Damage due to the drifting ships and its modeling by using EDEM

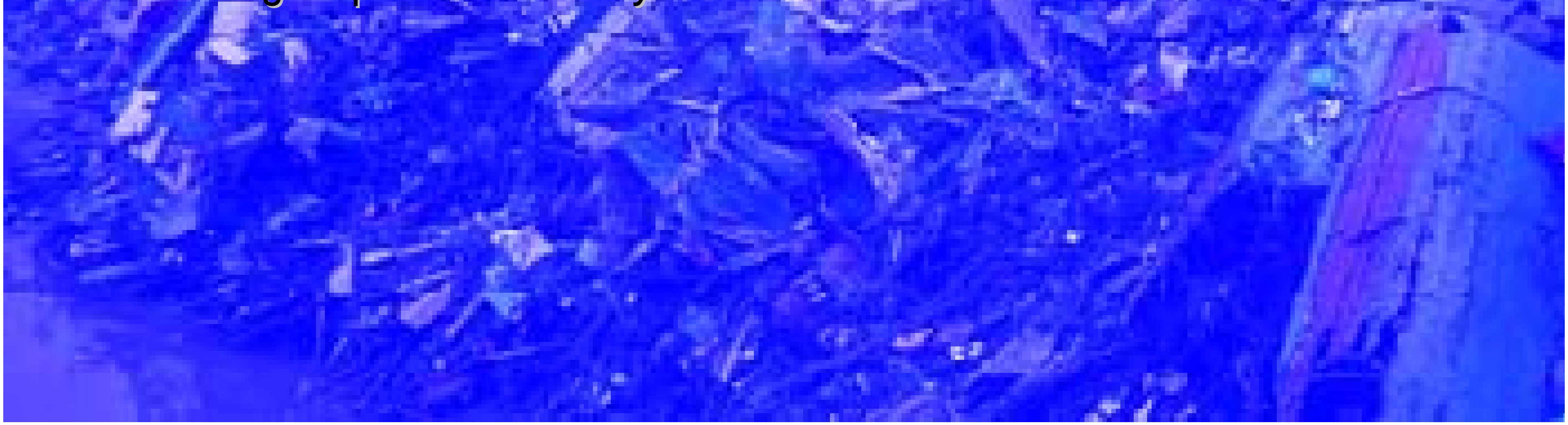
F.Imamura and N.Fujii

DCRC, Tohoku Univ., & TEPSCO

27 Dec. 2006

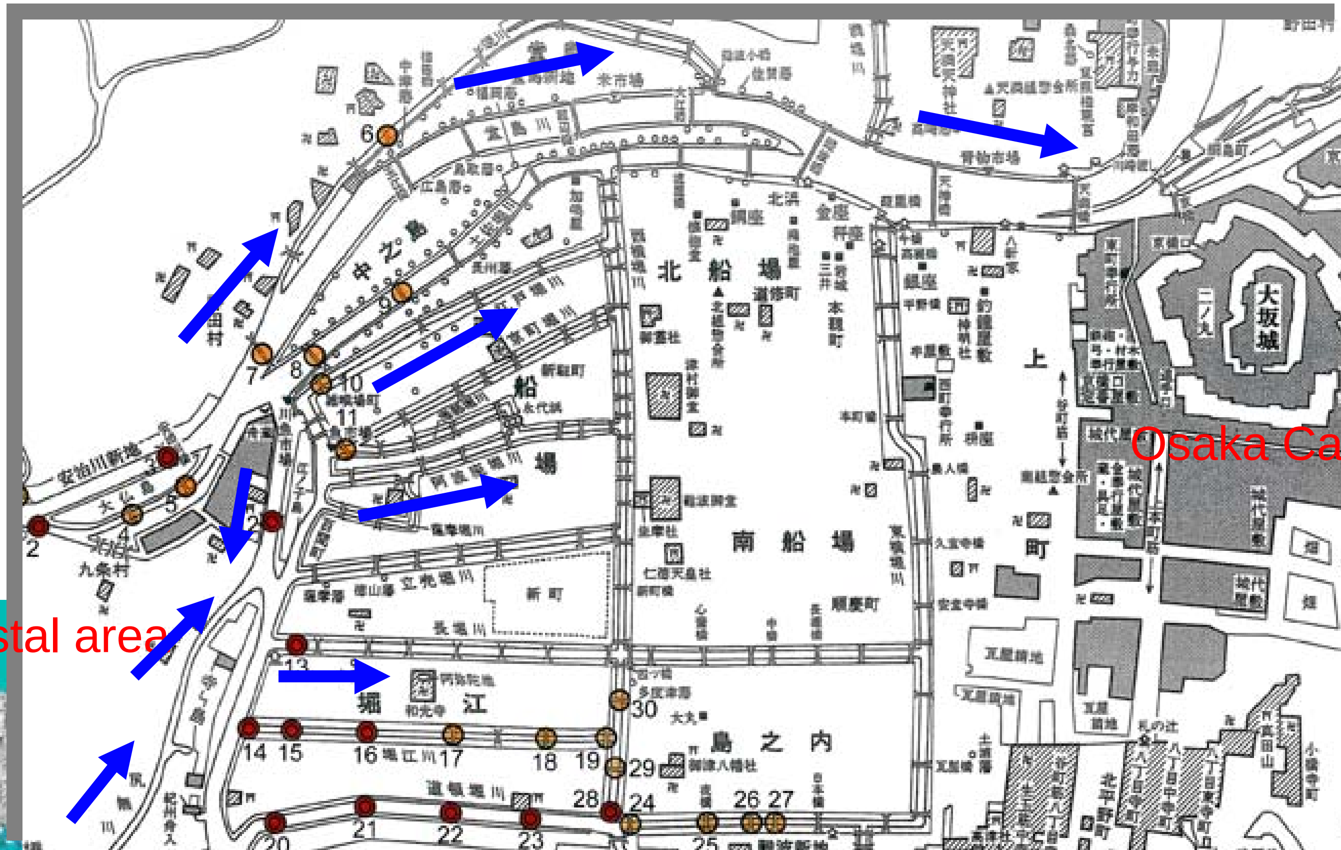
Background and motivation

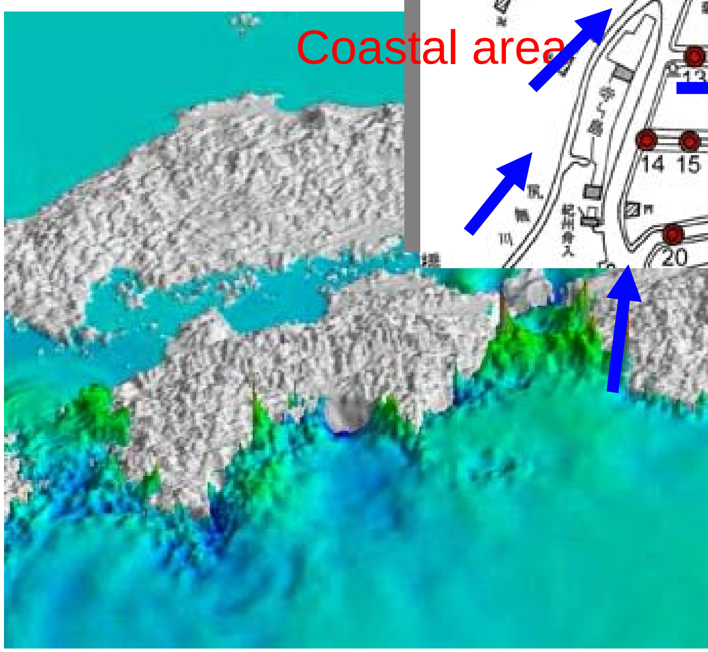
- When Tokai, Tohnankai and Nankai earthquakes in Japan happen, at the particular industrial zone, on the coastal zone the tsunami should cause greater damage than we estimate.
- Because, As seen in 2004 Indian Ocean Tsunami, drifting bodies including vessel of 3000 ton due to the tsunami would increase damage on houses/building on coastal area more, which is one of new features of a tsunami.
