A study of the method to reduce damages by tsunami applying flexible pipes

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Background

On March 11th, 2011 a Big earthquake occurred in the east-Japan

A lot of tsunami hit the coast

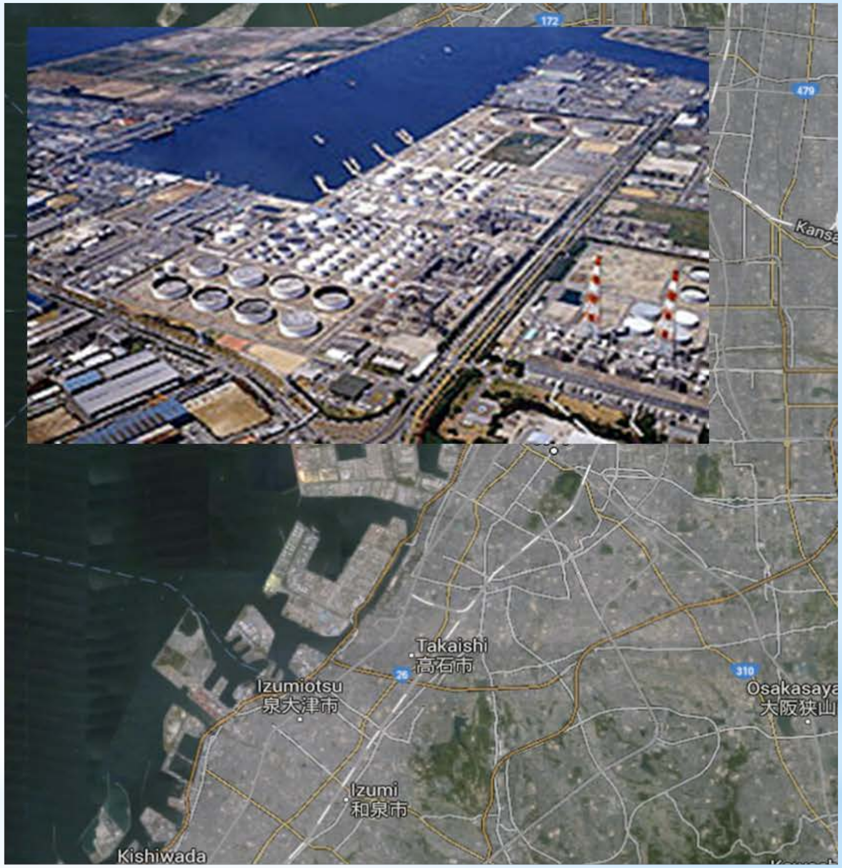
Breakdown of nuclear power generators and oil tanks

Radiation and fire disasters

Secondary disasters occurred

Estimation of the future earthquake

The Nankai trough earthquake and tsunami will happen in Osaka bay in near future



Necessity of setting up wave breakers to defend from the tsunami when a big earthquake occurs

Wave breakers which exist already :

Fixed Type

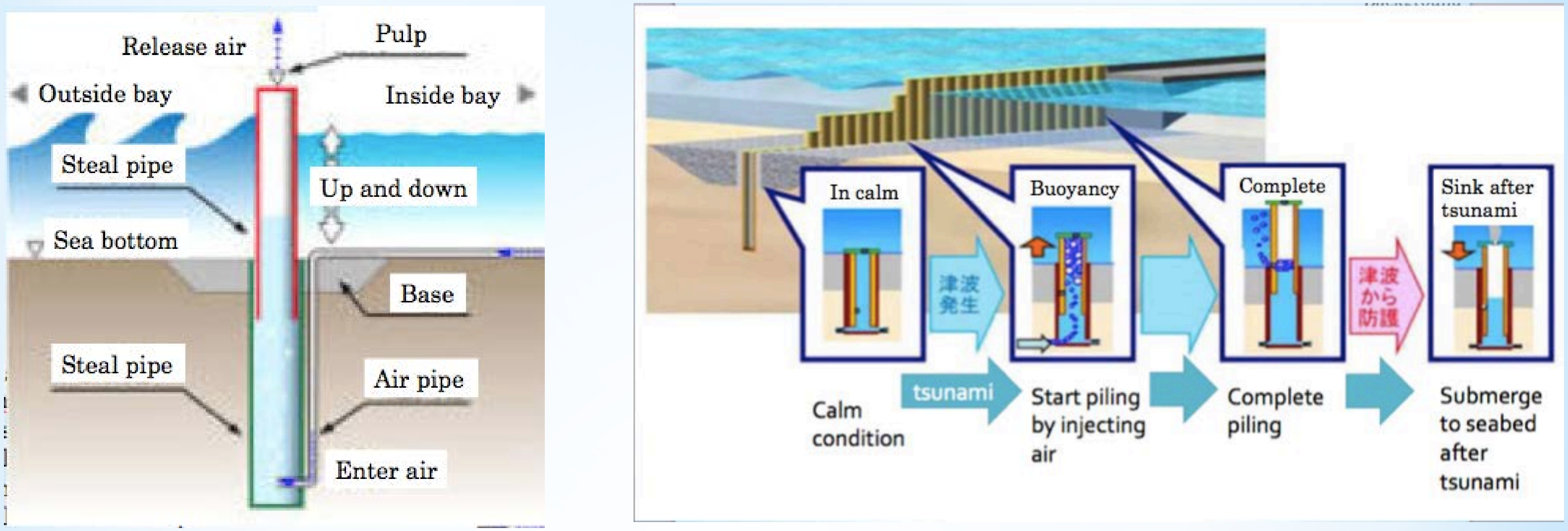
Seawall by concrete

Embankment by tetrapods

(-) They cause a big handicap for the traffics and the operation of ships

(-) They destroy the landscape and cause troubles to marine life

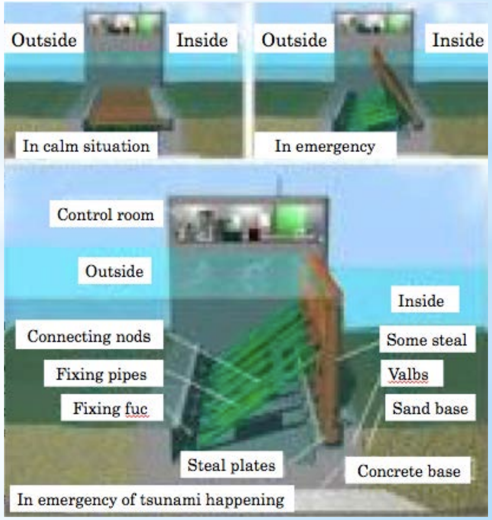
Wave breakers which exist already :
Mobile Type



Buoyancy-driven vertical piling wave breaker

(-) Costly + Long deployment time
(-) Needs sophisticated technology
(-) The system can get stuck and the barrier may not be able to be deployed due to earthquake

→Necessity to develop another system which doesn’t have these disadvantages



Flapgate wave breaker

Nature oriented countermeasure

Mangrove was found to be effective.

(In 2004 Thailand, India)

Giant kelp is also well-known to have the ability of breaking water.

