Sloshing of an oil tank in Osaka bay area caused by an estimated Nankai Trough earthquake

H. Hashimoto*, **Y. Hata****, **K. Kawamura*****,
Y. Taniguchi*, **T. Munesue***

* Kobe University
** Osaka University
*** National Maritime Research Institute

M S
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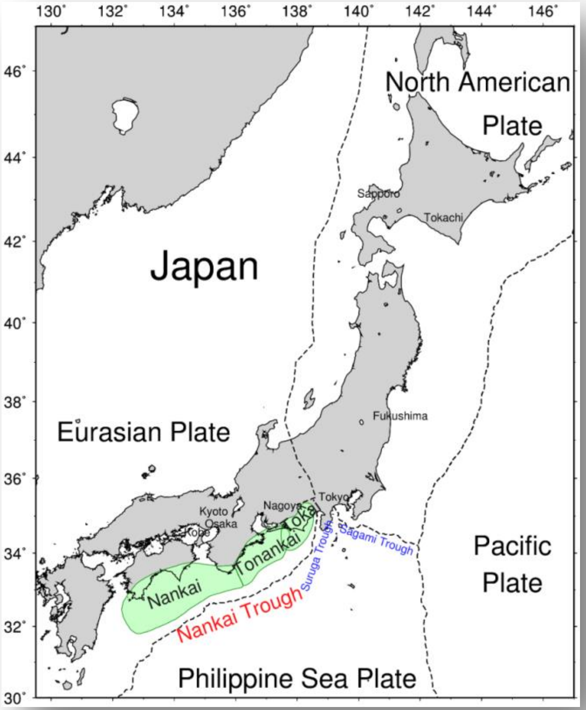
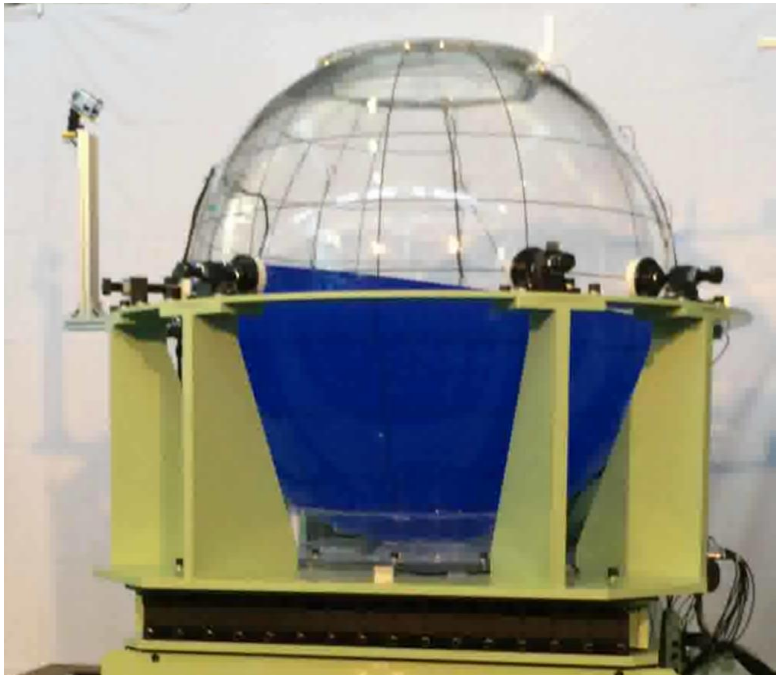
Introduction

- The 2011 great east Japan earthquake was the largest earthquake ever recorded in Japan.
- There is high-possibility of a more serious earthquake in the Nankai Trough subduction zone.
- The worst scenario is presumed as Mw 9.0.
- It is desired to realize a resilient system to earthquakes/Tsunamis.



Sloshing

- One of dangerous phenomena caused by earthquakes is sloshing in oil storage tanks which could lead to serious oil spill and fire disasters.



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What is sloshing?

- Resonance of liquid subjected to external oscillation.
  (oil storage tanks: ground motion of earthquake)
- Sloshing is large amplitude oscillation of liquid with complexly deformed free surface.
- For the prediction of sloshing, strongly nonlinear behavior of liquid and impact pressure need to be treated.
- Sloshing problems appear in many fields, e.g. oil tank, LNG carrier, auto mobile, nuclear reactor, liquefied hydrogen.