- It is an important to develop the tool for predicting behavior of the drifting ships interacted by the tsunami at industrial area.

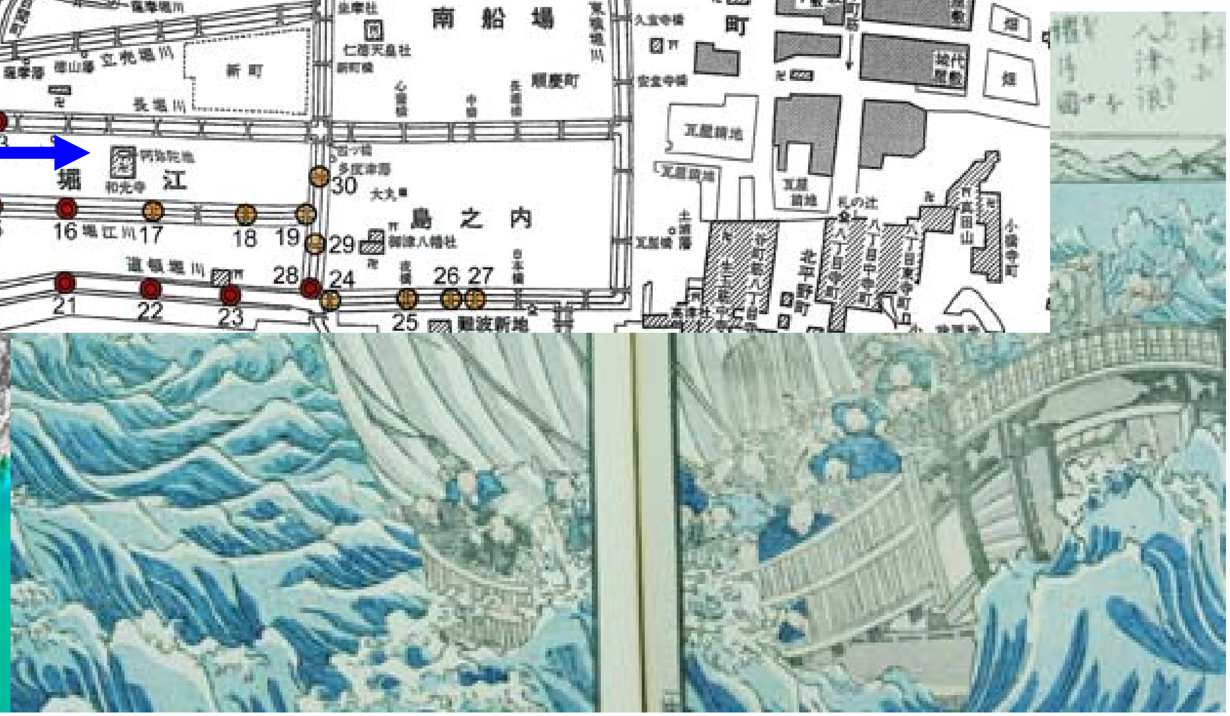


Bridges damaged by the drifting ships at the downtown of Osaka,at the 1701 Hoei and 1854 Ansei in the west Japan

Complex system of rivers and channels at the center of commercial area







Damage of ships at recent tsunamis

Date	Event	Damage of ship & vessel
1964.6.16	Niigata EQ	133
1983.5.26	Japan sea EQ	2612 (fishing boat)
1993.7.12	Hokkaido Nansei-oki EQ	1729