→Artificial structures which

imitate them

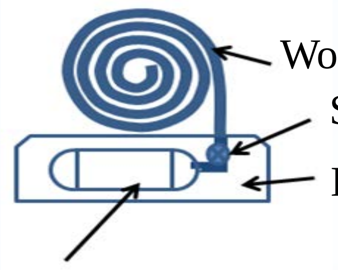
Purpose of this study

Develop an equipment that employs flexible pipes which reduce the damage caused by tsunami

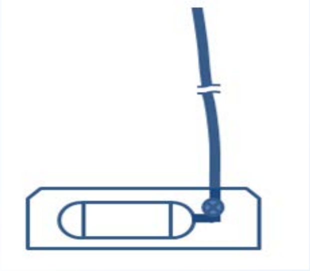
- Shaped of a pipe made from soft materials
- It is rolled up in idle condition
- Expanded by injecting compressed air from air bomb in emergency condition

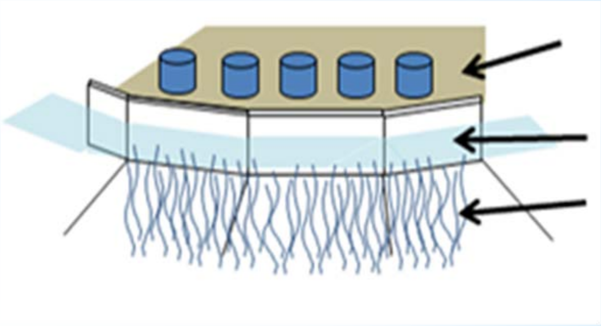
<Concept>

In idle condition



In emergency condition





Hydrodynamic functions
1. Decrease of water current energy
2. Decrease of wave energy

Advantages

- Don’t disturb marine traffics and don’t destroy landscape or environment.
- Cost less and take less time to construct.
- Work exactly without worrying troubles by earthquake.
- Very effective against tsunami which has large wave height.

Deformation test of the actual hose

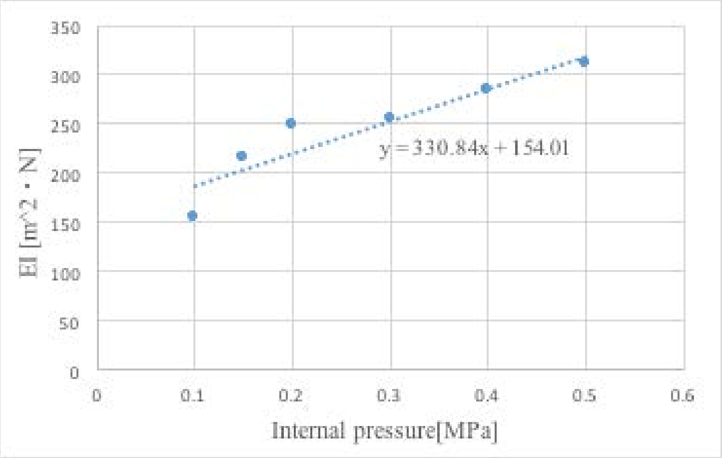
⑴A Fire hose is selected as the example of the flexible pipe.

→good tightness and can endure high pressure.

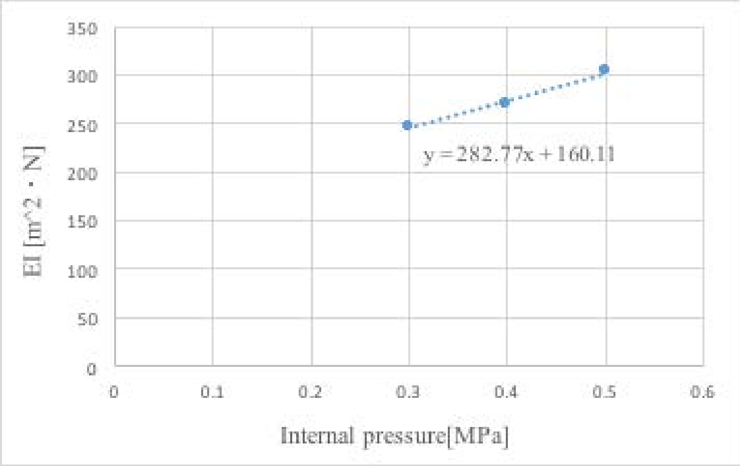
⑵Injecting compressed air to the fire hose, the bending stiffness(EI) was measured.

Double jacket hose

Results of the test



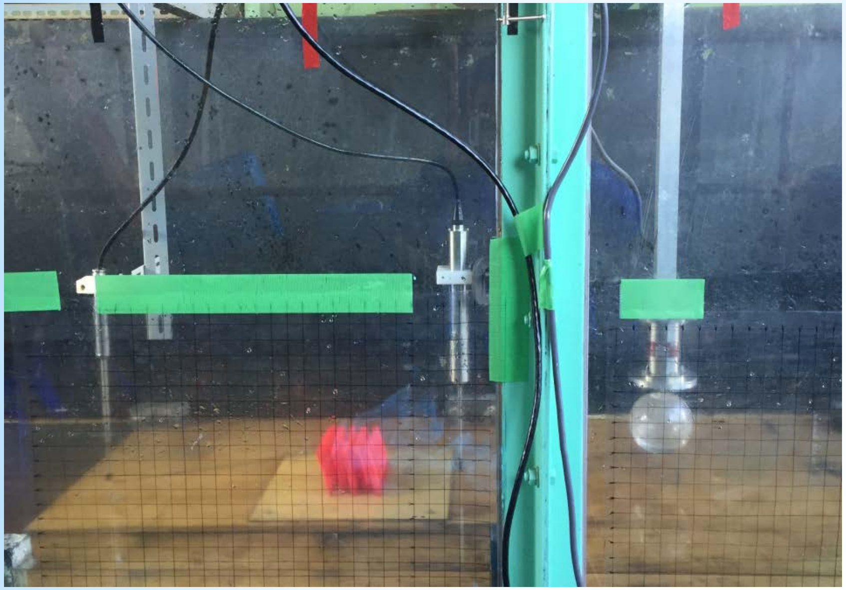
Internal pressure and EI (4kg)



Internal pressure and EI (6kg)

