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SENSORS

Intelligent Riser Angle Control DPS

Akihiko Imakita
Mitsui Engineering and Shipbuilding Co., Ltd. (Chiba, JAPAN)

Susumu Tanaka
Akishima Laboratories (Mitsui Zosen) Inc. (Tokyo, JAPAN)

Shinichi Takagawa and Yasutaka Amitani
Japan Marine Science and Technology Center (Yokosuka, JAPAN)

ABSTRACT

DPS (Dynamic Positioning System) is one of the key factors for riser drilling. The importance of the DPS increases as the drill operation progresses to the deeper area. Development/Construction Project of Scientific Ocean Drilling Vessel System for OD21 Program (Ocean Drilling in the 21st century) is now being on design stage in Japan, which will have the capability to drill the 4,000 m water depth sea bottom to MOHO.

Usually, the DP operator decides, keeps, and/or changes the ship position to optimize the riser angles, considering the environmental conditions such as directions/velocities of wind, wave, and current profiles. It becomes more difficult in the deep water drilling for the DP operator to decide DP target position.

This paper proposes a new DPS with automatic riser angle control. This new DPS drives the ship to the optimum position so that the sum of both the squared angles of the riser top and bottom becomes minimal. The control logic is based on neural network, which incorporates riser tension, mud density, top and bottom riser angles, water depth, and current surface velocity as input units. Effects of the dynamic riser deformations on these angles are taken into account in this DPS logic by using modal method. The DPS logic includes estimation of the latest ship position/velocity by using the real time signals of the riser top and bottom angles. That means the system does not need conventional position reference systems such as GPS (Global Position System), HPR (Hydro-acoustic Position Reference System), etc. Research results showed that it could estimate and control the ship position by these angles.

Two dimensional (2D) and 3D model basin experiments were performed using a ship model with a riser model under various current conditions. This paper focuses on 3D model test carried out in January 2000. The results of computer simulation corresponded well with the model basin experiments. Thus, the developed logic was confirmed to be feasible as the new DPS and the simulation method was found to be valid.

1. INTRODUCTION

In the riser drilling operations, the ship position should be kept within area in which the allowable conditions of riser system are satisfied. One of the allowable conditions is angle limit of upper and lower flex joints. API(American Petroleum Institute) requires that the mean lower and upper flex joint angles should be kept within 2 degree during drilling and, that the maximum non—drilling angles should be limited to 4 degree. Ship positioning becomes difficult in the deepwater riser drilling such as in the OD21 project1). OD21 is a project in which sample core will be taken out from 6000m under sea bottom. Scientific riser drilling in 2500m water depth is planed as Phase1. Final plan with riser drilling is in 4000m water depth.

Recent RMS2),3) (Riser Management System) indicates plot view of DP position with operational limits and optimum vessel position. Some RMS has a function in DPS that holds ship position according to flex joint angles.

Past research[4)] employed riser angles as position reference sensors. Utilization of riser end angles (flex-joint angles) has been investigated in many aspects and efforts have been made to assist DP operator to decide ship position and to make a DPS more reliable in case of deep sea drilling.

An essential purpose of the DPS is to optimize and keep ship position for the riser. Therefore it is natural to incorporate information from the riser into the DPS. One of the most important and indispensable information from the riser is the riser end angle. There are two subjects on the utilization of both end angles to the DPS. The first subject is how to know the optimum ship position in order to minimize these angles. The second is how to estimate the ship position by these angles. Difficulty lies in the complex and dynamic response of the riser. For the first subject artificial neural network was used to obtain the relations between ship position and riser end angles. For the second subject it was indispensable to consider riser deflection in the estimation of ship position. In the past research[5)] normalized modal function expressing riser dynamics was employed for the riser angle control logic. This kind of modal method was adopted to describe riser deflection in terms of riser end angles. The following is an overview of the DPS incorporating the riser end angles for the control of themselves.

2. NEW DPS CONCEPT FOR THE DRILL SHIP

In the operation of deep-sea drilling, it becomes increasingly difficult to keep the riser inclination angles at flex joints, which are called REA (Riser End Angle) in this paper, within the allowable degree. This paper, therefore, presents a ship position control method for REA in deep-sea drilling.

The first subject is how to obtain minimal REA by ship positioning. The second subject is how to perform ship positioning for REA mentioned above with riser angle sensors, without conventional ship position reference sensors. It would be important for the operability improvement of drilling with DPS to obtain the back up of conventional position reference like GPS.

2.1 DP MAIN CONTROLLER

DP main control algorithms, where the closed loop includes only sensors connected to the ship, are divided into two parts, namely:

1) The Kalman Filter as Ship Estimator

2) The PID Controller and Thrust Allocation

Figure 1 shows the DP main controller in the proposed new DPS. This logic has been adopted generally for many real DPS on board. Its performance and reliability have been confirmed in actual operations[6)].

2.2 DP CONTROLLER FOR RISER ANGLE

Figure 1 shows the major components of the New DP controller for drill ship. The control algorithm for REA was added to the well-experienced DP main controller. The additional control algorithm, where the loop includes sensors attached on the riser, is divided into two parts, namely:

1) The Intelligent Riser Estimator (IRE)
2) The Riser End Angle Positioning System (REAPS) consisting of Kalman filter and Ship Position Estimator

IRE specifies automatically a suitable target position of ship instead of a DP operator. REAPS evaluates ship's movement by riser angle sensors without conventional position reference such as DGPS, HPR and so on. These IRE and REAPS can be switched on or off in the DPS as shown in Figure 1.

2.3 The INTELLIGENT RISER ESTIMATOR (IRE)

When controlling the drill ship position, the best position to keep REA at minimal is not always just above a BOP. The aim of IRE is to keep riser at a configuration where the REA will be minimized by positioning the ship on a suitable point. Since ship position cannot be changed quickly due to her large mass, it should be sufficient to consider only a few parameters that will decide riser's quasi-steady configuration.

At first, relations between ship's position and REA were studied by numerical calculation. Consequently, it was found that the ratio of REA change to a unit offset of the ship from the BOP position was affected little by current flow nor by current profile, but affected by riser top tension and mud weight. Not only riser angles but also other parameters, therefore, were taken into account in order to obtain a suitable position of the ship in IRE. IRE was formed by artificial neural network7) where units in input layer were the followings:

è$_T$: riser top end angle

è$_B$: riser bottom end angle

T : riser top tension

ã : mud density

Vc : surface current velocity.

The output unit was changing rate of ship's target position as function of riser angle (= X/è). The neural network had a single hidden layer shown in Figure 2. In order to obtain representative function, in the case of 21 inch riser for 2500m water depth preliminary learning was performed by using simulations in which more than 200 cases were calculated in terms of the following variables:

Current distributions: 3 cases

Mud density: 3 cases

Riser tension: 3 cases

Riser end angles: 3 cases for each end

Evaluation function, J, for riser angles is to minimize sum of the square of both angles.

$$J = è_T^2 + è_B^2$$

Simulation method was based on a modal expansion of the deflection method[4)]. The equations of motion of ship and riser system are replaced by an infinite set of ordinary differential. This method was extended for an arbitrary current profile.

