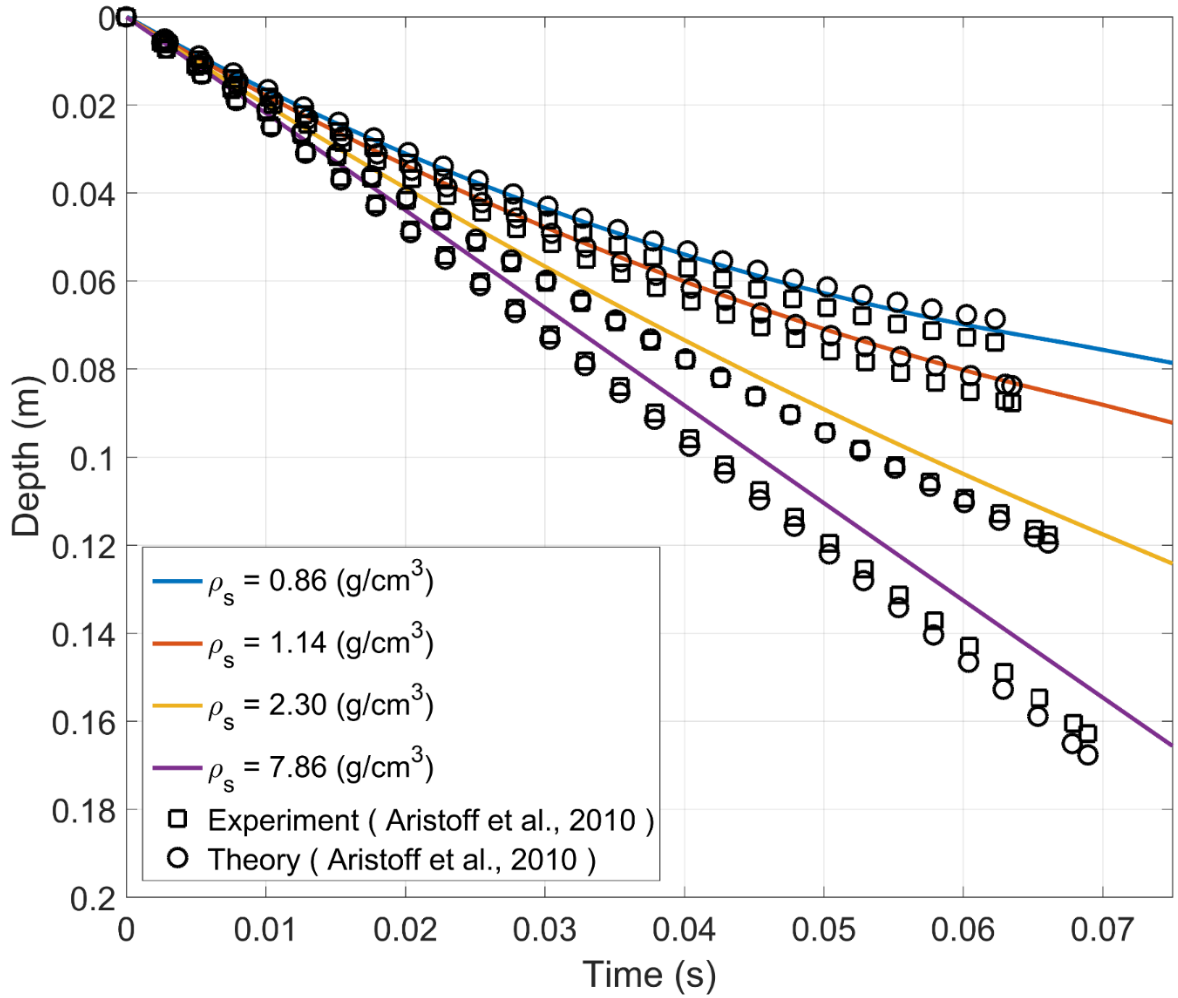


Partial Cell Treatment

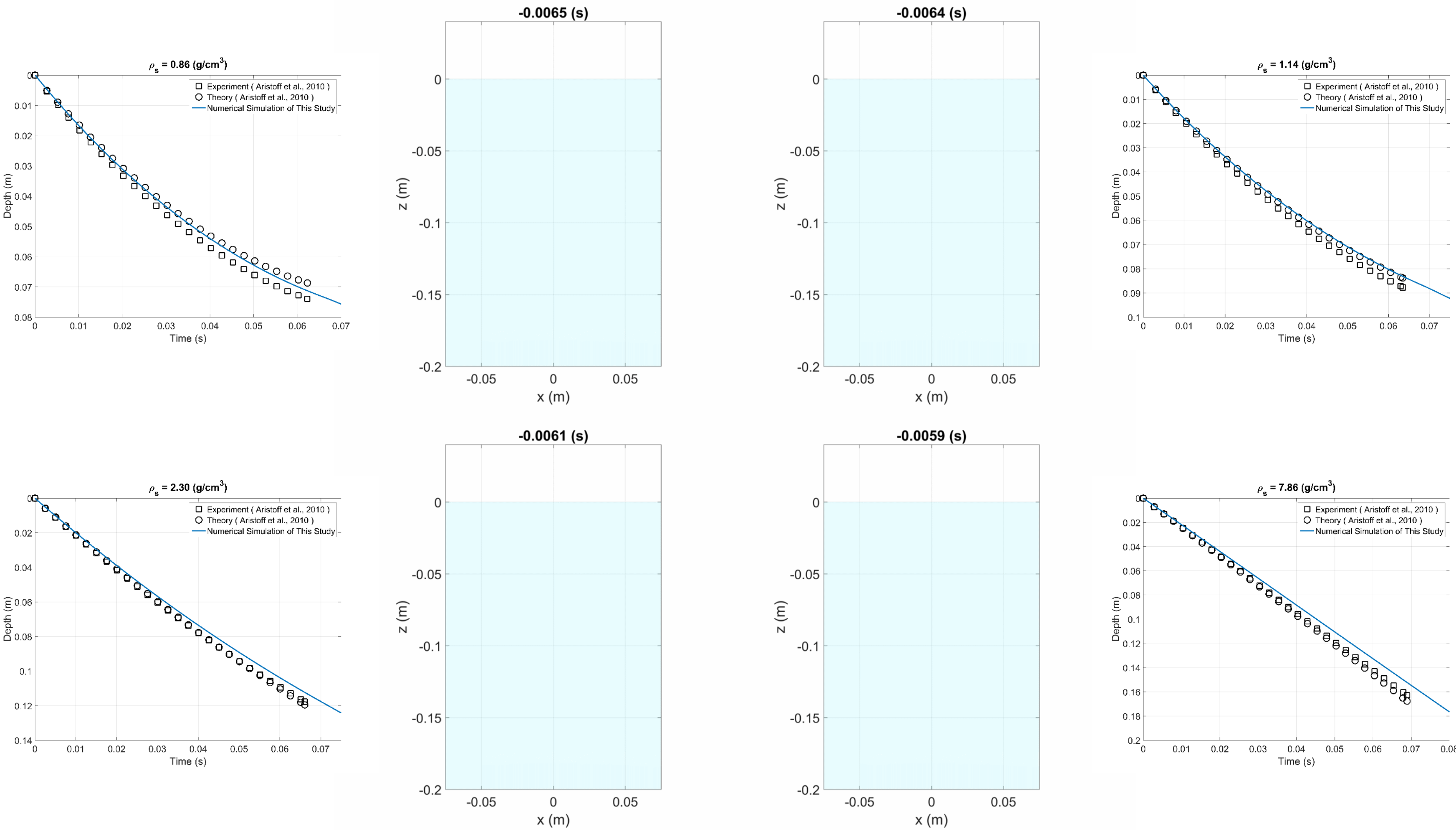
Model Validation
Water Entry Sphere







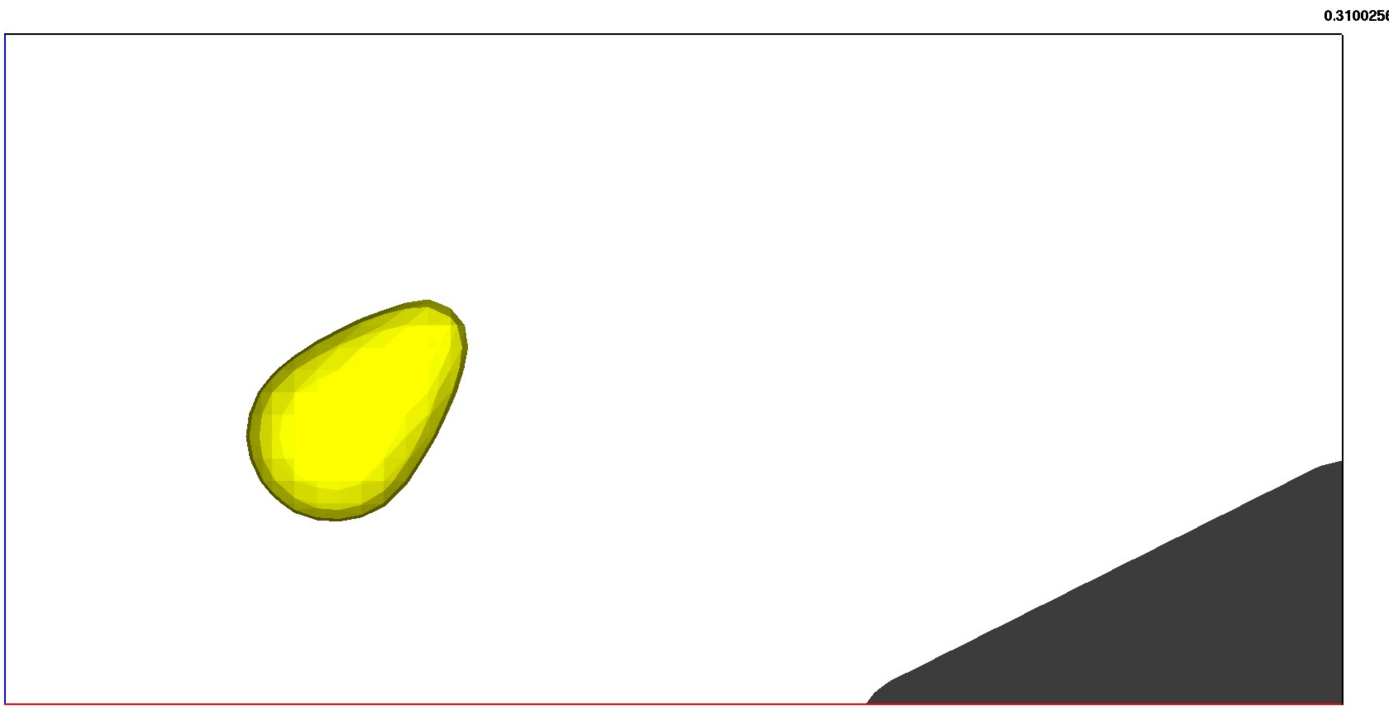
Depth (m)
Time (s)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
ρs = 0.86 (g/cm3)
ρs = 1.14 (g/cm3)
ρs = 2.30 (g/cm3)
ρs = 7.86 (g/cm3)
Experiment (Aristoff et al., 2010)
Theory (Aristoff et al., 2010)



ρs = 0.86 (g/cm3)
Experiment (Aristoff et al., 2010)
Theory (Aristoff et al., 2010)
Numerical Simulation of This Study
Depth (m)
Time (s)
-0.0065 (s)
-0.0064 (s)
z (m)
x (m)
ρs = 1.14 (g/cm3)
Experiment (Aristoff et al., 2010)
Theory (Aristoff et al., 2010)
Numerical Simulation of This Study
Depth (m)
Time (s)
ρs = 2.30 (g/cm3)
Experiment (Aristoff et al., 2010)
Theory (Aristoff et al., 2010)
Numerical Simulation of This Study
Depth (m)
Time (s)
-0.0061 (s)
-0.0059 (s)
z (m)
x (m)
ρs = 7.86 (g/cm3)
Experiment (Aristoff et al., 2010)
Theory (Aristoff et al., 2010)
Numerical Simulation of This Study
Depth (m)
Time (s)

Case 1
Projectile Motion

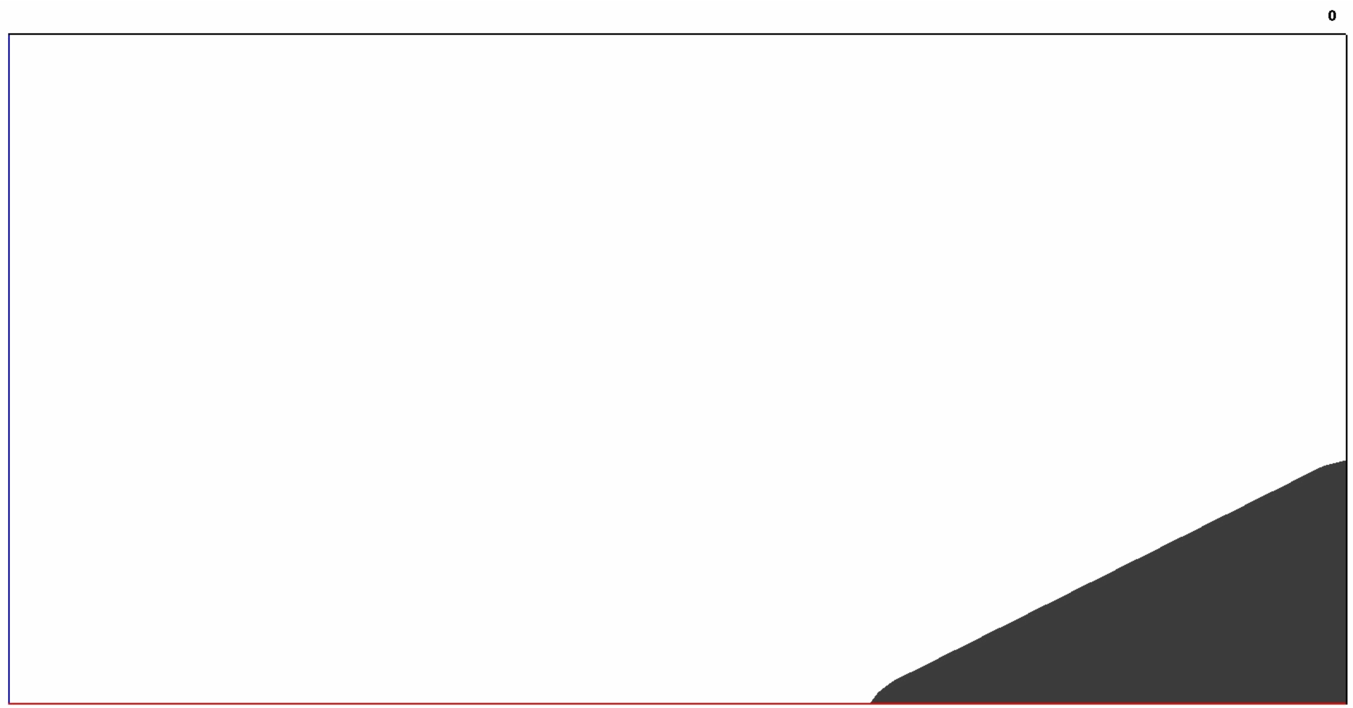
$V_0 = 10$ m/s



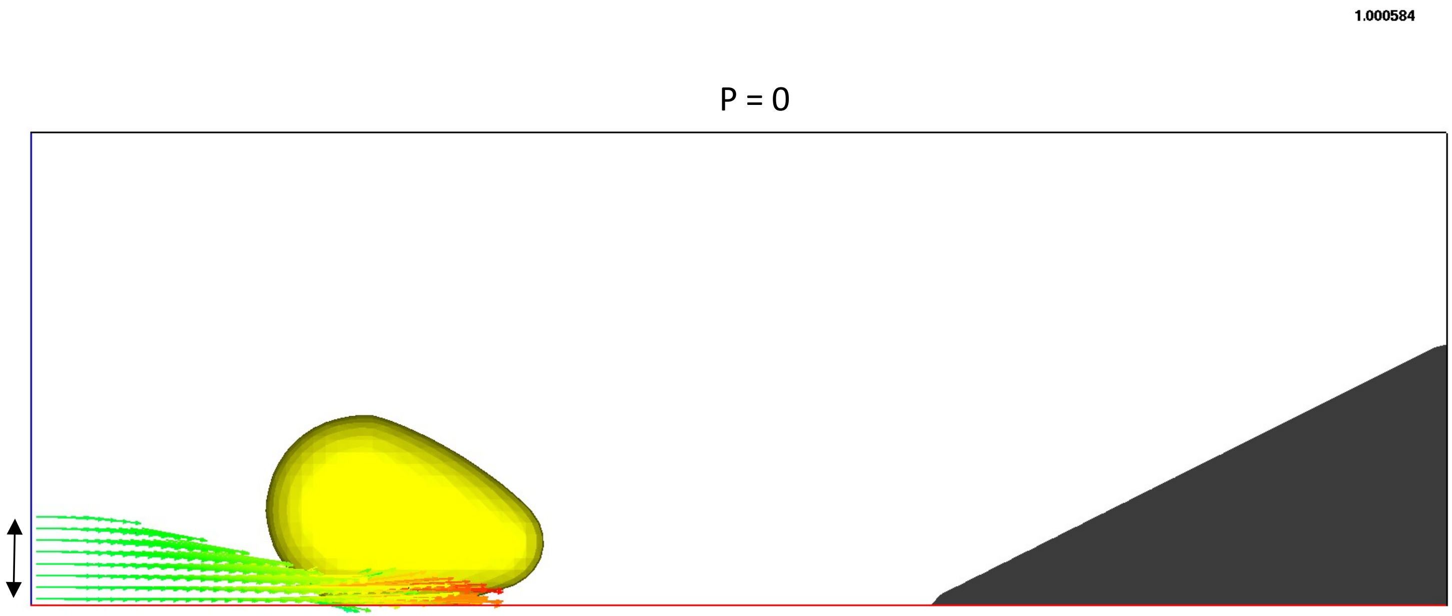
Case 1

Projectile Motion

V_0 = 10 m/s

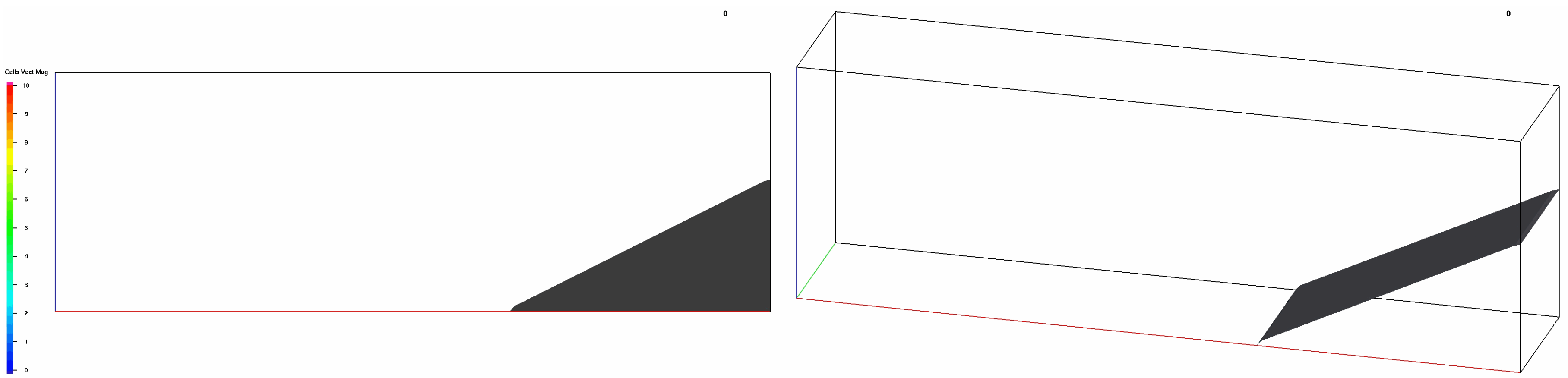


Case 2
Wave Impact and Solid Motion



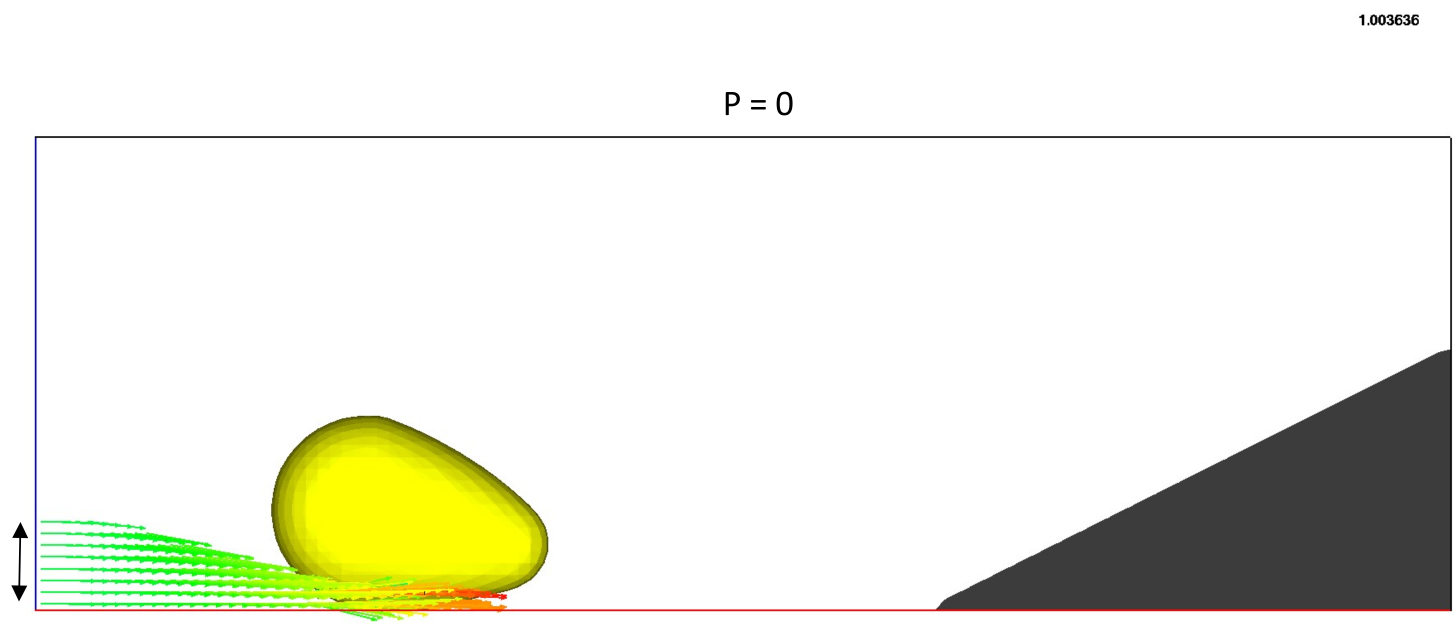
h = 2 m $C = \sqrt{gh} = 4.43\ m/s$ d = 1000 kg/m^3