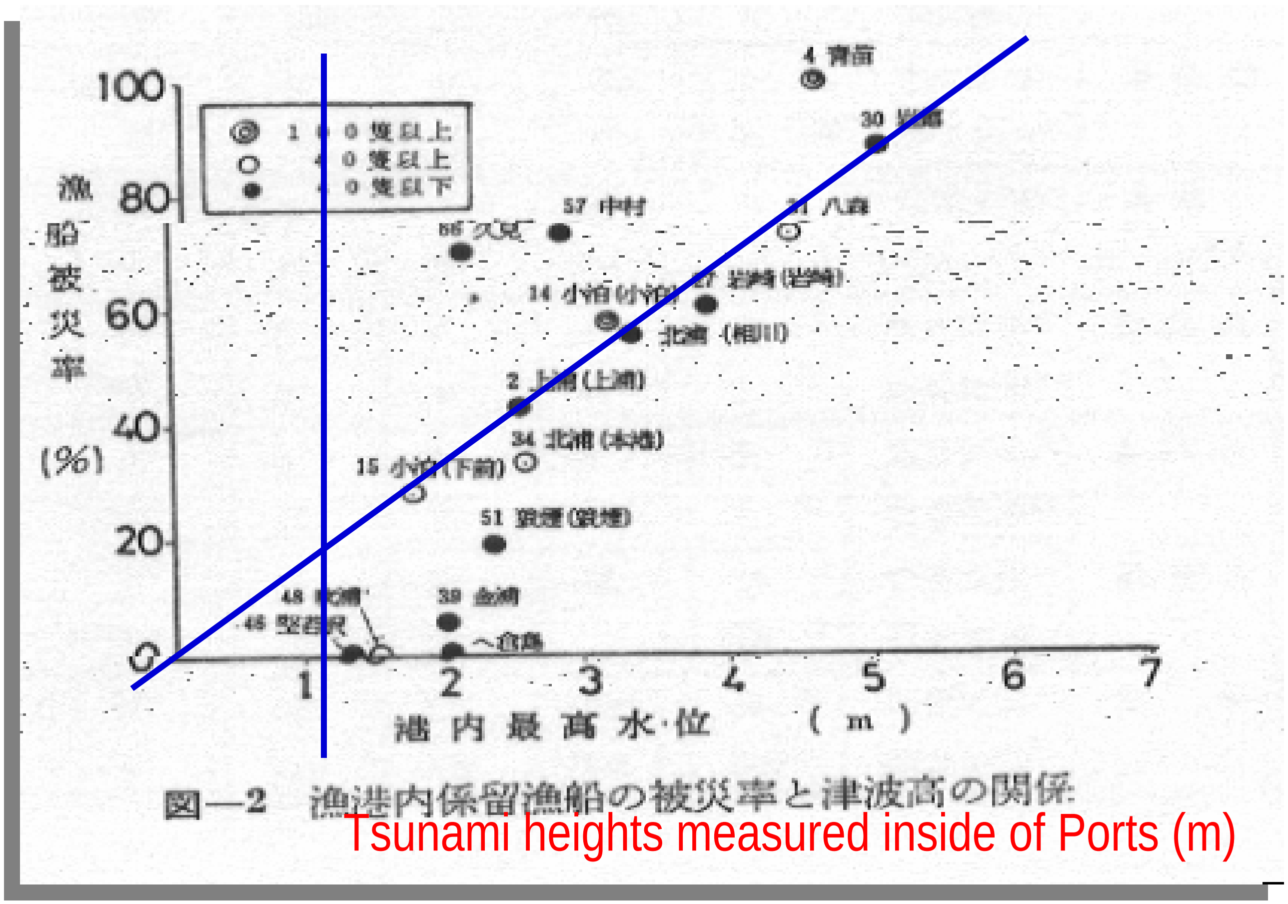
1960 Chilean tsunami

collision / crash

overturn

1993 Hokkaido nansei-oki tsunami

Ratio of the damaged to the total of moored boats (%)



Relationship between tsunami heights and Ratio of damaged to the total of moored boats inside of ports in the case of the 1983 Japan sea tsunami

Previous studies on the drifting bodies /floating material in Japan

Previous study	Brief summary
Sato et al. 1981), Irie et al. 1983 , Matsutomi 1999 , Ikeno et al. 2003	Proposed a collision forces by the experiment for timbers
Goto et al. 1982 , Goto 1983	Physical experiment and drifting simulation of timbers moved by a tsunami
Nakagawa et al.(1993,2001)	Physical experiment and simulation of drifting timbers moved by a flood
Takano et al.(2005), Nagao et al.(2005)	Experiment on the behavior of drifting bodies at a harbor entrance
Mizutami et al.(2005)	Experiment of the drifting containers and collision force when tsunami runs up on the apron at a harbor
Kobayashi et al.(2004)	Developing a drifting simulation model of a ship by Extended Distinct Element Method

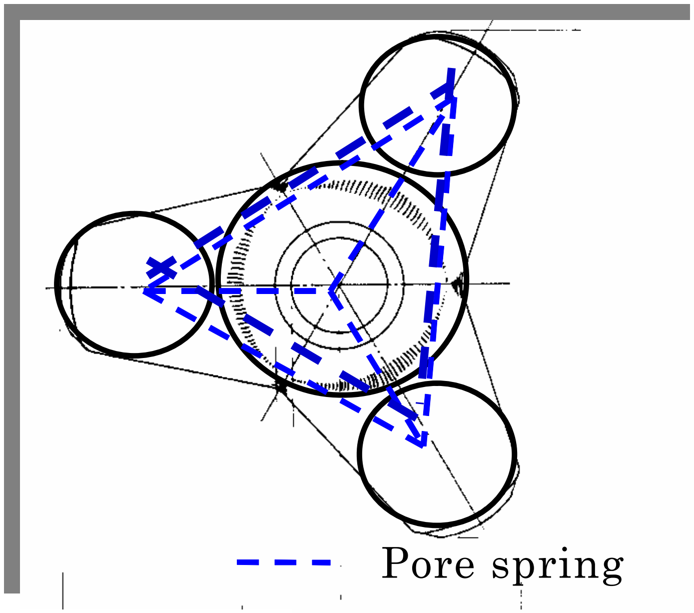
Problem and key points

Identified Problems	Key points in this study
The experiment that most were carried out by one - dimensional wave flumes	•Doing an experiment by two-dimensional wave tanks •The behaviors of the drifting in the harbor where vortex happens at the entrance
Not consider the collision among drifting bodies or between drifting bodies and structures	•Modeling interaction and collision between tsunami and drifting one by taking account interacting/contacting force
Not consider the phenomenon that drifting bodies runs from a sea area onto a land area.	•Modeling vertical drifting motion •The body runup on the land should cause more damage •The body attached the bottom should be easily damaged
Not consider the phenomenon that drifting bodies is carried away from land level to a sea area by a return flow.	
Shape of Drifting bodies, ships, timbers, containers, cars, etc are various.	•To make shape in EDEM (Extended Distinct Element Method)

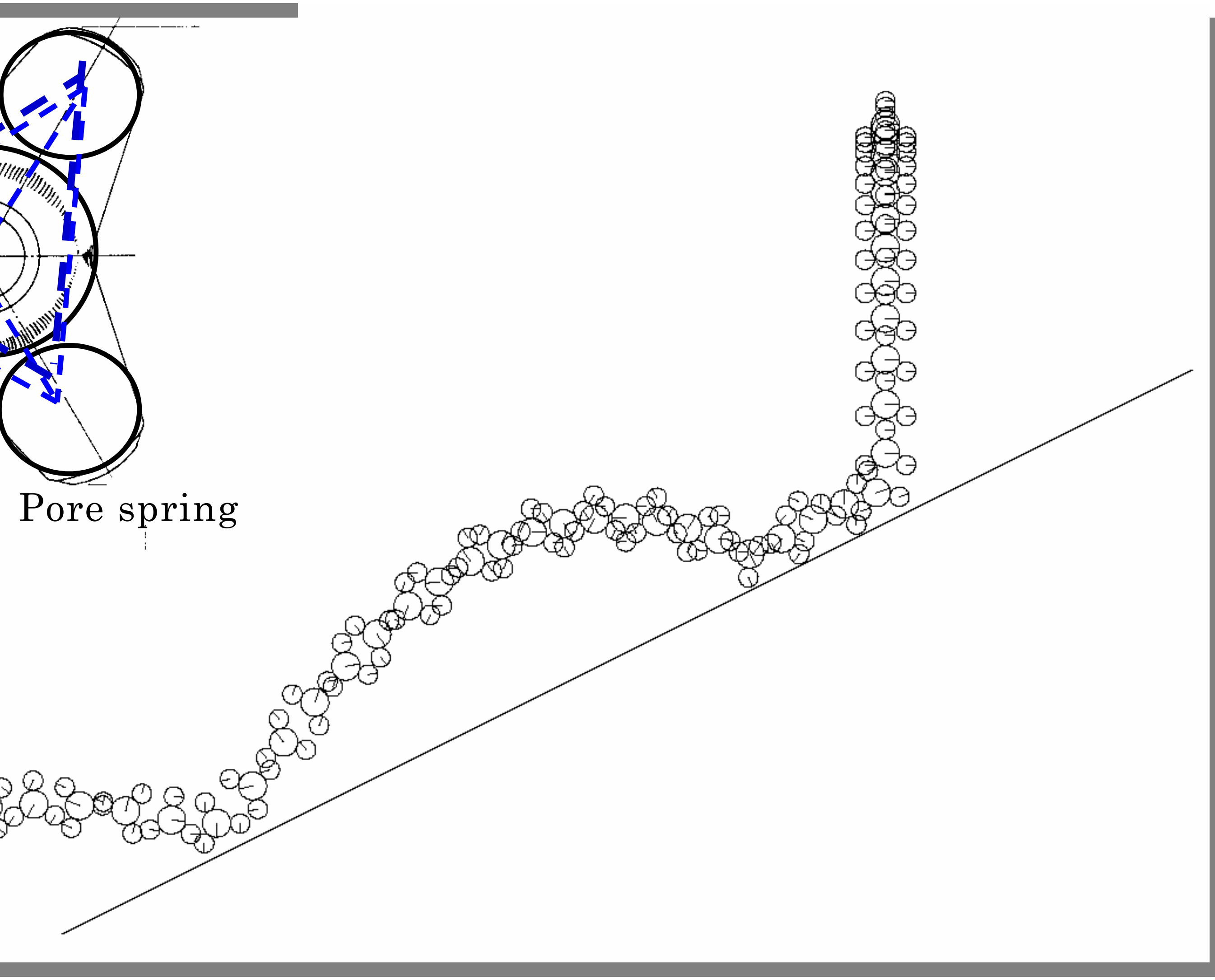
The discrete element method (*DEM*) was pironeered by Cundall & Strack (1979). The method utilizes a large ensample of discrete particles (usually spheres or discs) to represent the bulk behaviour of granular material. The particle interaction laws are based on contact physics and the equations of motion are typically integrated explicitly in time.   The resulting algorithms are simplistic, the physics involved is quite intuitive and yet complex phenomena may be simulated.

