Automated Measurement System for Actual Sea Model Basin

by

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Abstract

When conventional experiments on a ship model are carried out in a basin for added resistance in regular waves, different wave conditions, such as wave direction, height, and length are parametrically given for a single ship condition. An automated measurement system enables to ensure the efficiency and quality of the experiments.

An automated sequential measurement was developed for the Actual Sea Model Basin at the National Maritime Research Institute, National Institute of Maritime, Port and Aviation Technology (NMRI, MPAT). The measurement system combines the towing carriage, wave generator, data logger, sensors and analysis system. The functionality of the developed system was verified by comparing the acquired results with existing data gathered by the previous measurement method.

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1. Introduction

Tank tests in regular waves for a ship model tends to be carried out in a variety of wave lengths, wave heights and wave directions. Actual Sea Model Basin[1)] is applicable to this kind of tests in regular waves, which has the capability to generate various kinds of waves with 382 units of segmental flap type wave generators surrounding the whole periphery of the basin, forming the all-around wave generator[2)]. For the experiment with different wave conditions for a single ship condition, an automated sequential measurement system is an effective system which enhances the function of the basin by decreasing errors of operations for the measurement and by increasing the efficiency of the experiment.

Actual Sea Model Basin is equipped with the controlling system combines the towing carriage, wave generating system and wind generation system. Under the system, each sequence is connected with another sequence by manual procedures, and the measurement of data, the analysis of data, and the transmission of the setting signals to measurement devices are carried out apart from the system. For the improvement of the measuring accuracy and the future realization of all-robotically controlled test system, a timing control for the intervals between successive sequences and an inclusive automated sequential test system are indispensable.

The automated sequential measuring system has been developed for Actual Sea Model Basin at NMRI on the assumption that to be applied to resistance tests in regular waves. In this paper, the development of the automated sequential system and the verification tests of the developed system are described.

2. Installation of the automated sequential measurement system

2.1 Definition of the automated measurement system for stylized experiments

Automatization of the system for stylized experiments has been installed in several basins [e. g. 3), 4), 5)] mainly for tests in still water. As the control by the computer tends to be possible for the mutual relation between devices as well as for each single device, the automation for the experiment is supposed widely than ever. There are several levels supposed in the automatization. The supposed levels of stylized experiments for a ship model are listed in Table 1[6)]. For Actual Sea Model Basin at NMRI, the automatization of level 2 has been carried out. Firstly, for the automatization of sequential measurement, devices related to tests in regular waves are combined by the system, which is the towing carriage, the wave generator, the measuring device in waves, and the recording device for data measured by equipped devices. Secondly, for the automatization of the provisional analysis, the analysis program and the accumulating function for analyzed outputs are installed in the system.

Table 1 Levels of stylized experiments for a ship model.

Level	Remarks
Level 0	All conducted manually. (Setting of a ship condition, operation of a towing carriage and devices, measurement, analysis, and reporting)
Level 1	Automatization for the operation of a towing carriage and the data collection.
Level 2	Automatization of the control of test devices and the provisional analysis.
Level 3	Automatization of the definitive analysis and the implement of an appropriate re-measurement.
Level 4	Automatization of the reporting.
Level 5	Automatization of the conversion of a ship condition. (Conversion of draft and trim condition, and installation/removement of a propeller.)

2.2 Combined equipment by the system

For the implement of the automated measuring system to a test for the added resistance in regular waves, control functions for the towing device are combined by the system. In the test for the added resistance in regular waves, a ship model is equipped to the towing device which gives restoring forces and steady forces for three modes of ship motion in which the ship model does not have natural restoring force, that is surge, sway and yaw motion. In Actual Sea Model Basin, the measuring device named the large-sized measuring device for wave forces[1)] shown in Fig. 1 is generally used for the test in regular waves for the ship model with a length about 4.5 m. The device has load cells for measuring a longitudinal force, a transverse force and a yawing moment acted on the ship model, and potentiometers for measuring six degrees of ship motion, that is three kinds of translational motions: surge, sway, heave and three kinds of rotary motions: roll, pitch yaw. For surge, sway and yaw motion, the device gives restoring forces and steady forces to the ship model through a torque motor. The control panel for restoring forces and steady forces is shown in Fig. 2. Control signals are given via scaled knobs on the panel or electric signals input directly. In the automated system, control signals are given to the device in the manner of electric signals according to the setting parameters.