Case 2
Wave Impact and Solid Motion



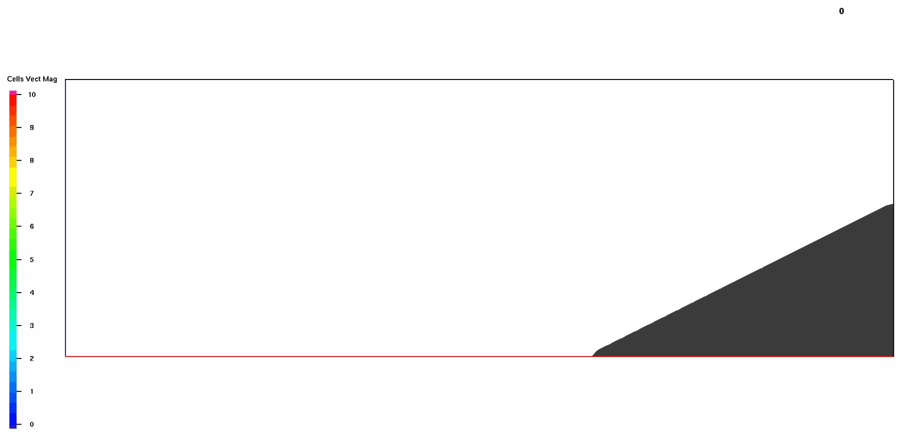
Case 3

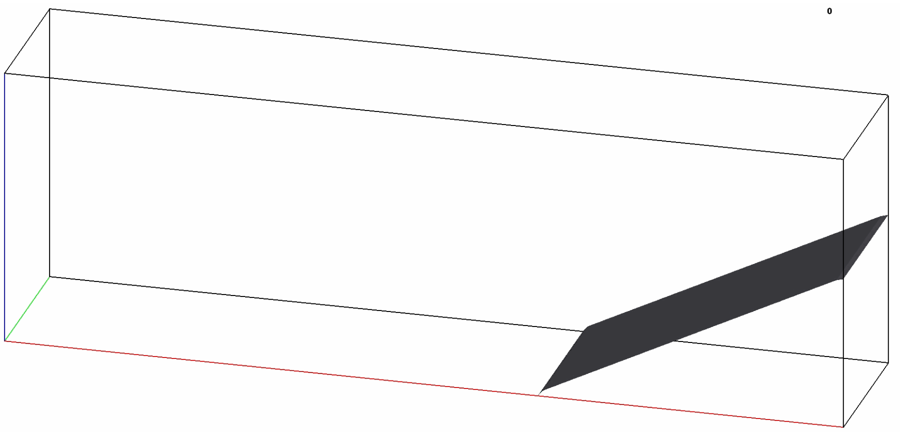
Wave Impact and Solid Floating



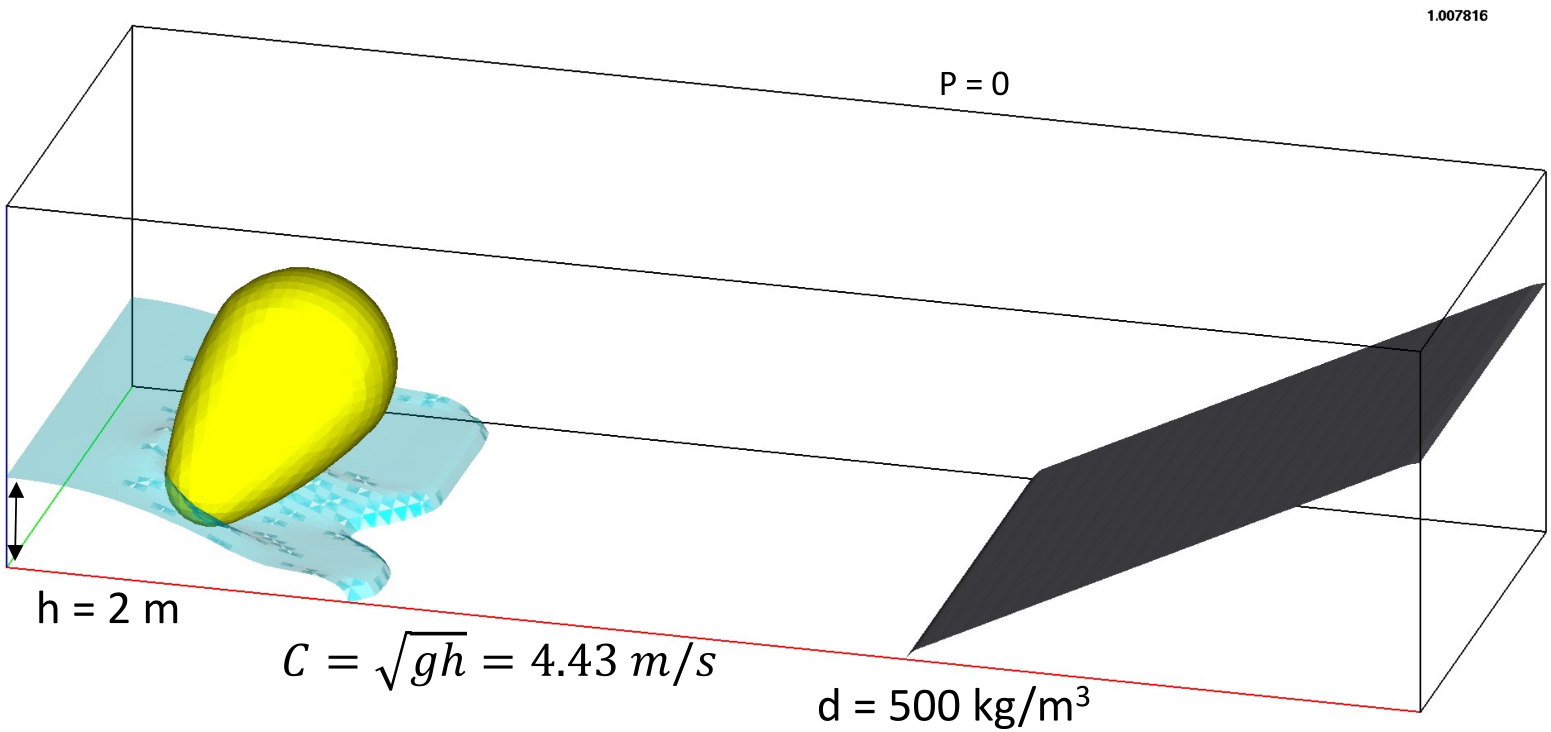
h = 2 m $\quad C = \sqrt{gh} = 4.43\ m/s \quad$ d = 100 kg/m^3