Difficulties for sloshing simulation

- The sloshing is fully arbitrary and high-speed free-surface flows => it seems to be unpredictable
- Formula for sloshing height using speed response spectra => useful but is applicable to Nankai Trough earthquake?
- Free-surface capturing and mass conservation of scattered oil is essential to estimate the amount of overflowed oil.

Particle method is one of the most suitable methods for the prediction of sloshing in oil storage tanks.

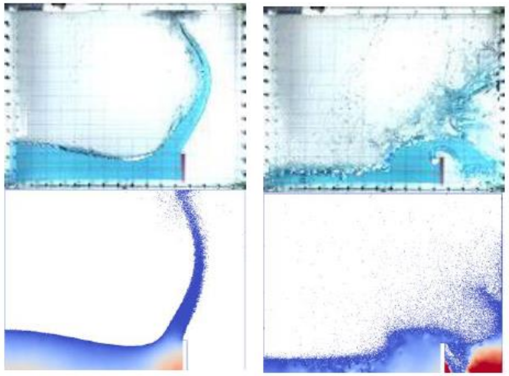
Particle method in fluid dynamics

- Meshless
  No need for making/deforming a mesh

- Lagrangian
  No convection term modeling
  => accurate for fast dynamics flows
  Naturally handles large deformations of the domain
  => arbitrary complex free surface

Non-diffusive interface
Perfect mass conservation
Multi-phase flow

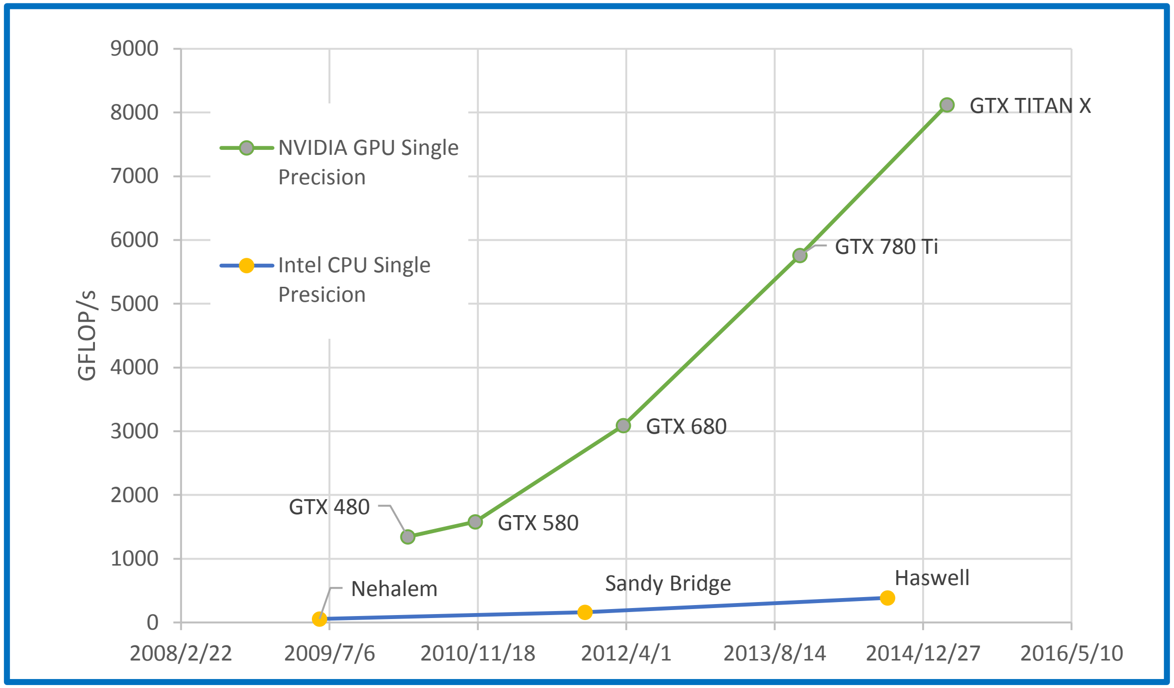
but CPU cost is high ...