The setting image of a ship model to the device is illustrated by Fig. 3(a) and the picture of an example of the setting is shown by Fig. 3(b). Three kinds of forces and six degrees of ship motion are measured by the device shown in Fig. 1. The wave gauge is set separately from the device in front of the ship model for the measurement of encountered waves without interference to the ship model.

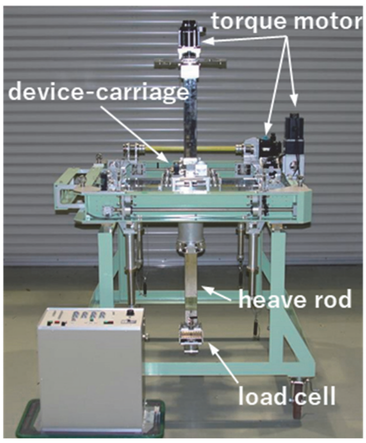
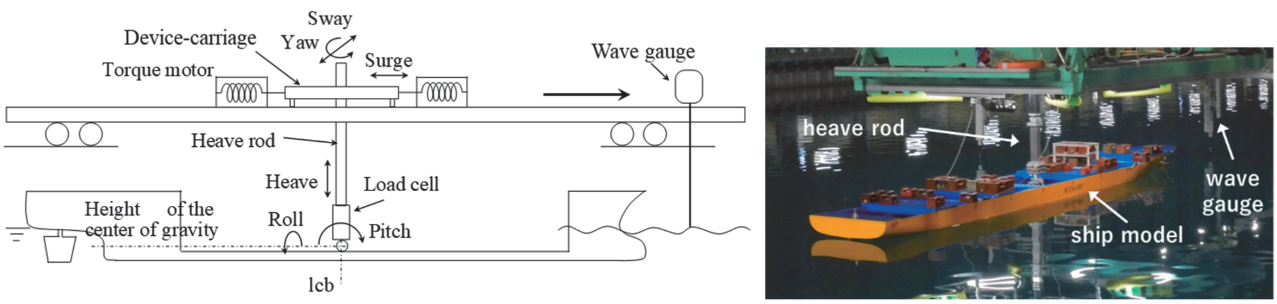


Fig. 1 Measuring device in waves

Fig. 2 Control panel for restoring forces and steady forces.



(a) Setting image of a ship model to the device. **(b) Picture of an example of the setting.**

Fig. 3 Measurement system for a test in regular waves.

A recording device is also combined by the system. Here a generalized recording device is used which can save measured time-series data in the text format.

2.3 Enhancement of the conventional system

The enhanced system arrangement and its features are shown in Fig. 4 and Table 2. Originally, the system only combines the towing carriage, wave generator, and trigger for measurement and operation of clamps. By the enhancement, the control of restoring forces and steady forces and the recording device have also been combined, and sequential measurement has been enabled automatically through the setting of parameters such as intervals between test runs while it was operated manually in the conventional system. The analysis function is also installed in the system, and analyzed results are accumulated in the system. The accumulated measurement data and its analyzed results are checked after sequential measurement.