Case 3
Wave Impact and Solid Floating

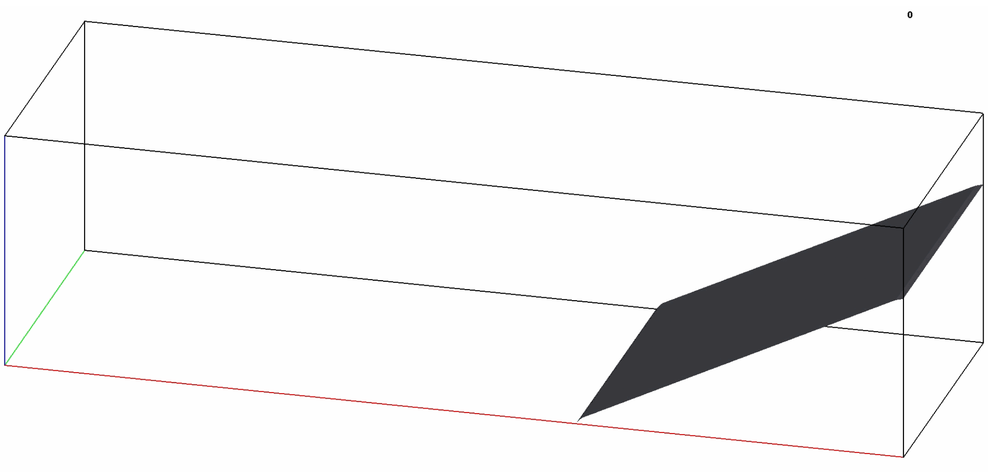


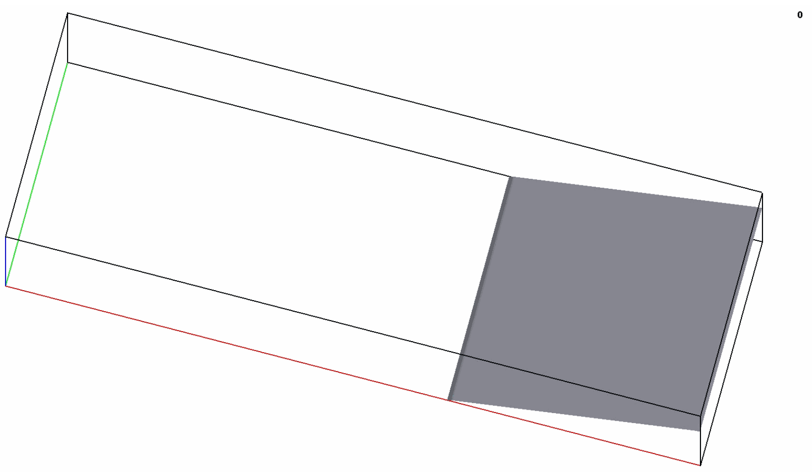


Case 4
Wave Impact and Solid Rotation

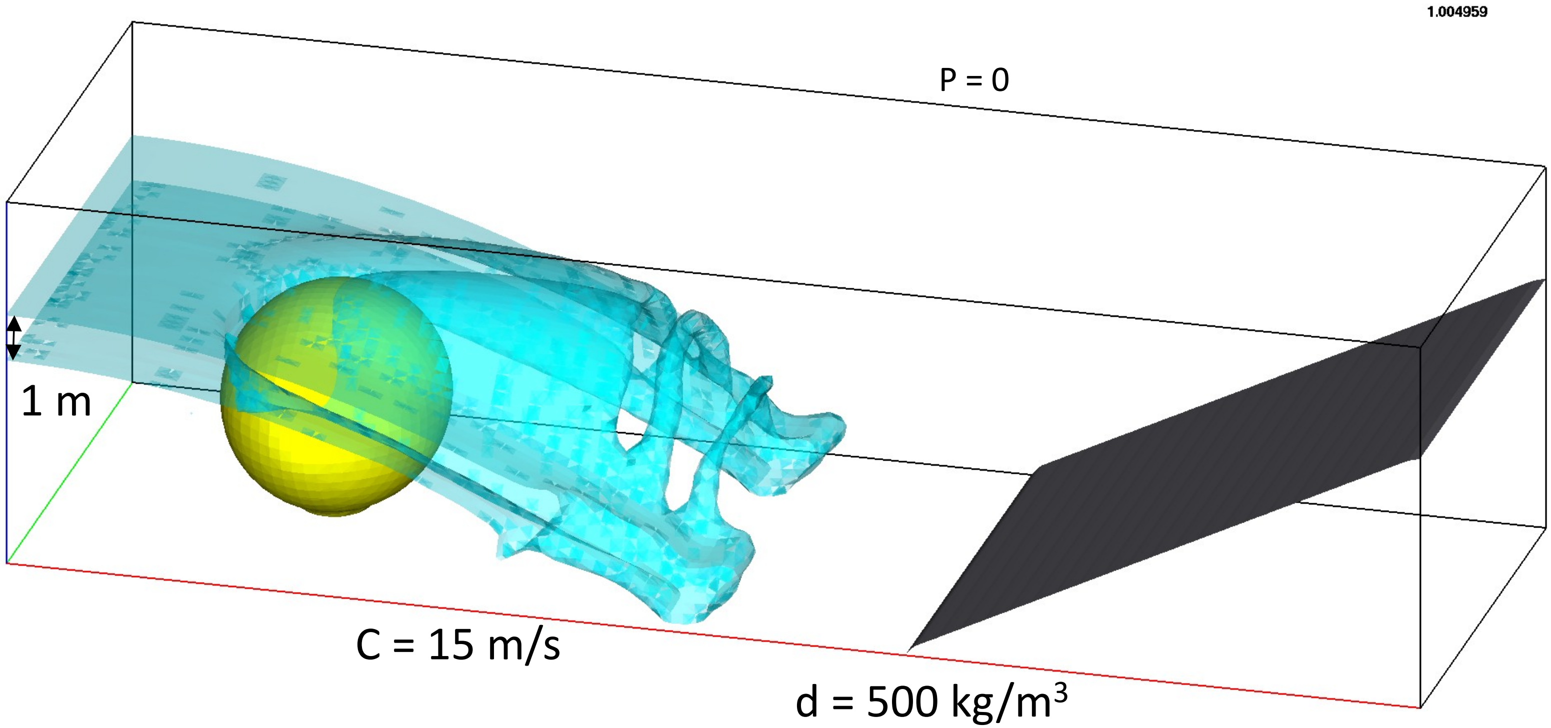


Case 4
Wave Impact and Solid Rotation



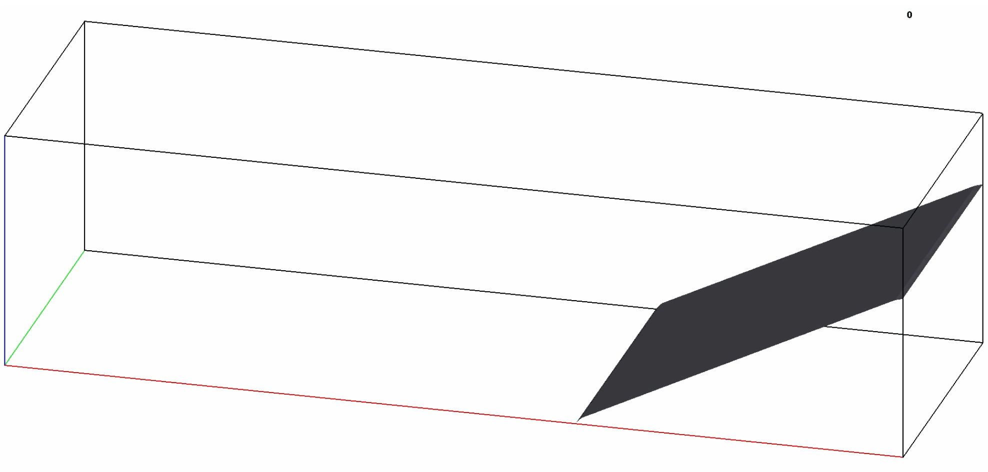


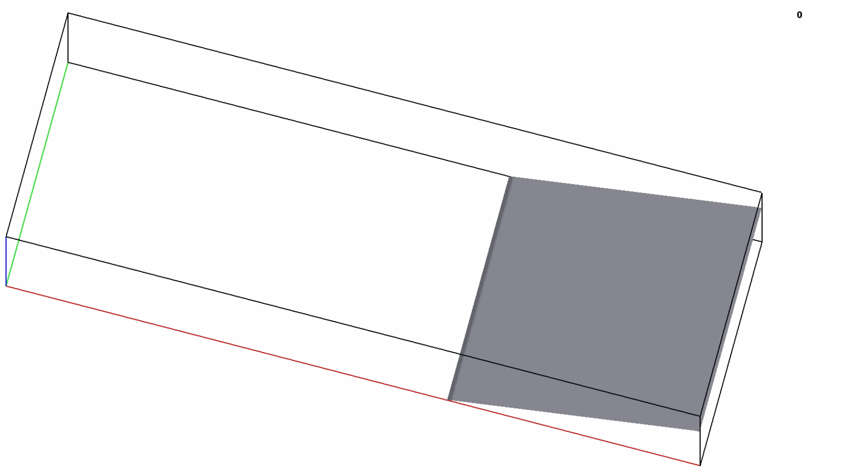
Case 5
Wave Impact and Solid Rolling



Case 5

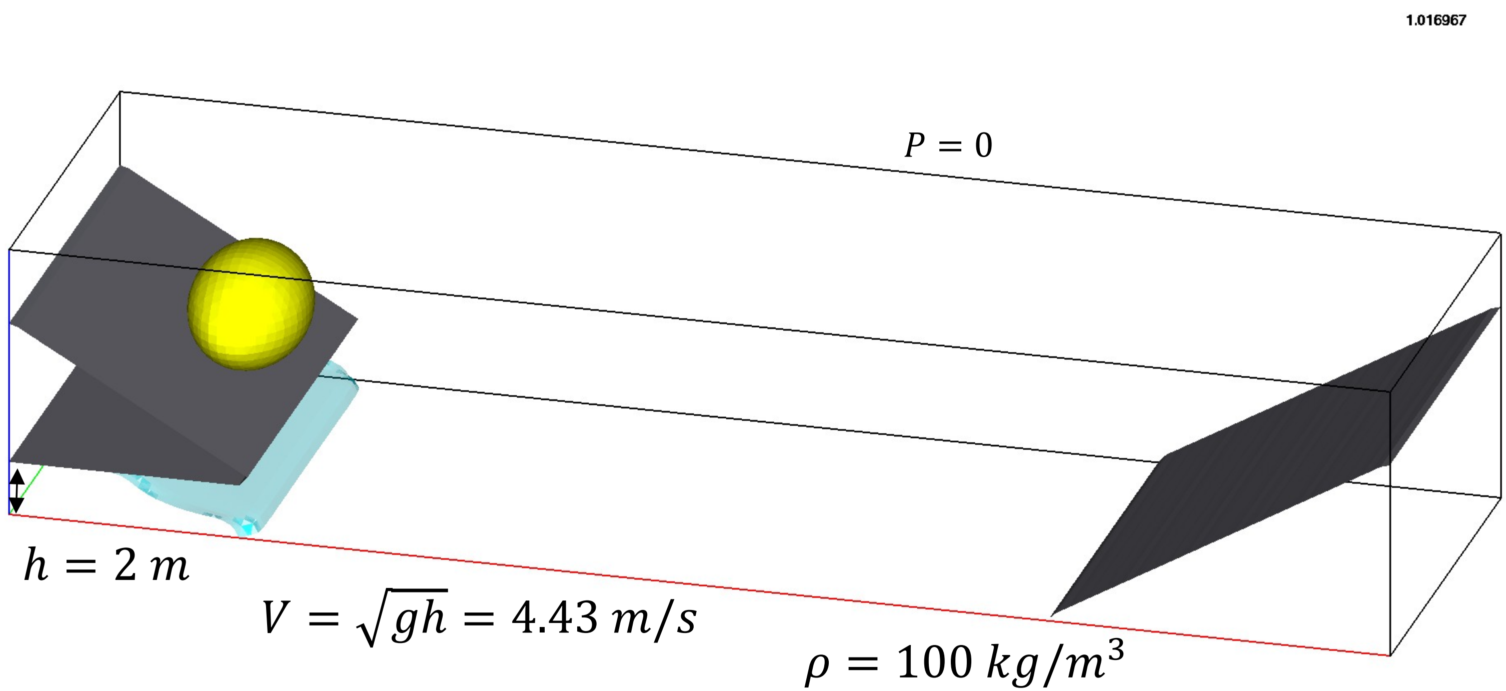
Wave Impact and Solid Rolling





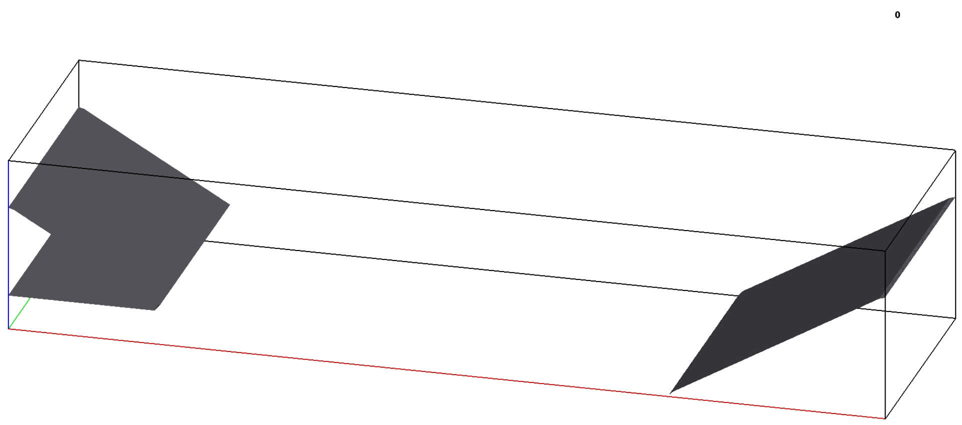
Case 6

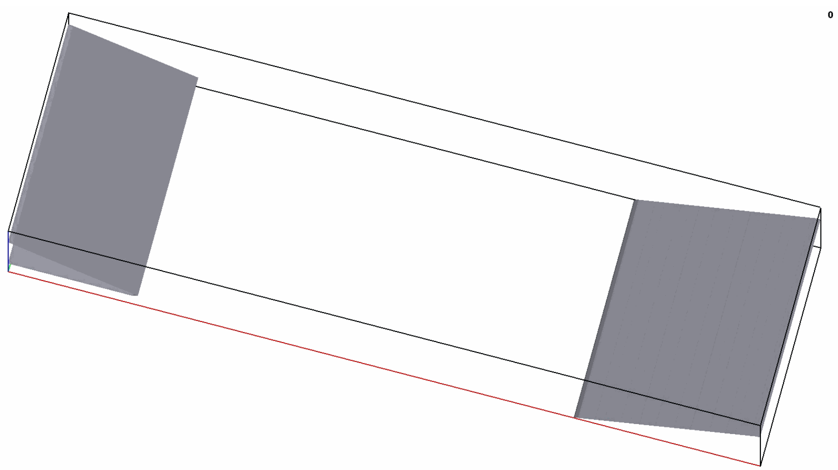
Bouncing, Rolling, Floating



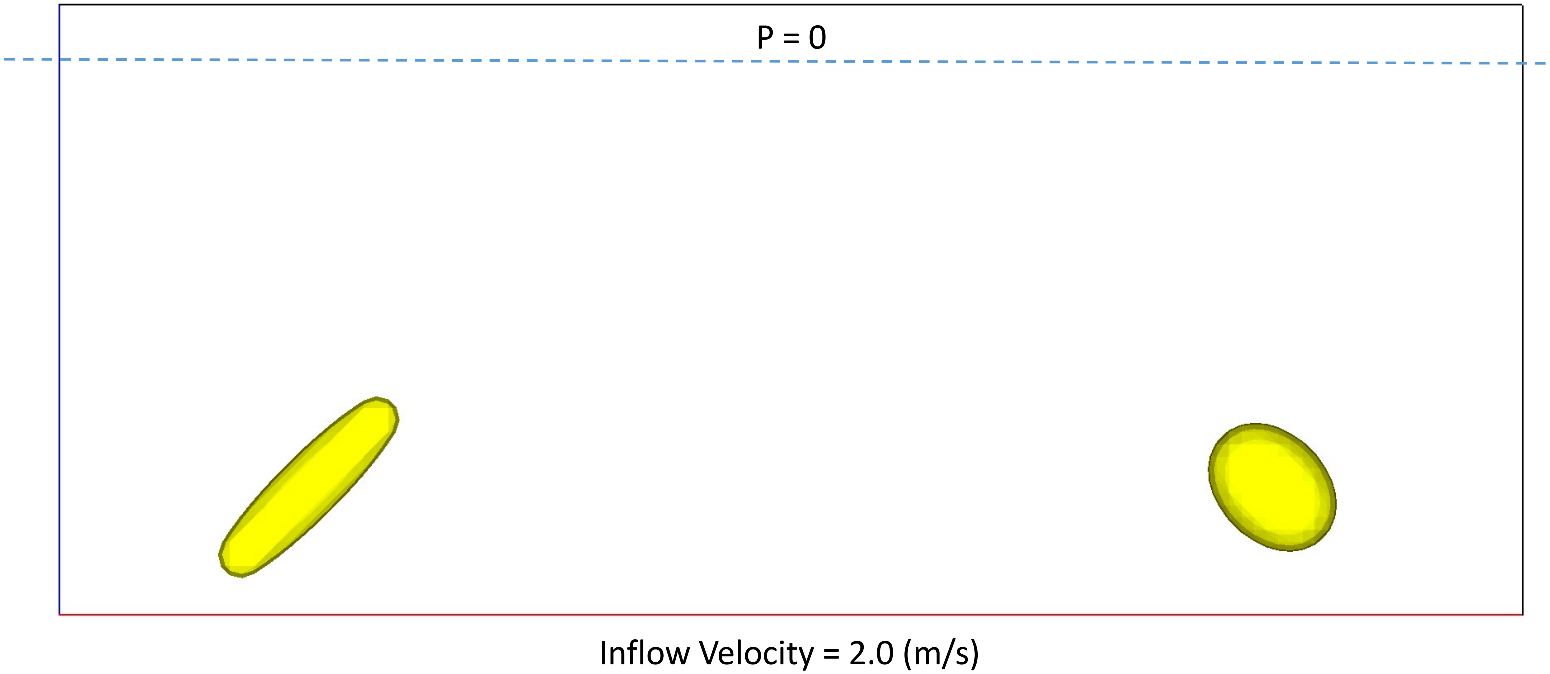
Case 6

Bouncing, Rolling, Floating





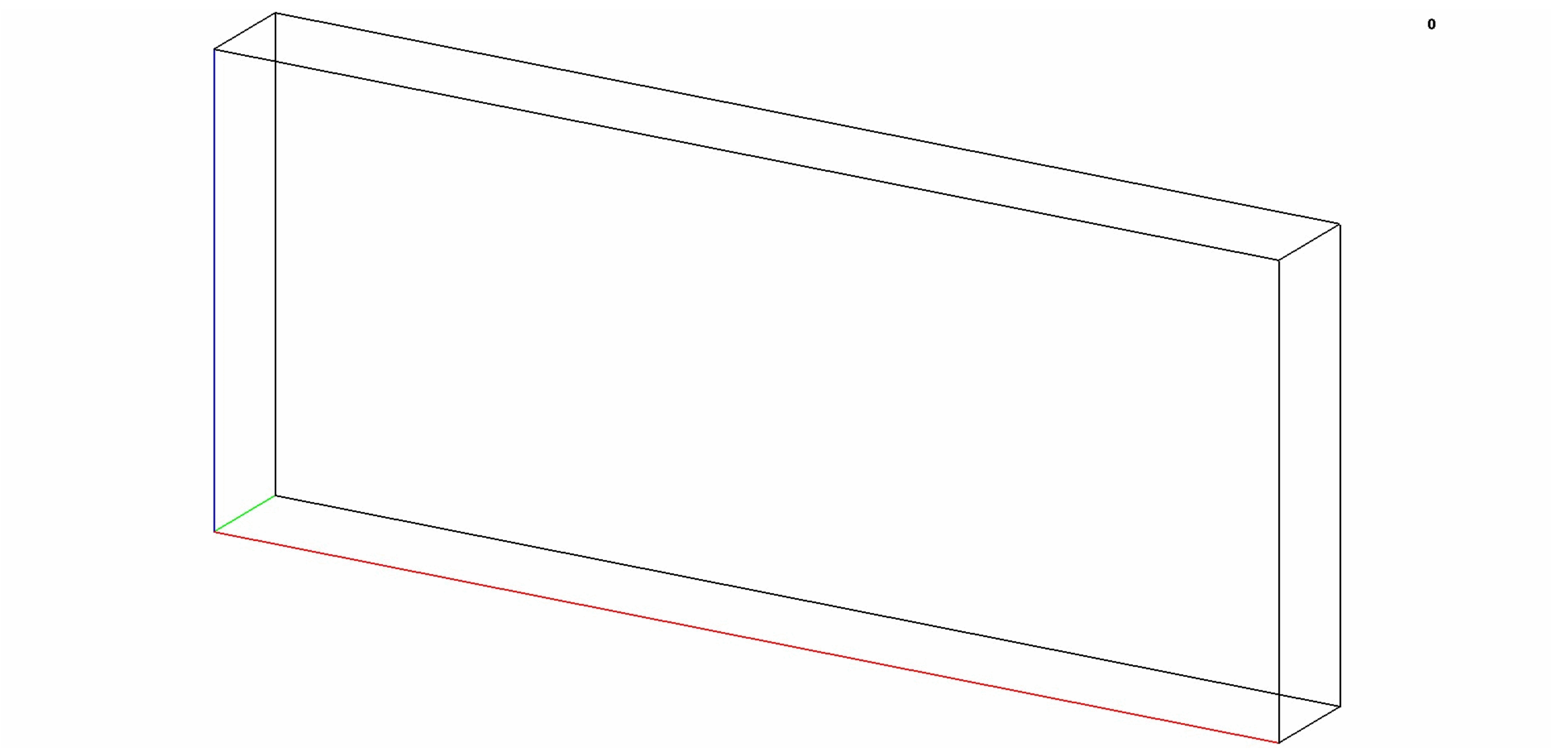
Case 7
Projectile Motion and Collision



Case 7 (2D-view)

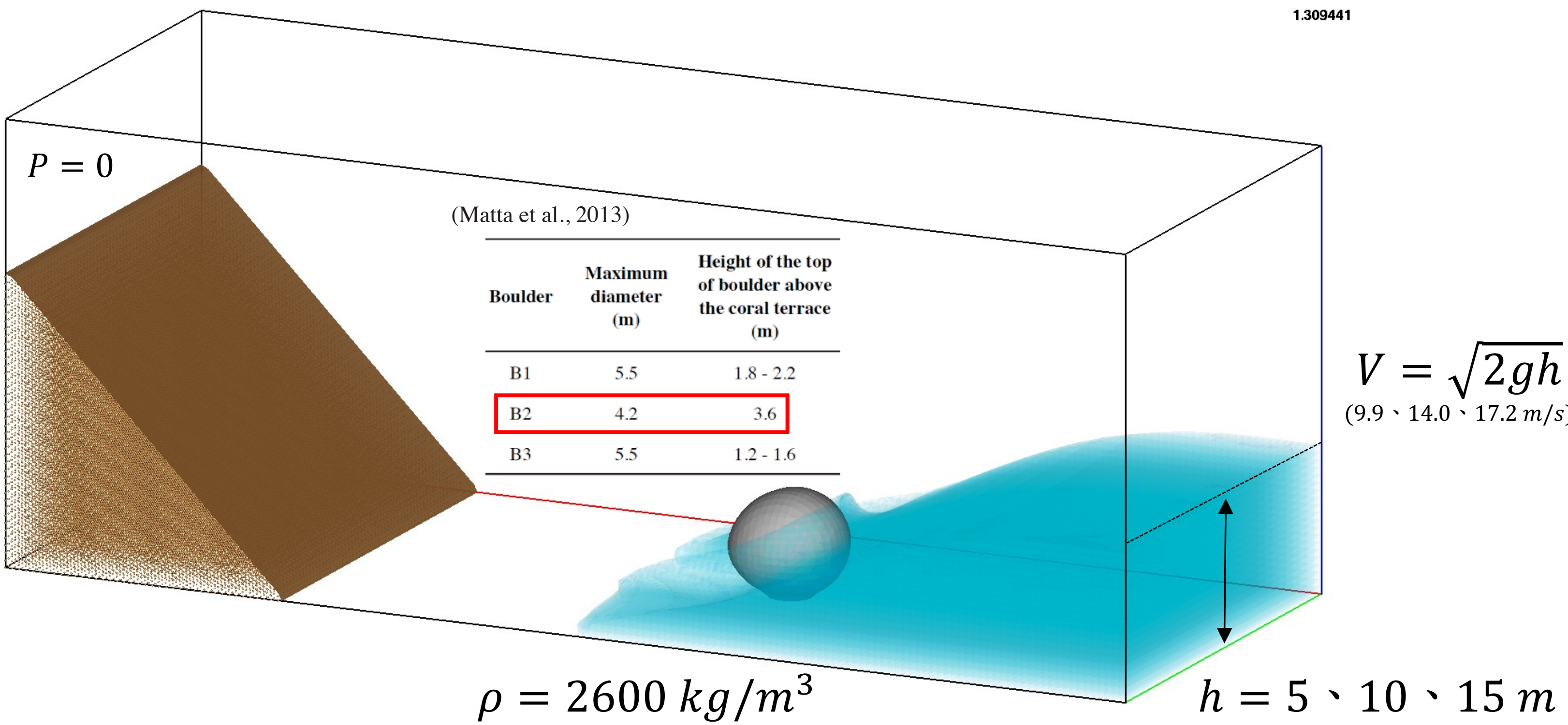
Projectile Motion and Collision

Case 7 (3D-view)
Projectile Motion and Collision



Results and Discussion

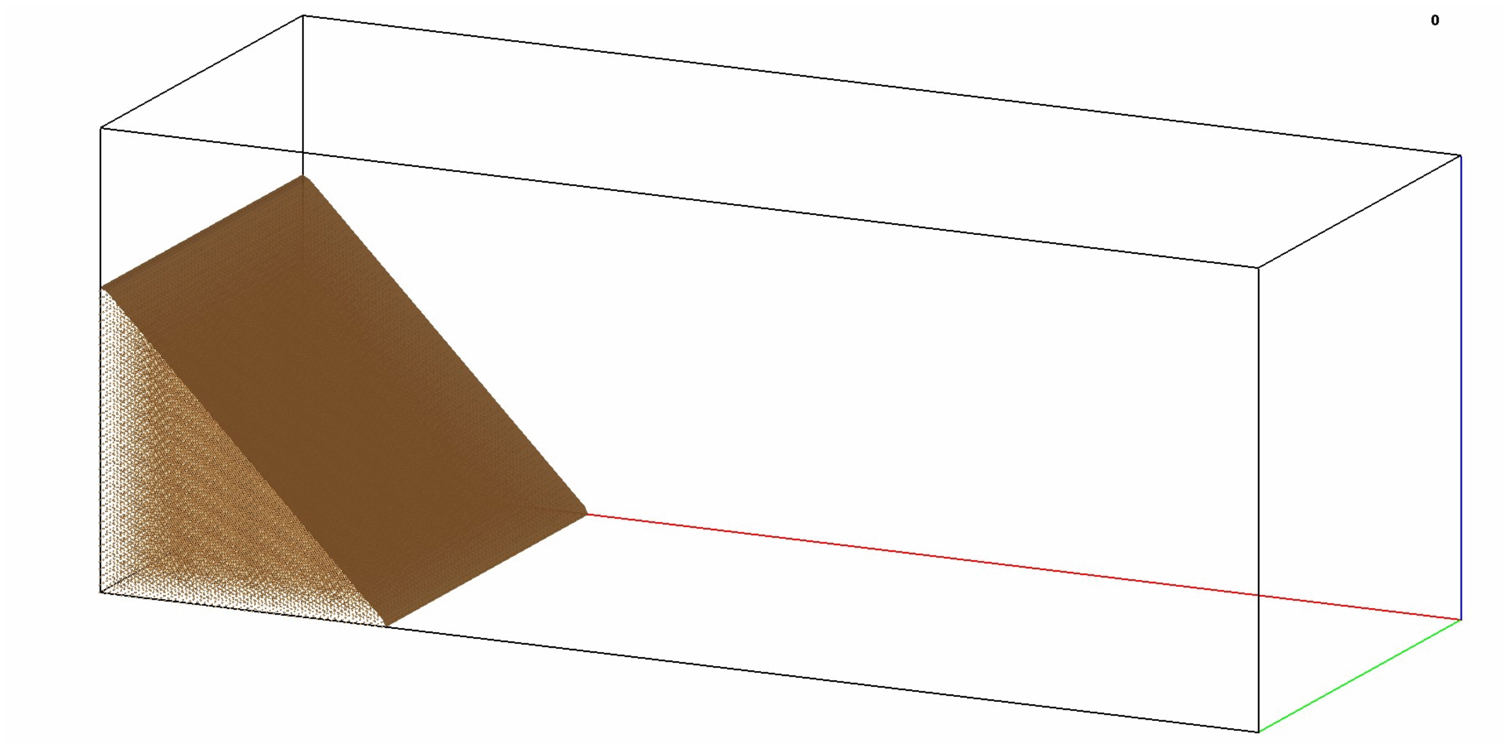
Simulation Setup



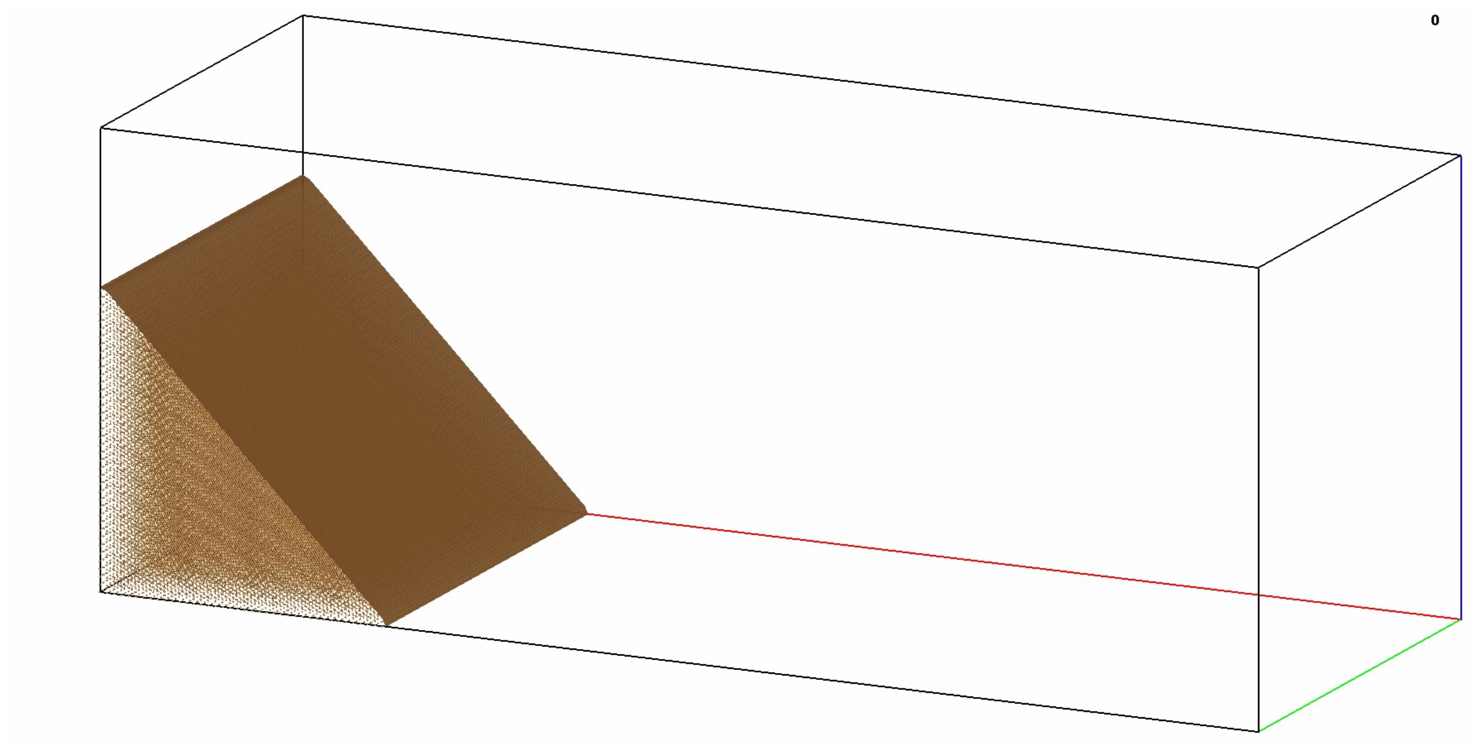
(Matta et al., 2013)