It should be pointed out that the simulation used in the preliminary learning was not dynamic but static. Dynamic effect was taken into account in the choice of the changing rate of ship's target position. The artificial neural network system can deal with changes of riser tension, mud density, and current surface velocity. Another merit of neural network is that the system does not down immediately right after the variable signal is lost. The system can continue to control the ship position for a while and give a DP operator a few precious minutes to check what is wrong.

2.4 The RISER END ANGLE POSITIONING SYSTEM (REAPS)

If the ship in the operation of drilling with riser loses the own positioning data such as the satellite signals, REAPS with riser angle sensor supports ship positioning. REAPS consists of Kalman filter and ship estimator as shown in Figure 1.

The deep-sea riser would be deformed due to external disturbances such as the ship motion and the current etc. Hence, generally, it will be very difficult to estimate the riser deformations precisely with information from limited number of the sensors attached to the riser.

At first, relation between controlled ship response and deep-sea riser behavior was investigated by numerical calculations. As a result of study, it was found that the lower order modes of riser deflection were the significant parameters to keep ship on the settled position. Therefore the following simple method was considered to be sufficient for the estimation of ship position.

Assuming that riser deflection or inclinations are expressed by sum of the normalized modal functions[5)], hence the modes of riser deflection are evaluated by measured riser angles as a following formula by modal filter.

$$Zi(t) = f(è_T(t), è_B(t)), \quad i=1,N$$

Zi(t):modal coordinate,

$è_T(t), è_B(t)$:measured riser angle,

N : order of riser deflection mode.

The differences of Zi(t) in time domain is estimated by Kalman Filter. This means that the proposed riser estimator is able to grasp the significant dynamics of riser. Getting modal coordinates of riser by riser estimator, ship position estimator can obtain the motion characteristics of the ship located at the top end of riser.

3. MODEL TEST

Main purpose of the model tests was to confirm feasibility of new DPS concept and validity of simulation method. In the project two model tests were carried out. The first test in 1999 used 2D apparatus in calm water. After investigating the results of the first test, the second using 3D apparatus was carried out in 2000. The results obtained in the first test were discussed in the reference 8). Therefore this paper focuses on the second test results.

Principal particulars of the models are given in Table 1. Before the test was performed in the basin, preliminary learning for the neural network was done by simulation using the riser model. In this learning the parameters in input layer were riser tension and REAs since mud was not included in the model.

Test apparatus is depicted in Figure 3 and 4. There was a pit in the basin where the total water depth was 5m. The basin had a wave maker and a flow generator. The wave maker can produce regular and irregular waves. The fans were set 30 degree with respect to longitudinal axis and produced irregular winds. Coordinate system used in the experiment and simulation is shown in Figure 5.

Riser model was made of rubber tube, brass, and buoyancy module. Length of the riser model was 5 m., which was 1/500 of the real structure. On the other hand, scale of the ship model was 1/55. Kinetic relationship between motion of the ship controlled by the DPS and riser deflection was adjusted by top tension and buoyancy module, and scaled to confirm validity of control logic for 2500m depth riser.

The ship model was free on the water surface and driven by the 6 azimuth thrusters. The model ship length was about 3.5m and had superstructures and a derrick. The azimuth angles and rotation speed were controlled by the DPS. 9)

REAs were measured and signals were put into the control logic. Riser top tension was kept by a tensioner on board. The measurement system is shown in Figure 6.

The current flow patterns were regular, two layer reverse, and two layer cross. Regular pattern (REGCP: Regular Current Pattern) was generated by tank flow generator and had constant velocity above the pit. The cross (CRSCP: Cross Current Pattern) and reverse pattern (REVCP: Reverse Current Pattern) were produced with small thrusters in the pit. By combining the flow above the pit and the flow generated by the thruster in the pit, two-layer current patterns were obtained.

Wind and waves were irregular in the experiments. The spectrums were ISSC for waves and HARRIS for winds. Significant wave height and average wind velocity were 4.5 m and 23 m/s respectively, which were set according to the design specifications.

In the model test three control modes were tested. Conventional DPS (CDPS) used conventional position reference, which was measured position in the experiment and DGPS or HPR in the real operation. Ship target position was given as an initial condition. In RDPS (Riser DPS) mode ship position was obtained from a position sensor and target position was given by the IRE, which gives the smallest riser end angles. In RAPS (Riser Angle Positioning System) mode the ship position and velocity are estimated by referring to riser end angles and target position was calculated by using IRE. Table 2 shows sensors used in three modes.

3.1 TEST and SIMULATION RESULTS

Table 3 gives optimum ship position calculated in real scale. The calculation was based on the relation obtained in the experiments between ship position and REA in calm water. In the experiment the several ship positions (off-set from BOP point) were fixed in calm water with 3 different current patterns and REAs were measured. The relations between REA and ship positions were represented in approximate curve. Then Static optimum positions were calculated so that the sum of the square of REA is minimal. In dynamic test, RDPS and RAPS should keep the ship position around these optimum positions, while the ship was subjected to the irregular winds and waves. Table 3 gives also experimental data, which was average ship position. Comparing these data, it is found that both RDPS and RAPS could keep the ship position around the optimum position regardless to the current pattern.

Figure 7 through 9 show average and standard deviation of REA and ship position in each current pattern. In CDPS mode the DP target position was set right above riser fixed point, which corresponded to the BOP point. Obviously the bottom angle in both RDPS and RAPS were reduced and smaller than those in CDPS mode, but sometimes top angle increased and larger than those in CDPS. The reason was that the evaluation function was sum of square of the REA. Depending on the relation between ship position and REA, there was a case where top angle increased as the sum of square of REA decreased. Simulation results are also shown in Figure 7 through 9. They corresponded well with the experimental results in both average and standard deviation. It was thought that difference between simulation and experimental results was due to disturbance of current velocity, wave, and wind in model basin.

It should be pointed out that the standard deviations in RAPS mode were equivalent to those in RDPS mode. This fact indicated that the estimated position by REAPS using REAs as position sensors had sufficient accuracy for ship positioning. Figure 10 shows comparison between measured and estimated position. The estimated values agreed well with the measured values.

Figure 11 and 12 shows time history of REA and ship position in REVCP as an example of test data.

4. CONCLUSIONS

The drill ship must be positioned to keep the inclination angles at the both ends of the riser within the allowable limits. Furthermore the positioning data such as the satellite signals are not always available. This paper has described the development of the DPS for a drill ship from the viewpoint of the operability of the deep-sea riser.

