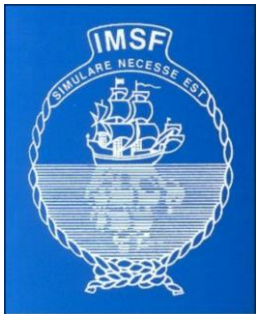
Investigation of Korean Ferry “Sewol” Incident by Free-running Experiments

Kazuhiko Hasegawa and Mariko Yamashita
Naval Architecture and Ocean Engineering
Osaka University
Japan



IMSF AGM and Workshop, Iława, Poland, June 14-16, 2016

Korean Ferry Incident

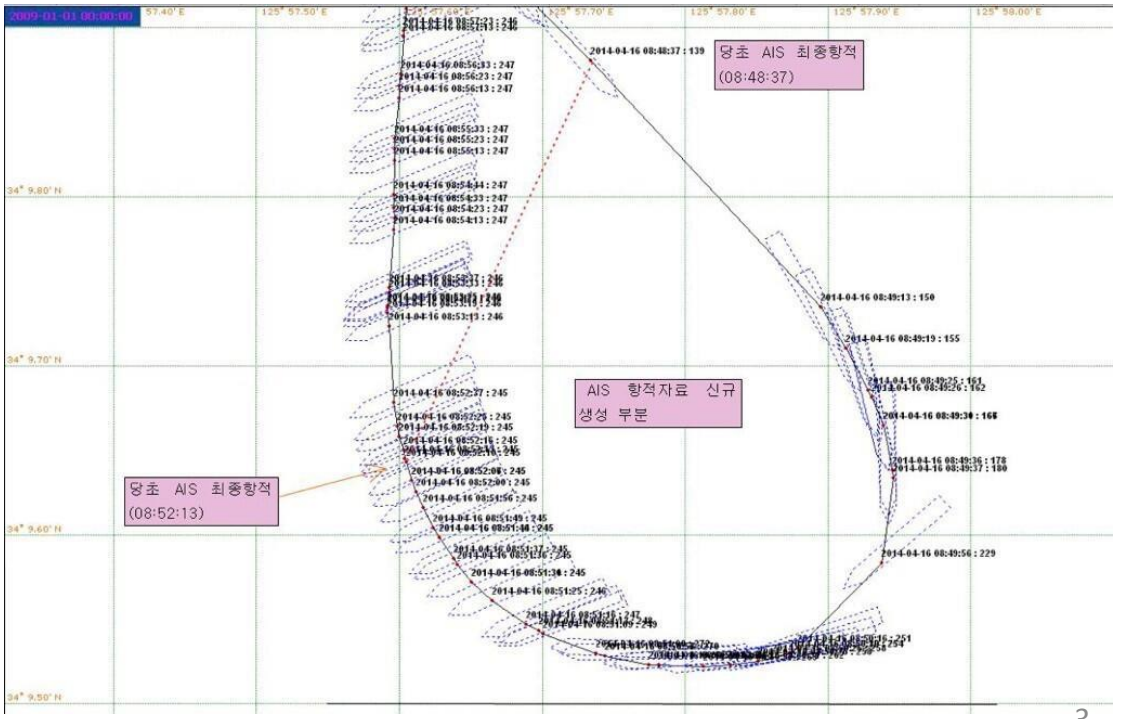
Occurred on April 16th, 2014 and 295 high-school students were killed.

Some Facts of the Incident

✓ Departure was around 3 hours late because of deep fog.

✓ The officer ordered the course instead of rudder angle, when it changes the course at the place.

✓ It leaned about 45 degrees and its engine stopped.



Causes

- ✓ additional cabin construction
- ✓ habitually overloaded condition
- ✓ reduction of ballast water to keep the draft
- ✓ inexperienced officer and helms-person

→ Make $GM_{(*)}$ small

* GM is a parameter of ship stability.

Issues at the Courts

captain, crews and ship owner (operator)

Whether or not they had an intentional killing will?

cargo handling persons and company

Whether or not it is possible that SEWOL leaned more than 20 degrees without a cargo shift?

Investigation Report provided by KRISO (Korean Research Institute of Ship and Ocean Engineering)

- Conducted exclusive captive model experiments to establish mathematical manoeuvring model.
- Done simulation study of ship turning based on this mathematical model.
- Concluded the maximum heeling angle of “Sewol” at that time was 19.2 deg. based on the estimated loading condition, if the cargo shift might not occur.
- Concluded the cargo shift should have occurred at the incident.

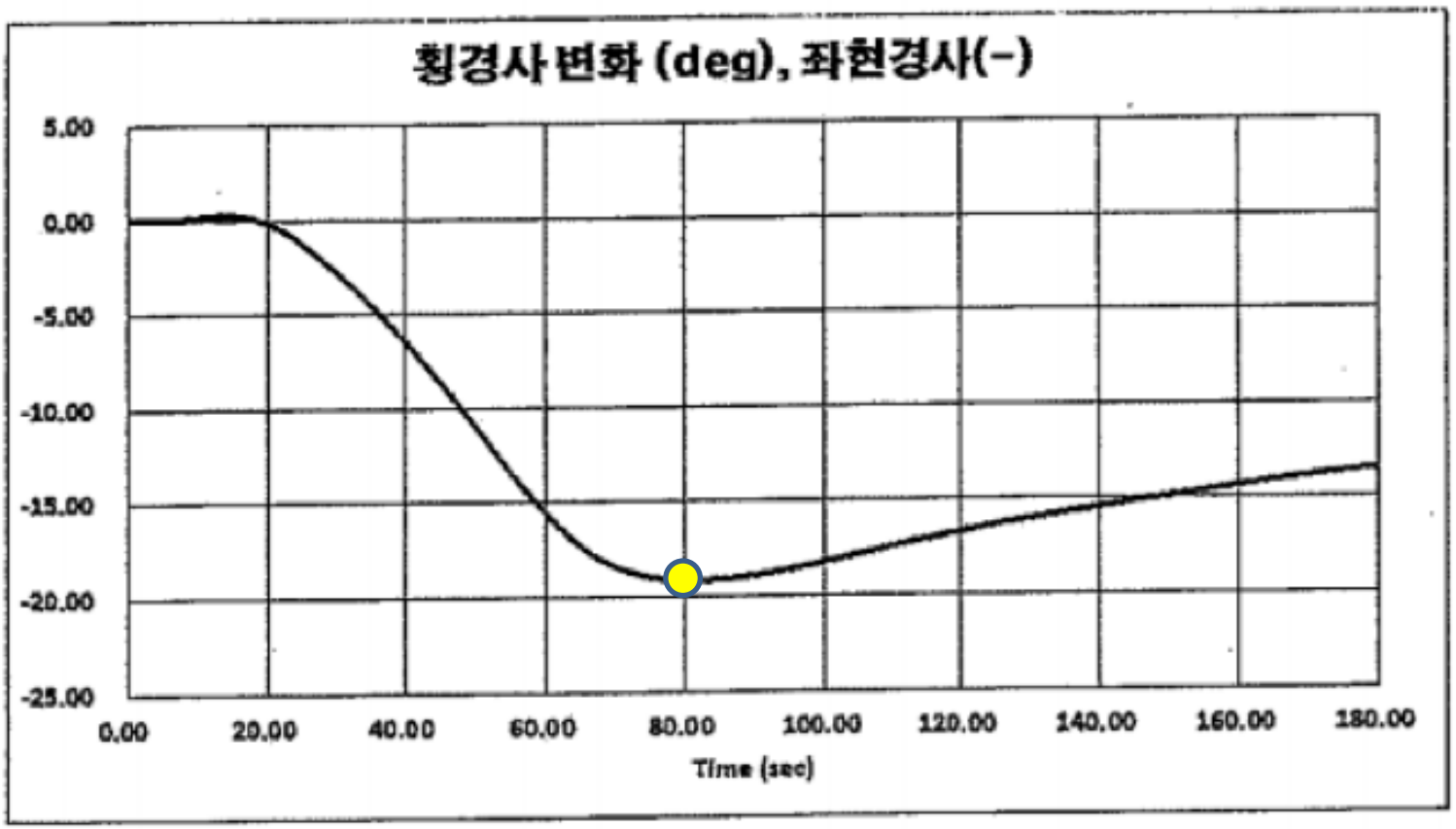
Investigation Report provided by KRISO (Korean Research Institute of Ship and Ocean Engineering)