Boulder	Maximum diameter (m)	Height of the top of boulder above the coral terrace (m)
B1	5.5	1.8 - 2.2
B2	4.2	3.6
B3	5.5	1.2 - 1.6

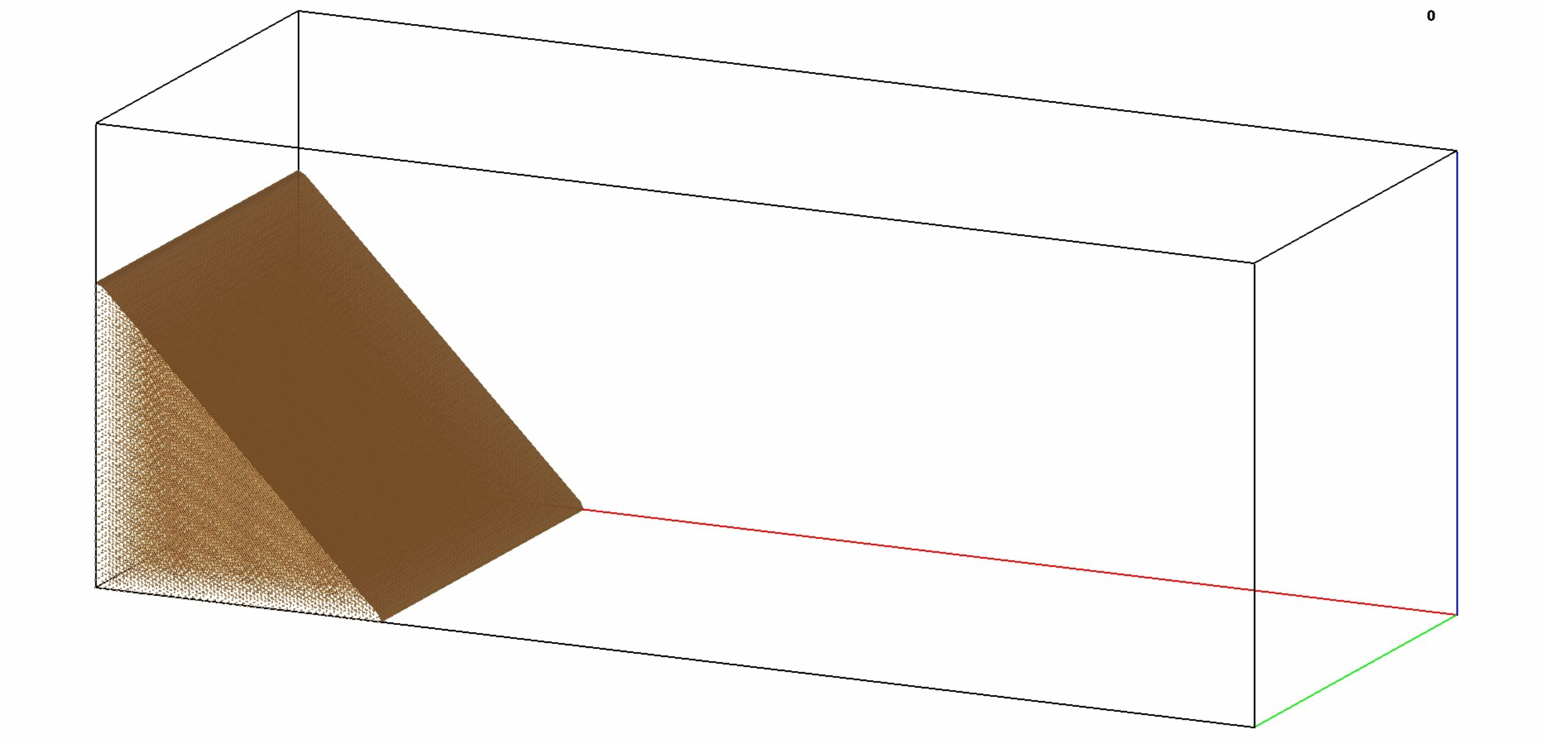
Run-Up Test
5 Meter Bore



Run-Up Test
10 Meter Bore



Run-Up Test
15 Meter Bore



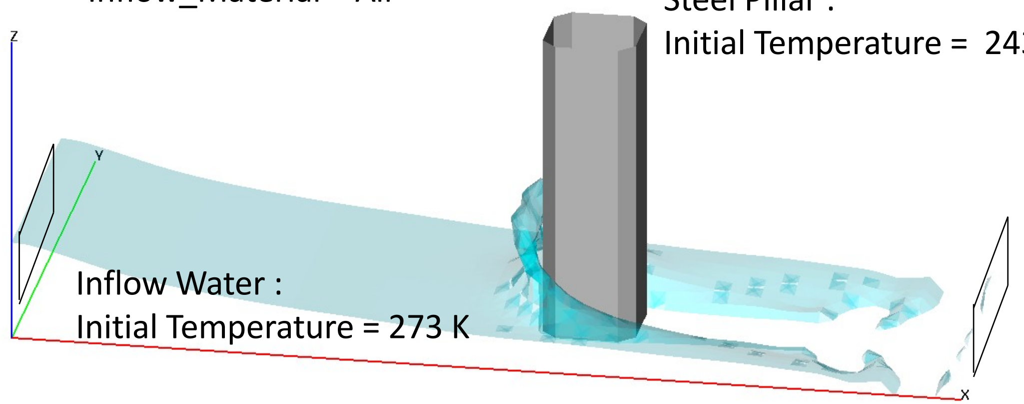
Heat Conduction Test Case 3
Inflow Water Icing with Steel Pillar

2.017826

Top Boundary , Pressure = 0
Inflow_Material = Air

Steel Pillar :
Initial Temperature = 243 K

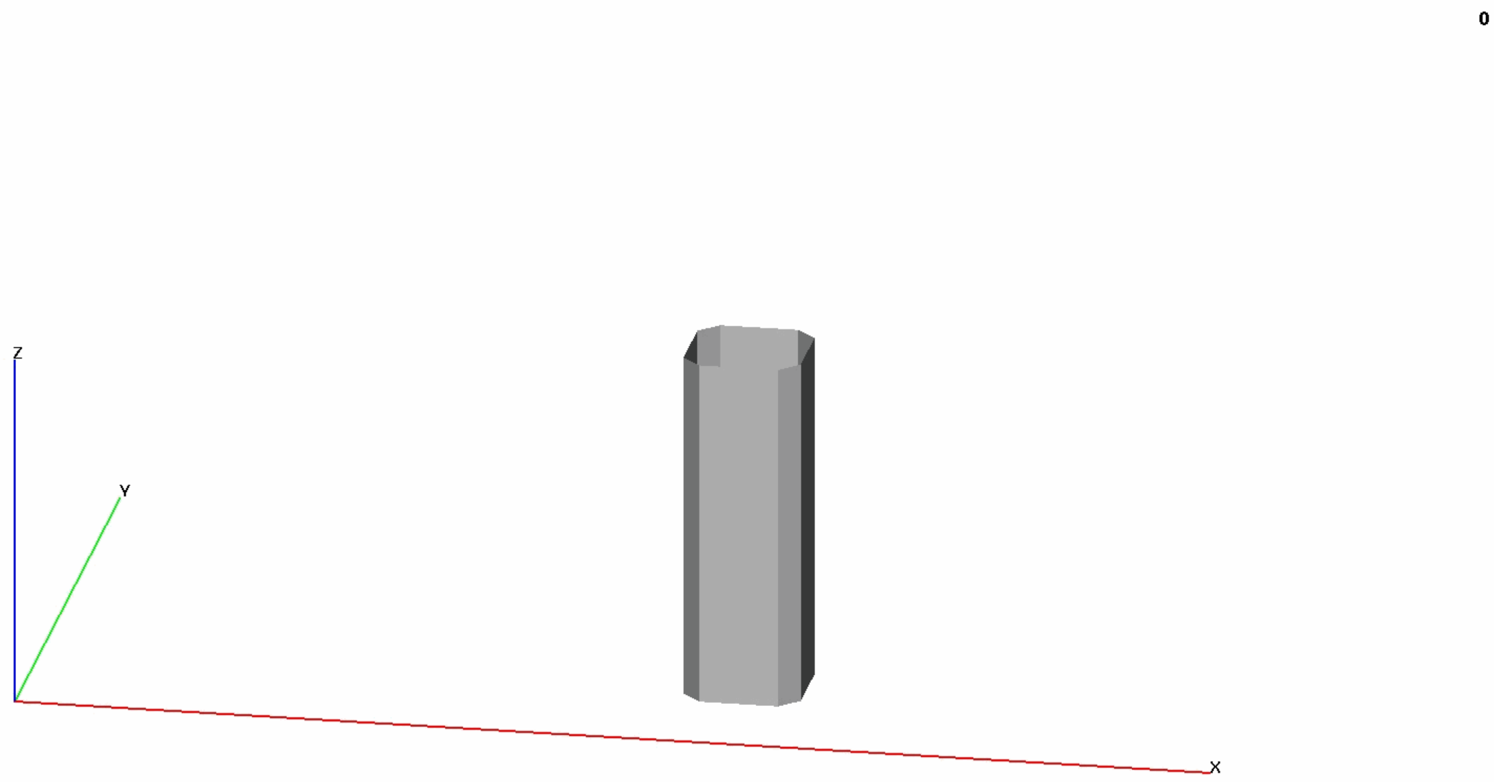
Bounding Box
Inflow Velocity = 3.0m/s



Inflow Water :
Initial Temperature = 273 K

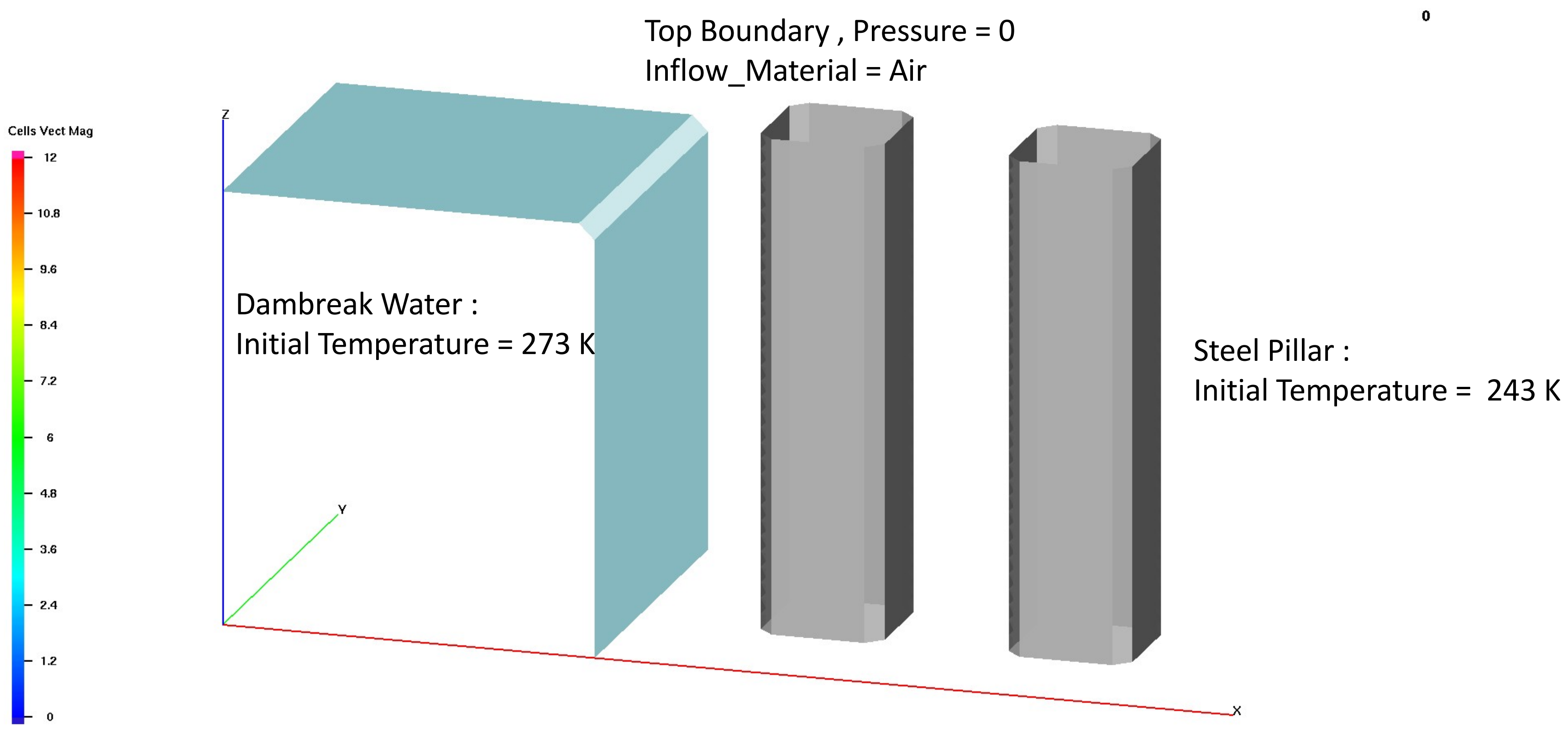
Bounding Box
Outflow Velocity = 3.0m/s

Heat Conduction Test Case 3
Inflow Water Icing with Steel Pillar



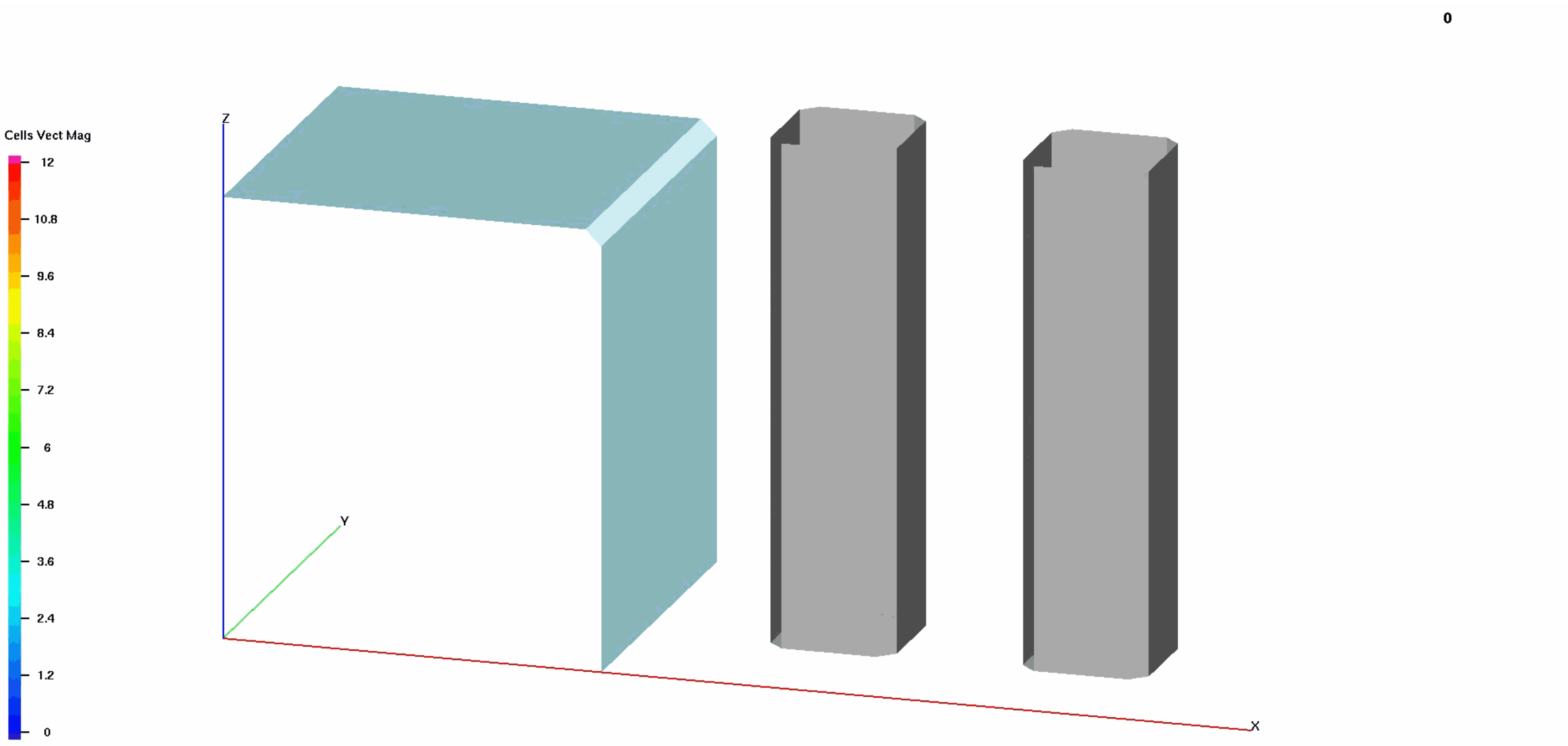
Heat Conduction Test Case 4

Dambreak Water Icing with Steel Pillar



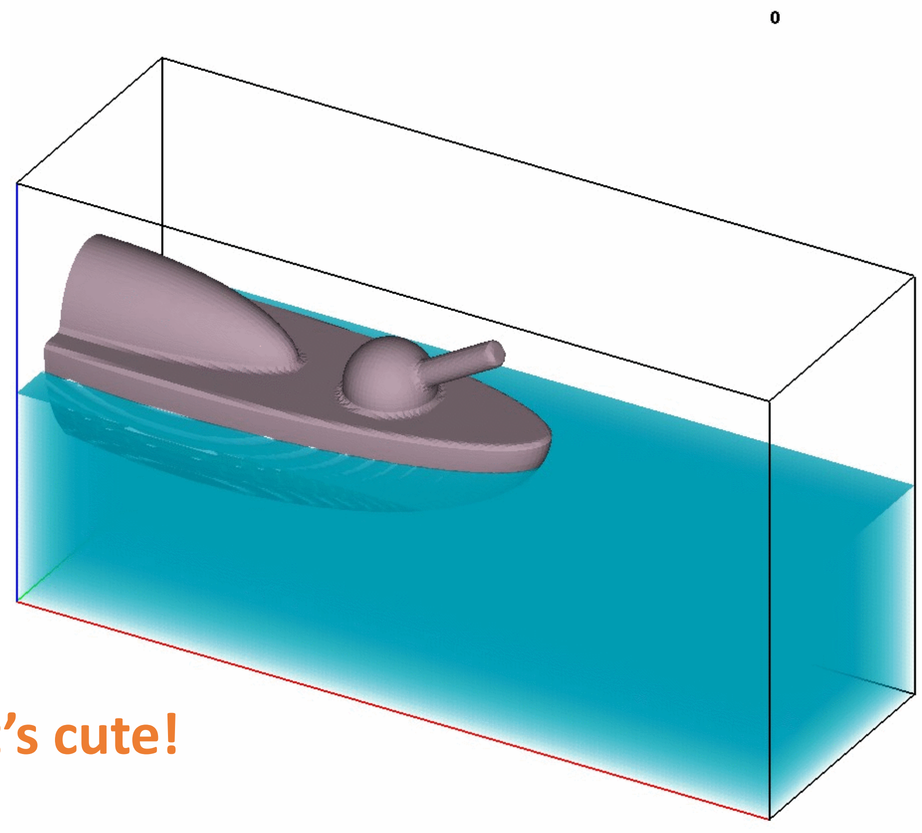
Heat Conduction Test Case 4

Dambreak Water Icing with Steel Pillar



Heat Conduction Test Case 5

Splash Water Caused by Projectile and Icing with Ship



Failed, but it's cute!