New DP controller concept for drill ship was proposed. Numerical simulation and the model basin test using 3D apparatus in irregular waves and winds confirmed new DP controller concept.

The major concluding remarks can be summarized as follows.

- A practical algorithm was proposed to automatically control REA by ship positioning.

- Even if ship's position reference sensors are not available, the new DP controller with REA sensors could support strongly ship positioning.
- Riser angles were controlled automatically by combining the new algorithm and the experienced DP logic.
- This control was confirmed to be feasible for various current flow profiles.
- Neural network will be effective to consider not only riser angles but also the other significant parameters with riser for riser angle control.
- Kalman filter with modal filter connected to riser angle sensors will be very useful and practical estimator of ship motion in the operation of drilling with riser.

5. FUTURE WORKS

The OD21 ship will be launched in 2002. The RDPS and RAPS will be included in the DPS. The proposed new logic for a real system onboard will be checked more in detail by simulation and tested in the field. Careful field tests are necessary before actual operations.

ACKNOWLEDGMENTS

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REFERENCES

1) Shinichi Takagawa; "Riser Drilling Technology for an Integrated Ocean Drilling Program (IODP)", JOIDES Journal, Vol.24, Number 2/Fall, pp31-33

2) Riser Management System, Product Description, KONGDBERG SIMRAD, 1999

3) Thomas R. Stockton , "A Real-Time Riser Management System for DP Drilling Vessels", , DP Conference , Oct. 13-14, 1998 Houston

4) Quenton W. Dean ,"A Riser Angle Positioning System (RAPS)" , OTC3755, 1980

5) H.Suzuki, K.Yoshida,and S.Ishida, "Operability Improvement of Deepsea Riser by Active Control", The Proceedings of the OMAE Conference,1995

6) Yukinobu Hamada, Toshiyuki Nakanishi, Yasutaka Amitani, Noriyoshi Kume, Shigeru Nonose, Kitao Yamamoto, "Dynamic Positioning System of the Underwater Work Test Vessel" JAMSTECTR 13(1984) in Japanese

7) D.E.Rumelhart et al., "Parallel Distributed Processing", The MIT Press, 1986

8) Imakita, A. et. al. "Intelligent Riser Angle Control DPS", OMAE2000, New Oreans.

9) Yoshino, I. et. al., "Model Tests for the DPS of the OD21 Drillship", DP Conference, Houston, Oct., 2000

Table 1 Principal particulars

	OD21	Full scale	Model	Comment
Drillship				
Length(Lpp)	192 m	192 m	3.491 m	
Breadth	38 m	38 m	0.691 m	
Design Draft	9.2 m	9.2 m	0.617 m	
Riser				
Water depth	2500 m	275 m	5 m	
Outer Dia.	1.32 m	3.0 m	0.055 m	buoyancy module
Top tension	1100 ton (10780 KN)	326 KN	1.962 N	
Material	Steel		Rubber	

Table 2 DPS mode and sensors

DPS experimental mode	sensors	
	Position reference	REA
CDPS		
RDPS		
RAPS		

Table 3 Calculated optimum ship position and test result

Current pattern	Test result (average x 55)				Calculation	
	RDPS		RAPS			
	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)
REGCP	+11	0	+11	-1	+8	+0.2
REVCP	-16	-1	-18	-2	-20	+0.1
CRSCP	+16	+17	+13	+20	+15	+18