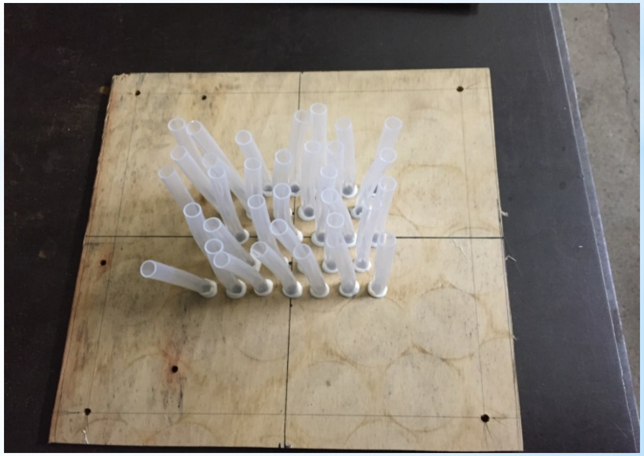
Approach

Scale Model Experiments

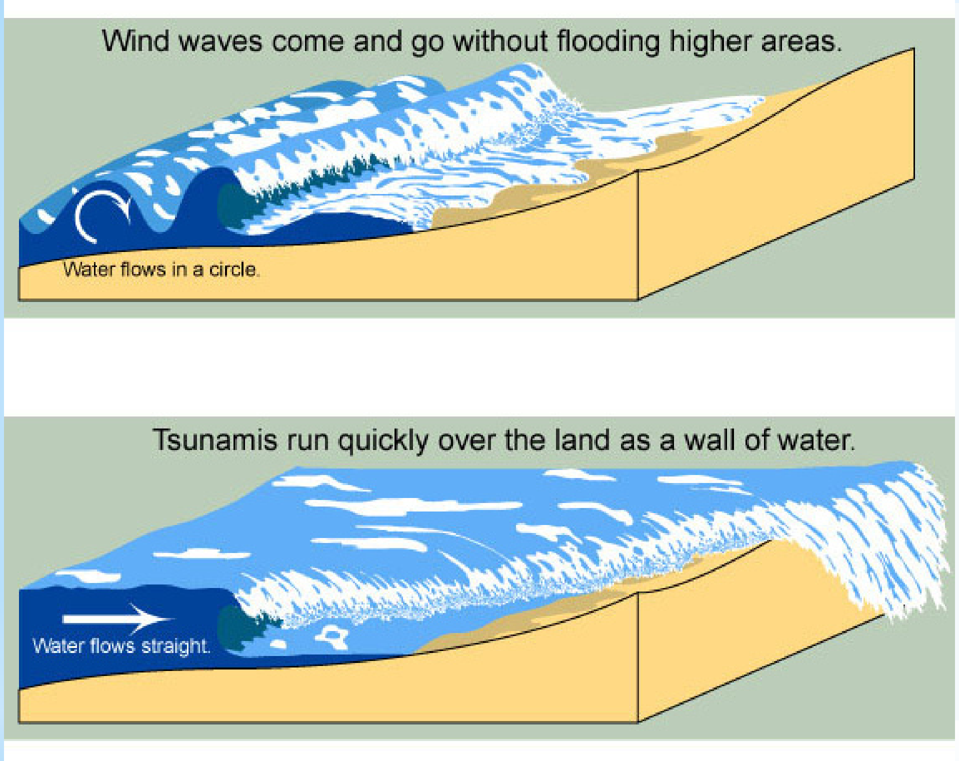


- Carried out in the tsunami basin.
- Tsunami was generated by dam break method.
- 4 sets of scaled-model pipes with different bending stiffnesses were tested and compared in order to investigate the effect of stiffness of pipes on tsunami damage reduction.
- The flow velocity in front of and behind the pipes as well as hydrodynamic force acting on the sphere that represents oil tanks is measured.

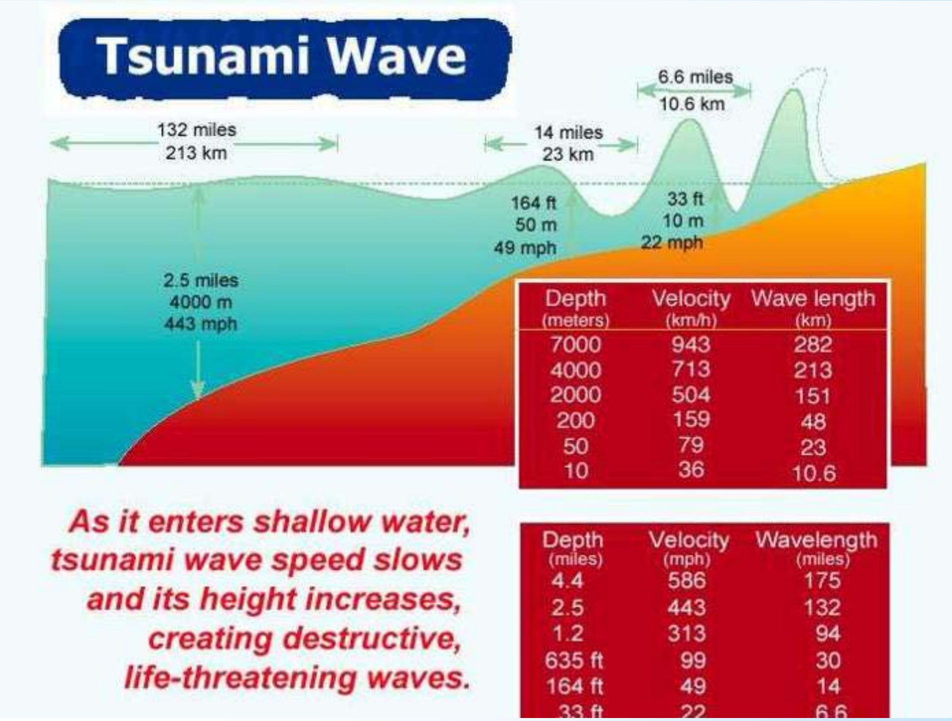
- When the diameter of the double jacket hose is 1.5m, the rubber pipe like the figure below, which made of silicon, has the scale of almost 1/150 of the double jacket hose in terms of diameter and EI.



Tsunami Wave: Phenomenon



Ordinary ocean waves vs Tsunami Wave
(Source: Seismic Safety Commission, California)



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

As it enters shallow water, tsunami wave speed slows and its height increases, creating destructive, life-threatening waves.

Depth (miles)	Velocity (mph)	Wavelength (miles)
4.4	586	175
2.5	443	132
1.2	313	94
635 ft	99	30
164 ft	49	14
33 ft	22	6.6

Tsunami Wave Characteristics
(source: Maine Geology Surveys)

Tsunami is a shallow water wave.