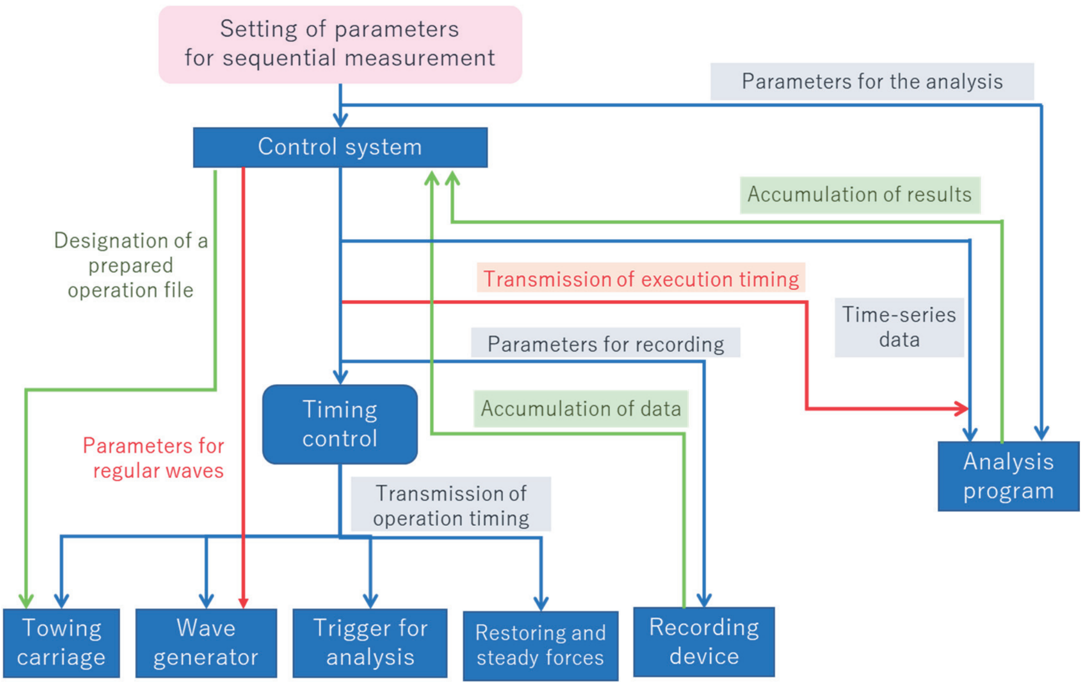


Fig. 4 Arrangement of the enhanced system.

Table 2 Comparison of the system for tests in regular waves.

Combination item	Conventional system	Enhanced system
Towing carriage	Designation of a prepared operation file	Designation of a prepared operation file
Wave generator	Designation of a prepared operation file for each test tun	Setting of parameters of wave condition for all test-runs (operational file is automatically updated in the sequential measurement)
Clamps	Setting of operation timing	Setting of operation timing
Restoring forces and steady forces for measuring devices	Manual control Separate control	Setting of parameters
Recording device	Manual control Separate control	Setting of parameters
Trigger for analysis	Setting of timing	Setting of timing
Provisional analysis	Manual control Separate execution	Setting of execution timing
Sequential measurement	Manual sequence	Automated sequence Setting of intervals

3. Experiments with the system

Figure 5 shows the test flow for added resistance in regular waves. Here, measurement of a zero-point is conducted to obtain a base value for each item for each run. A mode of the wave-absorbing could be changed for intervals between successive measurement in the light of the condition of the water surface of the tank. In the measurement, the mode of wave-absorbing starts just before the measurement of zero-point and stops just after the measurement of each run. For the execution of sequential measurement, each timing on the flow and necessary parameters are requested to be input.

Requested parameters are listed in Table 3. In the system, the pattern file for the operation of the towing carriage is separately made, and the combined system simply designates an appropriate pattern file for each single measurement. Other parameters are directly set on the combined system. For the analysis, calibration coefficients for measured items are requested for the conversion of measured electrical signals to physical quantities.

Timing for each execution on the flow shown in Fig. 5 is set in the system. Timing requested to be set is listed in Table 4. Firstly, timing for the towing carriage and clamps is set according to the test speed. Then for tests of added resistance in regular waves, timing for the wave generator is to be adjusted with the condition of the towing carriage and clamps. Here, for shortening the convergence time of motion induced by release of a ship model from clamps, timing for the ship model encountering waves is to be after the release of the ship model from clamps. Therefore timing for the start and the stop of the wave generator is to be determined according to the wave condition. Then, for decreasing an overload to measurement devices, timing of the restraint of the ship model with clamps is to be after the last encountering waves passing the ship model since ship motion and acted forces on the ship model tend to be large when the ship model does not have an advance speed.