The typical DEM model needs very few input parameters (as material properties) because the behavioral complexities of the particle system arise as emergent properties

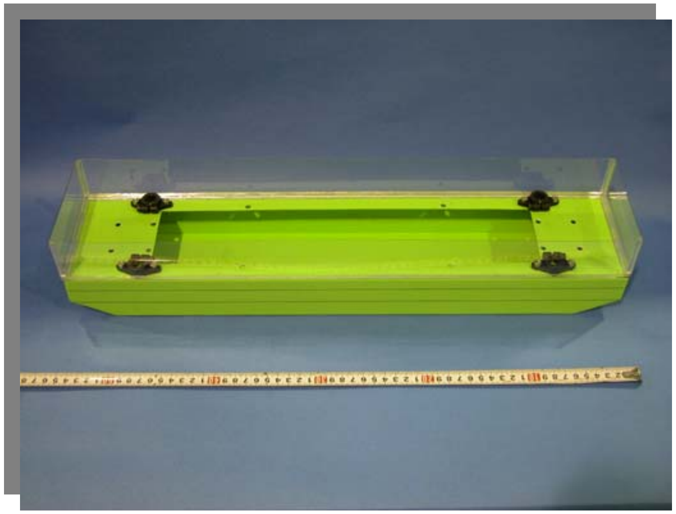
Pore spring



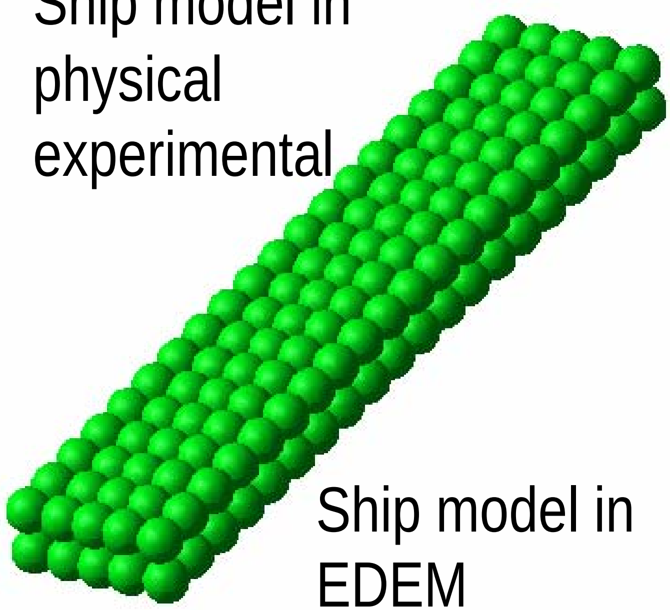
the fall of a block on the slope



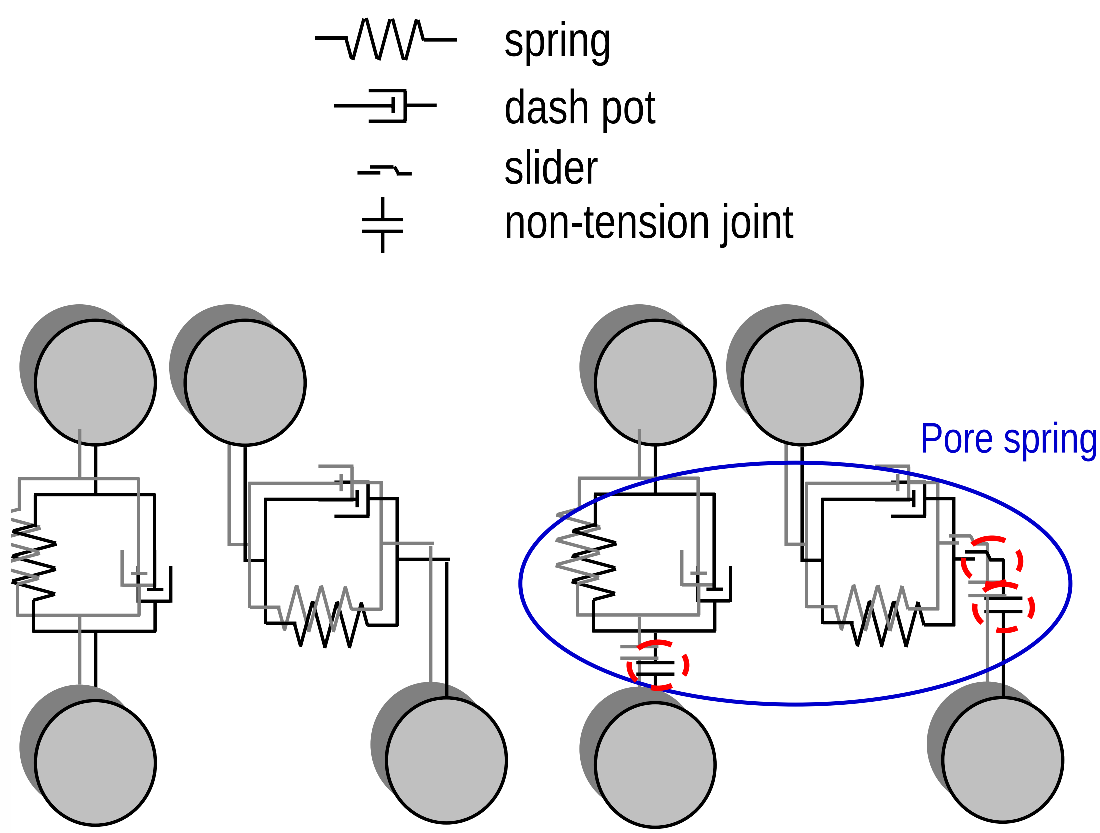
Extended Distinct Element Method (EDEM)