The simulation conditions (GM)

	CASE 1	CASE 2
Displacement (ton)	9610.0	9553.7
Draft (Molded) (m)	6.077	6.042
KG(m)	10.53	9.61
KM(m)	11.23	11.26
GM(m)	0.70	1.64
GoM(m)	0.59	1.54

KRISO, p.37 of the Investigation Report, 2015

Investigation Report provided by KRISO (Korean Research Institute of Ship and Ocean Engineering)



The simulation condition (G_0M=0.59, δ=-35)

KRISO, p.86 of the Investigation Report, 2015

Questions

- Whether or not the ship leaned more than 20 degrees without cargo shift?(*1)
- How much was the GM?(*2)
- How much was the rudder angle?(*3)

*1) “No cargo should not shift equal to or less the 20 deg.” by Korean domestic regulation at that time. After this incident, Korean government has changed the maximum allowable heeling angle to prevent cargo shift to 25 deg.
*2) KRISO has estimated it based on the layout of containers and passengers recorded, but the height of C.G. was assumed.
*3) There are some press reports about it, but not confirmed at the courts.

Model Ship

Model ship (scale 1/75)

L (O.A.)	1.9 [m]
L (P.P.)	1.76 [m]
Bm	0.29 [m]
dm	7.67 [m]
Cb	0.46

The model is too small to install high accuracy instruments.

System

	Measured by	Recorded by	Controlled by
Ship speed	SCraMP®	SCraMP®	Remote Control
Ship motion	SCraMP®	SCraMP®	

An iPhone/iPad App. The Small Craft Motion Program (SCraMP) displays the device's accelerometer, gyroscope, and location data. A collection of motion warning indices are implemented for boating operations. Motion data can be recorded at user-selected nominal sample rate; location data is recorded at device-selected sample rate.

Additional Measurement for Roll Angle

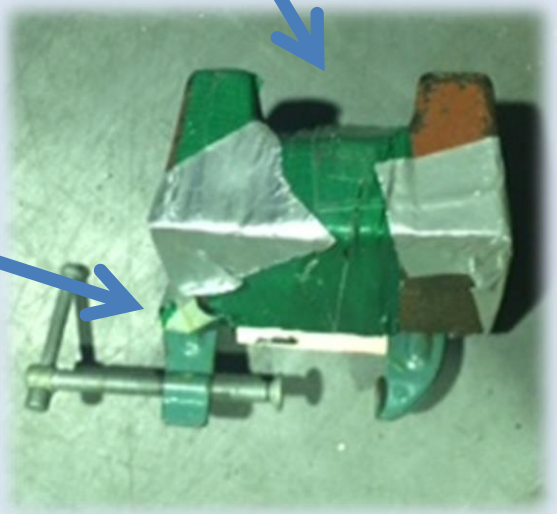
↑Camera

↑analog clinometer

How to change GM efficiently

weight

clamp



Scale is written to make easy arranging the mark

Mark of appropriate GM

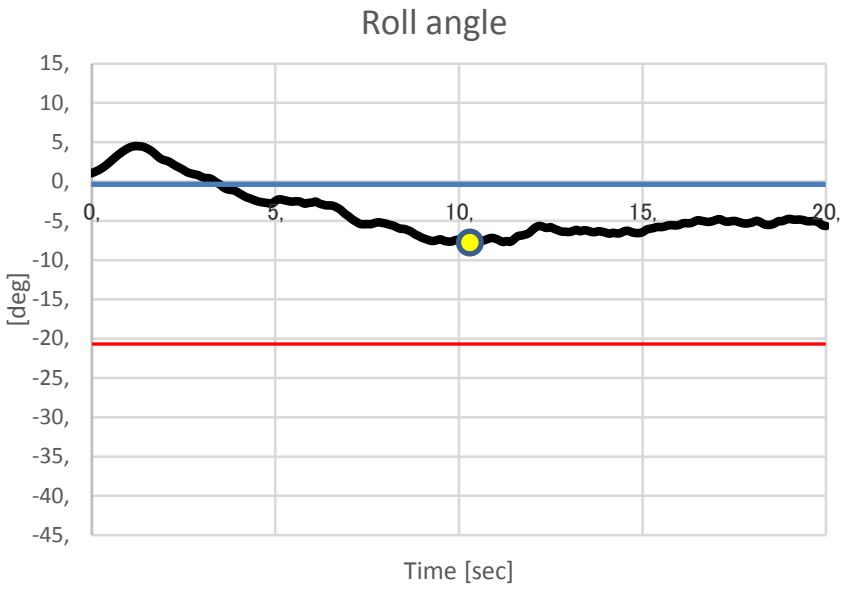
Moving weight is cramped in the scaled pillar

Experiment Conditions

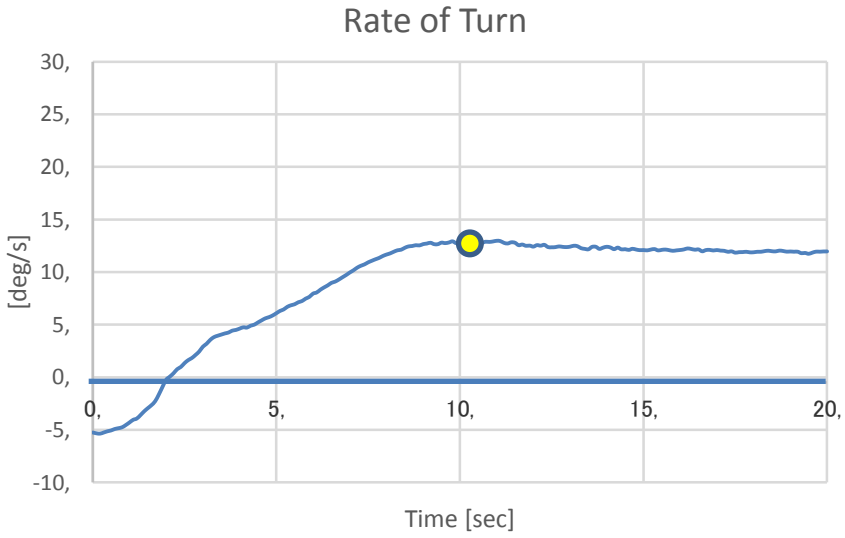
GM \ Rudder angle δ	15 [deg.]	35 [deg.]
0.9 [m]	1	2
0.6 [m]	3	4
0.3 [m]	5	6
0.2 [m]	7	8

Experimental number is written in the table.