GPGPU computation

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
15	GSIC Center, Tokyo Institute of Technology Japan	**TSUBAME 2.5** - Cluster Platform SL390s G7, Xeon X5670 6C 2.93GHz, Infiniband QDR, NVIDIA K20x NEC/HP	76032	2785.0	5735.7	1399

http://www.top500.org/lists/2014/06/



Moving Particle Simulation (MPS)

- Originally developed by Koshizuka et al. (1995)
- For incompressible/weakly compressible fluids
- Fully Lagrangian
- Truly meshless

Good for multi-physics/FSI analysis

- Particle interaction models for PDE discretization
- Compact support with a weight function

$$\frac{D\rho}{Dt} = 0 \qquad \frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho}\nabla p + \upsilon\nabla^2\mathbf{u} + \mathbf{g}$$

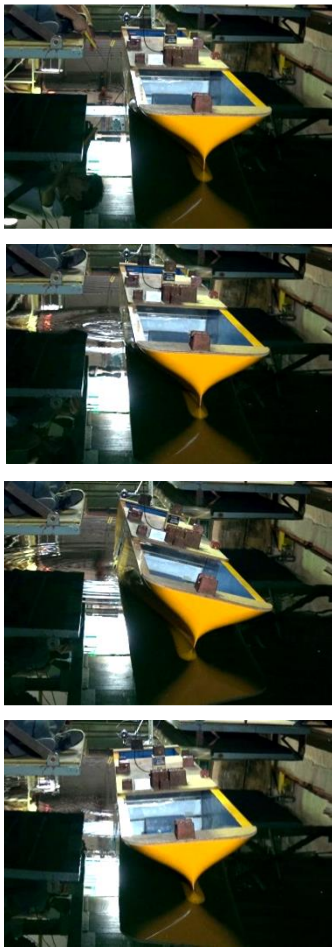
MPS-HYDRO

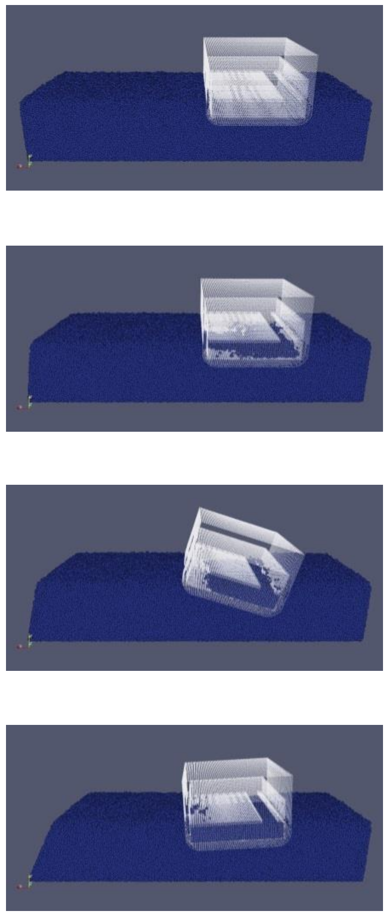
In-house code based on Moving Particle Simulation

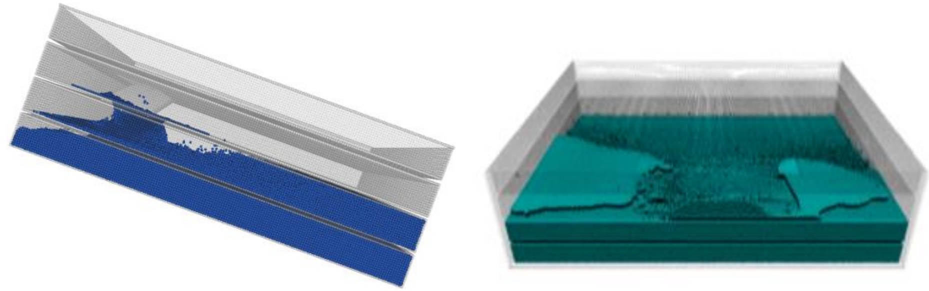
MPS-HYDRO	
Incompressible fluid	Weakly compressible fluid
Semi-implicit	Explicit
Particle interaction model	
Single weight function	Multi weight function
Poisson equation	State equation
Ghost particle / Mirror-image symmetry B.C.	
CPU (Sueyoshi et al.) (Hashimoto et al.)	**GPU** (Kawamura et al., 2016)