Exhibit Case 1

Purpose : Simulate the stability of long-shape floating object when rockfall

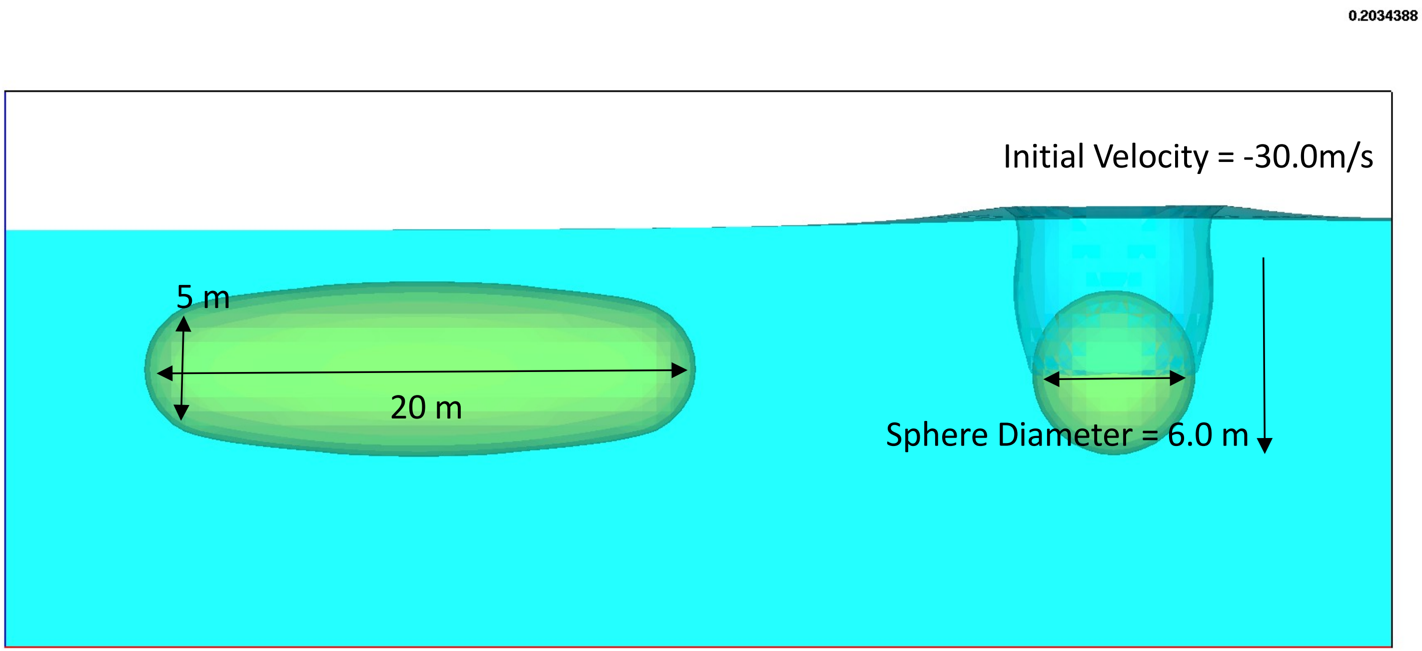


Exhibit Case 1

Purpose : Simulate the stability of long-shape floating object when rockfall

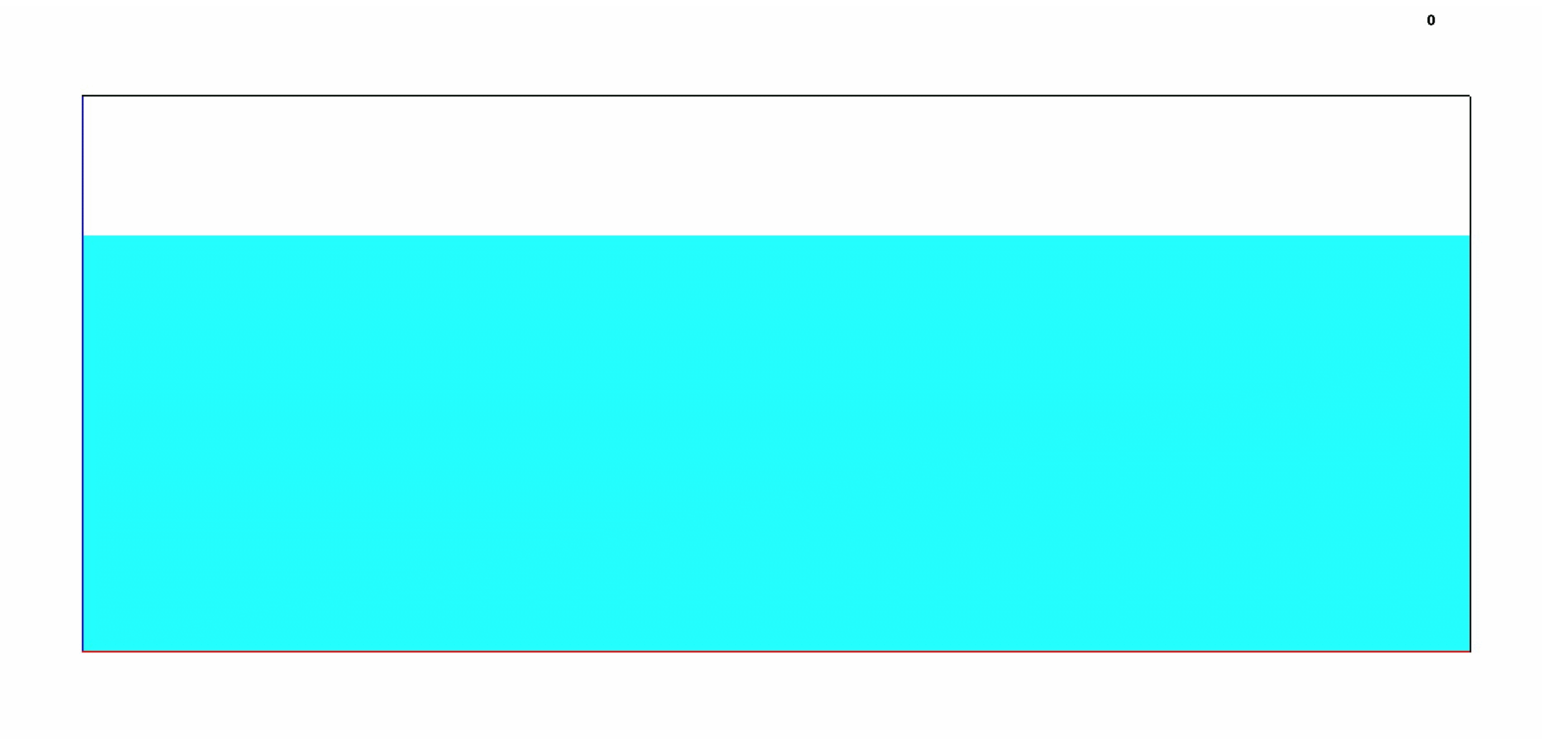


Exhibit Case 2

Purpose : Simulate the stability of long-shape floating object when mudflow

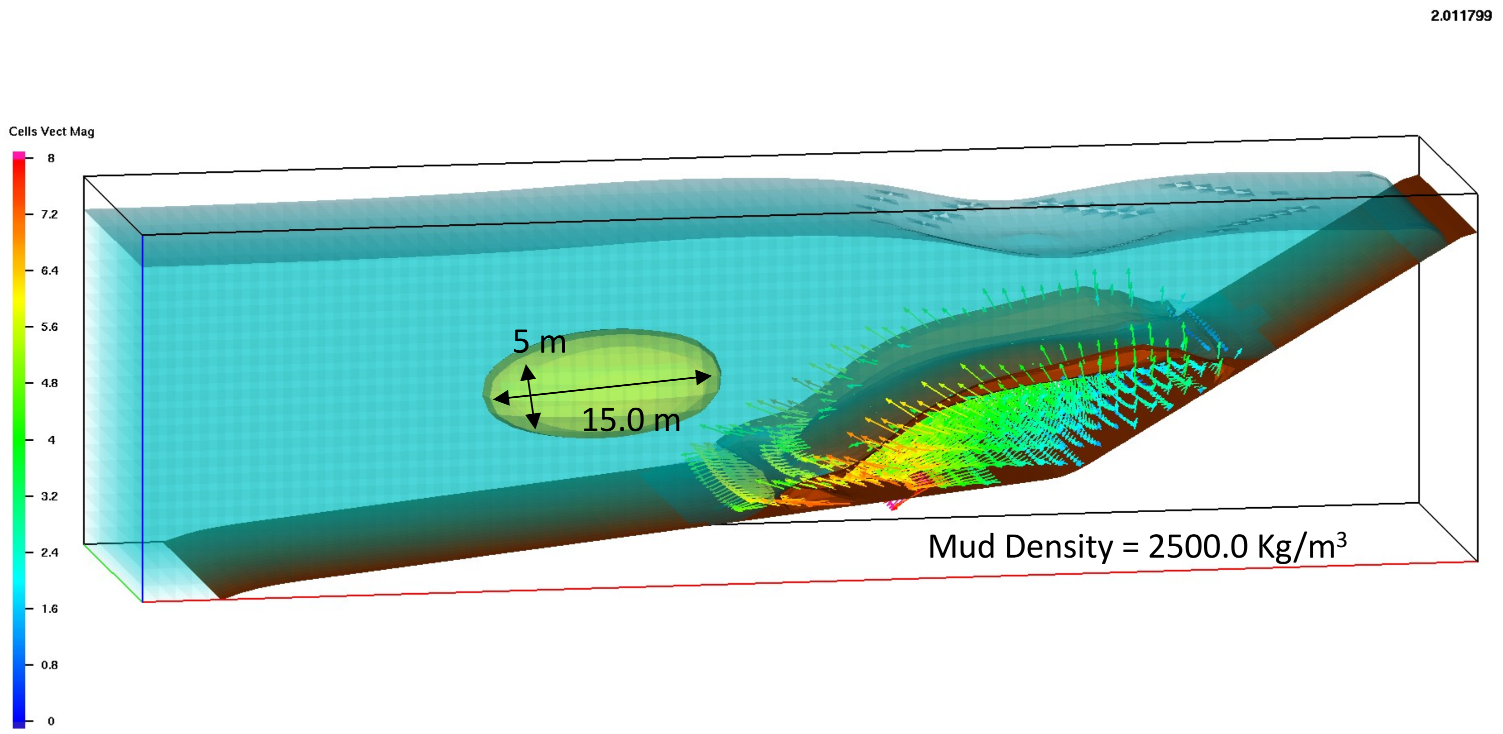
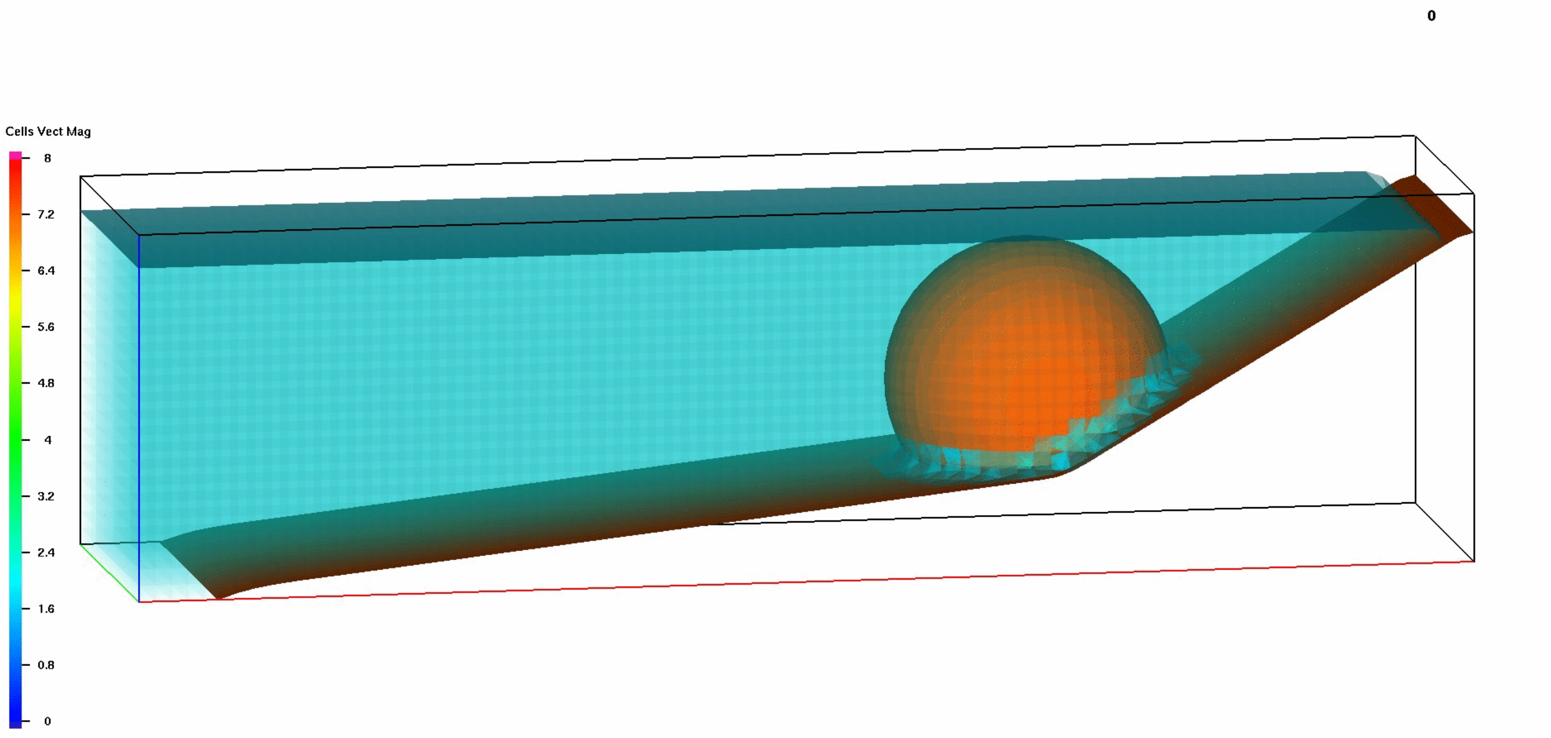


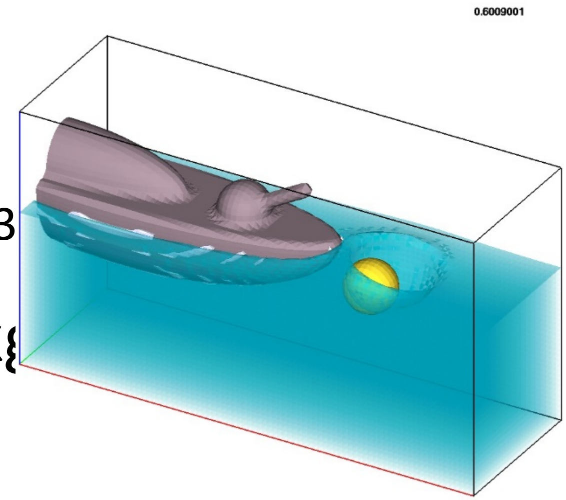
Exhibit Case 2

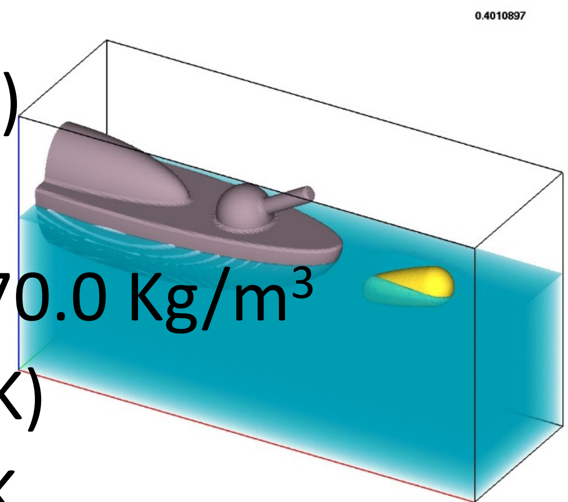
Purpose : Simulate the stability of long-shape floating object when mudflow



Parameter of Exhibit Case 3 - 4

Total Cells = 540,000
Resolution dx = 0.5 m





- Sea Water Density = 1025.0 Kg/m^3
- Water Heat Capacity = 3900.0 J/(kg
- Water Initial Temperature = 278.0
- Sea Ice Density = 915.0 Kg/m^3
- Ice Heat Capacity = 2000.0 J/(kg.K)
- Latent Heat = 334000.0 J/kg
- Ship Material : Steel Density = 7870.0 Kg/m^3
- Steel Heat Capacity = 450.0 J/(kg.K)
- Steel Initial Temperature = 223.0 K

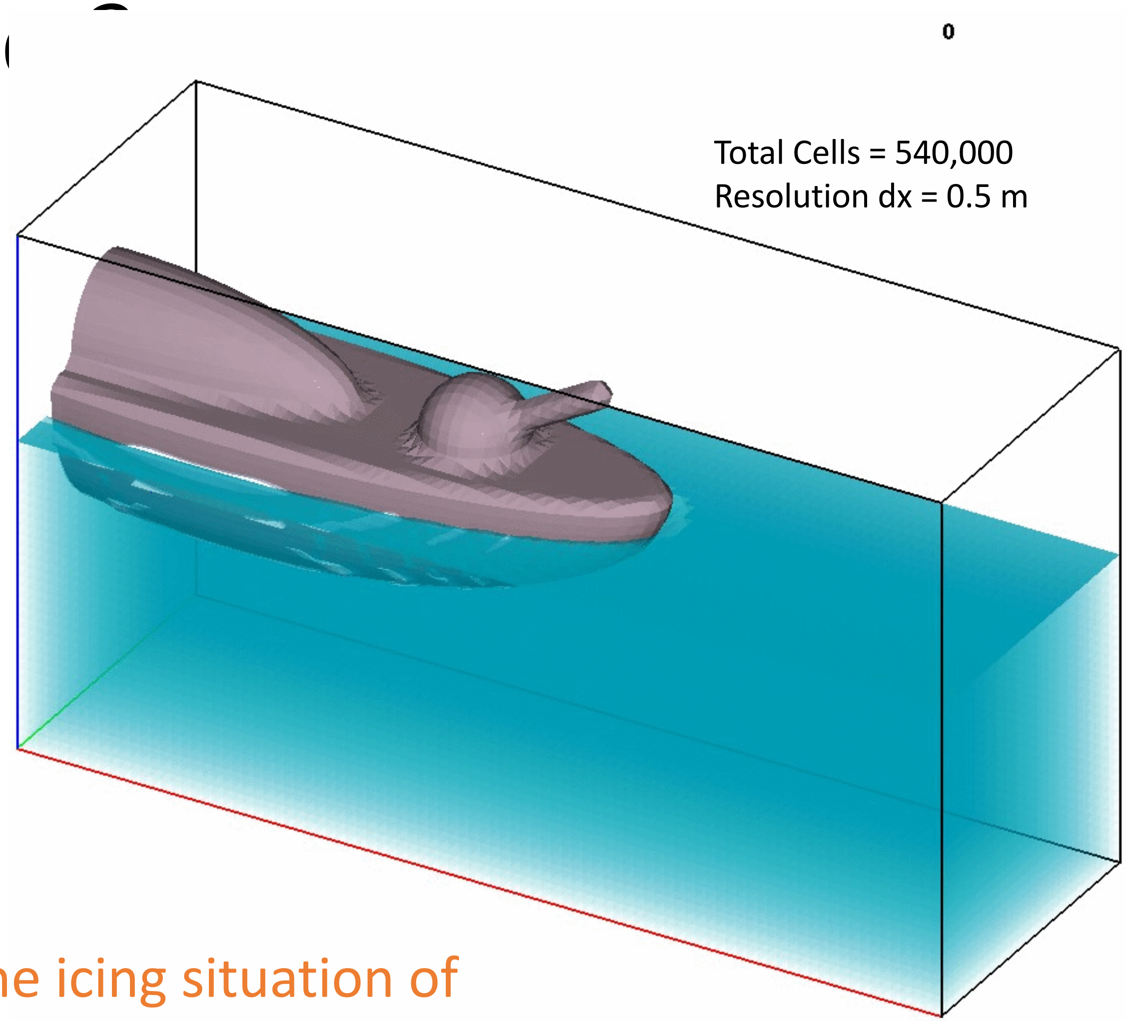
Exhibit Cas

Ship Length = 65.0 m (in the domain)

Ball Diameter = 10.0 m

Ball Initial Velocity_X = -40.0 m/s

Ball Initial Velocity_Z = -30.0 m/s



Purpose : Simulate the icing situation of
low-temperature ship with splash water caused by a sphere

Bingham Constitutive Model

Shear stress → $\tau = 2\mu(\bar{D})\bar{D}$ ← strain rate

Bingham viscosity (2)

Yield stress (Bingham yield) (1)

$$\mu(\bar{D}) = \begin{cases} \mu_B + \dfrac{\tau_0}{\sqrt{\frac{1}{2}\bar{D}:\bar{D}}} & \text{if } \frac{1}{2}\tau:\tau > \tau_0^2 \\ \mu_\infty \text{ and } \bar{D} = 0 & \text{if } \frac{1}{2}\tau:\tau \le \tau_0^2 \end{cases}$$

(3) μ_∞: A large number indicating the solid behavior

$$\bar{D} = \dot{\gamma}_{ij} = \frac{\partial \dot{u}_i}{\partial x_j} + \frac{\partial \dot{u}_j}{\partial x_i}$$

There are three unknown variables only.