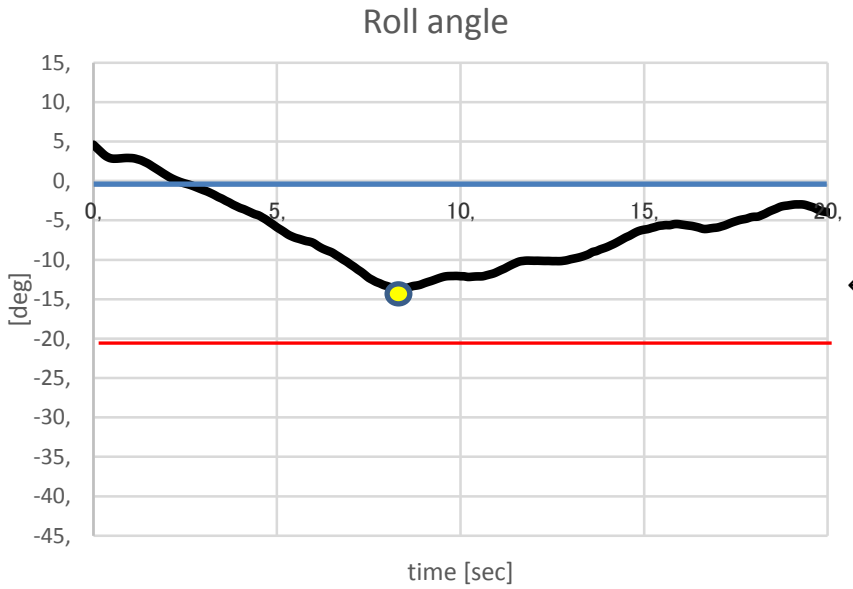
1. GM=0.9 m, δ=15 deg



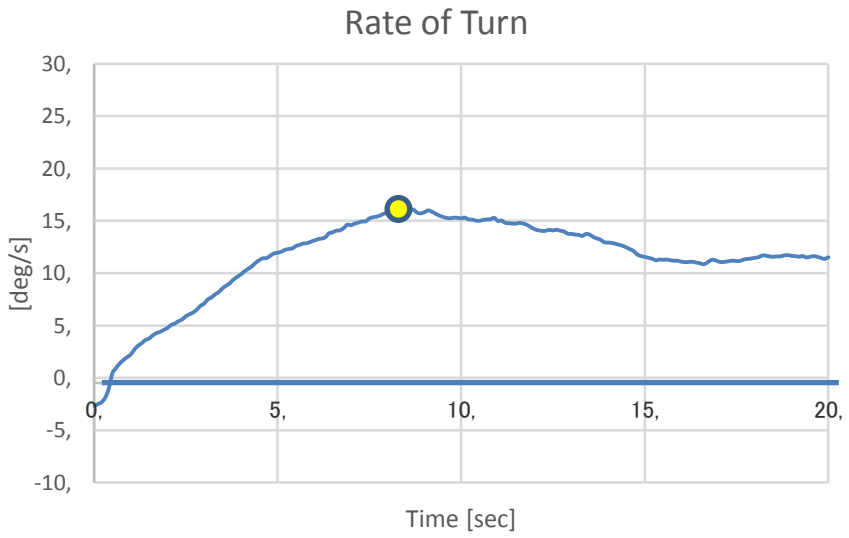
←7.7

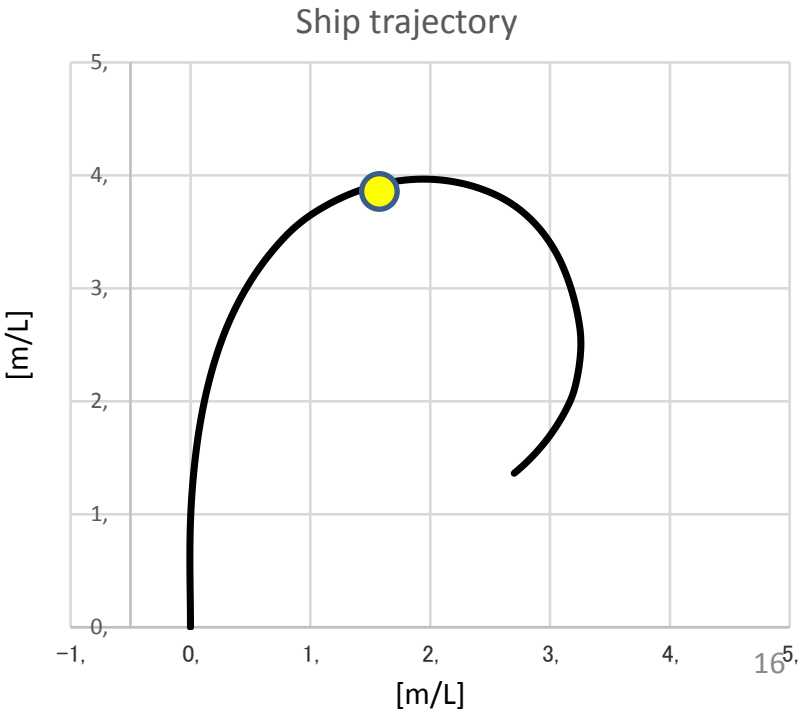


2. GM=0.9 m, δ=35 deg

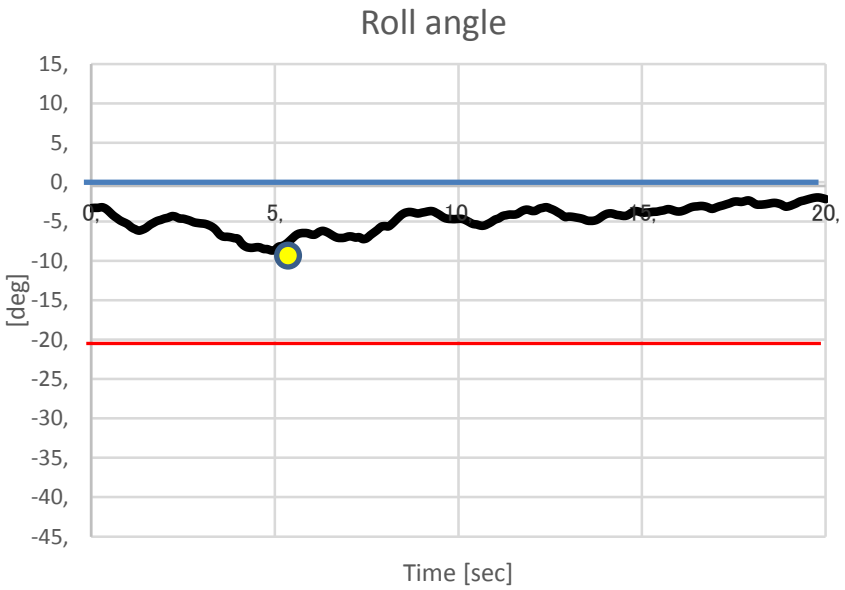


←13.6

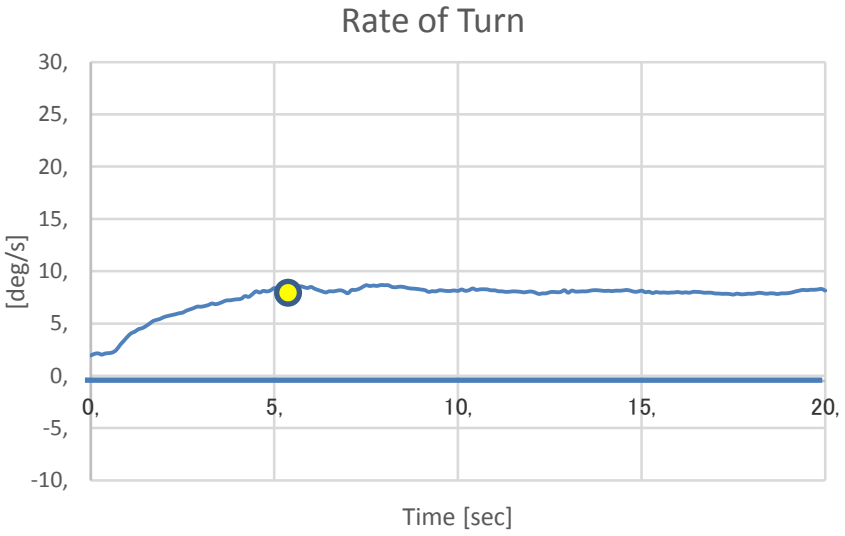