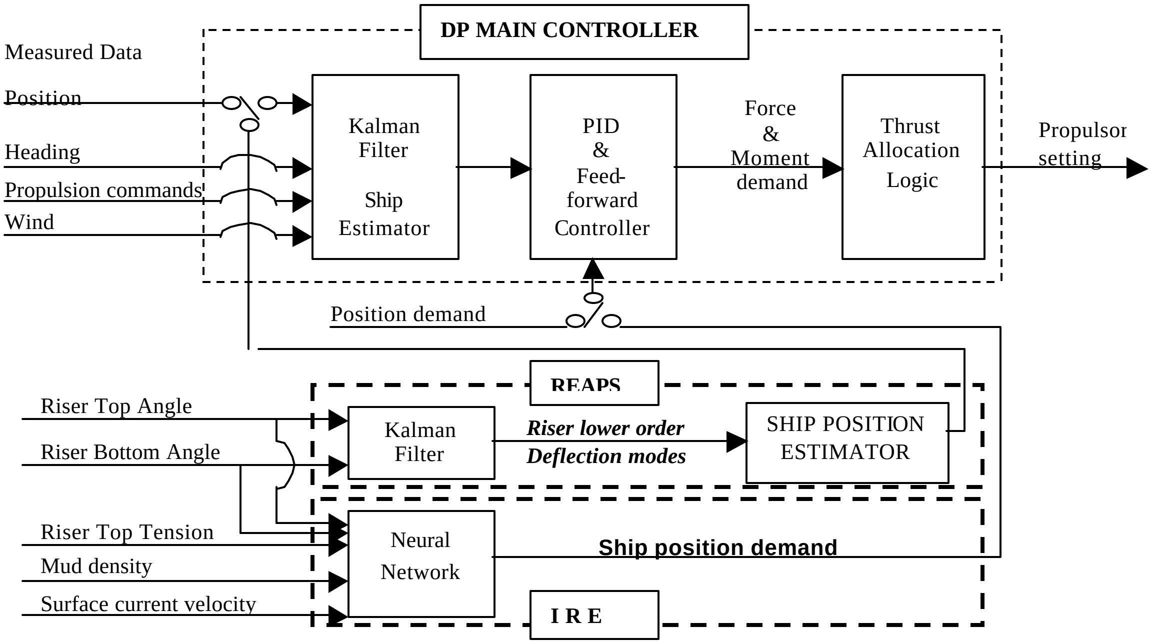

Figure 1 New DP controller concept for drill ship

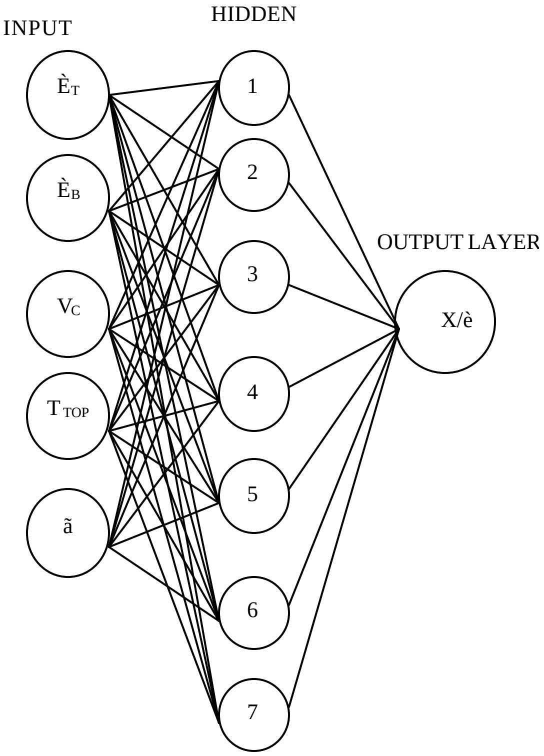

Figure 2 Neural network for INTELLIGENT RISER ESTIMATOR

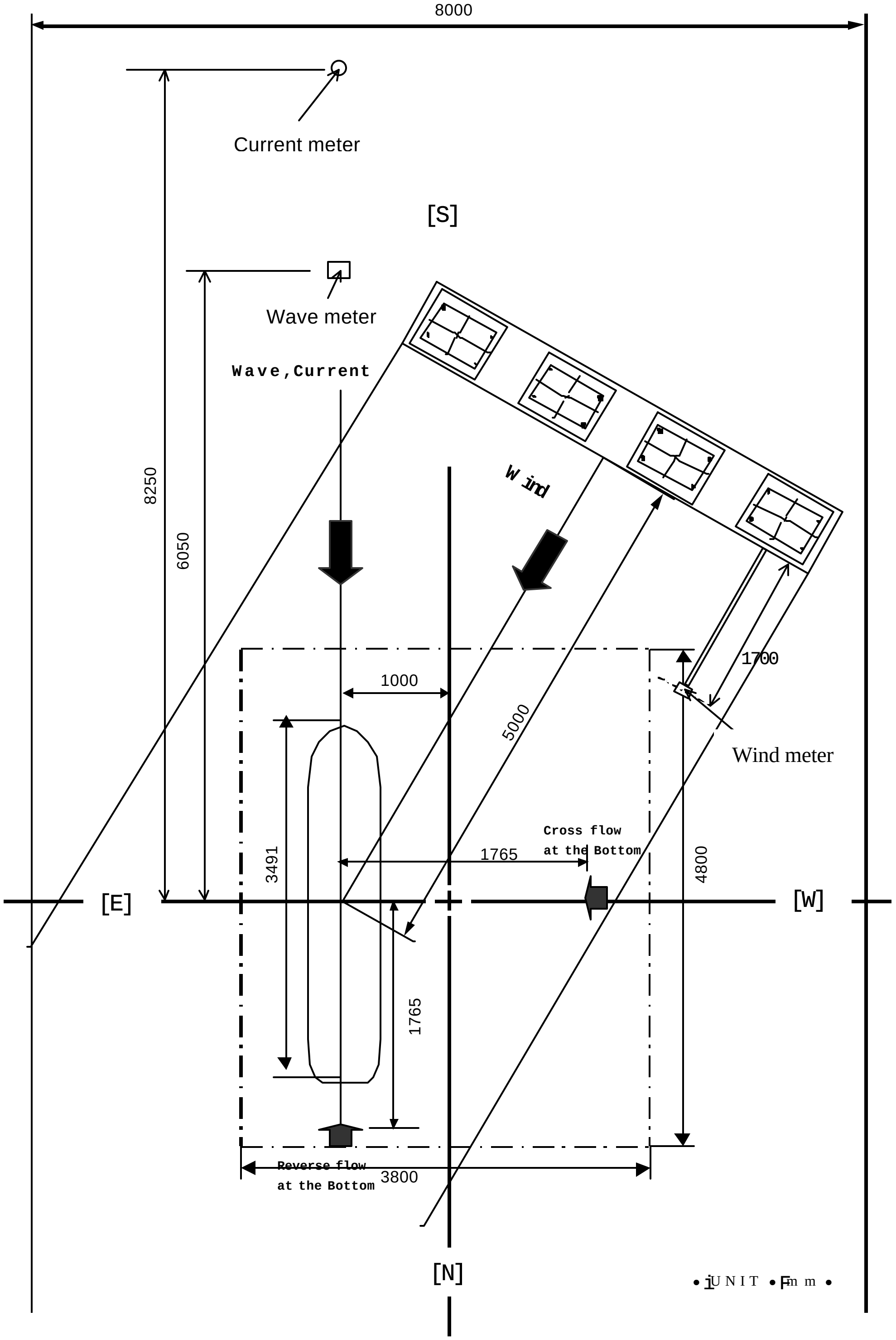

Figure 3 Test apparatus (plane)