μ_∞ is just a huge value to keep the rigidity

1. Pressure Gradient Channel Flow (Bird et al. 1983)

Newtonian Fluid

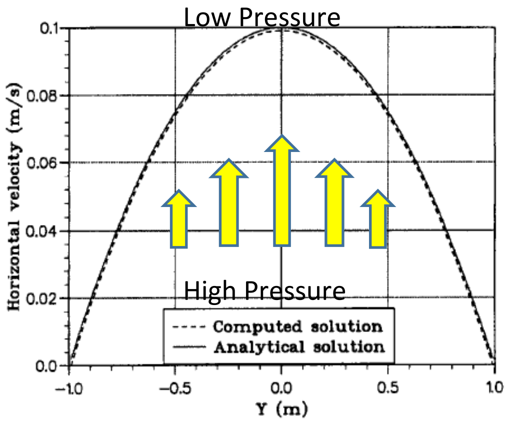


FIG. 2. Comparison between Computed and Analytical Velocity Profiles for Newtonian Fluid

Bingham Fluid

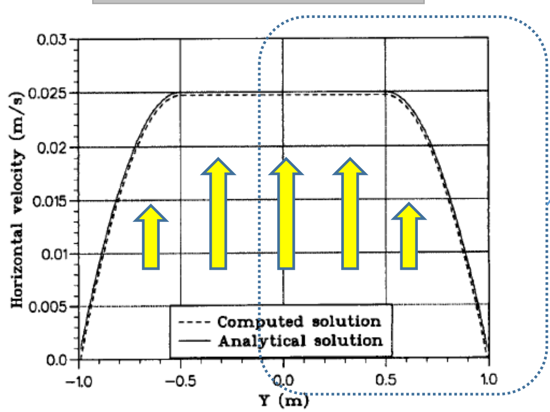
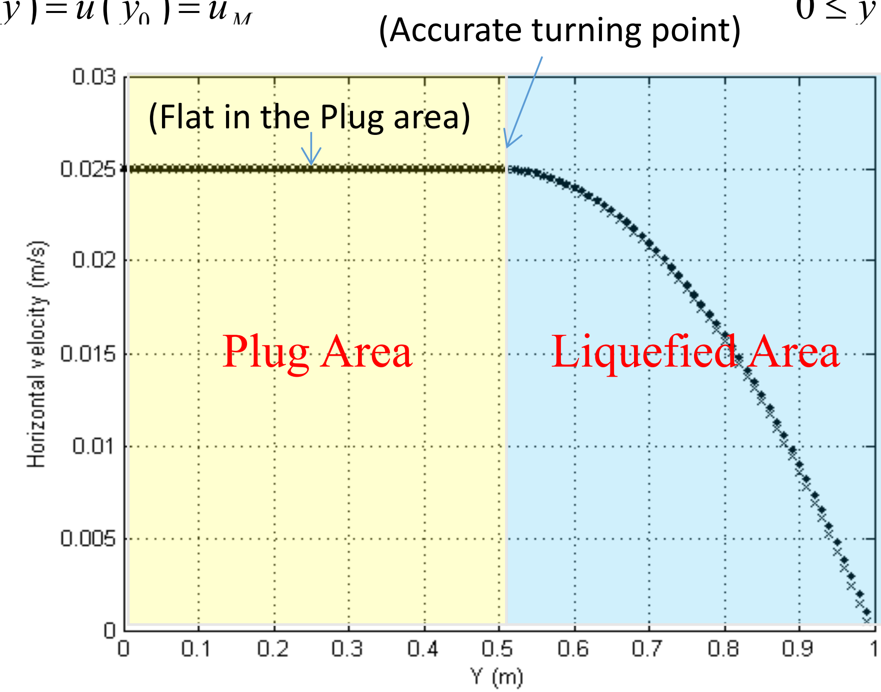


FIG. 3. Comparison between Computed and Analytical Velocity Profiles for Bingham Fluid

Analytical Solution of Bingham Fluid in a Channel

$$u(y)=\frac{(P_0-P_L)B^2}{2\mu_B L}\left[1-\left(\frac{y}{B}\right)^2\right]-\frac{\tau_0 B}{\mu_B}\left(1-\frac{y}{B}\right) \qquad y_0 \le y \le B$$

$$u(y)=u(y_0)=u_M \qquad 0 \le y \le y_0$$



$\mu_B = 5.0\ \mathrm{Pa\cdot s}$ $\tau_0 = 0.5\ \mathrm{Pa}$

$$\mu_\infty = 1e6\ \mathrm{Pa\cdot s}$$

2. Spreading of Bingham fluid on an inclined plane

Liu and Mei (1989) 推導出斜板上之賓漢流理論解

Experiment settings

Length : 332 cm Width : 7.62 cm Height : 15.24 cm

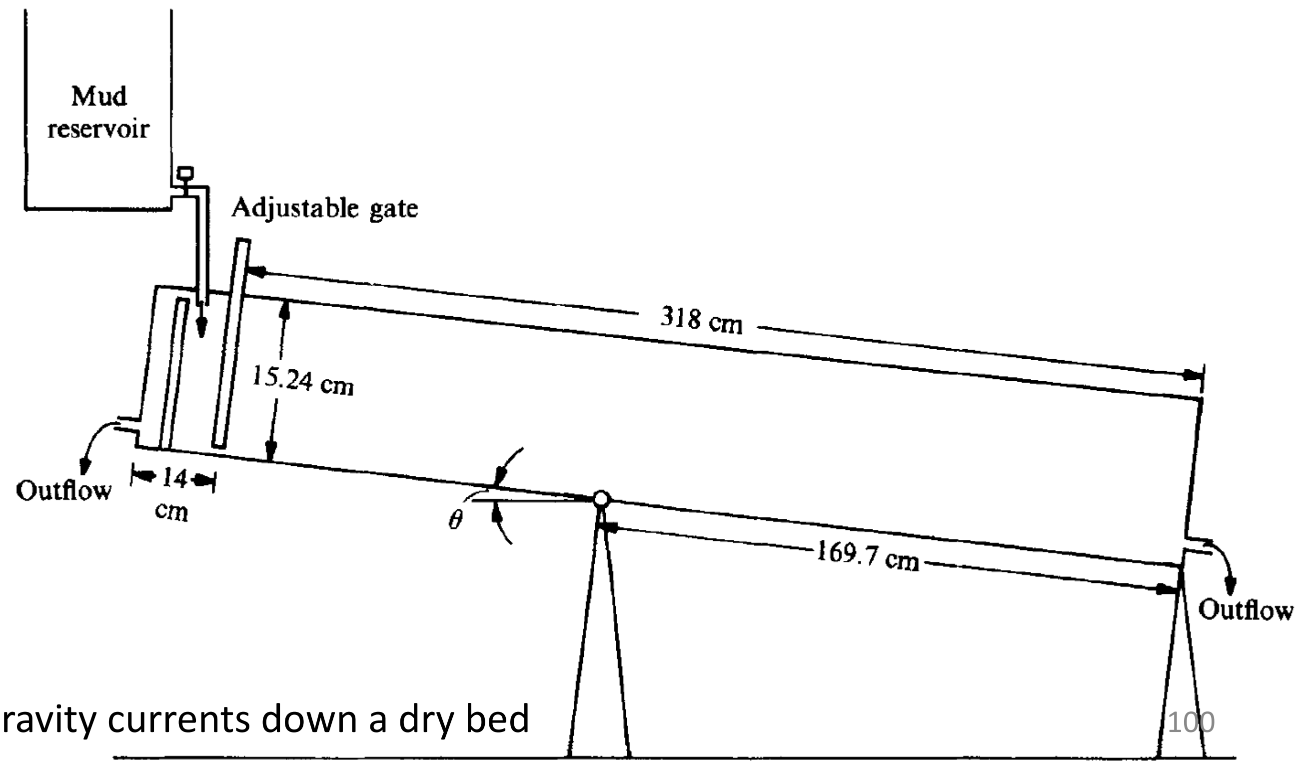
θ: 1.47°

Material : Kaolinite mixed with tap water

ρ: 1.106 g/cm^3

τ_0 : 0.875 Pa

μ: 0.034 $Pa \cdot S$

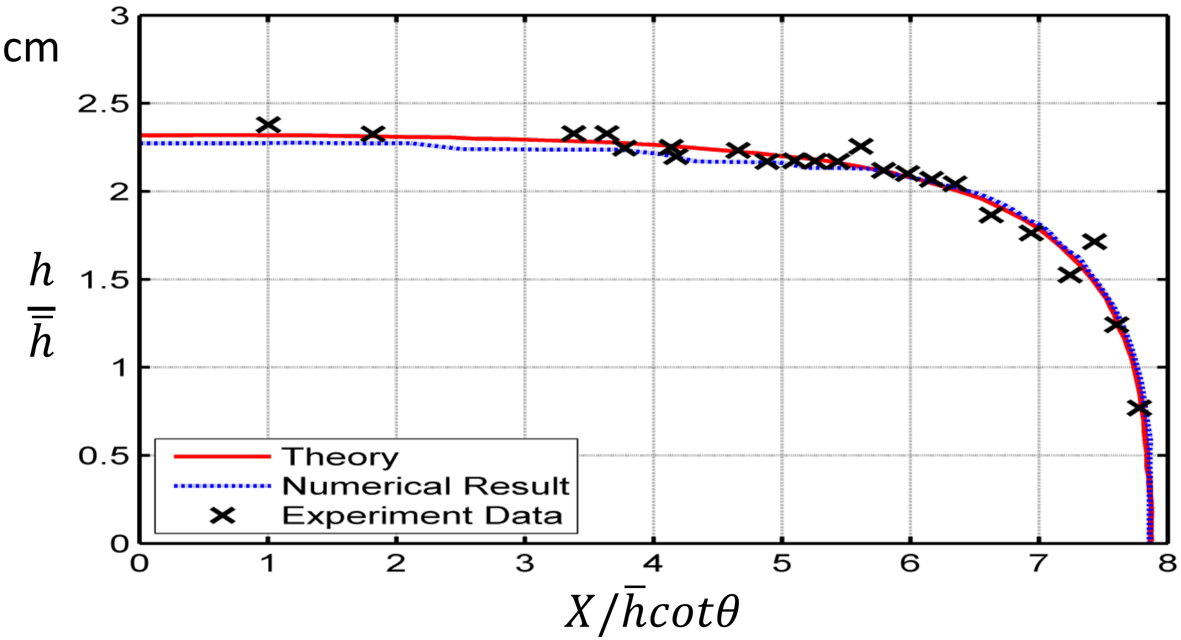


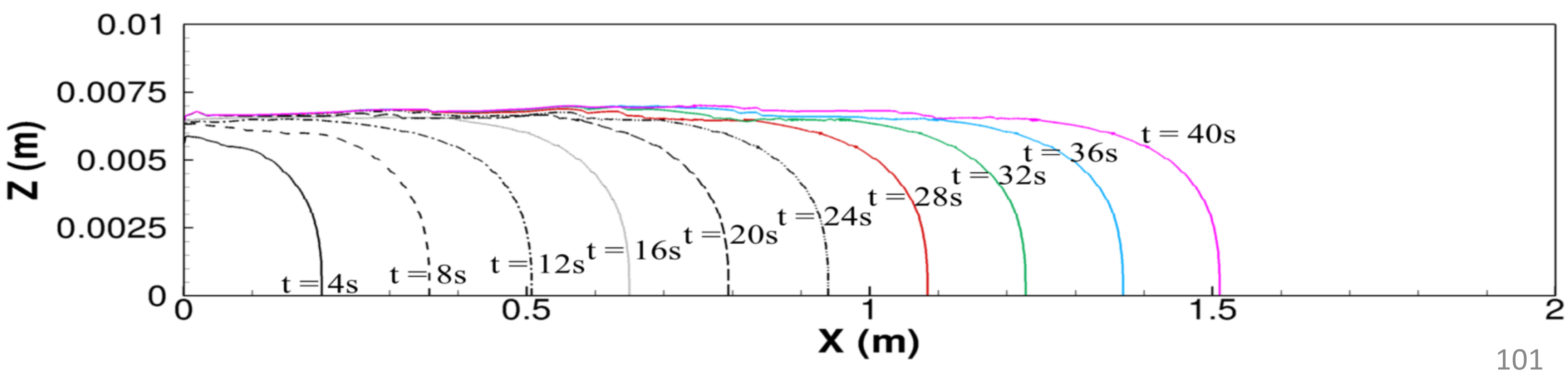
Experimental set-up for gravity currents down a dry bed

Spreading of Bingham fluid on an inclined plane

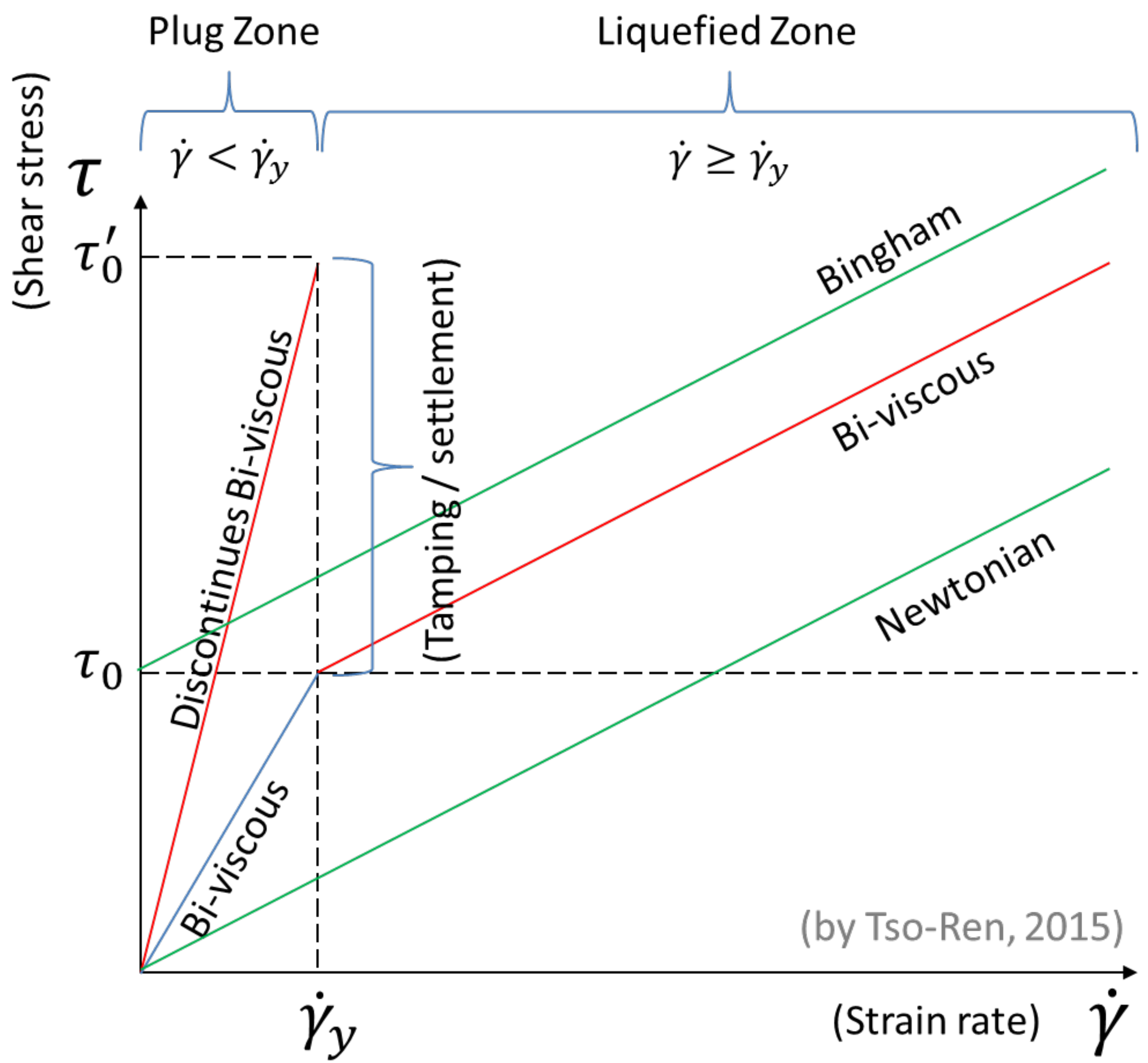
Numeric settings

Domain : 200.0 cm * 0.05 cm * 1.0 cm
Cells : 4000 * 1 * 20
θ: 1.47°
dx = dy = dz = 0.05 cm
ρ: 1.106 g/cm^3
τ_0 : 0.875 Pa
μ: 0.034 $Pa \cdot S$
μ_{inf} : 10^{10} $Pa \cdot S$

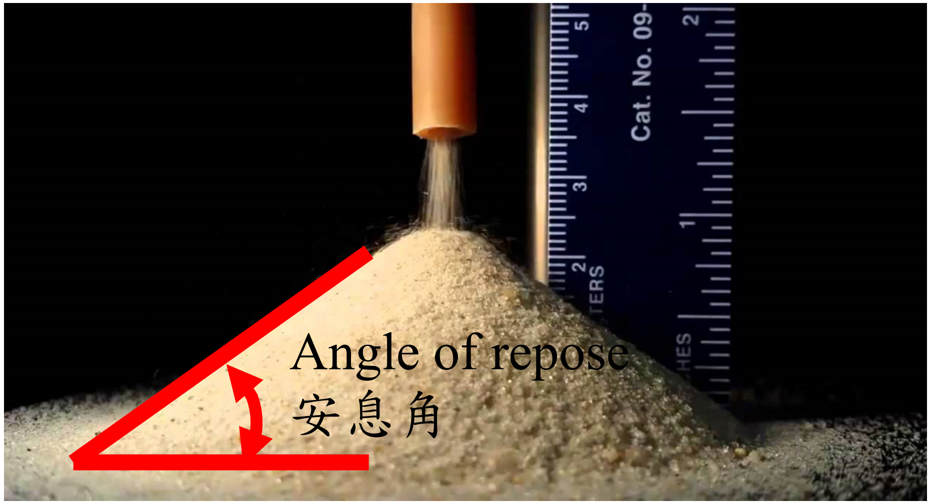




Schematic of Discontinuous Bi-viscous Model (DBM)