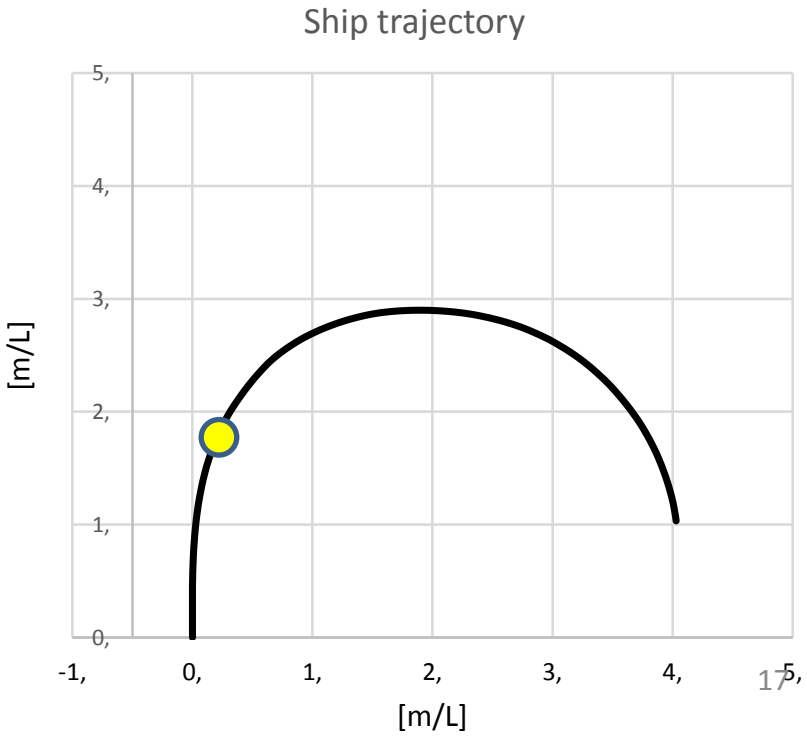


3. GM=0.6 m, δ=15 deg

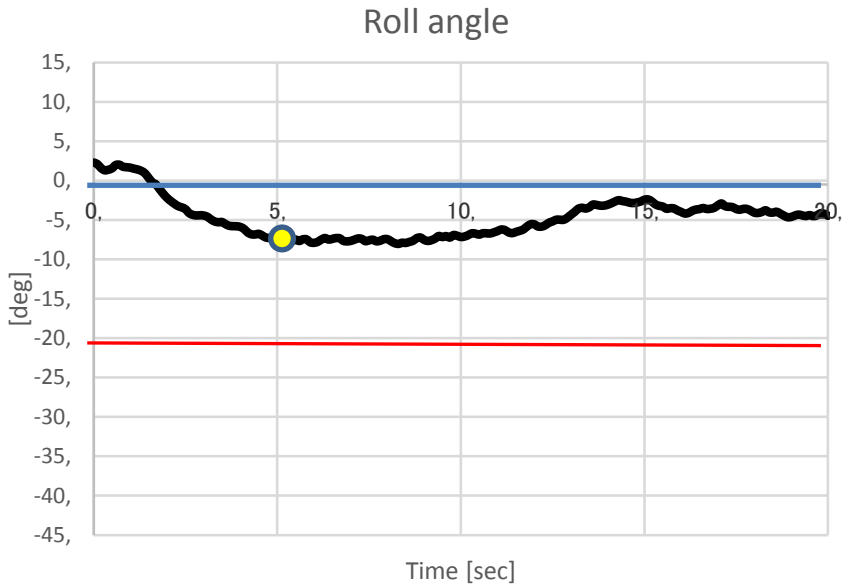


←8.6

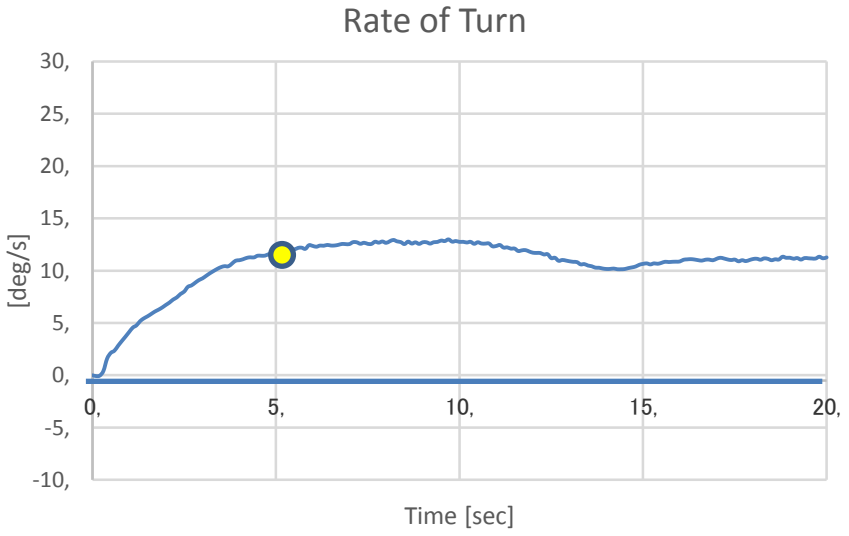


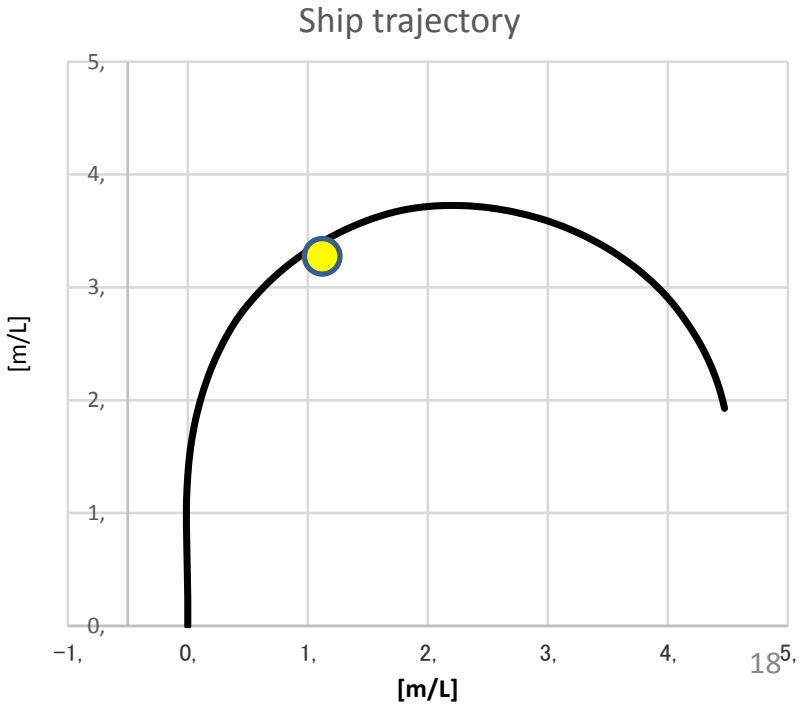


4. GM=0.6 m, δ=35 deg