Additionally, timing for change of steady forces is also to be adjusted with the condition of the towing carriage. Originally, steady forces are given to the ship model so as to keep the position of the heave rod in the center of the device or so as to shorten the time taken to become stable from release of the ship model from clamps. For the former purpose, steady forces depend on the forces acted in waves, and for the latter purpose it corresponds to a resistance acted on the ship model just after releasing from clamps. Here the latter purpose is prioritized. The timing for the change of steady forces should be adjusted in automated measurement. Then the timing for the start of the change of steady forces is set to meet with the acceleration of the towing carriage, and the timing for the return of steady forces is set to meet with the deceleration of the towing carriage. As described above, since the ship model is supposed to be in still water when the model is released from clamps, the steady force corresponding to a resistance in still water is given to the model in the measurement.

Of course, timing for the trigger for the analysis should be set according to the ship and wave conditions. That is, the trigger for the analysis should be turned on when the ship motion, measuring forces and encountering waves are periodically stable.

Timing for the recording device can be set arbitrarily as long as the analysis range is included for recording.

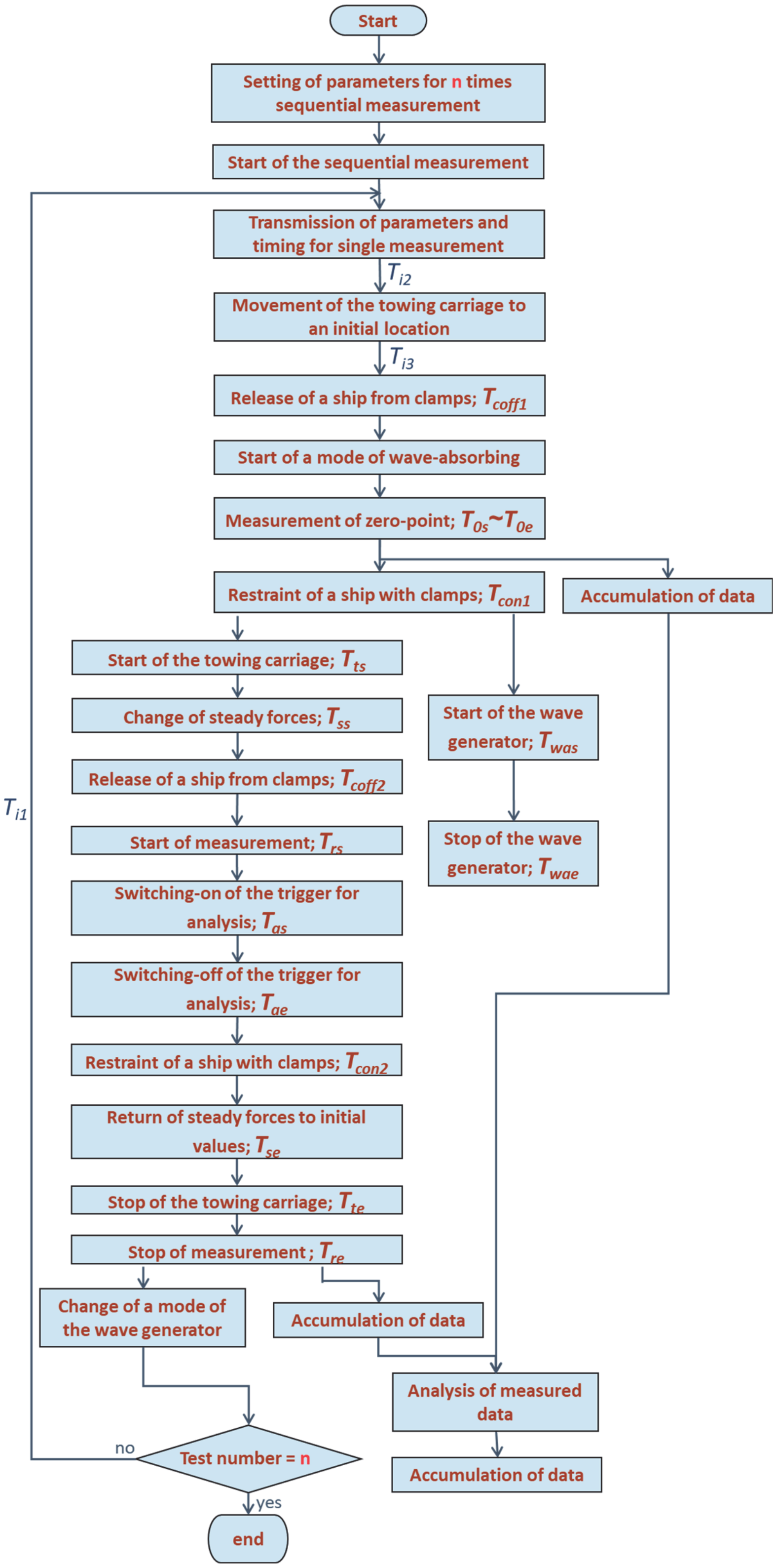


Fig. 5 Flow of the sequential tests for added resistance in regular waves with the system.

Table 3 Requested parameters for automated measurement.

Category	Item	Remarks
Towing carriage	U	Speed of the towing carriage
	D	Direction of the movement of the towing carriage
	β	Drift angle of a ship against D
	X_0	Initial position of the towing carriage in the longitudinal direction of the basin
	Y_0	Initial position of the towing carriage in the transverse direction of the basin
Wave generator	ζ_a	Amplitude of regular waves
	λ	Wave length
	χ	Wave direction
Measurement device	k_x	Spring constant for restoring force in surge mode
	k_y	Spring constant for restoring force in sway mode
	k_ψ	Spring constant for restoring force in yaw mode
	S_x	Steady force for surge mode
	S_y	Steady force for sway mode
	S_ψ	Steady moment for yaw mode
Analysis	N_{ch}	Number of measurement channels
	f_s	Sampling frequency