Ship model in physical experimental



Ship model in EDEM



(a) Normal element model (b) Pore spring model

EDEM by Meguro et al.(1988)

Numerical simulation of drifting body by E   in case of tsunamis

Tsunami simulation with Nonlinear long wave theory → Outputting water level and velocity

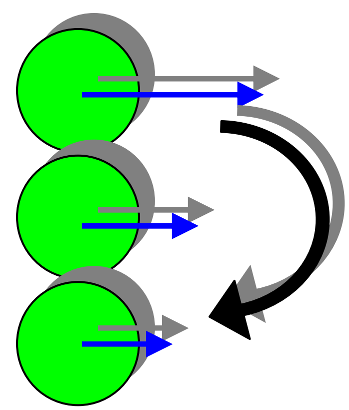
Horizontal interactive-force on drifting body calculated with Morrison eq. (same as Goto et al.,1982,1983) at each element

$$F_x = C_M \rho V \frac{\partial u}{\partial t} + C_D \frac{\rho u^2}{2} A_x$$

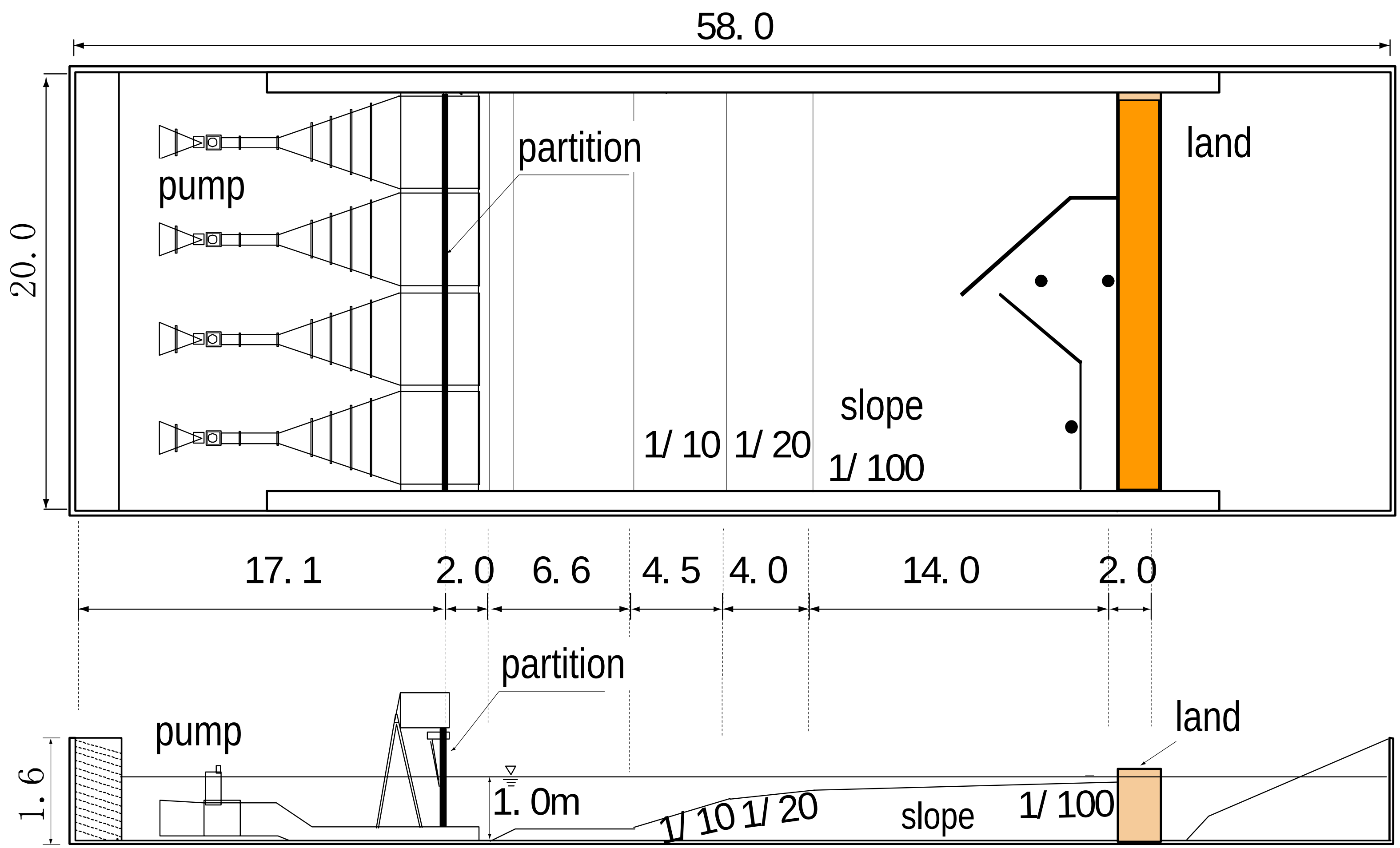
Vertical motion considering buoyancy, gravity and drag force.

Calculating all wave forces on each element, which move the drifting one

Change of velocity on each element cause the rotation, which is new function in the EDEM



Experimental set up with 2-D wave tank, Kajima Co Ltd



(Unit : m)