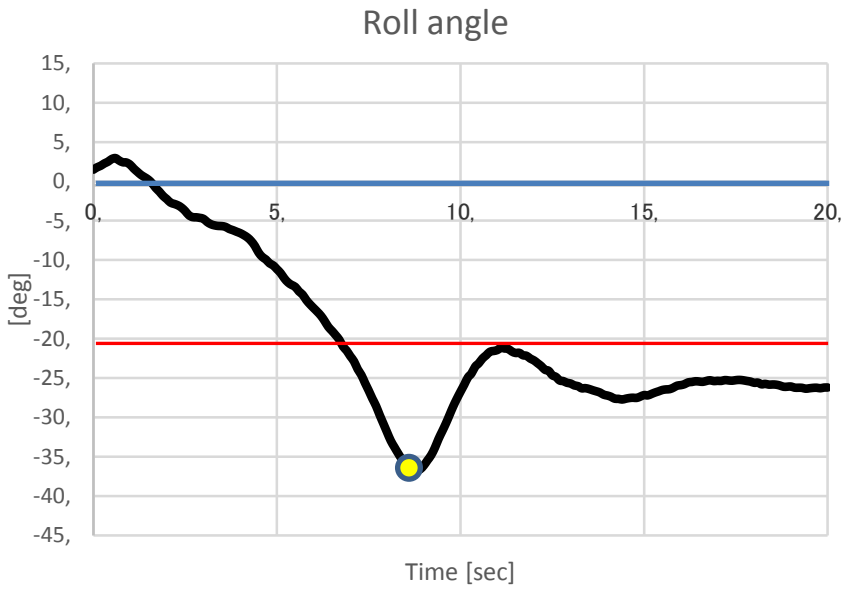


←8.0

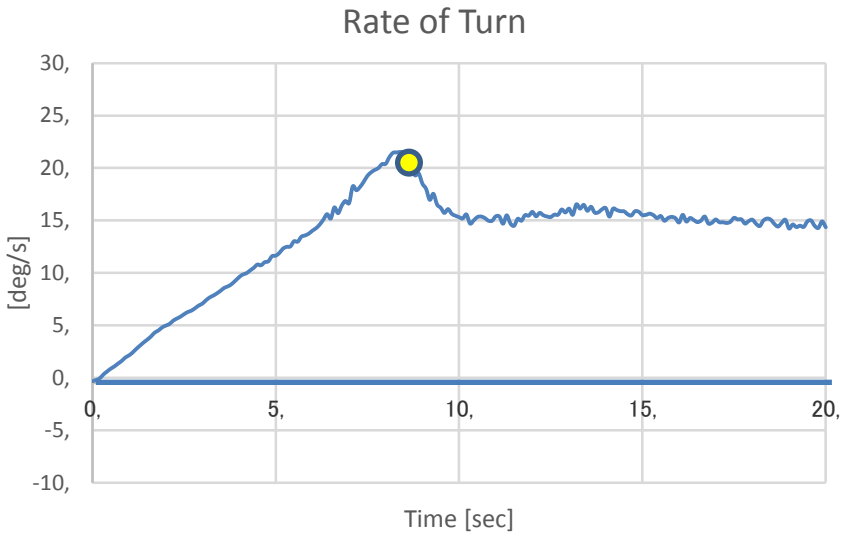


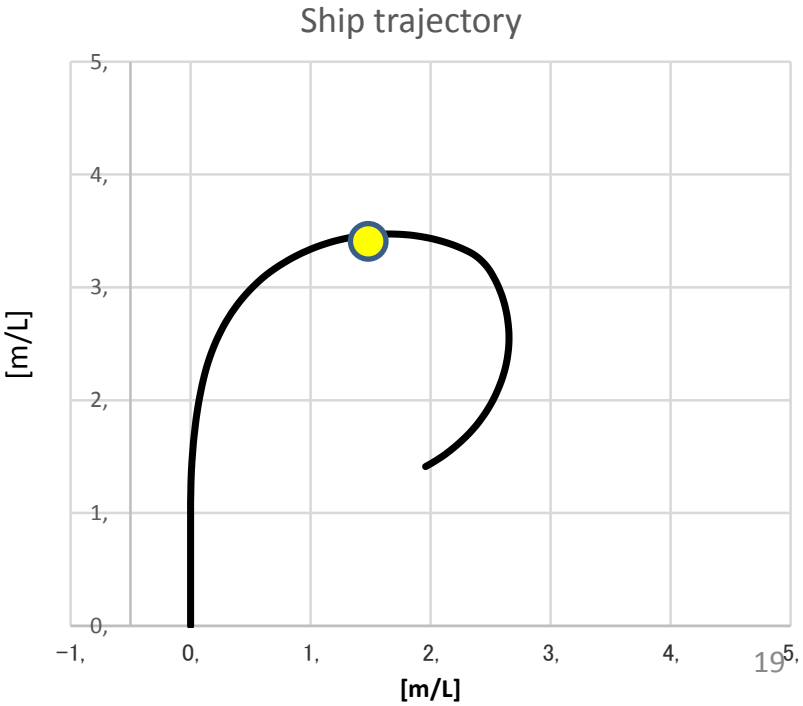


5. GM=0.3 m, δ=15 deg

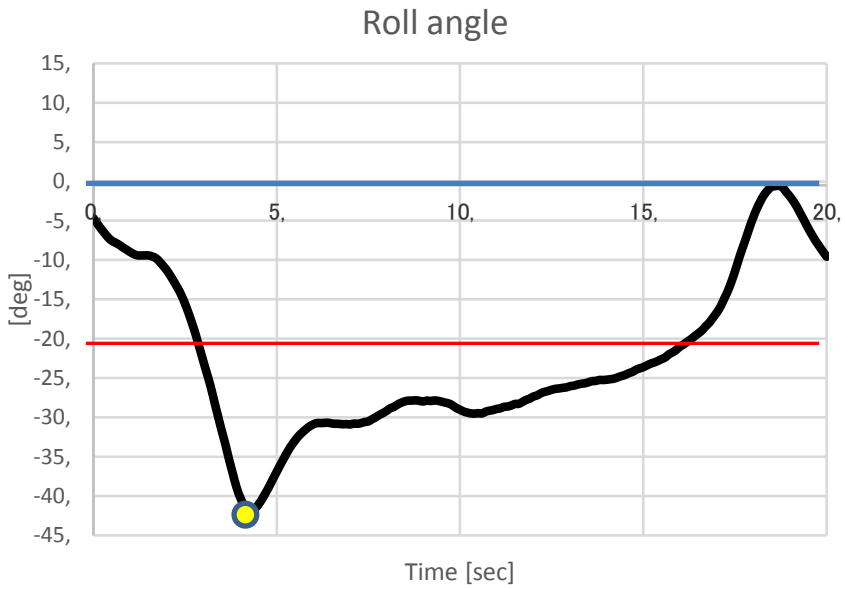


←36.7

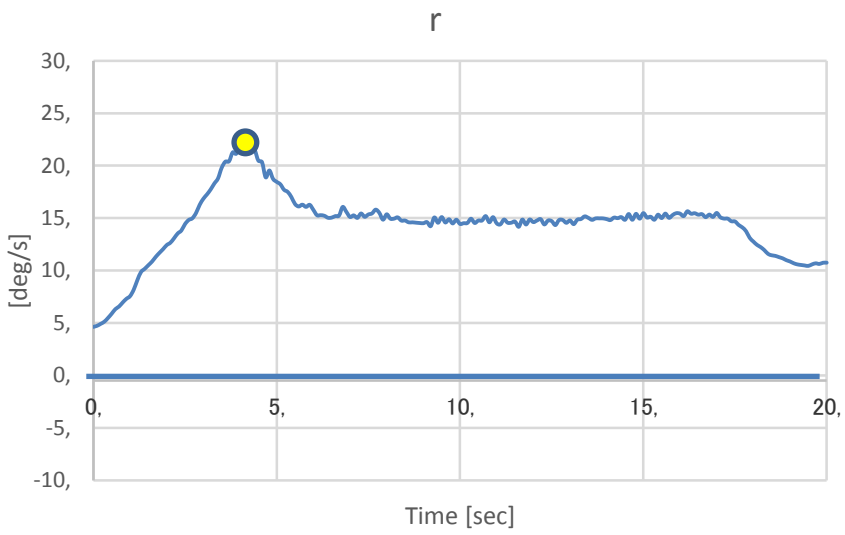