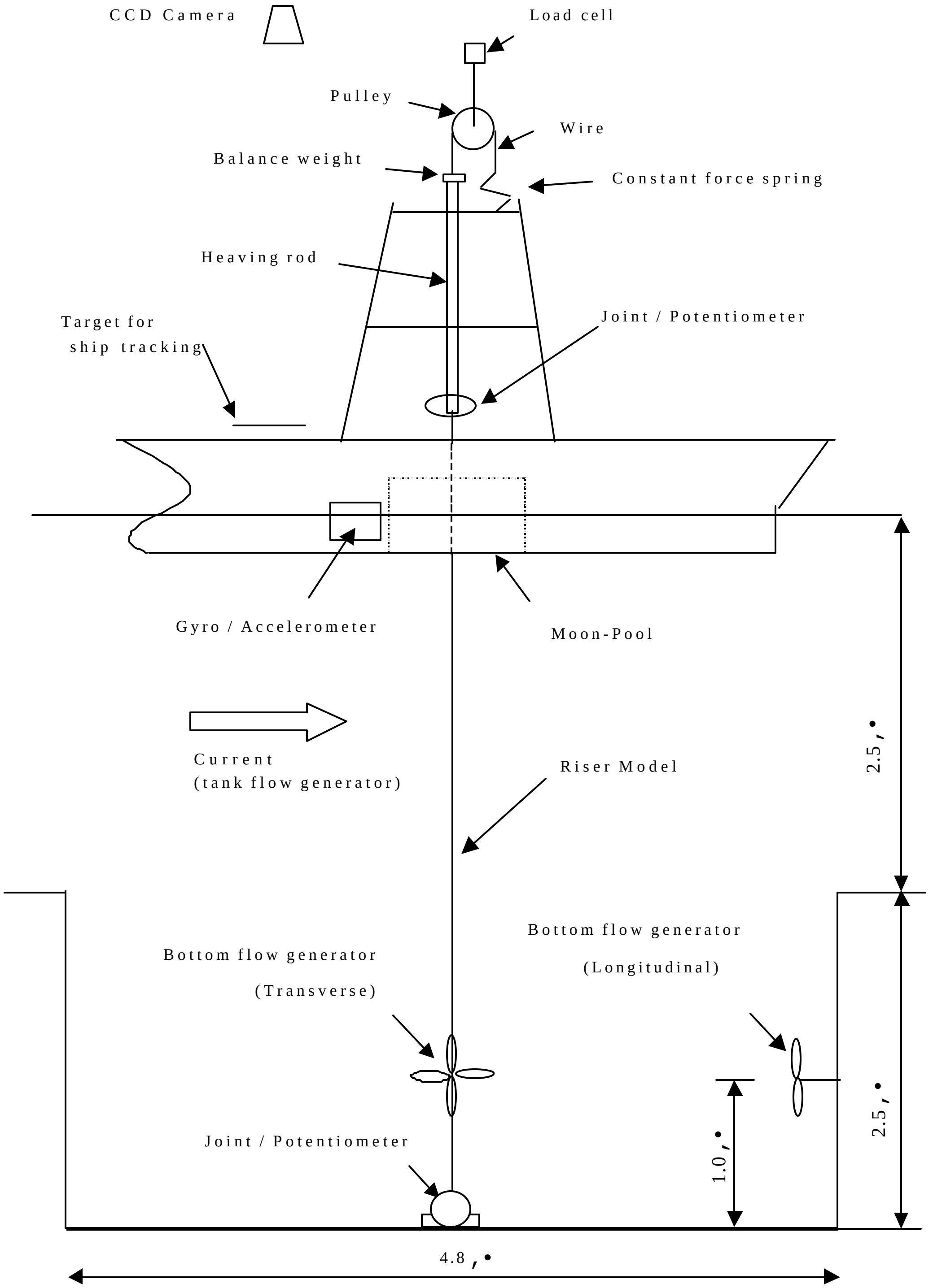

Figure 4 Test apparatus (side)

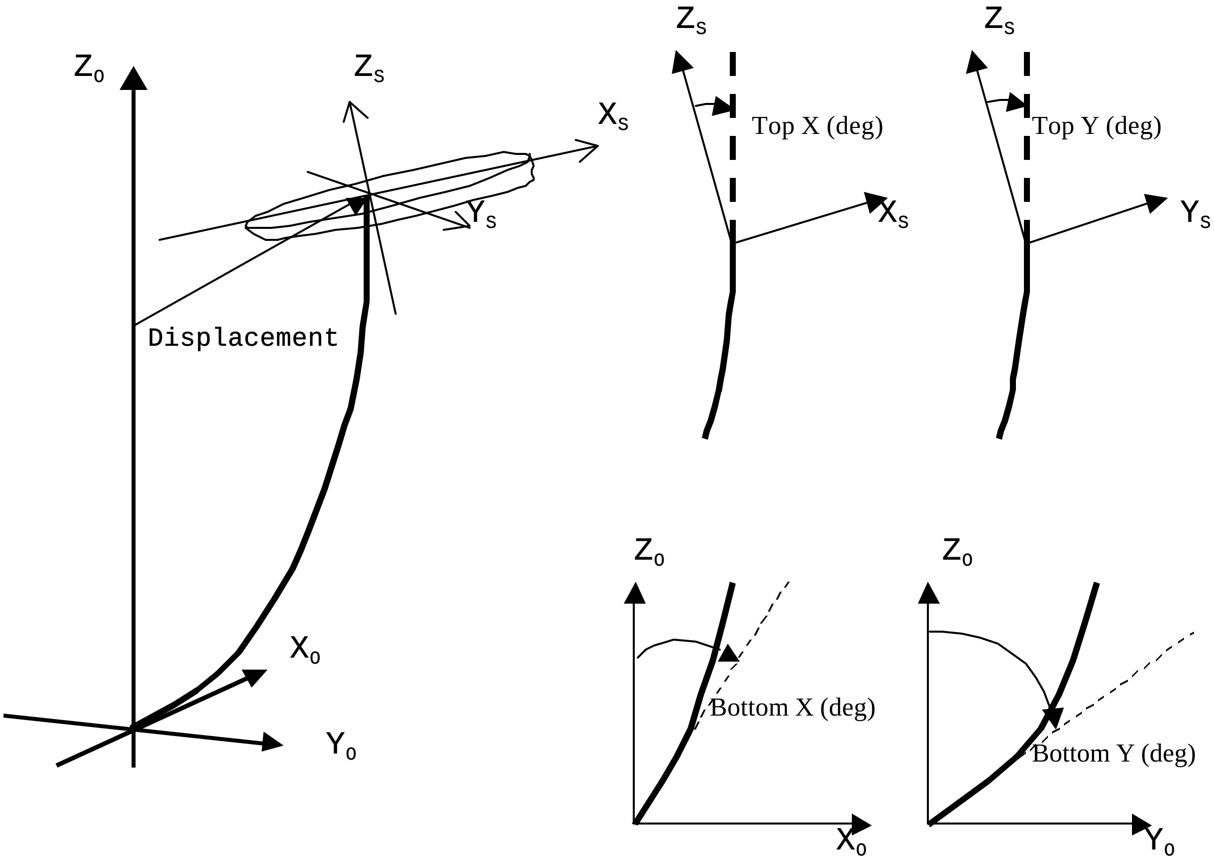

Figure 5 Coordinate system

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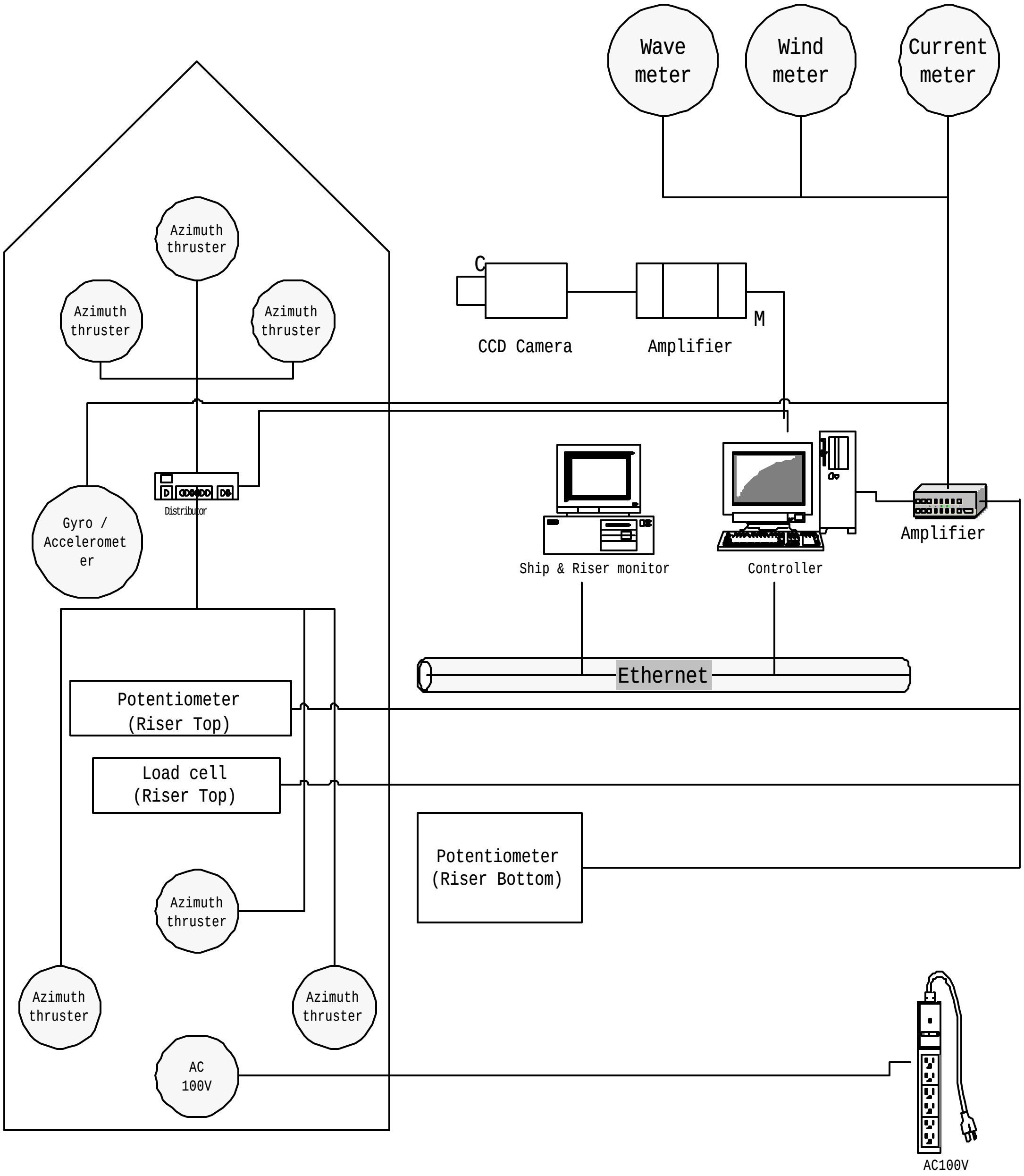