A, B, C : Initial positions of ships

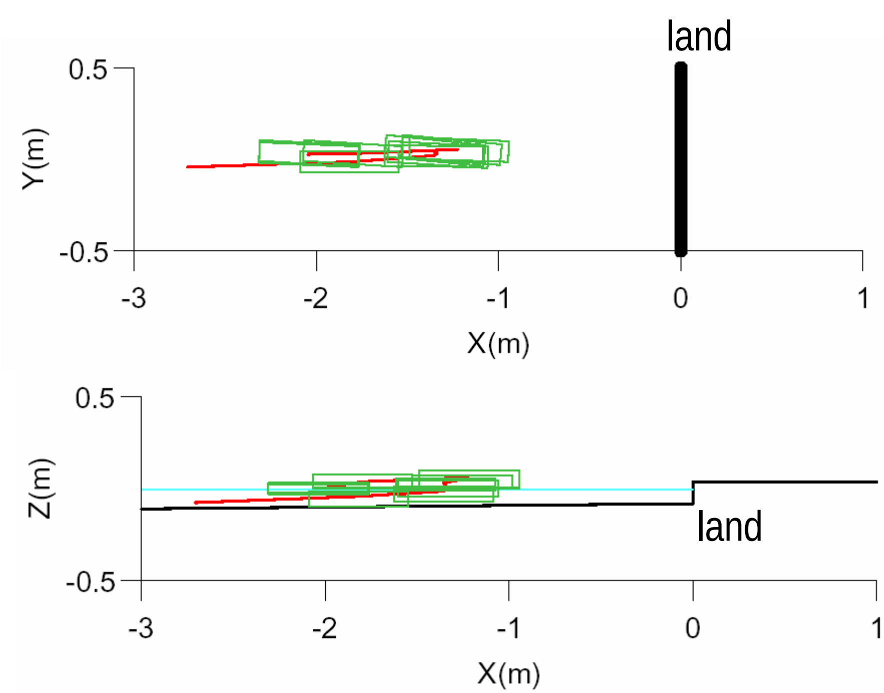
Experiment of drifting ship

H=10cm   T=90s, without breakwater

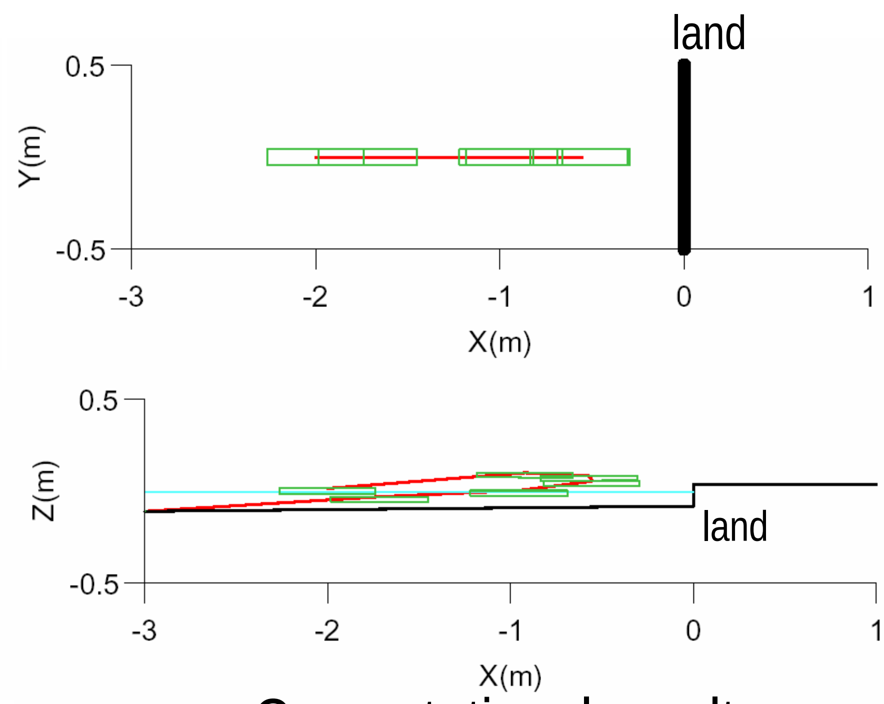
QuickTimeý Ç²
DV/DVCPRO - NTSC êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç ÅB

Comparison of horizontal/vertical motion of drifting in the coast

H=7.5cm T=30s, without breakwater



Experimental result



Computational result

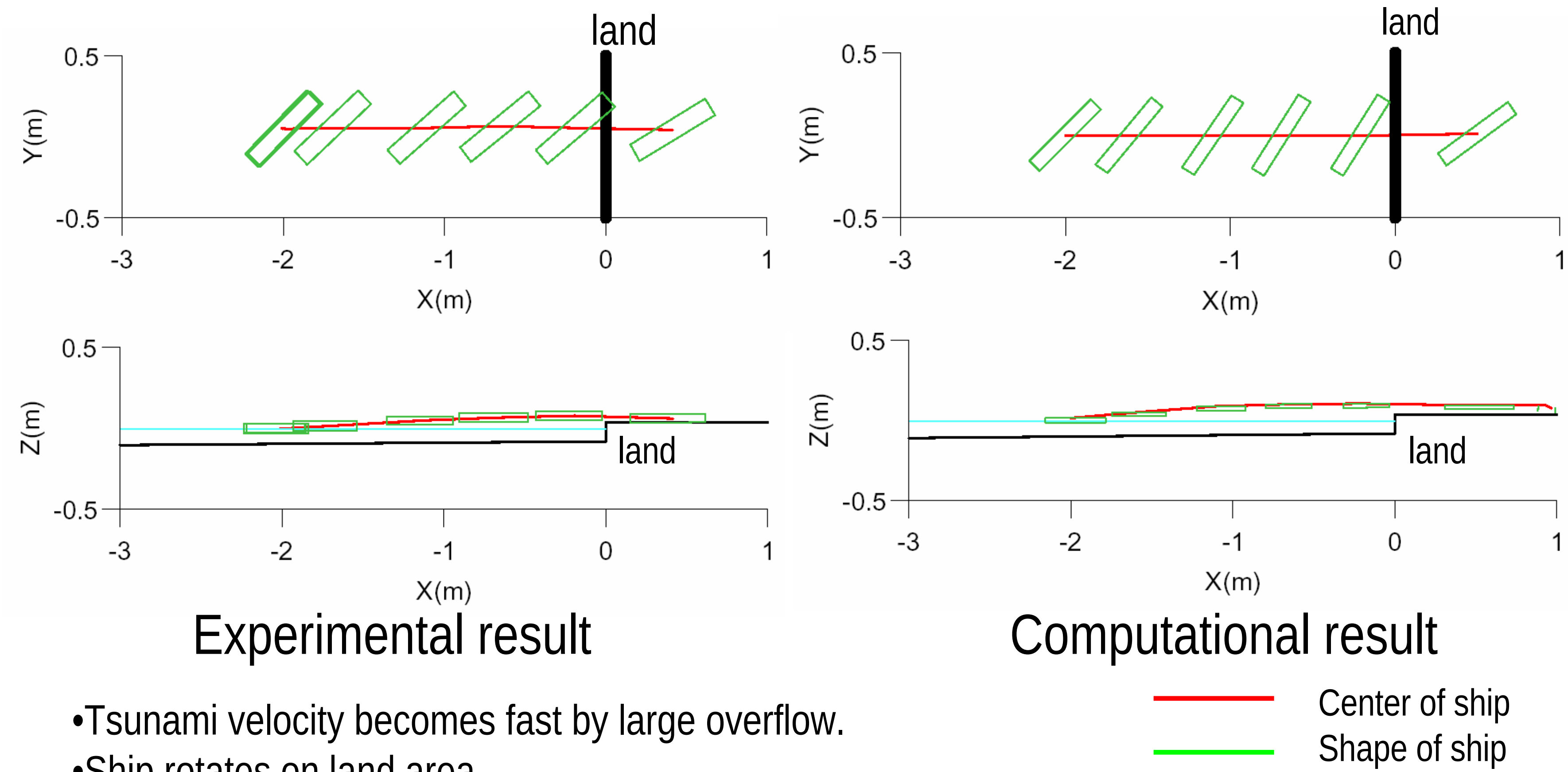
Center of ship

Shape of ship

- Tsunami propagate faster than a ship
- The ship did not reach to land by reflection wave and moved to offshore