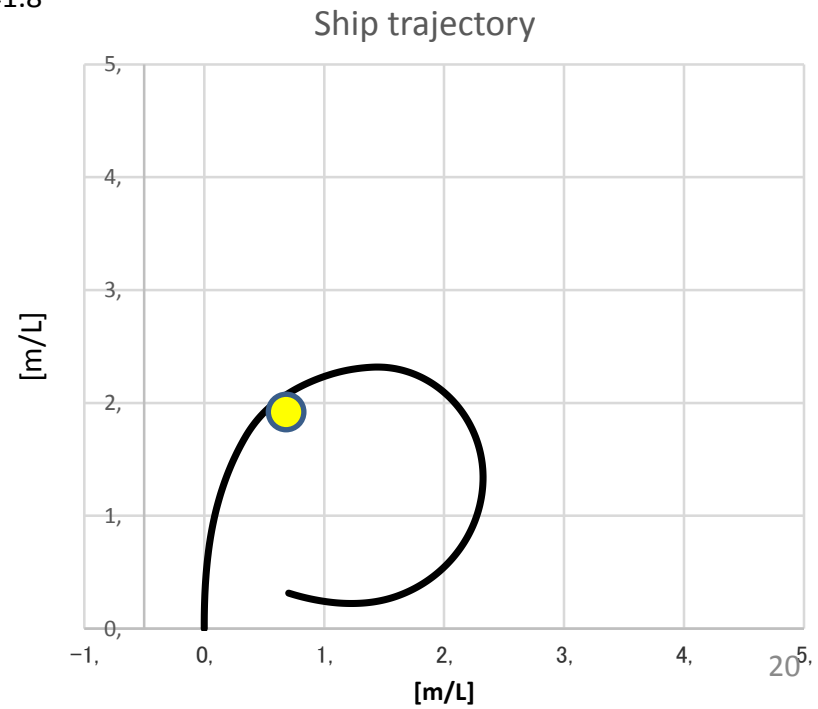


6. GM=0.3 m, δ=35 deg

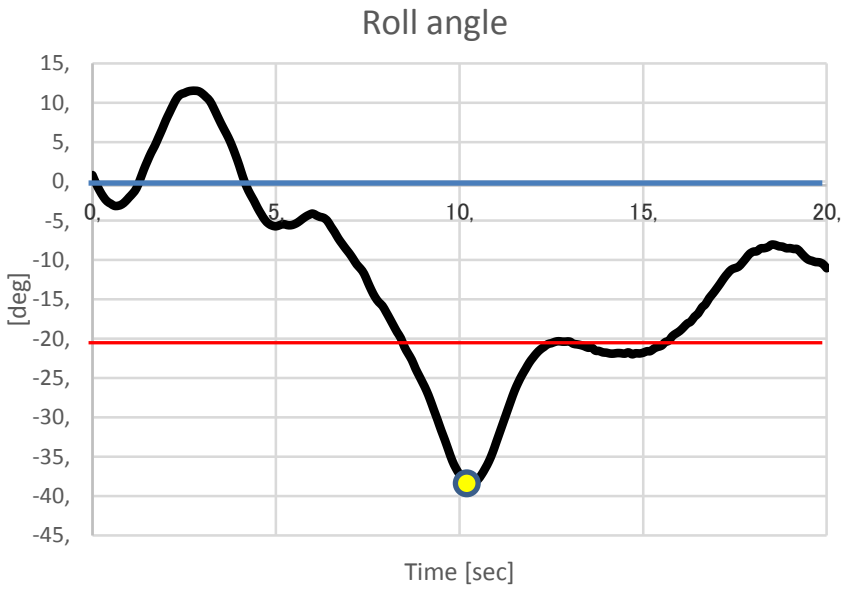


←41.8

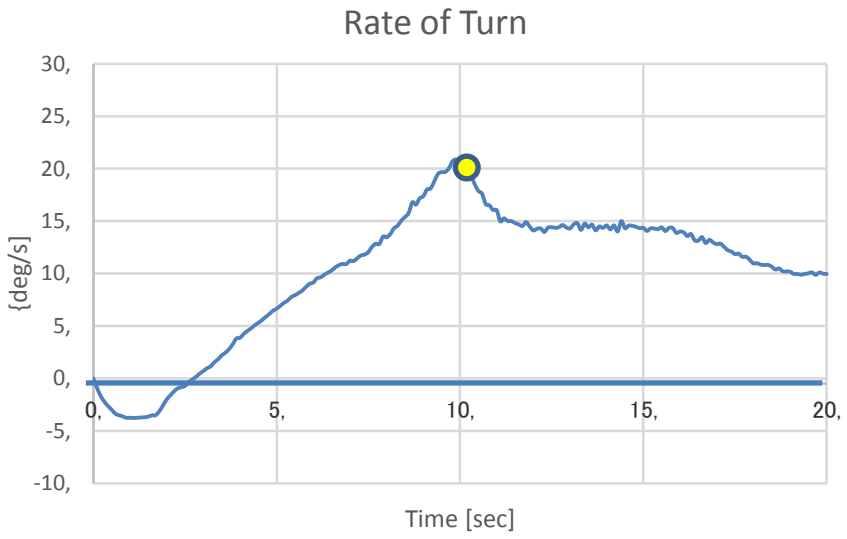


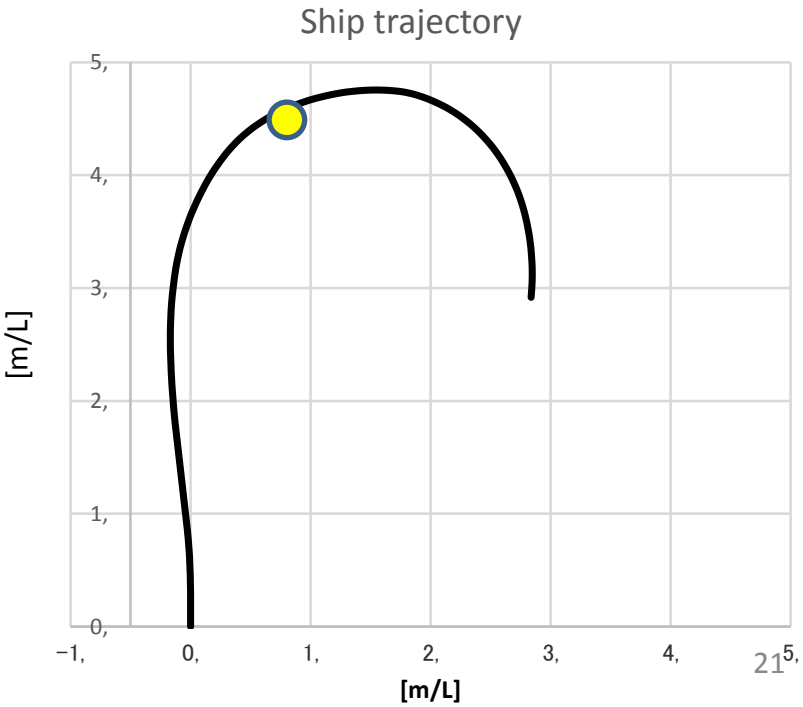


7. GM=0.2 m, δ=15 deg

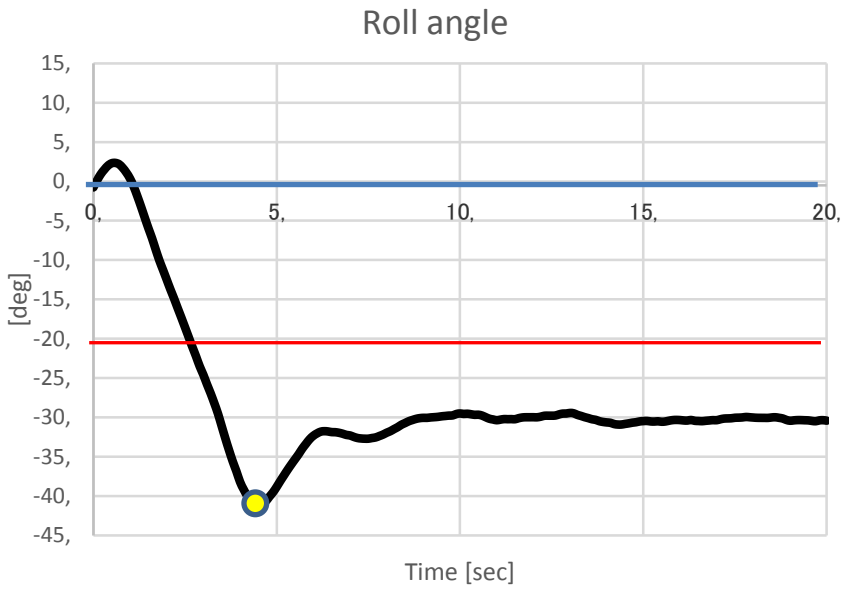