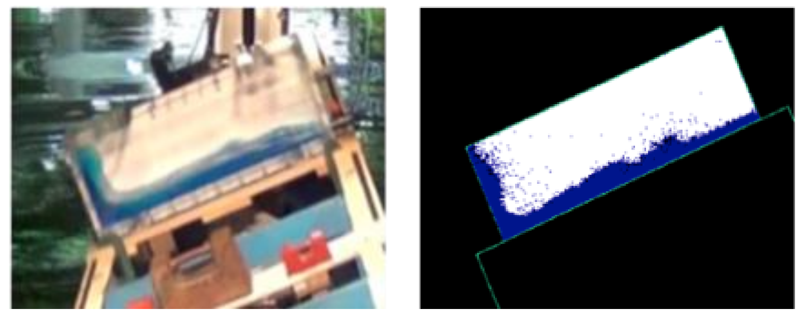
Highly stabilized and efficiently parallelized code
Thin structure, arbitrary wall particle distance etc.

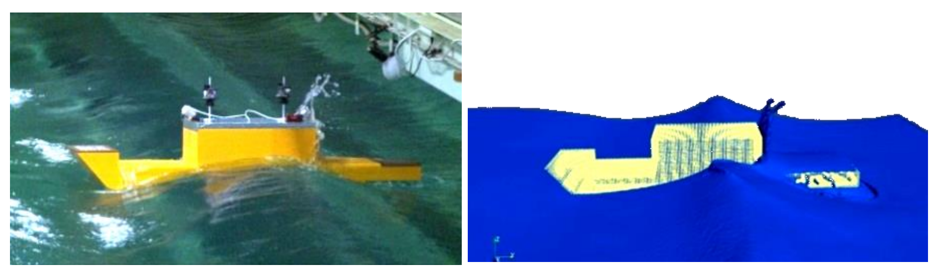
Applications in naval architecture











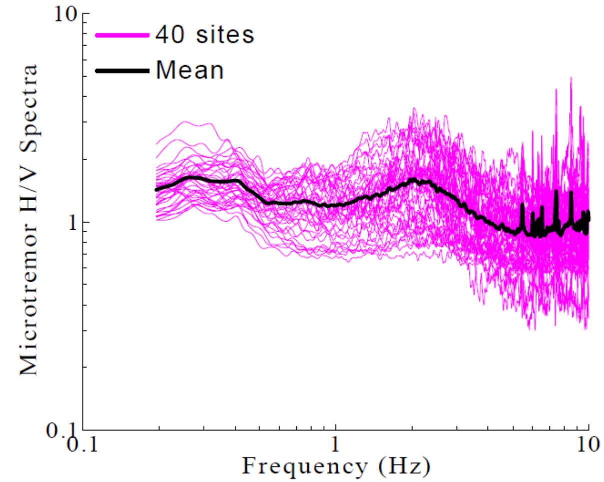
(Hashimoto et al.)