Thus, $v = \sqrt{g(d+H)}$

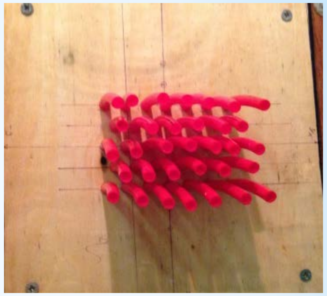
Tsunami Basin Experiment

Tsunami Basin

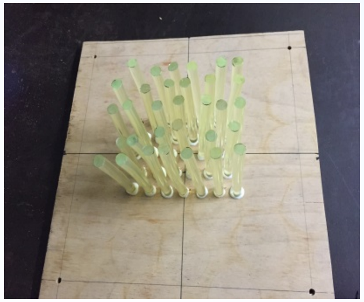
L x W x D : 100m x 0.7m x 0.9m

Flow Velocity: around 1.2 m/sec

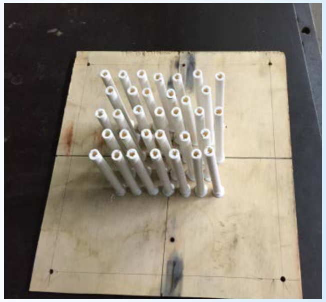
1. Rubber Pipes



2. Plastic Pipes



3. Urethane Pipes

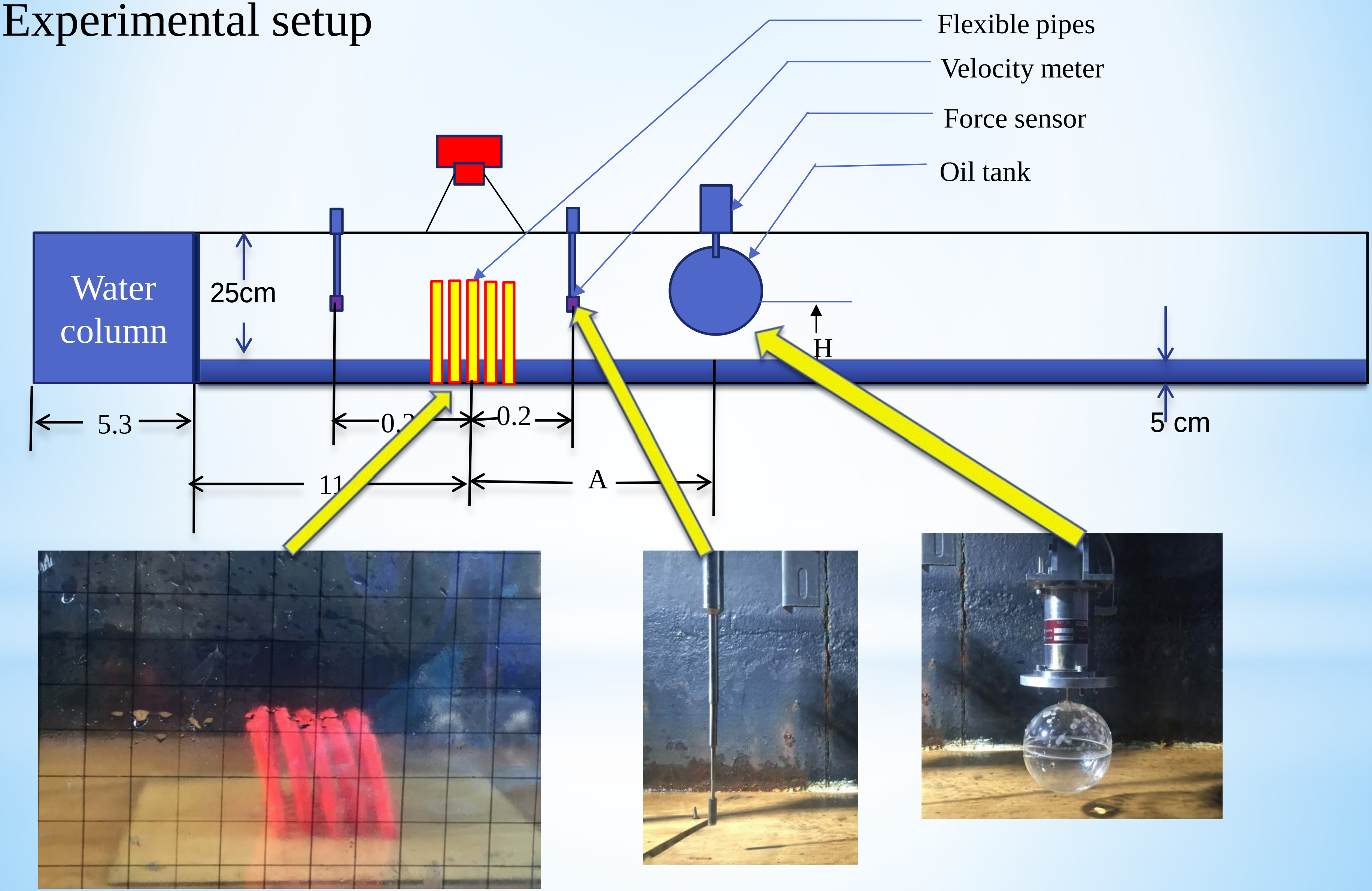


4. Rigid PVC Pipes

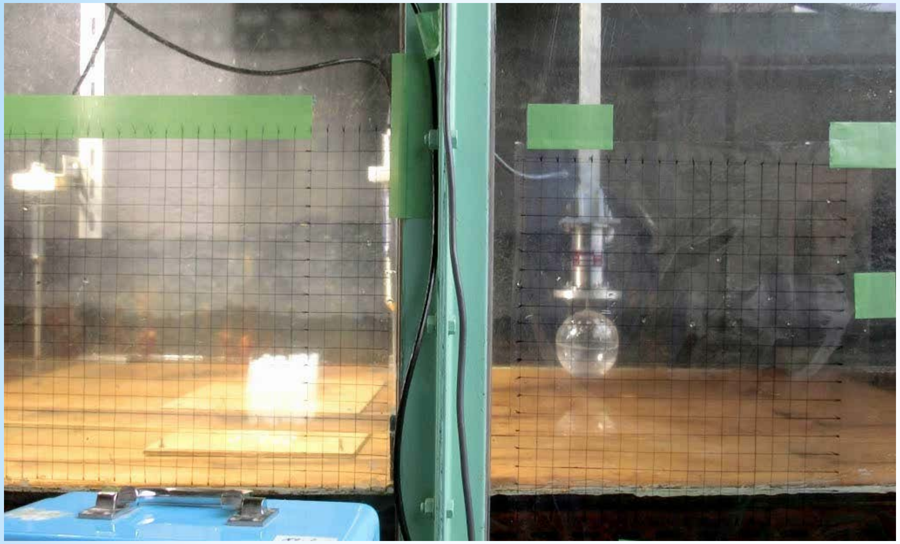
No.	**Type**	**Bending Stiffness (EI)**
1	Rubber Pipes	7.59×10^{-9}
2	Plastic Pipes	2.38×10^{-8}
3	Urethane Pipes	2.64×10^{-8}
4	Rigid PVC Pipes	Regard as rigid

Tsunami Basin Experiment

Experimental setup

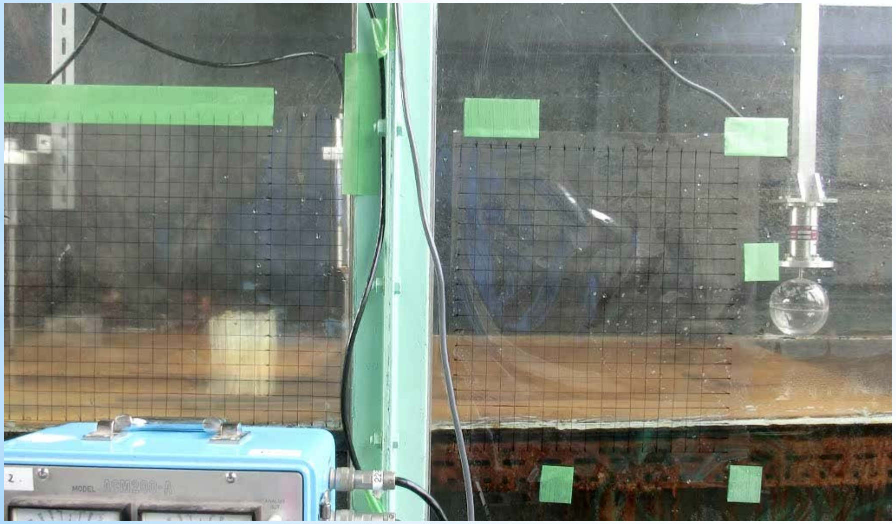


Tsunami Basin Experiment



Rubber pipes (EI : 7.59×10^{-9}, most flexible)

Plastic pipes (EI : 2.38×10^{-8})

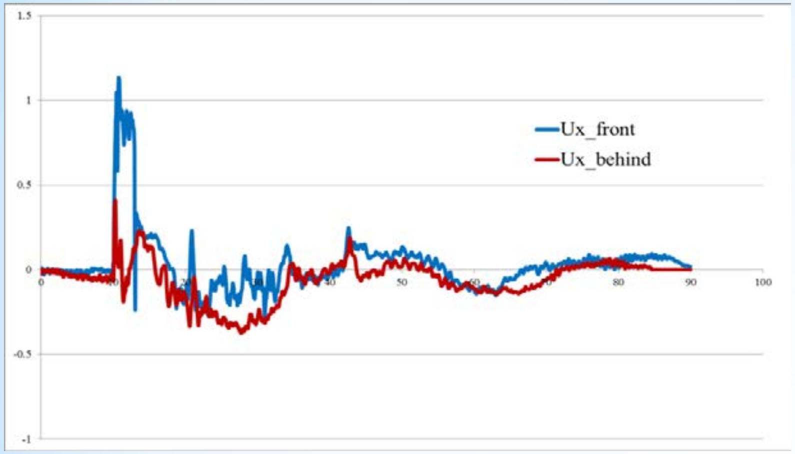


Urethane pipes (EI : 2.64×10^{-8})