←38.4

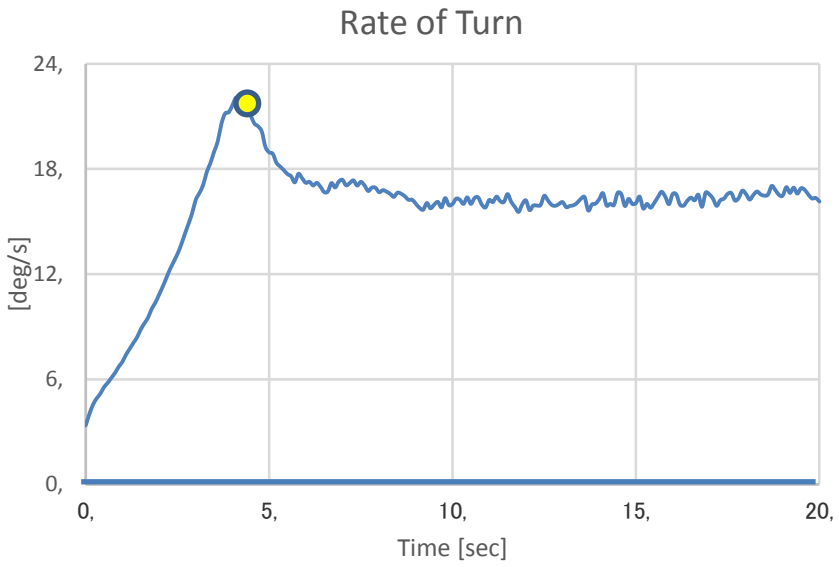


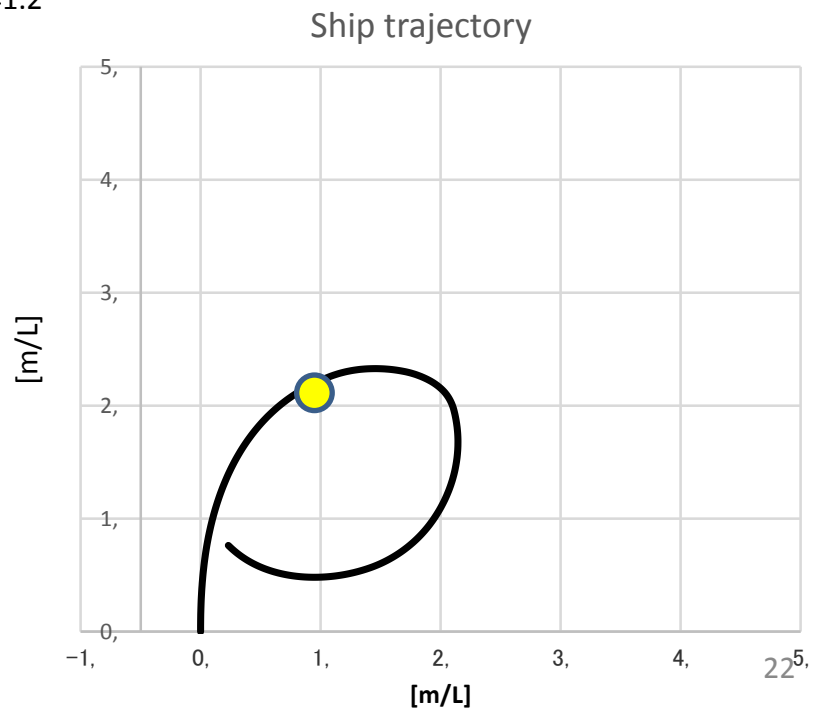


8. GM=0.2 m, δ=35 deg



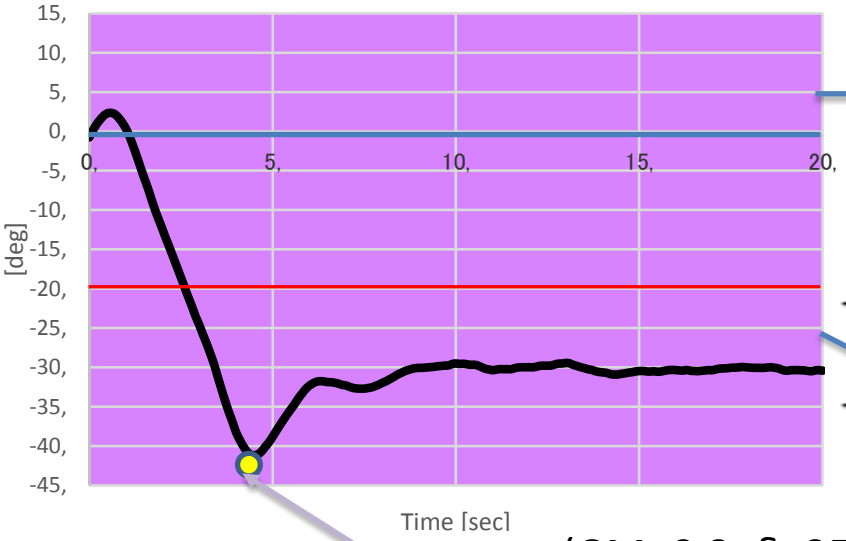
←41.2



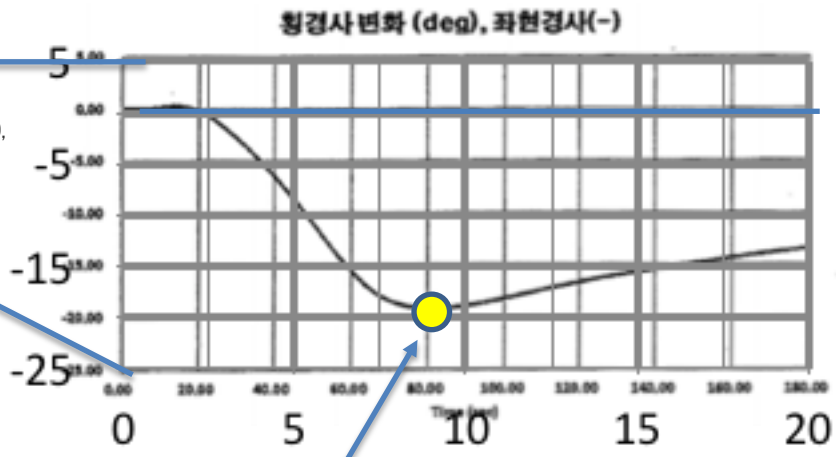


Comparison btw Exp. and Sim.