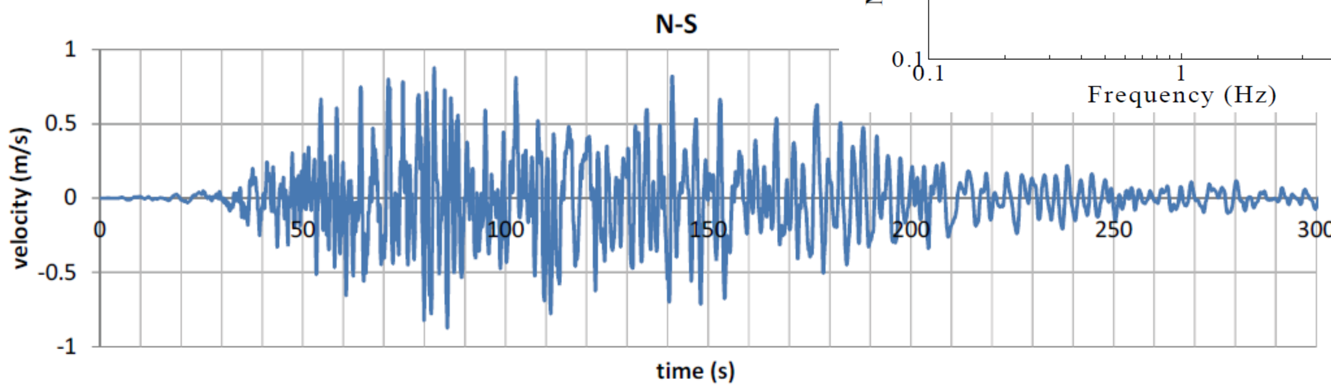
Ground motion of Nankai Trough

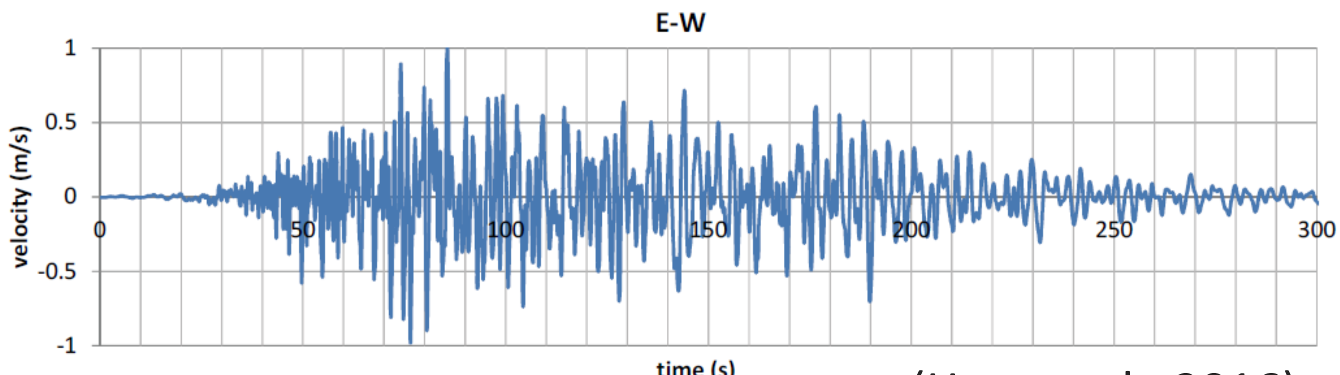
- Evaluation of ground shaking characteristics is important.
- Micro-tremor measurements are carried out in an industrial complex located in Osaka bay.
- Strong ground motion during a scenario earthquake with Mw 9.0 along the Nankai Trough is estimated based on the SMGA models. (source location: off Kushimoto)
- The empirical site amplification and phase characteristics are taken into account for the estimation of a ground motion.

(Hata et al., 2016)

Estimated ground motion

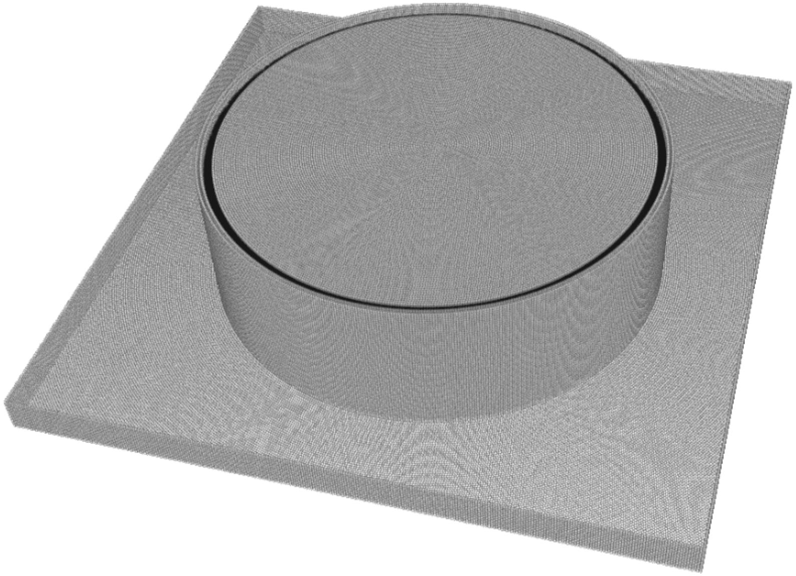


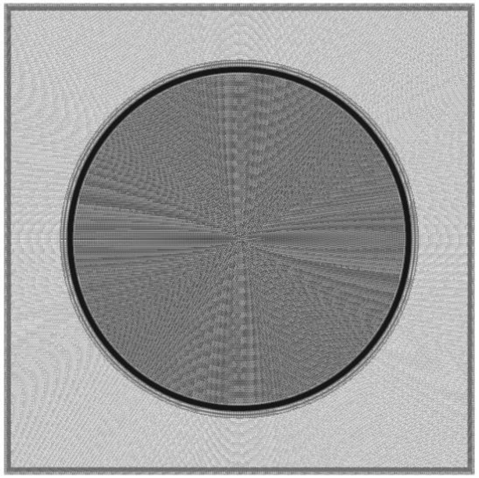




(Hata et al., 2016)