PVC pipes (regard as rigid)

Comparison of Flow Velocity

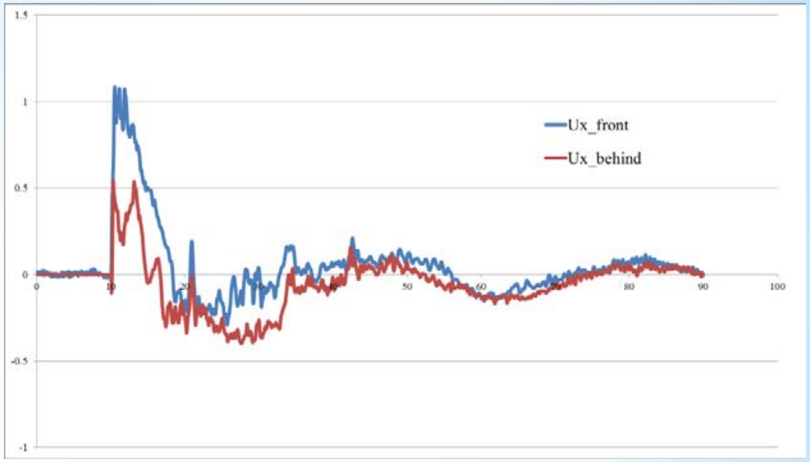
Rubber Pipe



Flow velocity[m/s]

Time[s]

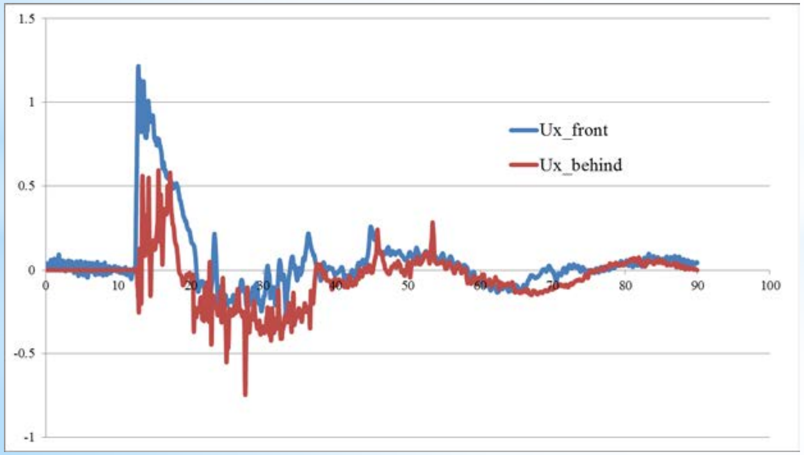
Plastic Pipe



Flow velocity[m/s]

Time[s]

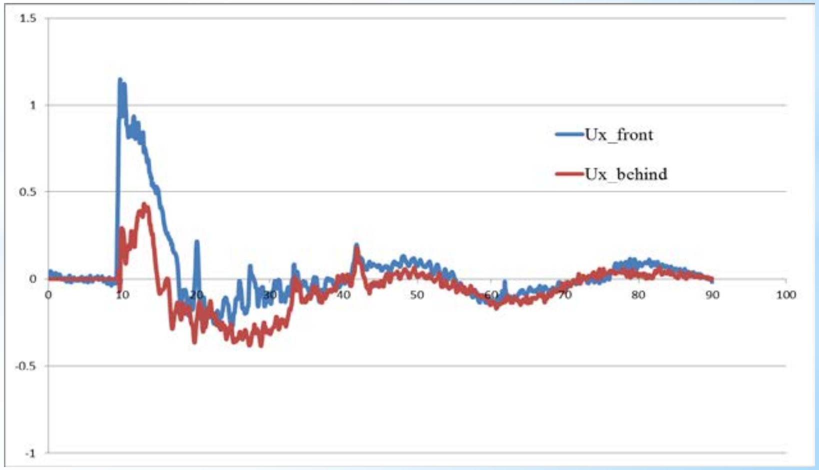
Urethane Pipe



Flow velocity[m/s]

Time[s]