- Loose structure without tamping:
  Angle = Angle of repose
- 未夯實，結構鬆散：
  角度為安息角



- Tight structure after tamping or settlement:
  Angle > Angle of repose
- 夯實後，結構緊實，角度大於安息角

(Chinatimes)

Discontinuous Bi-viscous Model (DBM) Equations of Rheology

$$\tau = \mu\left(\bar{D}\right)\bar{D}$$

$$\mu\left(\bar{D}\right) = \begin{cases} \mu_\infty & ,\text{if } \bar{D} > \bar{D}_y \\ \mu_B + \dfrac{\tau_0}{\sqrt{\dfrac{1}{2}\bar{D}:\bar{D}}} & ,\text{if } \bar{D} \le \bar{D}_y \end{cases}$$

$$\bar{D} = \dot{\gamma}_{ij} = \frac{\partial \dot{u}_i}{\partial x_j} + \frac{\partial \dot{u}_j}{\partial x_i}$$

Only 4 unknown variables: $\bar{D}_y \quad \mu_\infty \quad \mu_B \quad \tau_0$

BM vs DBM

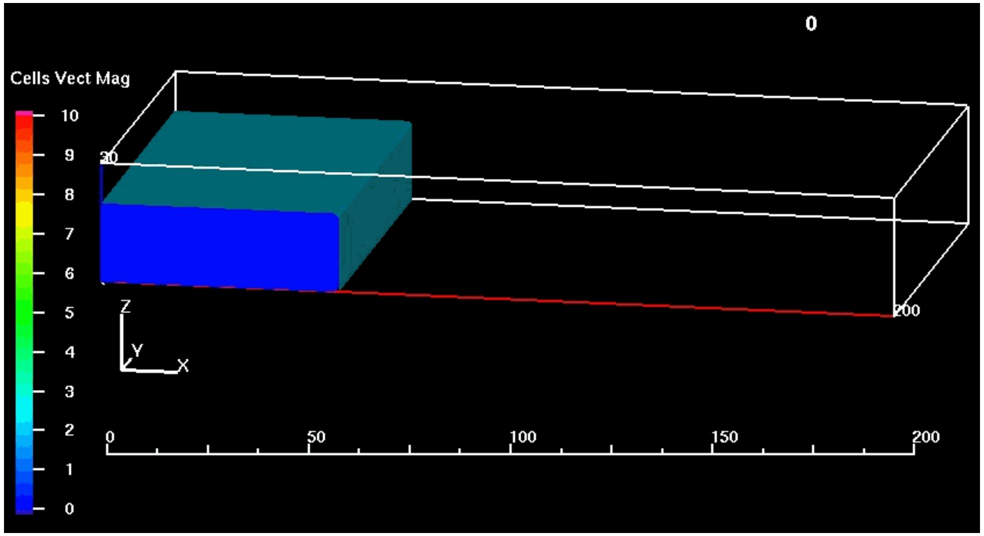
Bi-viscous Model (BM)

$\tau_0 = 1000.0\ (Pa)$

$\mu_b = 50.0\ (Pa \cdot s)$

$\mu_\infty = 2.e3\ (Pa \cdot s)$

$ssc = 0.5\ (1/s)$



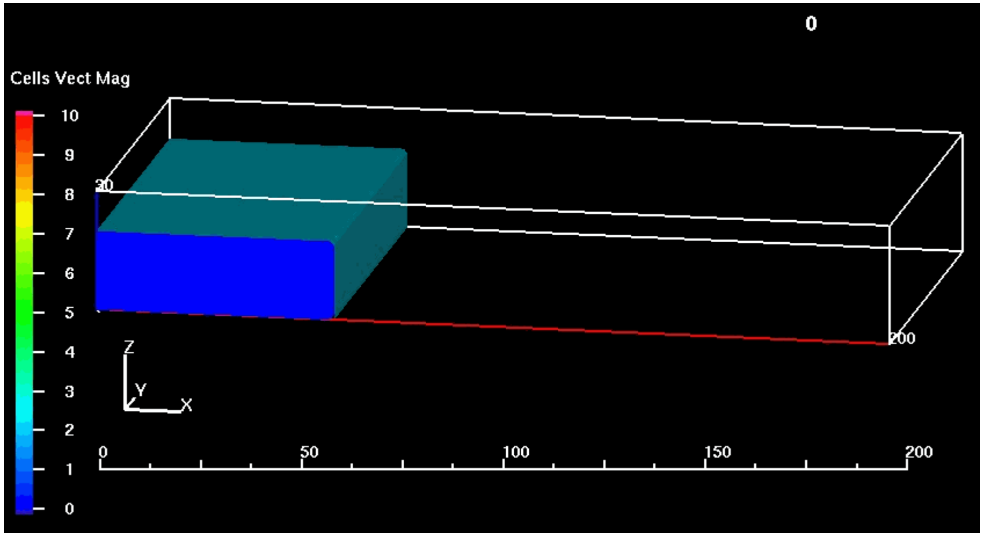
Discontinuous Bi-viscous Model (DBM)

$\tau_0 = 1000.0\ (Pa)$

$\mu_b = 50.0\ (Pa \cdot s)$

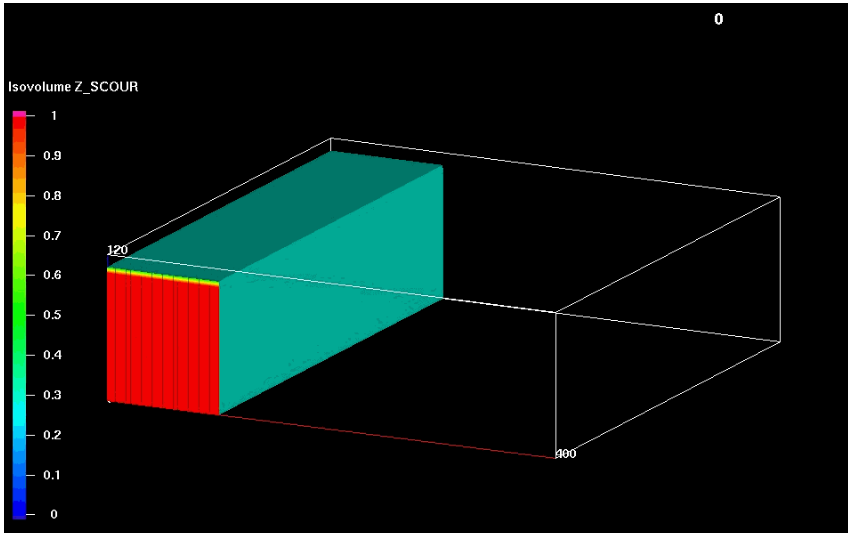
$\mu_\infty = 1.e8\ (Pa \cdot s)$

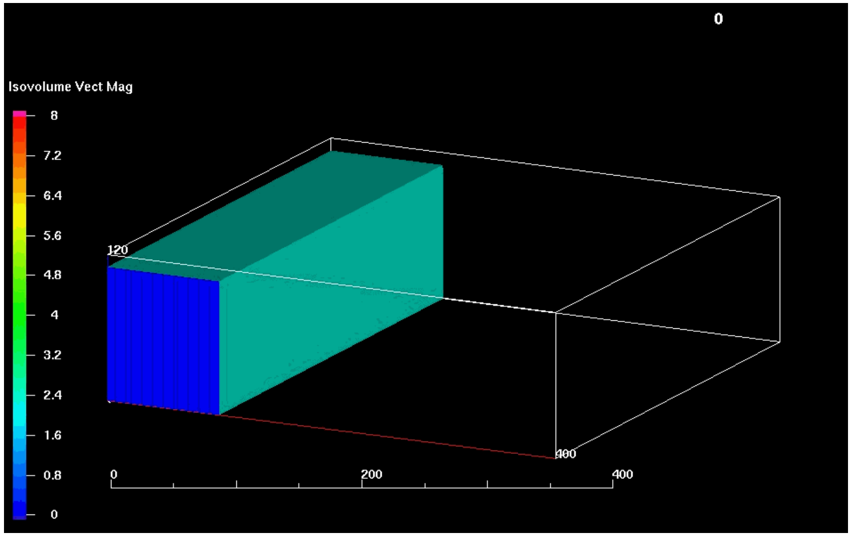
$ssc = 0.5\ (1/s)$

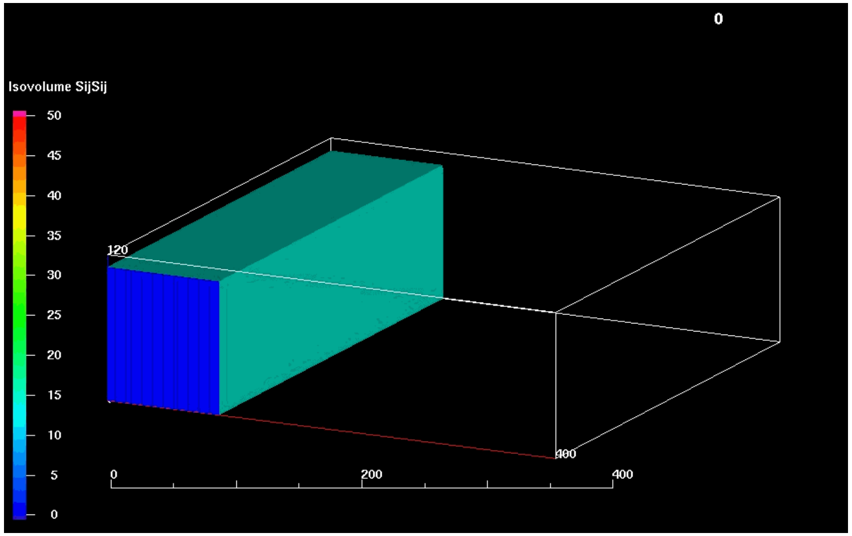


The development of Slip surface can be seen clearly

Simulation on the Sand Sliding Down by DBM







3. Failure of Gypsum Tailings Dam East Texas, 1966

Jeyapalan (1983)

Initial Height of Dam : 11 m

Material : Gypsum Tailings

Bed Slope : 0°

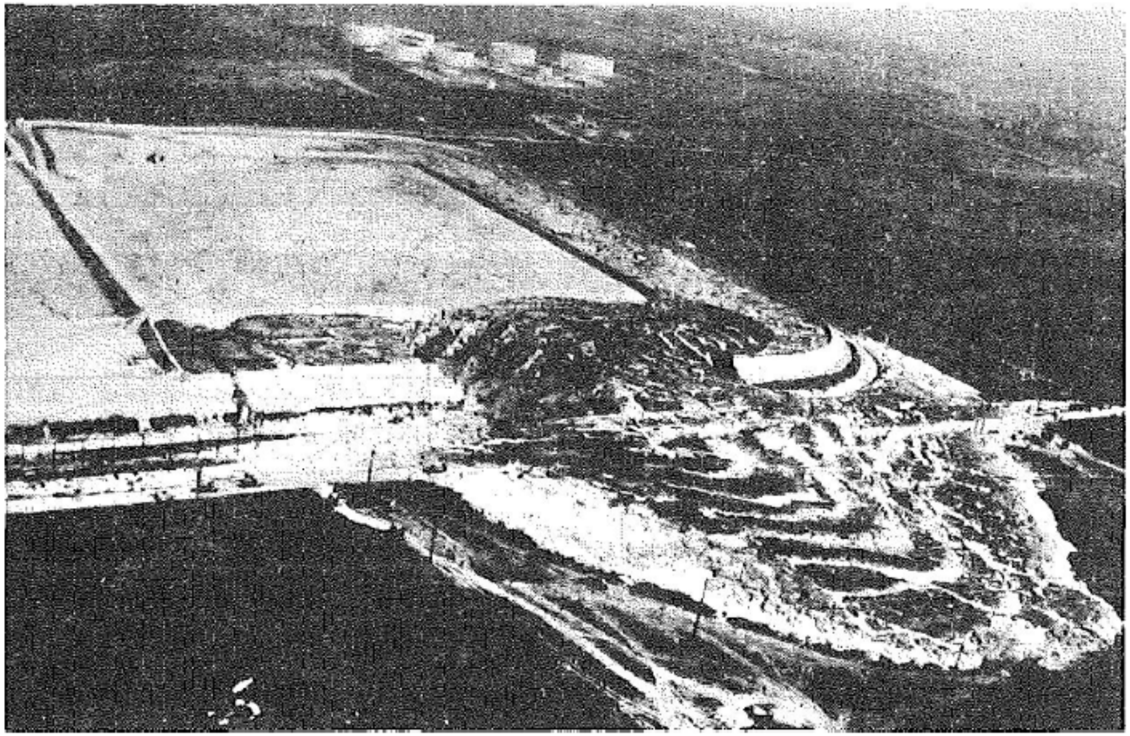
Properties of Tailings :

ρ = 1400.0 kg/m^3

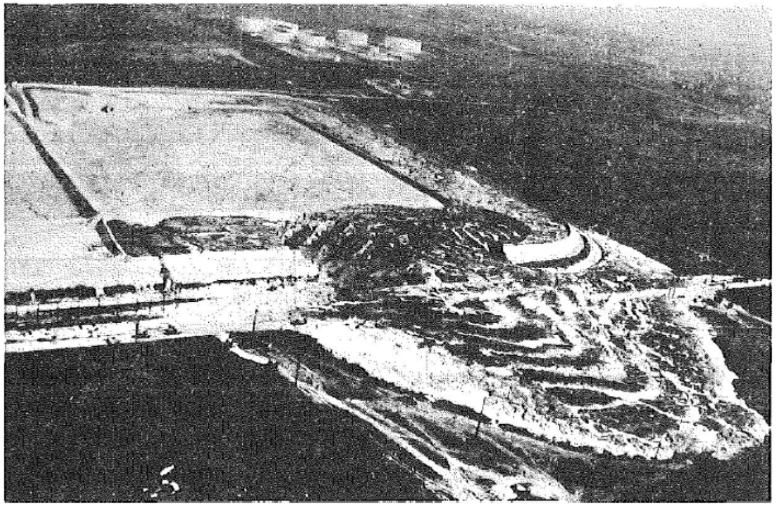
τ_0 = 1000.0 Pa

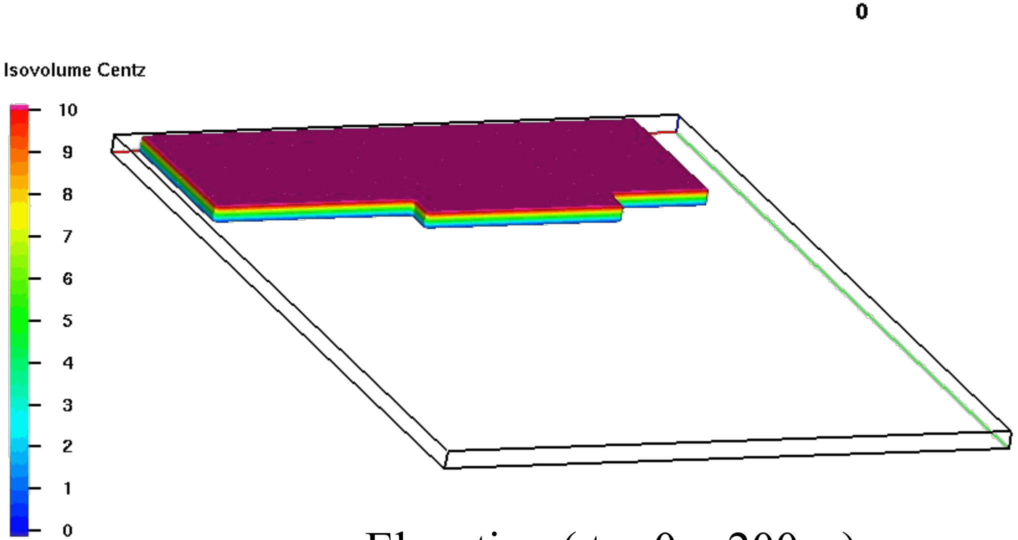
μ = 50.0 $Pa \cdot S$

Mu_max=1.e6, ss_c=0.2

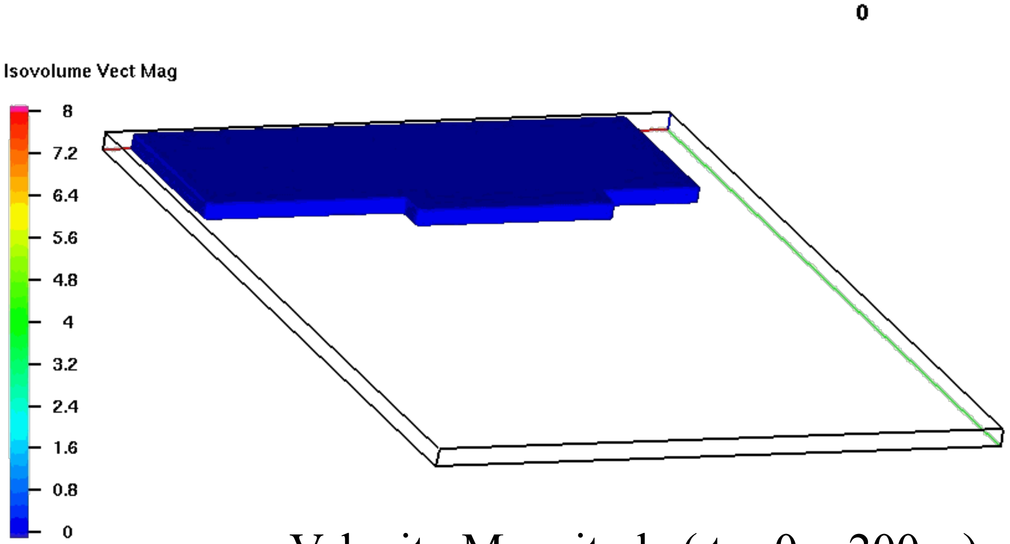


Flow of Liquefied Tailings from Gypsum Tailings Impoundment (1966)

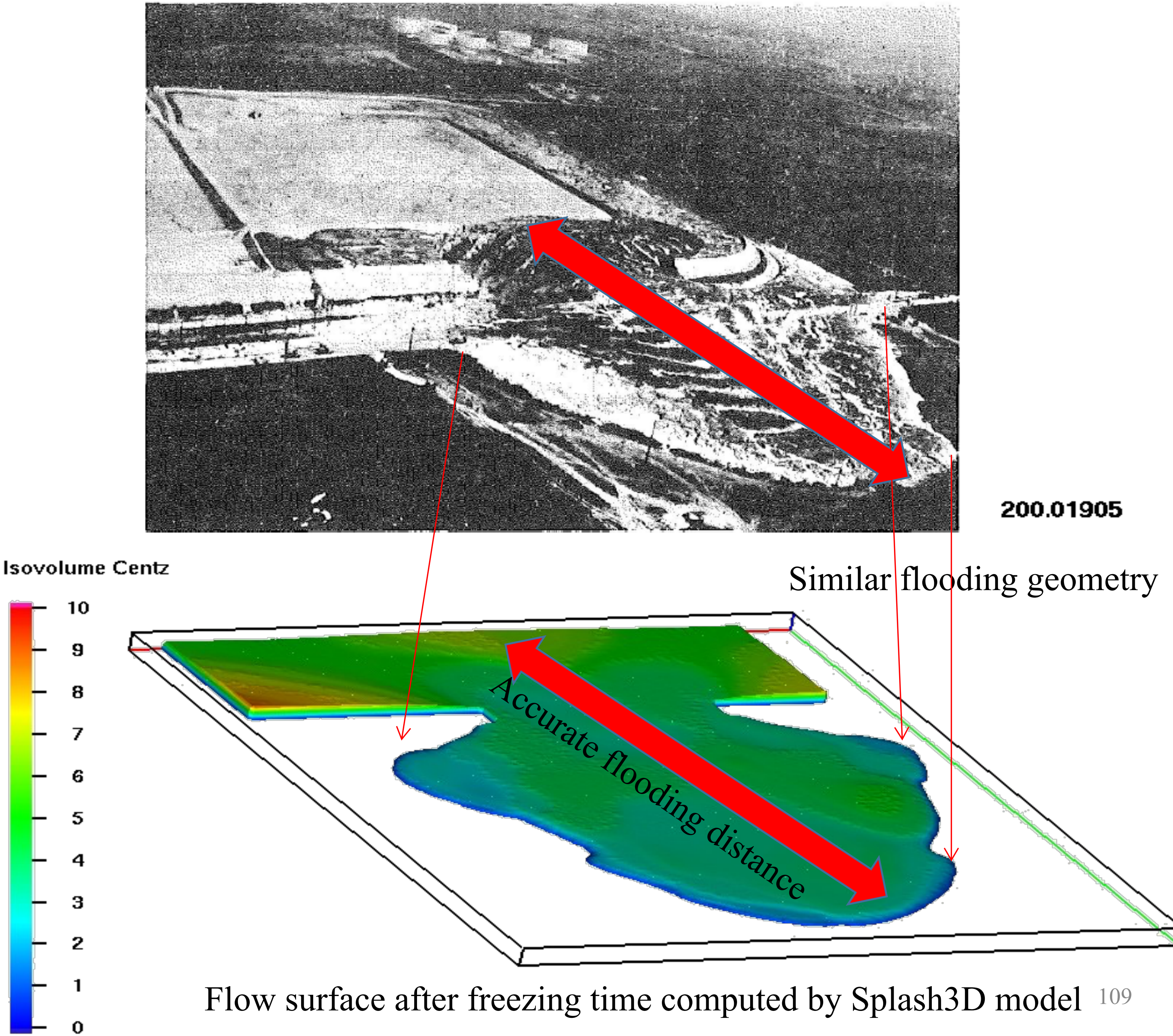




Elevation (t = 0 ~ 200 s)