Numerical condition



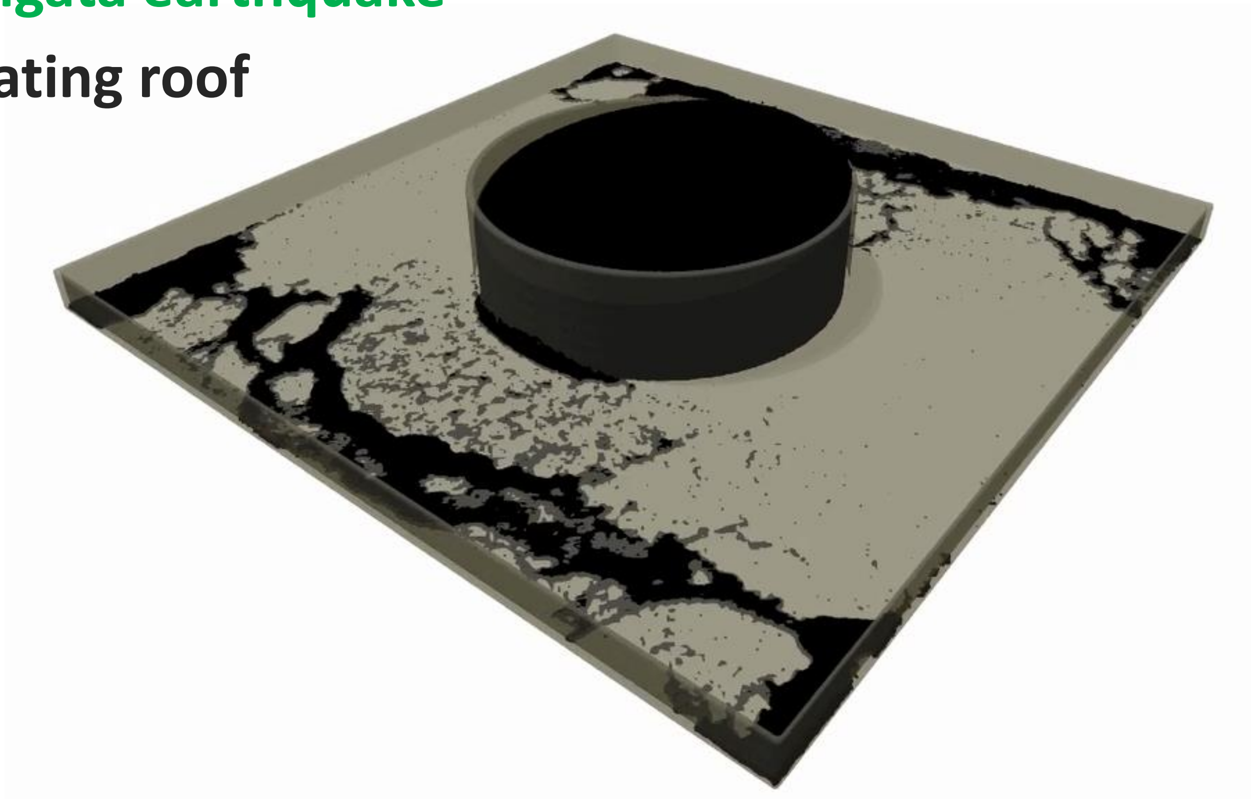


Diameter (tank)	70.0 m	Kinematic viscosity	5.0E-5 m^2/s
Diameter (roof)	66.5 m	Particle distance	0.35 m
Height	23.0 m	No. of fluid particles	1,967,360
Liquid level	20.7 m	Speed of sound	96.5 m/s
Liquid	volatile oil	Time step	0.00837 S