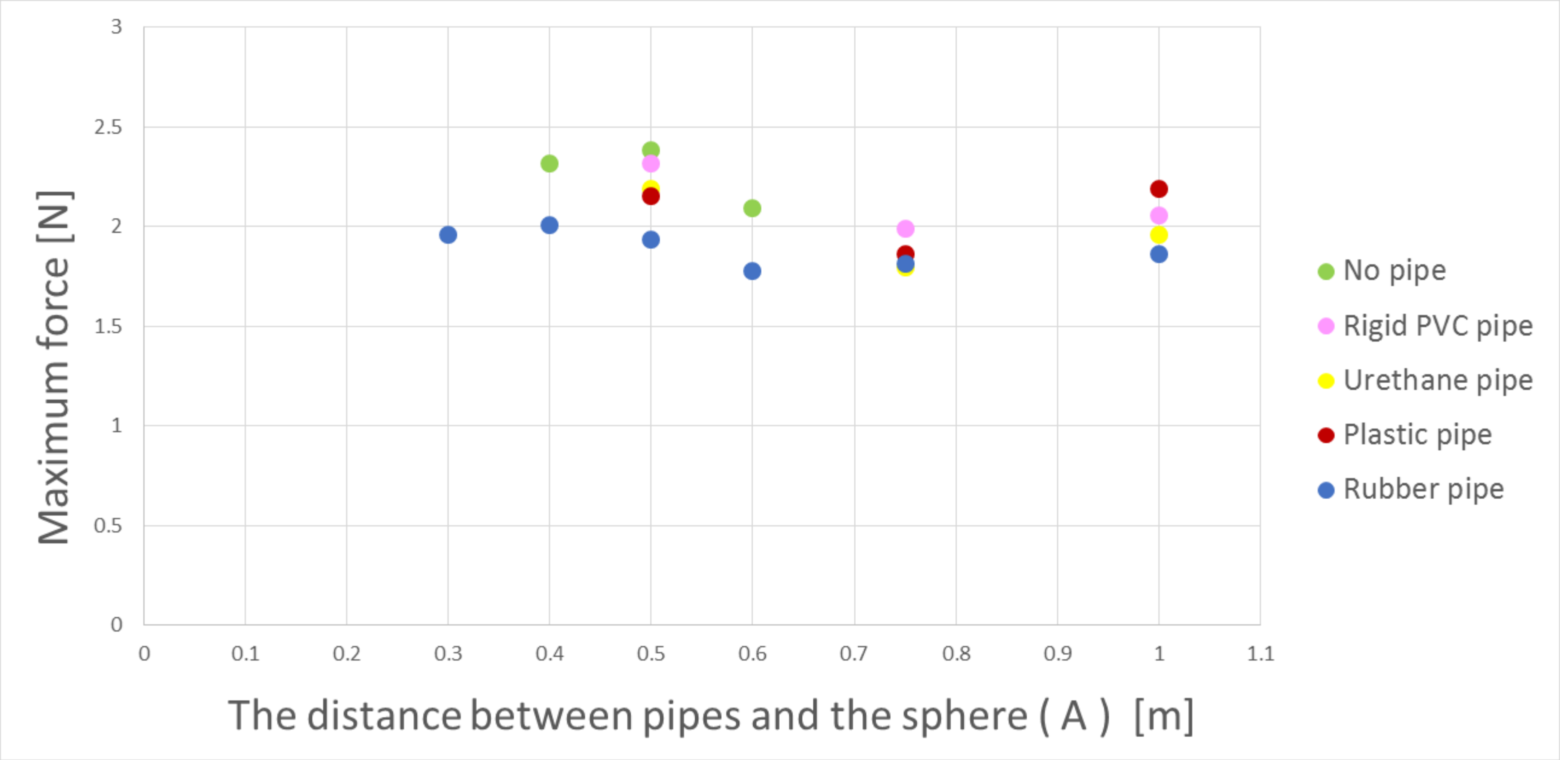
PVC Pipe

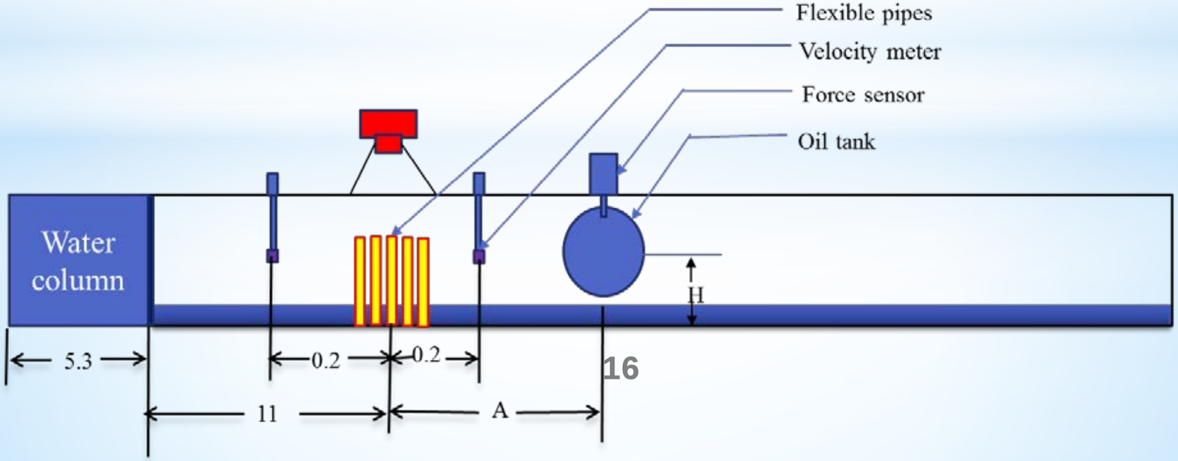


Flow velocity[m/s]

Time[s]

Maximum force to the sphere





Morison’s Equation

Morison equation is used to analyze the hydrodynamic force acting on the sphere due to the tsunami flow. Morison equation can be written as follows:

$$F = \rho\, C_m\, V\, \dot{u} + \frac{1}{2} \rho\, C_d\, A\, u\, |u|$$

Where,

F (t) = the total inline force acting on the object

u = flow velocity

u’ = acceleration, i.e., time derivative of the flow velocity

C_m = inertia coefficient, where $C_m = 1+C_a$ where C_a is added mass coefficient

C_d = drag coefficient

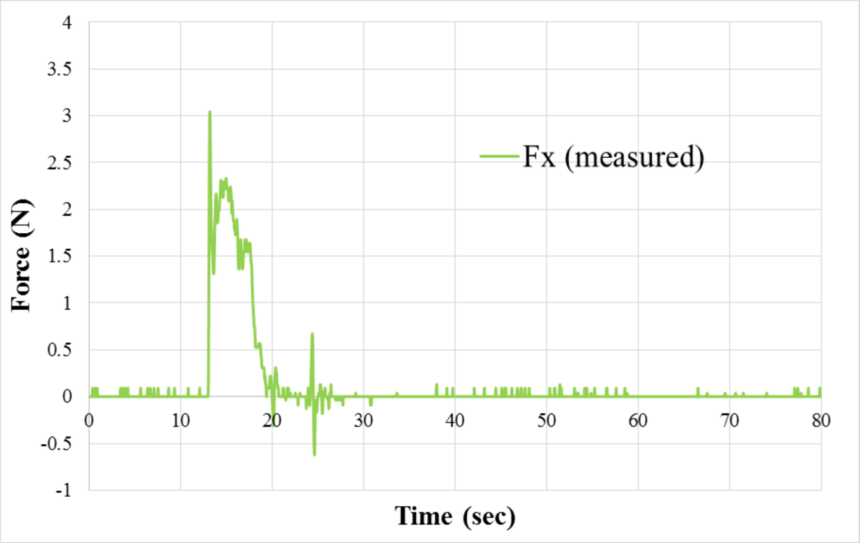
V = volume of the object

A = reference area of the object, e.g. cross-sectional area of the object

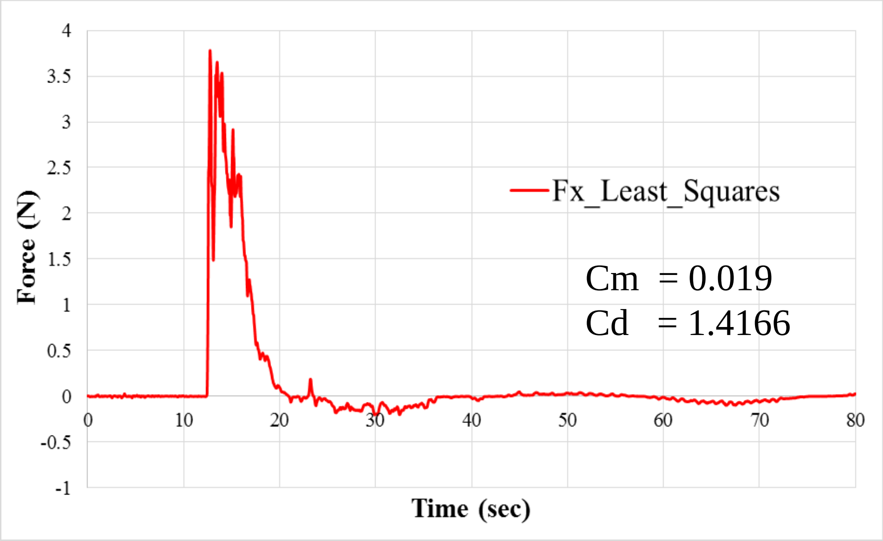
Morison Equation Results

No Pipes Case

Fx_No Pipes(Measured)

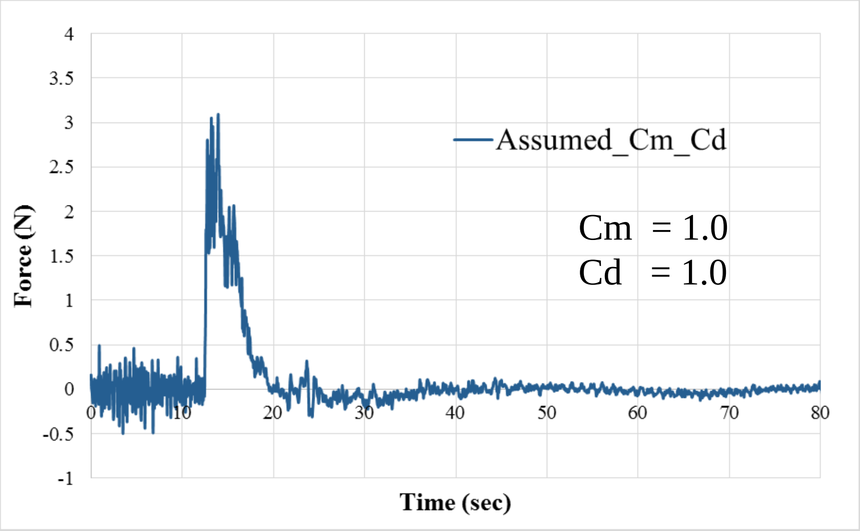


Fx_No Pipes(Least Squares Method)