Figure 6 Sensors and signal processing system

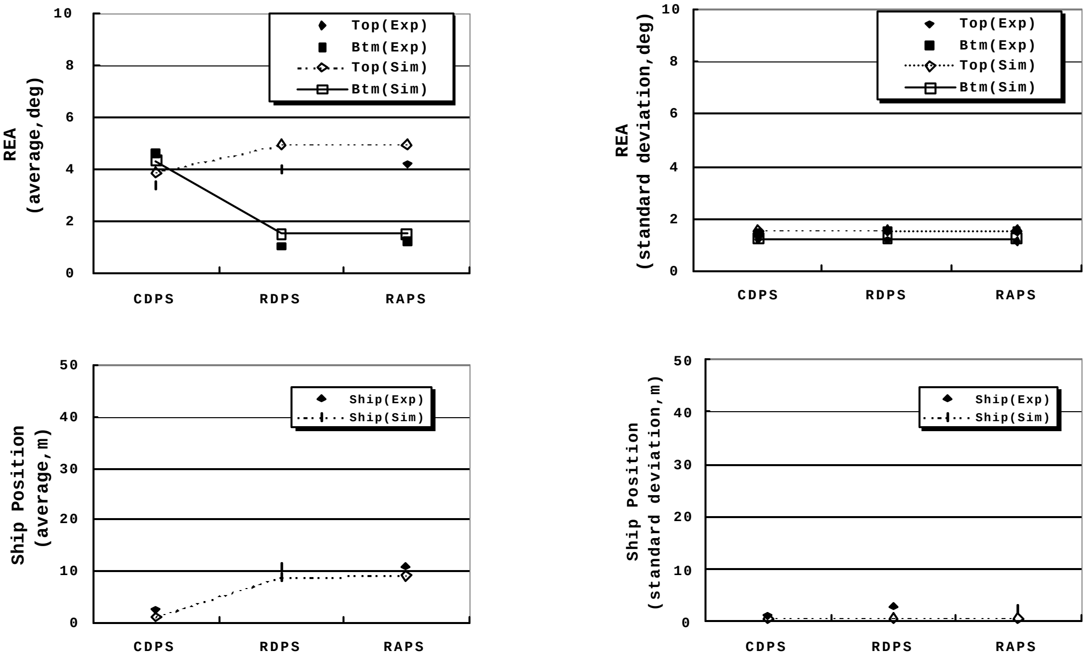


Figure 7 Test and simulation result
REA and ship position in REGCP