	$C(i)$	Calibration coefficient for each item (i = 1, 2, ..., N_{ch})
	$Name(i)$	Name for each item (i = 1, 2, ..., N_{ch})
	$Unit(i)$	Unit for each item (i = 1, 2, ..., N_{ch})

Table 4 Timing list to be set for automated measurement.

Category	Item	Remarks
Towing carriage	T_{ts}	Start of the towing carriage (start of acceleration)
	T_{te}	Stop of the towing carriage (start of deceleration)
Zero-point	T_{0s}	Start of the zero-point measurement
	T_{0e}	Stop of the zero-point measurement
Clamp	T_{coff1}	Release of a ship from clamps after the movement of the towing carriage to an initial location
	T_{con1}	Restraint of a ship with clamps after the zero-point measurement
	T_{coff2}	Release of a ship from clamps after the acceleration of the towing carriage
	T_{con2}	Restraint of a ship with clamps before the deceleration of the towing carriage
Wave generator	T_{was}	Start of the wave generator
	T_{wae}	Stop of the wave generator
Recording device	T_{rs}	Start of data recording
	T_{re}	Stop of data recording
Measurement device	T_{ss}	Change of steady forces for surge, sway and yaw modes
	T_{se}	Return of steady forces for surge, sway and yaw modes to initial values
Analysis	T_{as}	Switching-on of the trigger for the analysis
	T_{ae}	Switching-off of the trigger for the analysis
Intervals	T_{i1}	Interval between the change of a mode of the wave generator after the test run and the transmission for the sequential measurement
	T_{i2}	Interval between the transmission of parameters and timing and the movement of the towing carriage to an initial location
	T_{i3}	Interval between the movement to an initial location and the release of a ship from clamps before the measurement of zero-point

4. Validation

For the validation of the automated sequential system, tests for the added resistance in regular waves have been carried out for Duisburg Test Case container ship (DTC)[7], and results have been compared with those by the conventional manual method. Principal dimensions of DTC are shown in Table 5. Validation tests have been carried out from head waves to following waves of λ/L_{ps} = 0.4 and 0.9 or λ/L_{ps} = 0.4 and 0.7, where λ is the wave length and L_{ps} is the length between perpendiculars. Ship speed for the test is 18 knot for full scale, which corresponds to F_r =0.157, where F_r is the Froude number based on L_{ps}. Conditions for waves and ship speed are shown in Table 6.

Table 5 Principle dimensions of DTC.