Comparison of horizontal/vertical motion of drifting in the coast

H=10cm T=90s, without breakwater



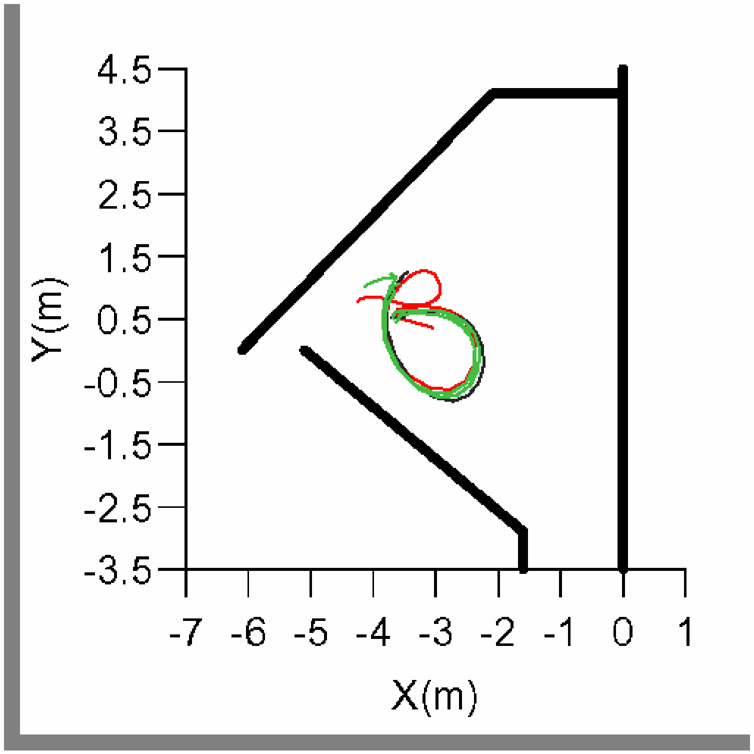
•Tsunami velocity becomes fast by large overflow.
•Ship rotates on land area
•Tsunami force is different from the stern with the bow.

Experiment of drifting ship at a harbor

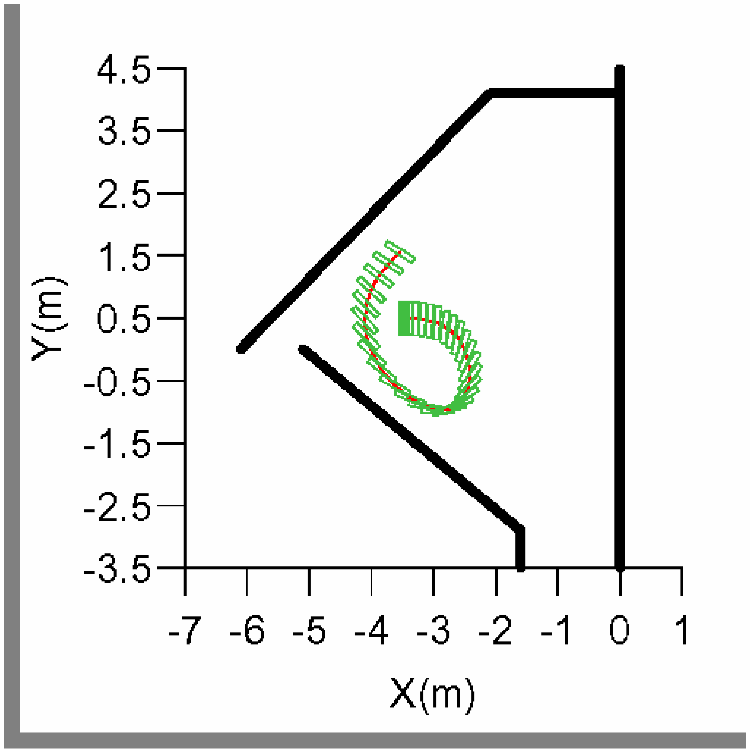
H=10cm   T=90s, with breakwater

QuickTimeý Ç²
DV/DVCPRO - NTSC êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç   ÅB

Comparison of drifting movement at harbor H=7.5cm T=90s



Experimental result

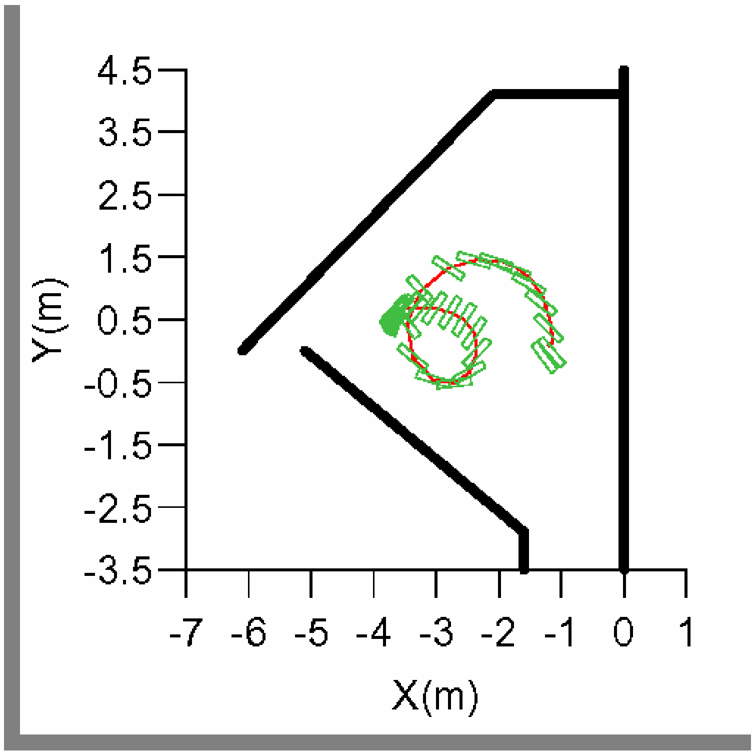


Computational result

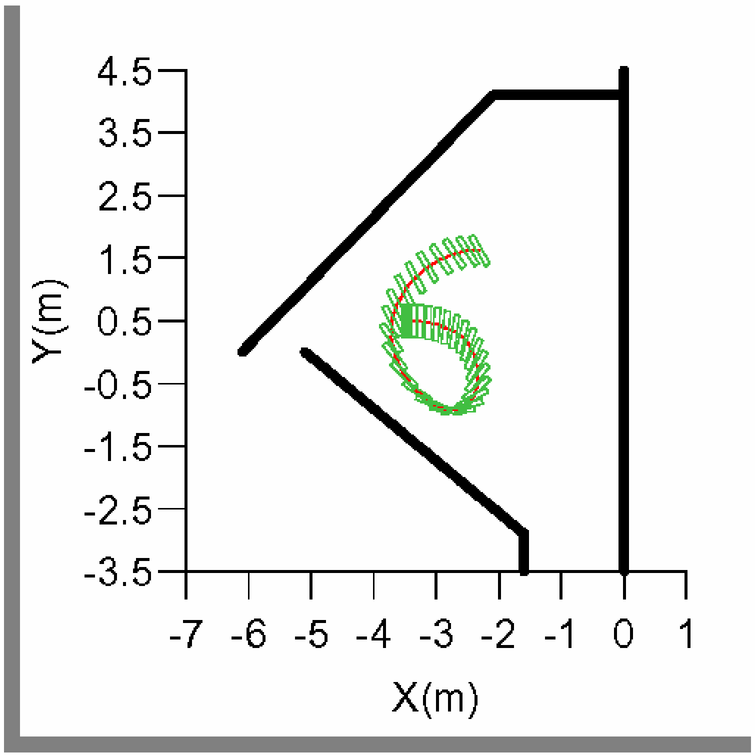
Center of ship
Shape of ship

- The ship drifts at a harbor entrance.
- Circulation flow is small area and is slow speed.