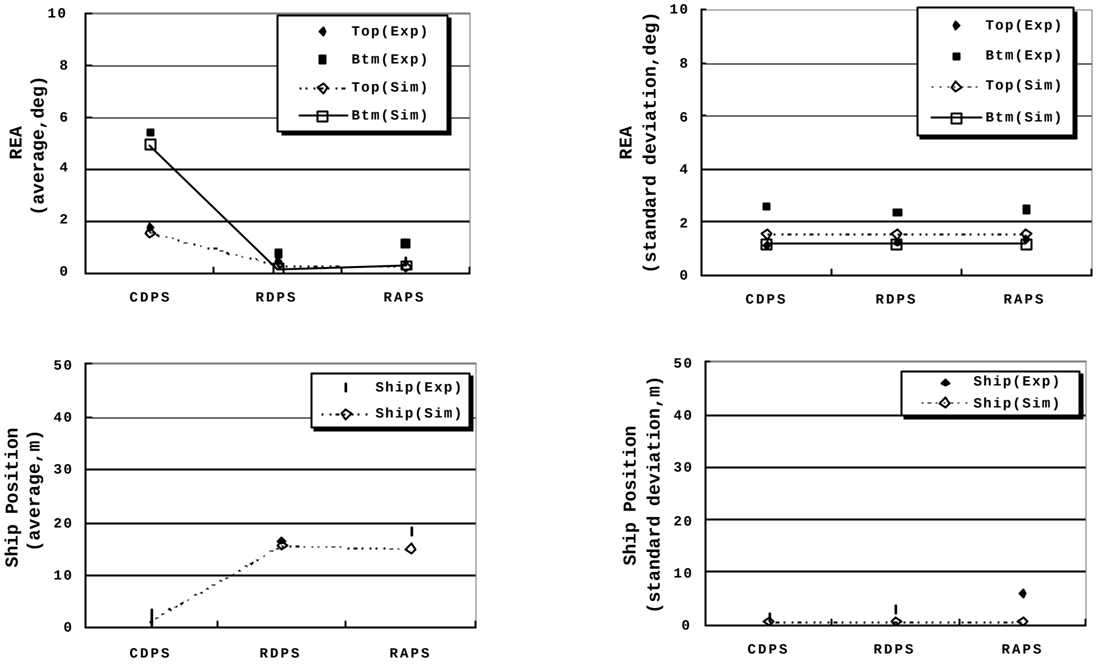


Figure 8 Test and simulation result
REA and ship position in REVCP

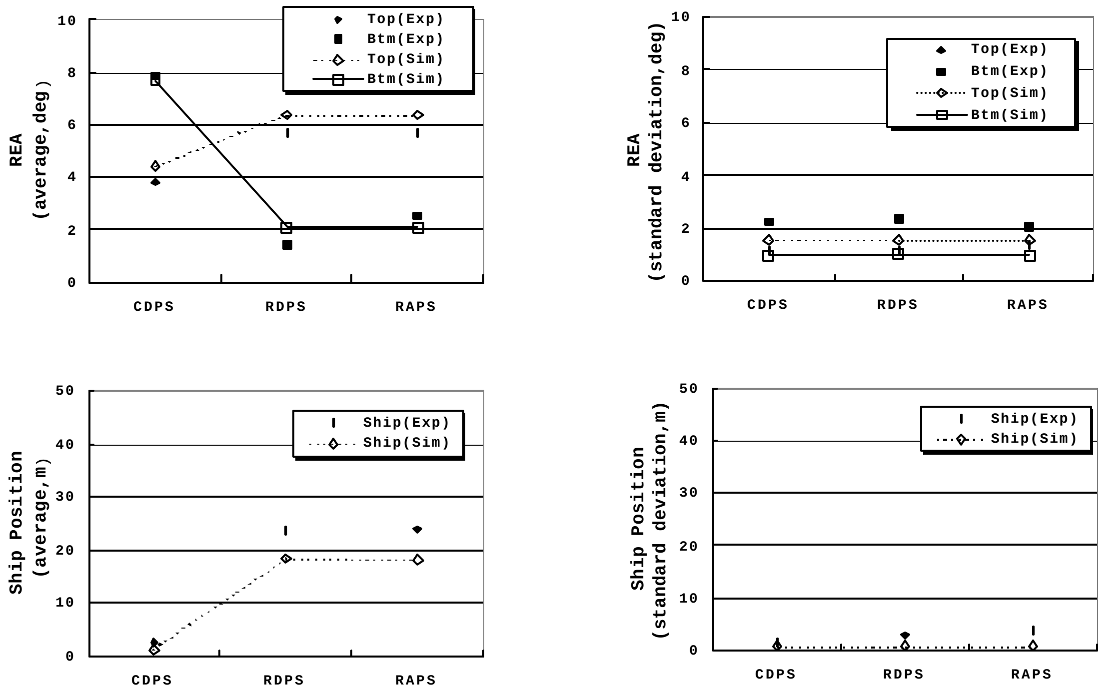
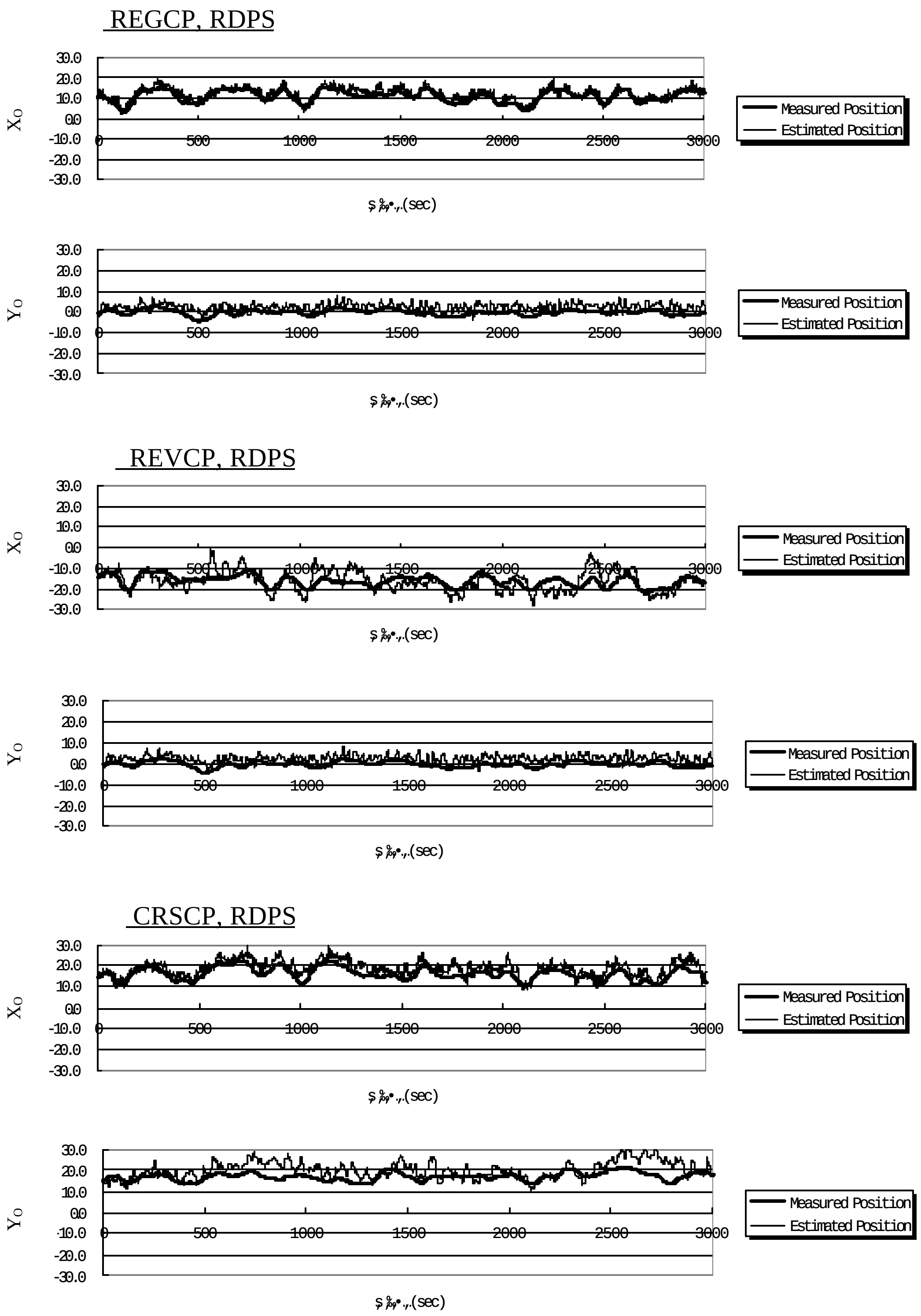