Accuracy check

1964 Niigata earthquake

w/o floating roof



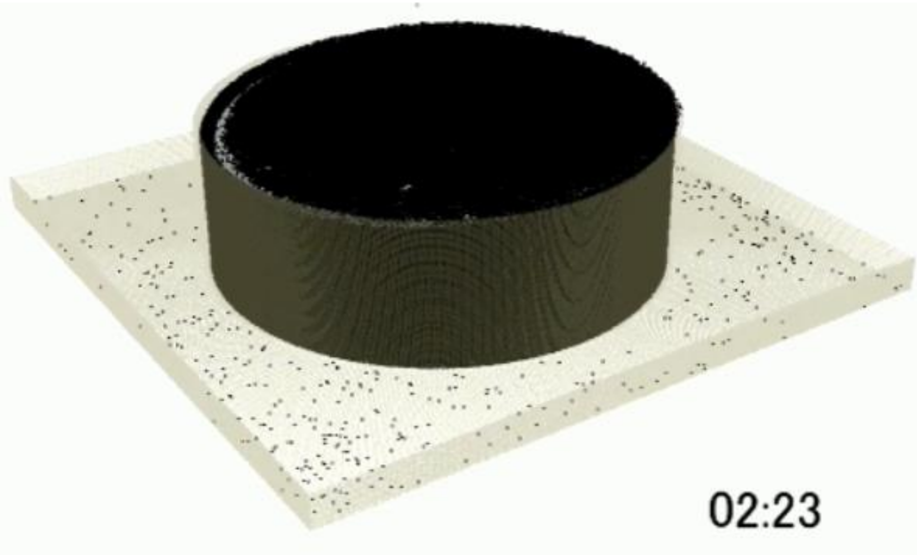
Amount of overflowed oil

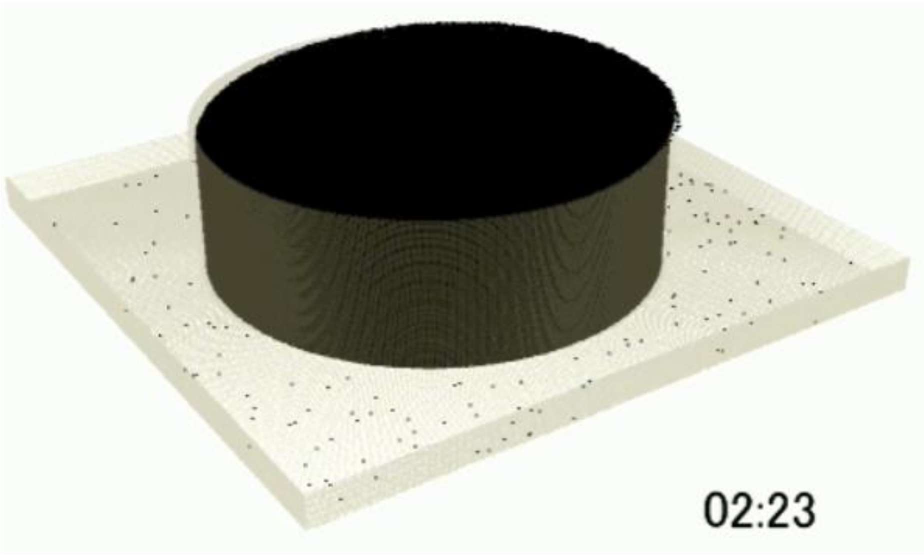
Estimated 924 Kl ≈ Actual 1000 kl

(Nishi et al., 2008)