Comparison of drifting movement at harbor H=10cm T=90s



Experimental result



Computational result

- Ship moves clockwise
- The angle of ship rotates
- The movement radius of computational result is large

Center of ship
Shape of ship

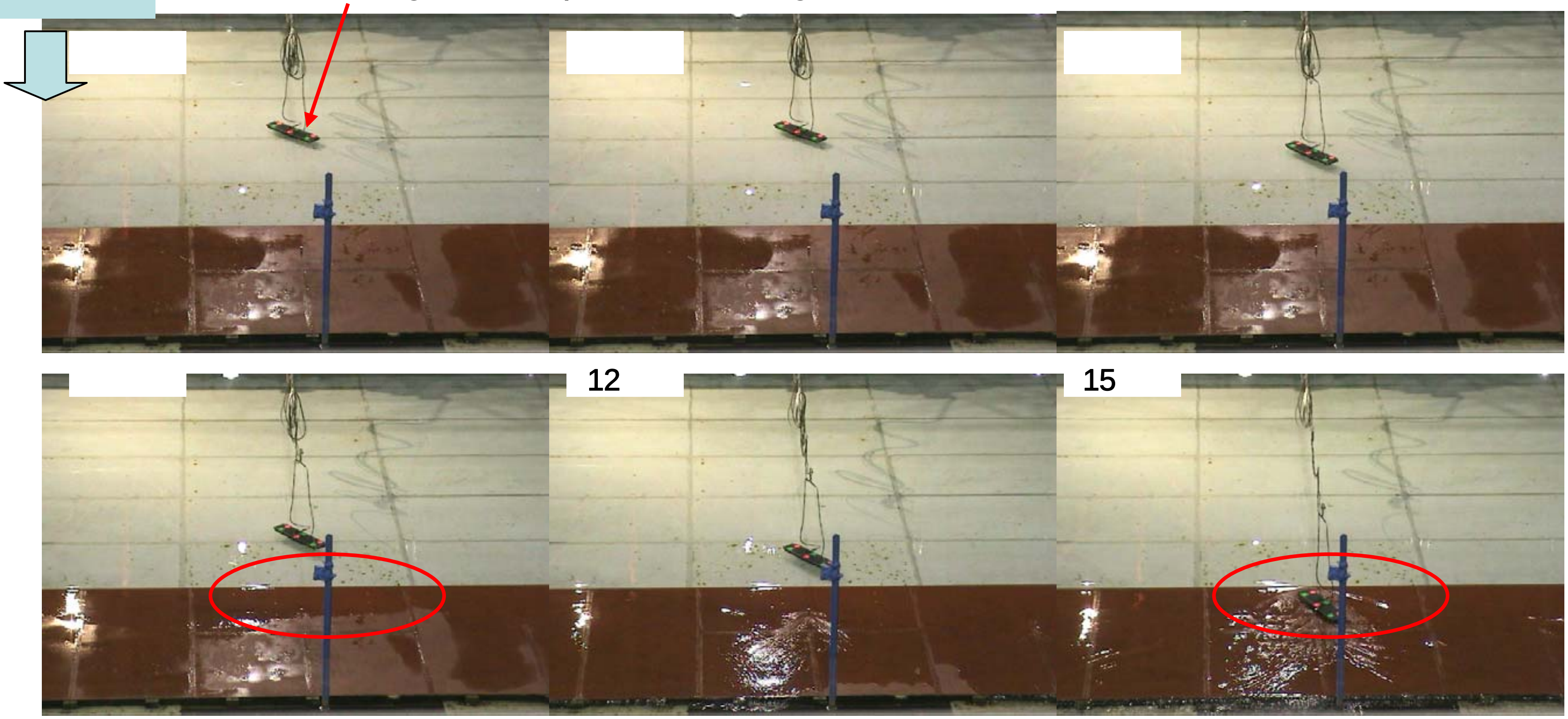
Results and future problems

- The physical experiments of the drifting body were carried out at the port with/without break water.
- The model of the drifting body on EDEM could simulate its behavior better than we expected.
- However, the following problems remains;
  - ✓ Coefficients in Morrison equation and others in EDEM should be verified.
  - ✓ In the case of large number of drifting bodied, the diffusion coefficient that Goto(1982), Nakagawa(1993) introduced in the simulation might be used.

Example of experimental study without breakwater

Tsunami

Initial angle of ship sets 45 degrees for wave direction



Tsunami run up

Ship run on the land

- In the sea, drifting ship keeps initial angle
- On the land, ship slightly turns clockwise

Purpose of the research

- The purpose is to evaluate the following items which are important to evaluate the tsunami damage in the coastal area;
  - To improve the behavior model of drifting bodies in the sea and on the land through experiments
  - To develop the evaluation model of tsunami force and drifted collision force acting on coast facilities

QuickTimeý Ç²
TIFFÅià èkÇ»ÇµÅj êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç ÅB

http://www.itascacg.com/pfc_dem.html

The motion and interaction of a system of disks/spheres is simulated by a time-marching scheme that integrates the equations of motion by a central, finite-difference method that ensures excellent accuracy and freedom from drift. Even quasi-static systems are solved with the same dynamic scheme, allowing physical instability and path dependence to be tracked without numerical problems.The explicit calculation cycle (illustrated opposite) solves two sets of equations   motion and constitutive. In both sets, variables on the right-hand-side of expressions are all known, and can be regarded as fixed for the duration of the step. Thus, nonlinear contact relations (even extreme examples of softening, such as brittle bond breakage) are used without difficulty, because only local conditions are relevant during the timestep. No iterations are necessary to follow nonlinear laws, and no matrices are formed. The formulation is based on that of Cundall & Strack (1979), with several enhancements, such as bonded contacts (Potyondy & Cundall, 2004), alternative damping schemes, and more general wall logic.In parallel with the mechanical calculations, there is continuous activity to detect new contacts between particles and delete contacts when particles separate. The algorithms are invisible to the user of *PFC*, and they are optimized to consume very little calculation time. For example, the detection logic is only triggered at a local level when movement sufficient to allow potential new contacts has accumulated. Overall, the searching and detection scheme executes in a time that is linearly dependent on the number of particles.Cundall, P. A., and O. D. L. Strack. "A Discrete Model for Granular Assemblies," *Geotechnique*, *29*(1), 47-65 (1979).Potyondy, D. O., and P. A. Cundall. (2004) "A Bonded-Particle Model for Rock," *Int. J. Rock Mech. Min. Sci.*, *41*, 1329-1364.