Roll angle (GM=0.2, δ=35)

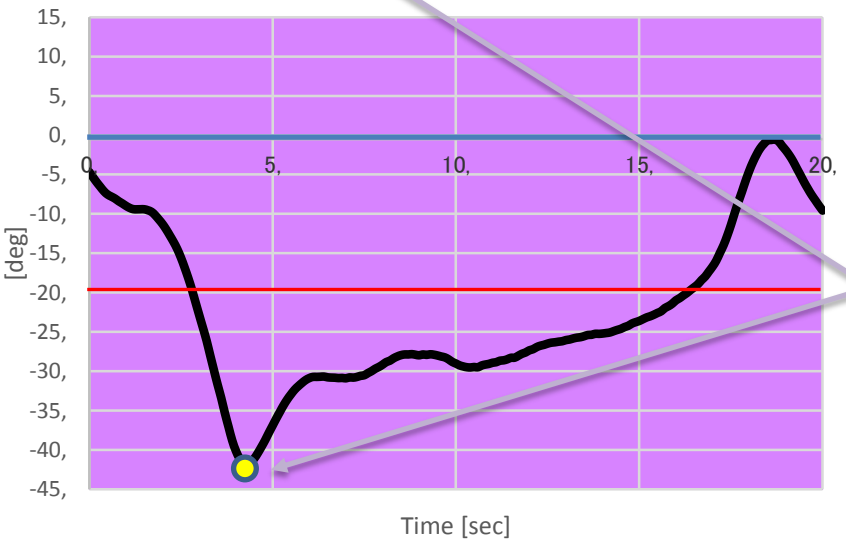


(GM=0.59, δ=35)



Maximum Heeling Angle =-19.2 deg.

Roll angle (GM=0.3, δ=35)

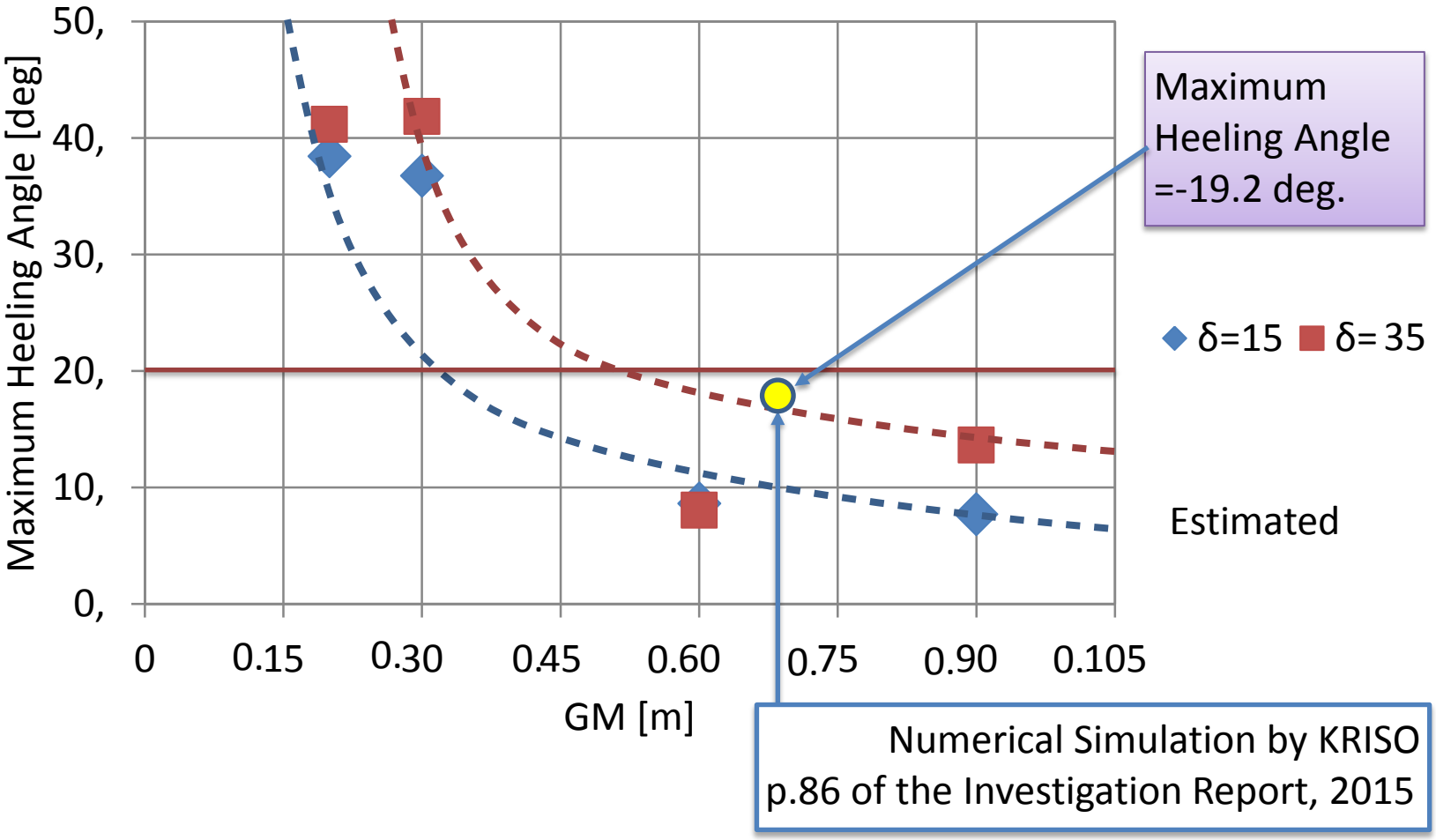


Numerical Simulation
by KRISO
p.86 of the Investigation Report, 2015

Maximum Heeling Angle exceeds 20 deg.

Free-running Experiments
by Osaka University

Relation between GM and maximum heeling angle in initial turning



Conclusions

By free-running experiments, it is found that;

✓ The maximum heeling angle due to turning manoeuvre is highly depending on GM.

✓ The *maximum heeling angle is more than 20 deg.*, if *GM is less than around 0.3 m*.

✓ Therefore the estimation of GM is quite important.

✓ Further investigation including free-running experiments and numerical simulation is under being planned.

Discussions

✓ Measurement system for small model ships

✓ Importance of the setting of GM, moment of inertia etc. for free-running experiment for small-size and/or high-speed crafts

✓ Importance of rudder-roll coupling influence for mathematical manoeuvring model

✓ Rapid progress in CFD may bring new era, and therefore still free-running experiments are important tool to validate it.

✓ Simulator vs. simulation, importance of human factors

✓ etc. etc. - - -