Cm = 0.019
Cd = 1.4166

Fx_No Pipes (Assumed Cm Cd)

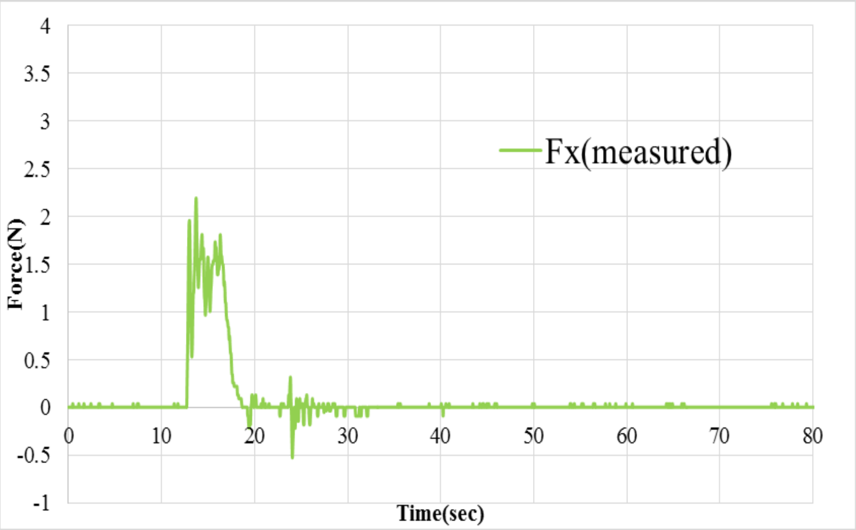


Cm = 1.0
Cd = 1.0

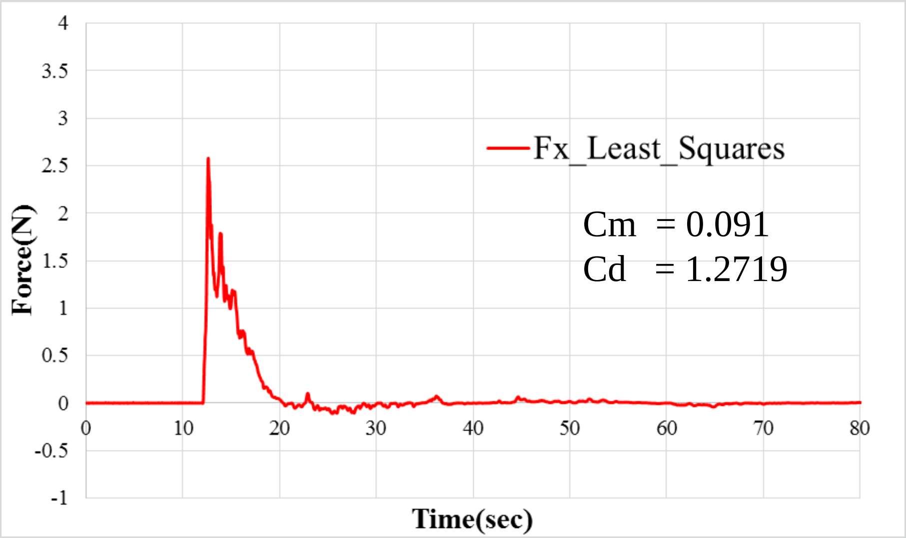
Morison Equation Results

Rubber Pipes Case

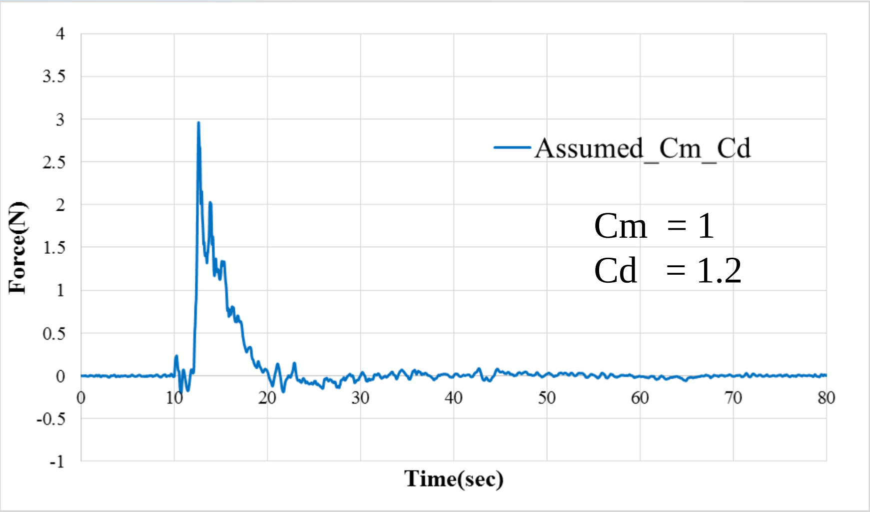
Fx_Rubber Pipes(Measured)



Fx_Rubber Pipes(Least Squares Method)



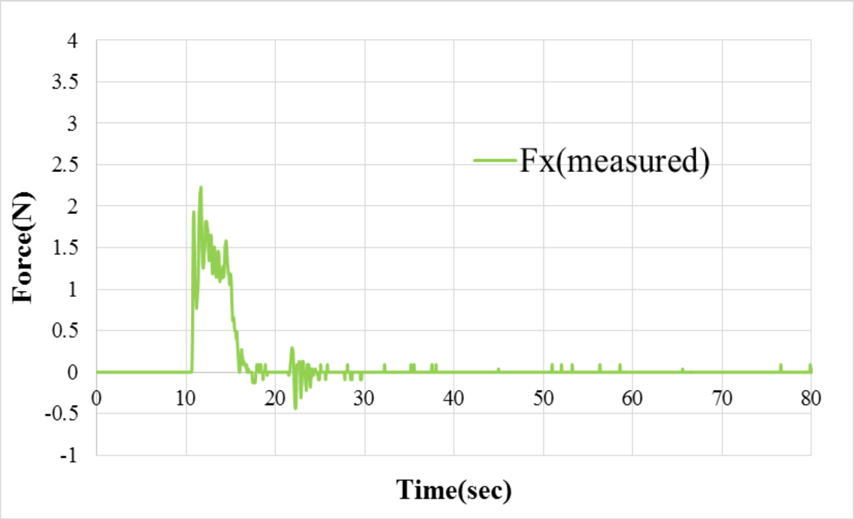
Fx_Rubber Pipes (Assumed Cm Cd)