Nankai Trough earthquake

w/ floating roof | **w/o floating roof**





Overflow 70 Kl

Overflow 67 Kl

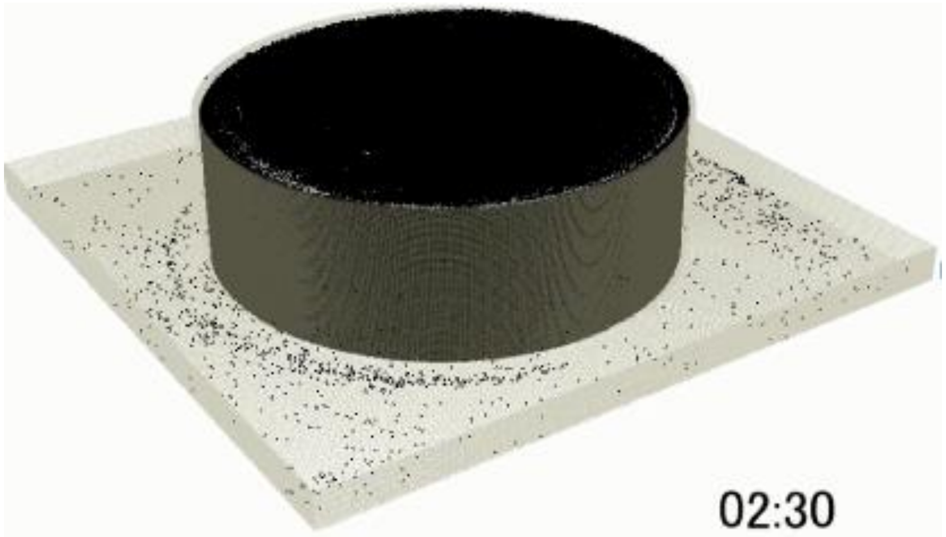
Accumulation of the oil on the floating roof is serious!

Seriousness of Nankai Trough earthquake

- It is an urgent task to examine the seriousness of the Nankai Trough earthquake for large tank sloshing.
- Numerical simulation is repeated for the same size tank (D=70.0m) with the estimated Nankai Trough earthquake and the 2003 Tokachi-oki earthquake.
- Numerical conditions are same for both the simulation, so the ground motion is only the difference.

Seriousness of Nankai Trough earthquake

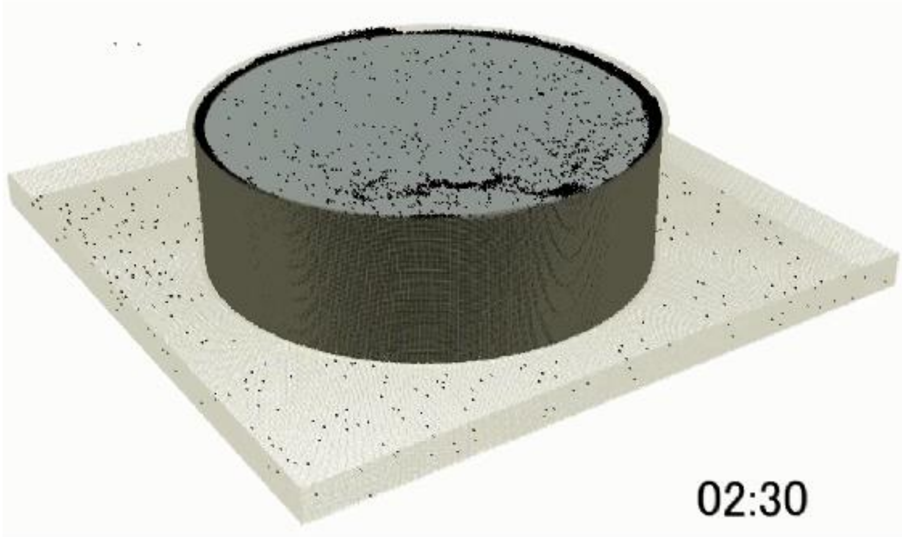
Nankai Trough



Overflow 70 Kl

On roof top Max. 1660 kl

2003 Tokachi-oki



Overflow 24 Kl

On roof top Max. 200 kl

Future work

Local assessment

Micro-tremor measurement (ground motion) + Sloshing simulation (spilled oil)

Diameter (m)	Overflow (kl)	On roof top (kl)
10.0	?	?
20.0	?	?
30.0	?	?
40.0	?	?
50.0	?	?
60.0	?	?
70.0	70	Max.1660
80.0	?	?

×

No. of tanks in an industrial complex
10
10
0
20
0
0
5
0

=

Total amount (kl)
?
?
0
?
0
0
(70+1660)×5= 8650
0

Sum ?

Total assessment (Osaka bay area)

Concluding remarks

- Sloshing situation is simulated for a large oil tank in Osaka bay with an estimated ground motion of Nankai Trough earthquake.
- For a tested site and tank, sloshing itself is not so serious but significant amount of oil is accumulated on the floating roof.
- Further investigation on the local assessment (industrial complex) and the total impact assessment (Osaka bay) should be done as the next step.