Velocity Magnitude (t = 0 ~ 200 s)



Flow surface after freezing time computed by Splash3D model

Result Competition

	Inundation distance （m）	Freezing time （s）	Mean velocity （m/s）
Observed values	300	60-120	2.5-5.0
Theoretical results from charts	550	132	4.2
Result using TFLOW （Jeyapalan, 1983）	470	85	5.5
Result computed by Pastor et al. （2004）	170	120	1.4
Result computed by Chen （2006）	200	120	1.7
Result using Splash3D model	310	130	2.4

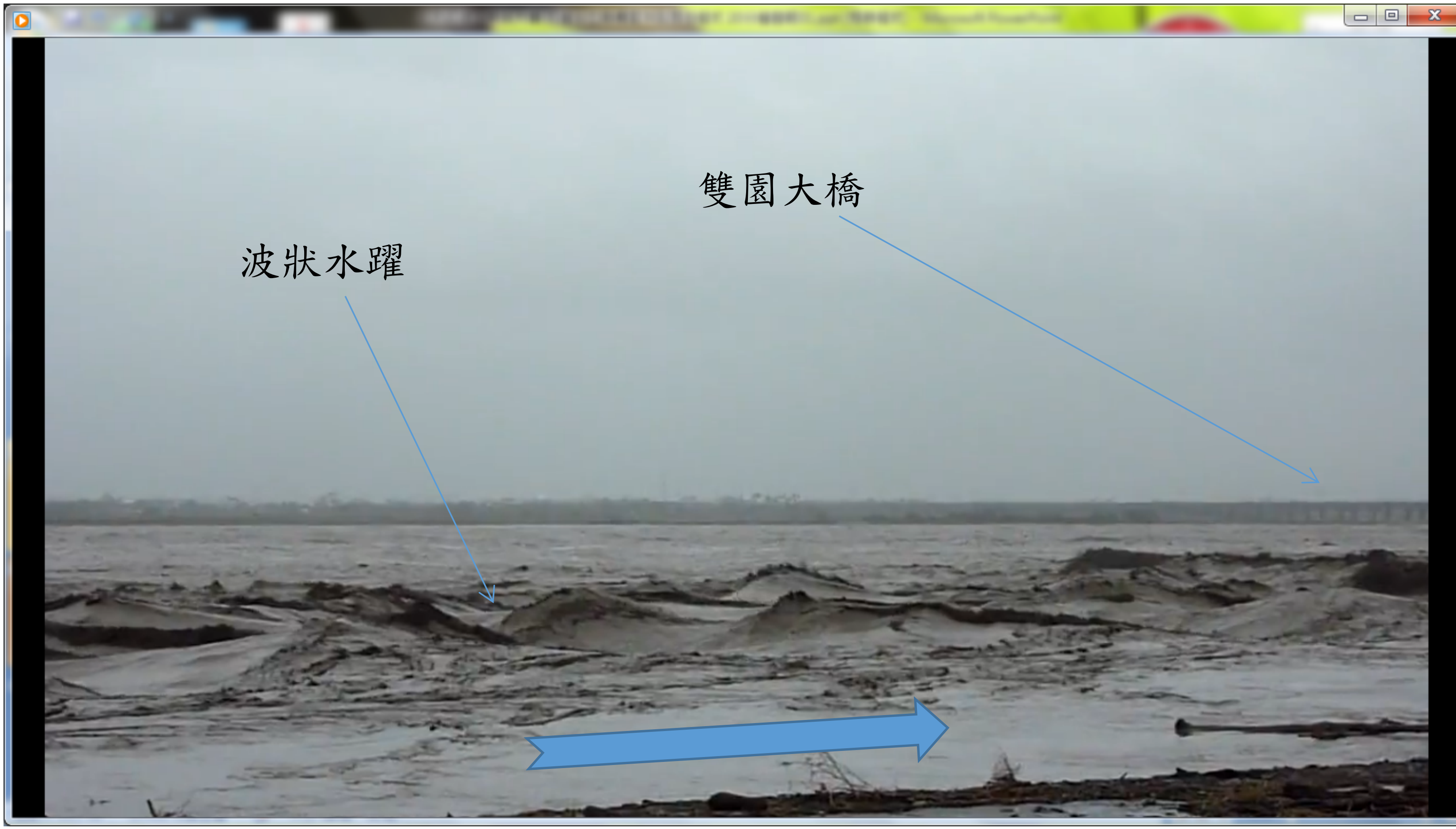
5. Simulation on the failure of Shuan-Yuan Bridge

in the event of 2009 Typhoon Morakot

The undular waves imply
the uneven soft bottom

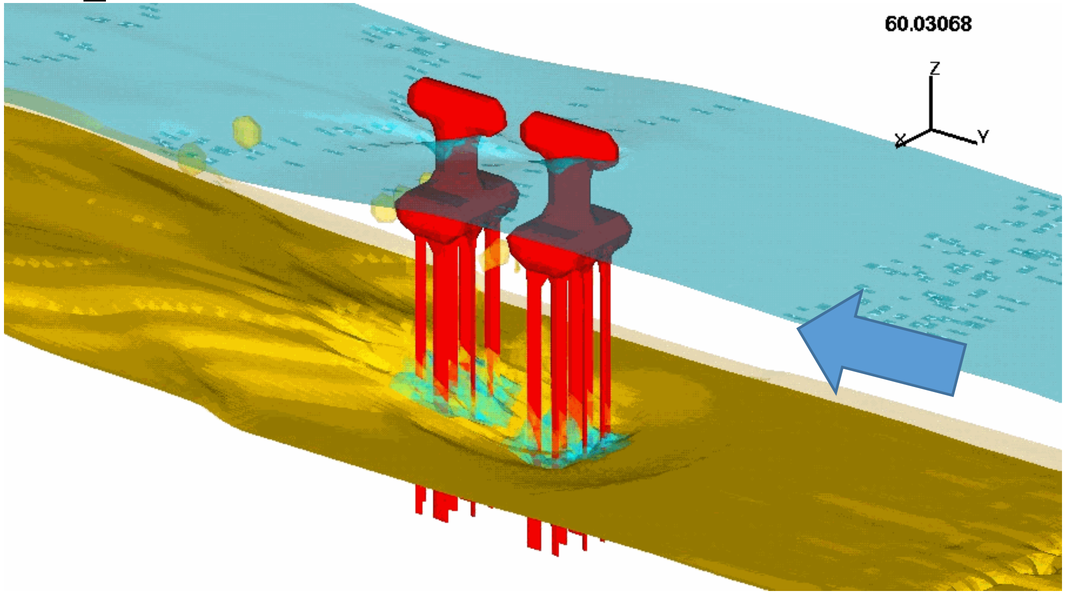
基礎沖刷

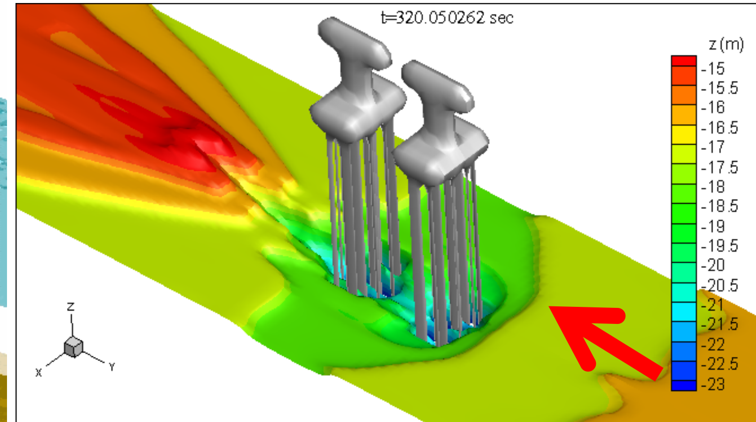
波狀水躍的發生，通常意味底泥鬆軟：基樁之局部沖刷嚴重

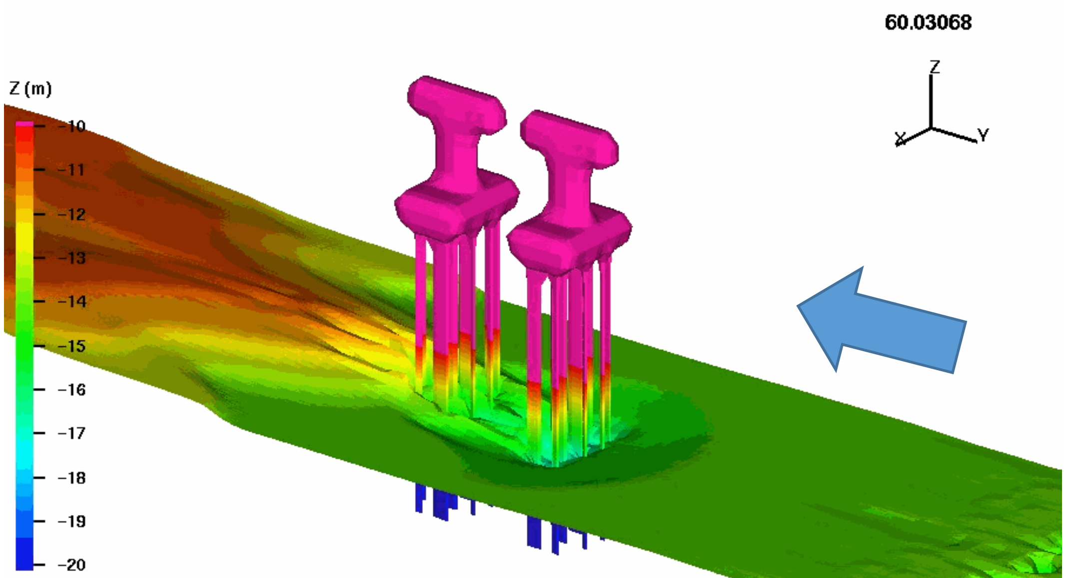


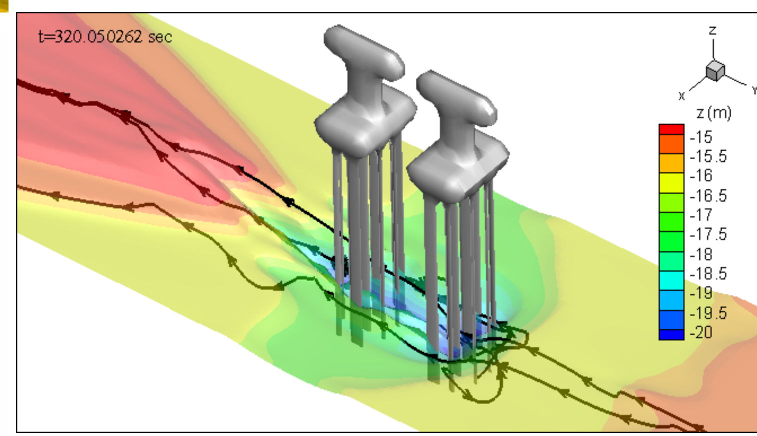
3D Local scour induced by the strong flood

mud_vof =0.05









Comparison to the Field Survey Data

Maximum Scour Depth:

Right in front of the bridge piers:

Field survey: about 23 m.

Numerical: 23 m.

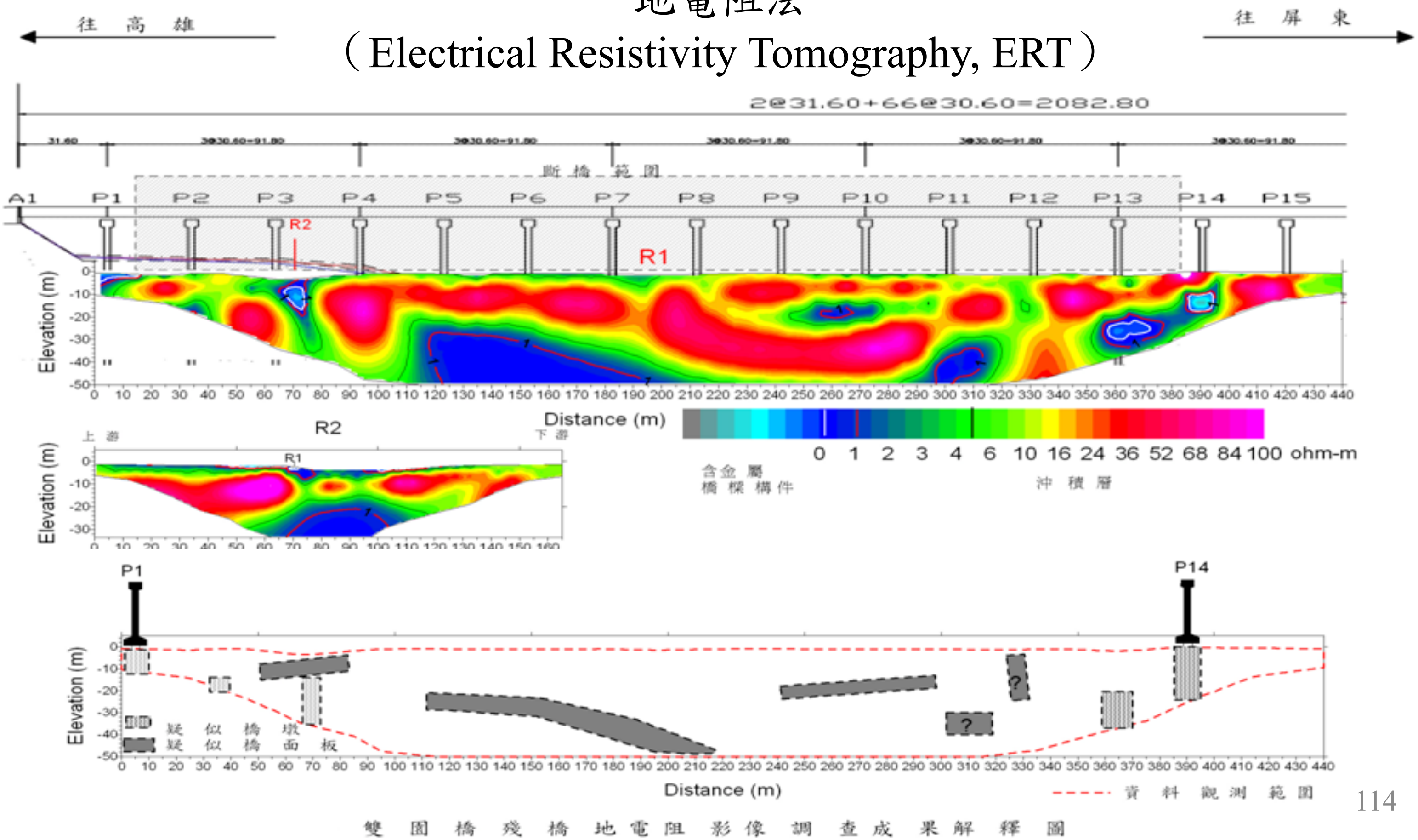
30 m upstream away from the bridge piers:

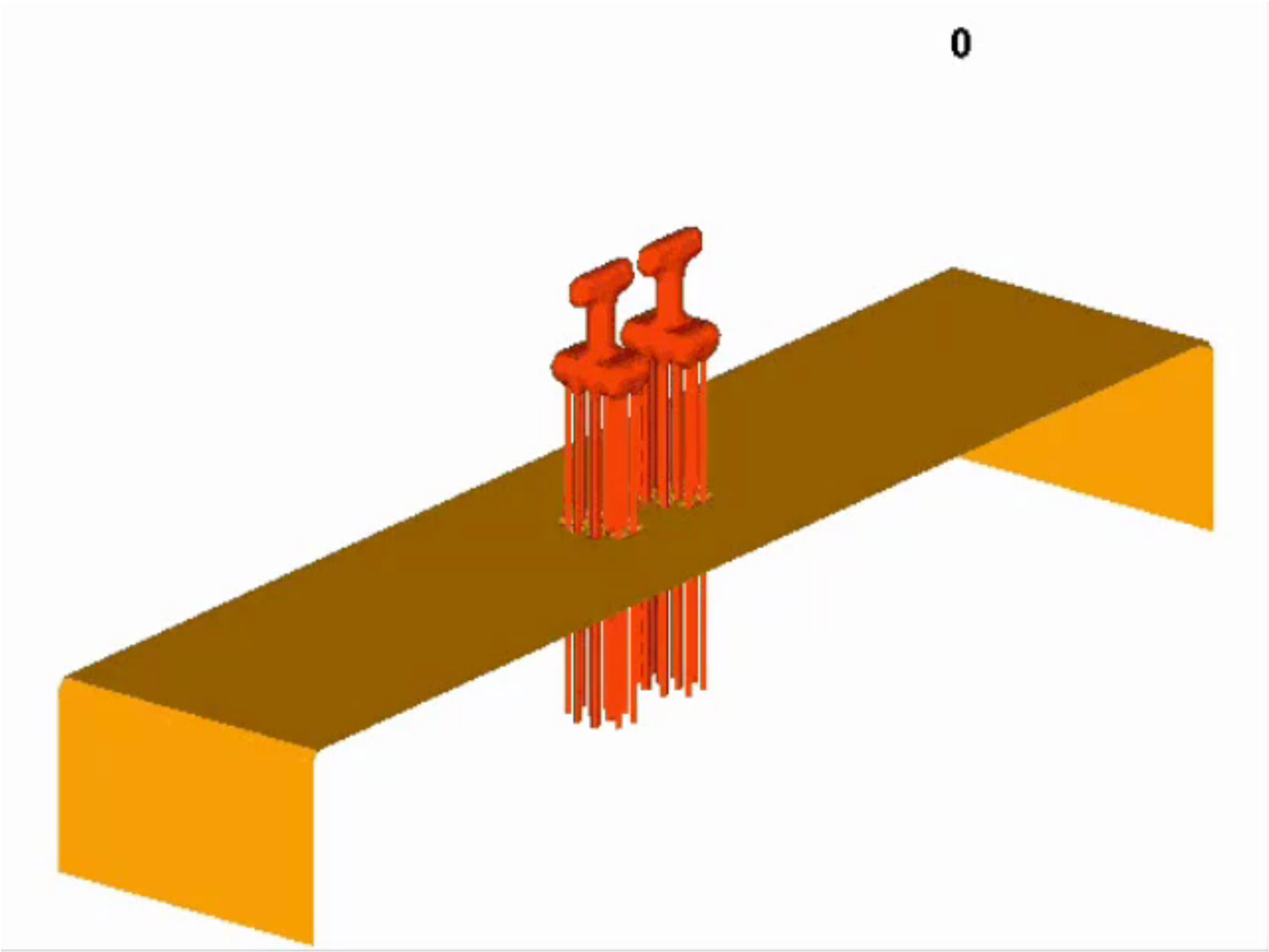
Field survey: 15 m

Numerical: 15 m

地電阻法

（Electrical Resistivity Tomography, ERT）

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Dirty harbor in Japan?