**Figure 9 Test and simulation result
REA and ship position in CRSCP**


REGCP, RDPS

REVCP, RDPS

CRSCP, RDPS

Figure 10 Ship position

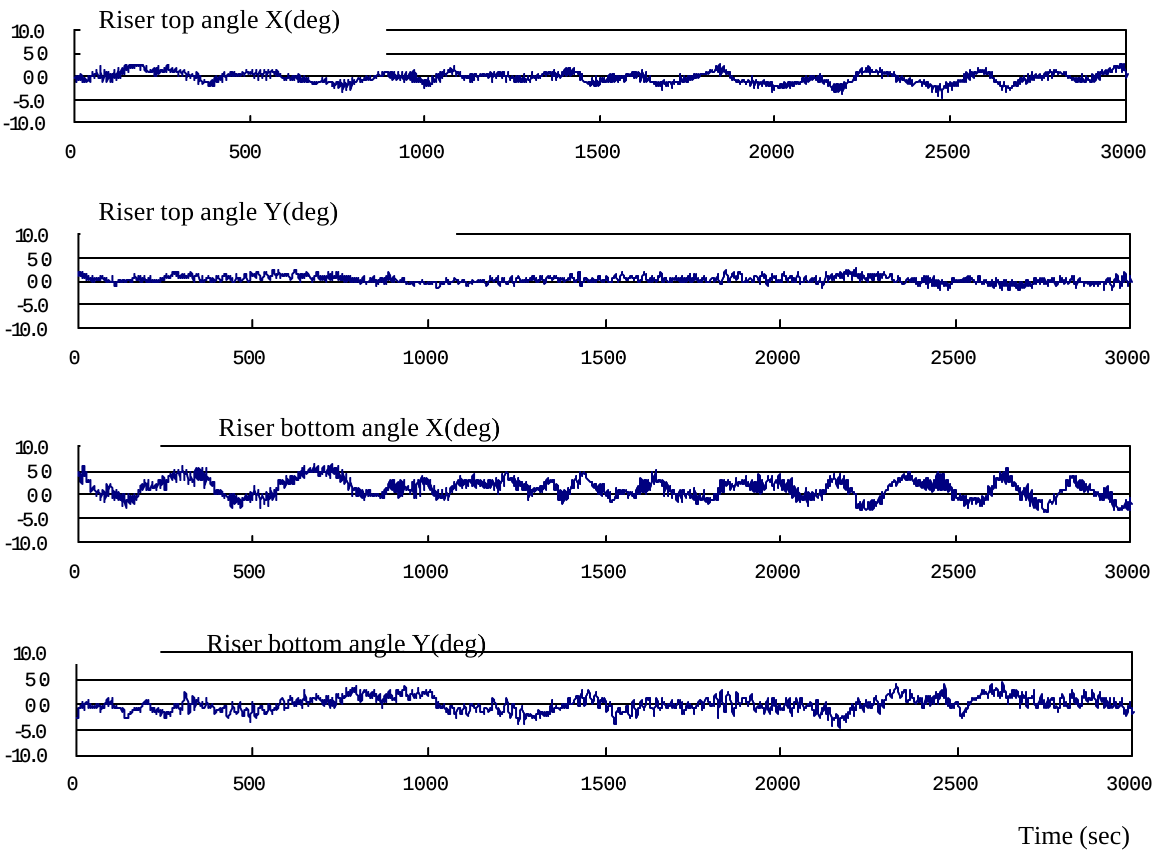


Figure 11 REA Test result (time history)
(RAPS mode, current: REVCP)

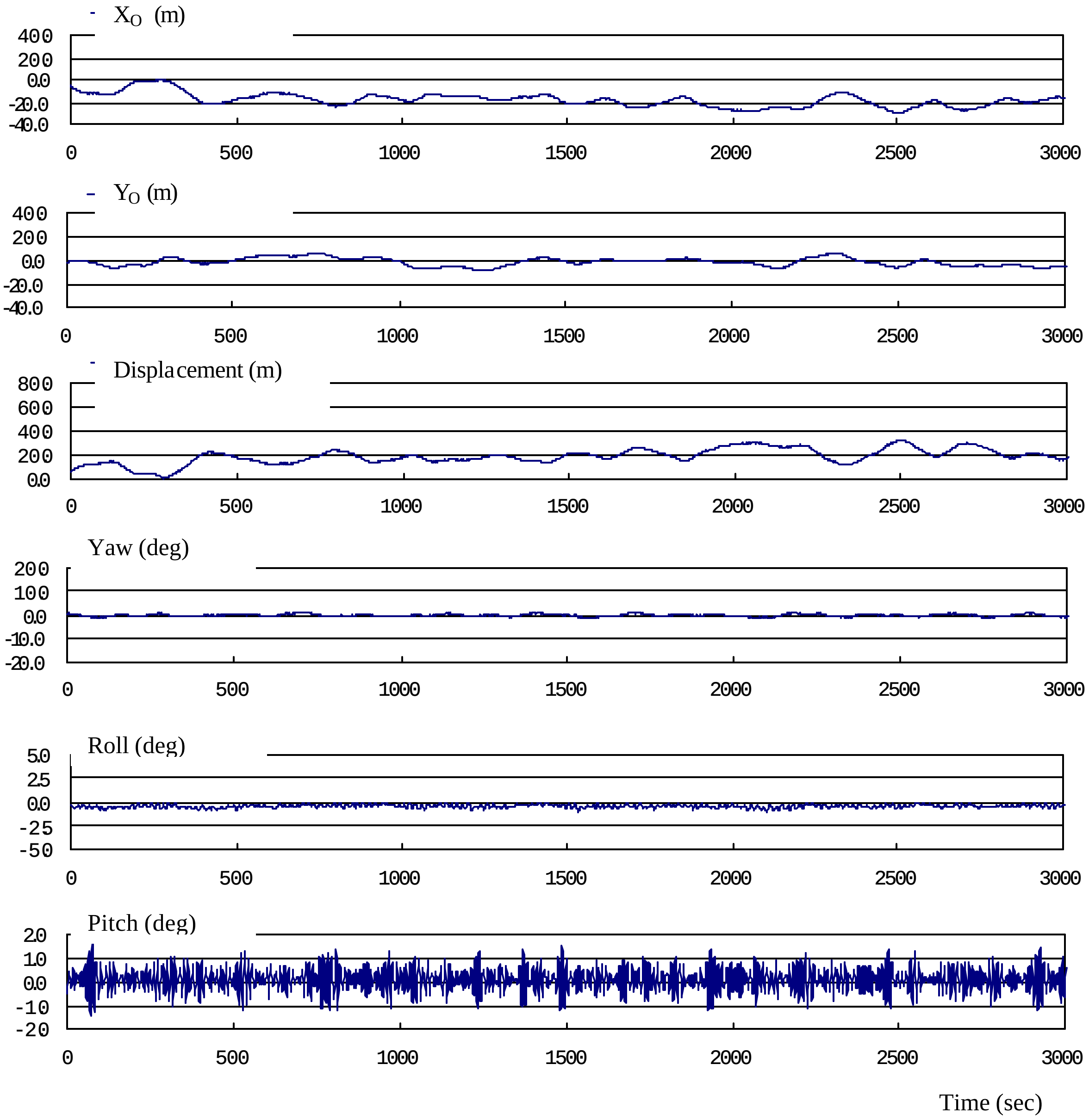


Figure 12 Ship motion Test result (time history)
(RAPS mode, current: REVCP)