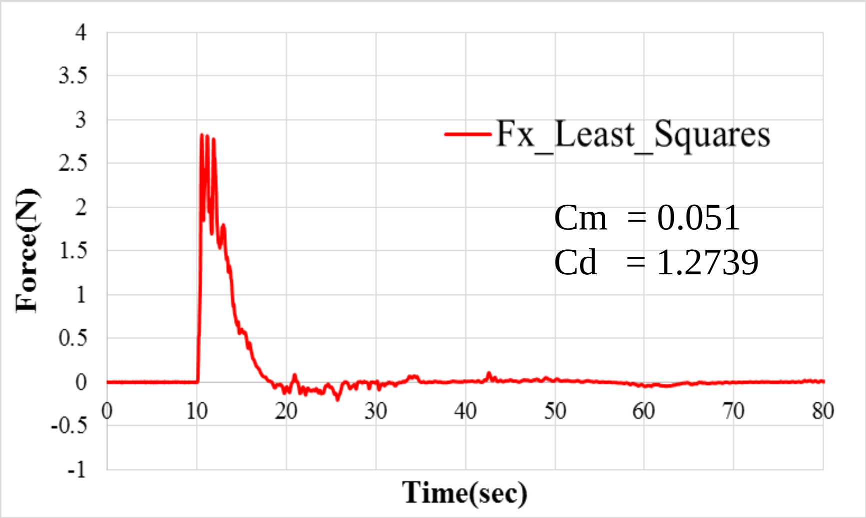
Morison Equation Results

Plastic Pipes Case

Fx_Plastic Pipes(Measured)

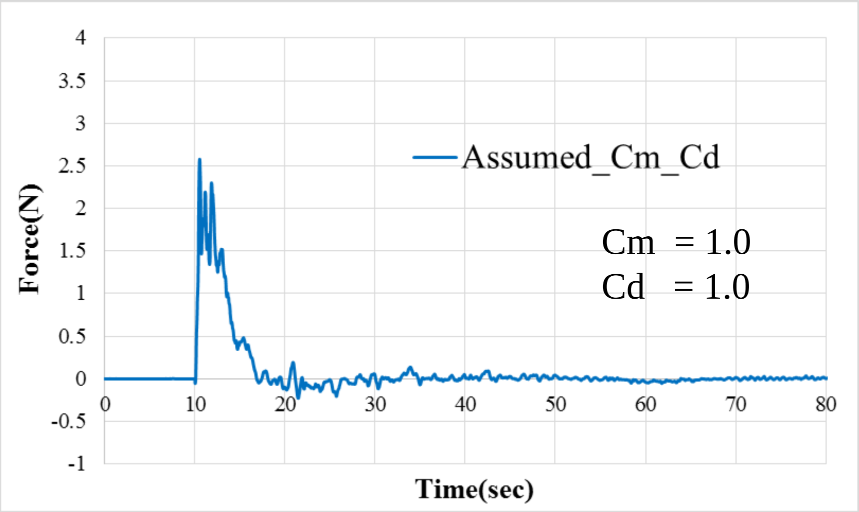


Fx_Plastic Pipes(Least Squares Method)

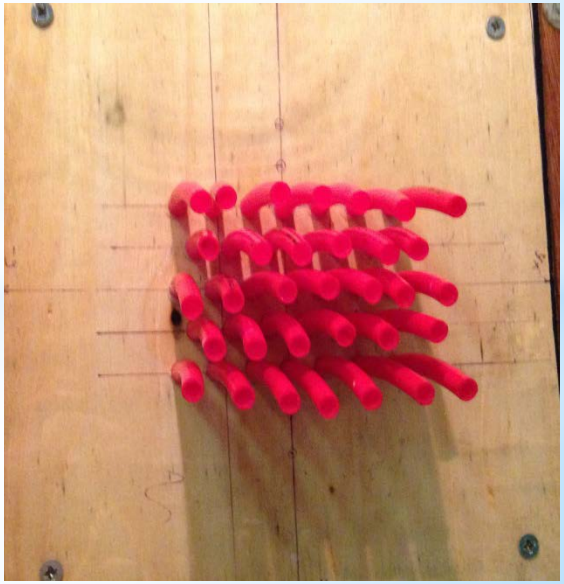


Cm = 0.051
Cd = 1.2739

Fx_Plastic Pipes (Assumed Cm Cd)

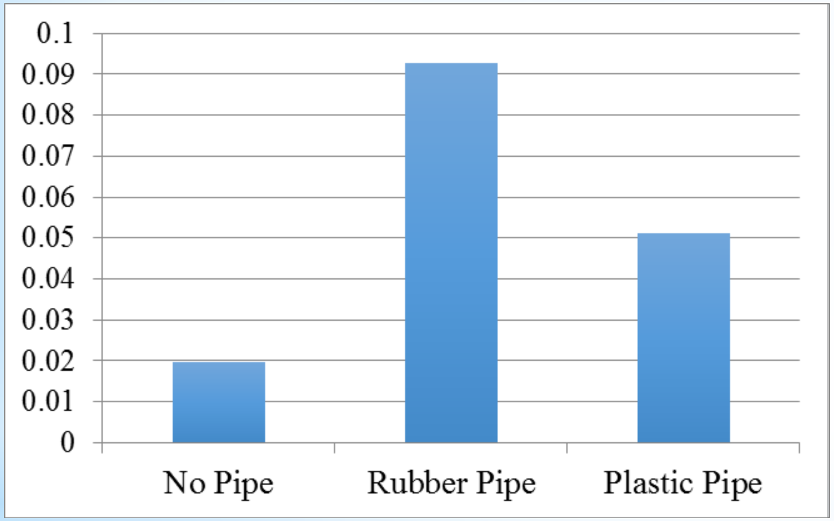


Cm = 1.0
Cd = 1.0

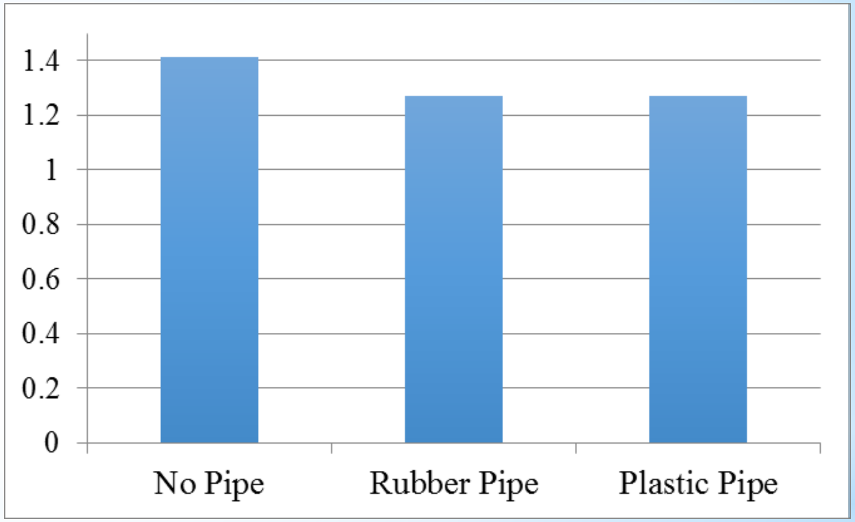


Summary of Morison's equation result

Inertia Coefficient : Cm



Drag Coefficient : Cd



Conclusion

- From the tank experiment, it was observed that around 30 per cent of hydrodynamic force could be reduced by the use of pipes of different stiffnesses.
- Although the velocity reduction by the pipes was very high (up to 70 per cent), only up to 35 per cent of the hydrodynamic force could be reduced due to the insufficient height of the pipes.
- By the application of Morison Equation, the tsunami attack force was separated into drag and inertia components. The hydrodynamic force acting on the tank was drag dominant rather than inertia force.
- In the actual situation, it’s better to put the flexible pipes about 90m-110m away from the facilities around the coast.
- Using more flexible pipes have better effectiveness to reduce tsunami energy about the model used in this experiment.

Future work

- The use of longer and more flexible pipes should be considered.
- Time history of wave height shall be recorded and comparisons of wave height should be made for between each type of pipe.

Thank you for your kind attention.