Item	*Full scale*	*Model*
Length between perpendiculars [m]	355.0	5.500
Breadth [m]	51.0	0.790
Draft [m]	14.5	0.225

Table 6 Conditions for waves and ship speed.

Item	*Value*
Wave direction α [deg.]	0 (head waves), 45, 90, 135, 180(following waves)
Wave length - ship length ratio λ/L_{ps} [-]	0.4, 0.7 (except for head waves), 0.9 (head waves)
Wave height H [m]	3 (full scale)
Froude number F_r [-]	0.157

Test results for the frequency response of the added resistance in regular waves are shown in Fig. 6. Measurements were carried out 3 times for each wave condition, and the repeatability has been examined. Measurements were also carried out by the conventional manual system, and the equivalence for quality of results was examined through the comparison. For both measurement system, time intervals between runs are set to be almost the same. For this test, the interval is set to be about 15 minutes. Here K_{AW} is the coefficient of the added resistance in regular waves nondimensionalized by Eq. (1), where R_{AW} is the added resistance in regular waves, $\bar{R}$ is the mean resistance in regular waves, R_0 is the resistance in still water, ζ_a is the wave amplitude, ρ is the fluid density, g is the gravitational acceleration, B is the ship breadth. The solid line in Fig. 6 is calculated results by VESTA[8] shown as a reference with C_U= 35.1 obtained from tank tests, where C_U is the coefficient of advance speed for the added resistance due to wave reflection. KAW_m is results by the conventional manual system, KAW_auto is results by the automated measurement system. In the conventional manual method, the analysis range for obtaining an averaged value of the resistance and an amplitude of encountered waves is determined manually according to the steadiness of measured time series data. Results by the automated measurement system KAW_auto are the analyzed results by the system, which is not re-analyzed manually. Calculated results of VESTA are in the good agreement with experimental values in short head and bow waves, and is likely to be smaller in longer waves or in other wave directions. In following waves, calculated values are relatively unstable, while the experimental values collect to near 0 in both waves lengths.

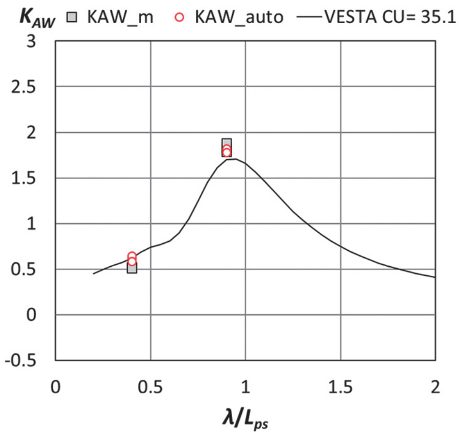
Time series data of measured longitudinal forces acted on a ship model R (positive aftward) and encountered waves ζ (positive upward) by the automated measurement system are also shown with the analysis range in Fig. 7 and Fig. 8 , for example, for head waves and oblique waves. In the same wave condition, time series data of the representative test by the conventional manual system are shown in Fig. 9 and Fig. 10. Here the abscissa axis is the data number where the sampling frequency is 100 Hz, and the time series of encountered waves are modified in consideration with the distance between the load cell and the wave gauge since the wave gauge is located in front of the ship model as shown in Fig. 3. The analysis range is set to be latter part of measured time series data for eliminating the effect of the release from clamps as much as possible. The analysis range is rearranged in the analysis program so as to be the integral multiple of the encountered wave period even if the start and end points of the analysis range are not adjusted to the phase of periodical time series data. According to the ITTC Recommended Procedures[9)], it is recommended that the average amplitude and period of at least 10 cycles be obtained in determining the motions. Here we focus on the added resistance in waves and in cases like that the added resistance in oblique waves or in following waves is measured, it is difficult to ensure 10 cycles. Then measurements should be conducted in several times and the repeatability is confirmed for guaranteeing the accuracy.

$$K_{AW} = \frac{R_{AW}}{4\rho g \zeta_a^2 \left(B^2 / L_{ps}\right)} = \frac{\overline{R} - R_0}{4\rho g \zeta_a^2 \left(B^2 / L_{ps}\right)} \tag{1}$$

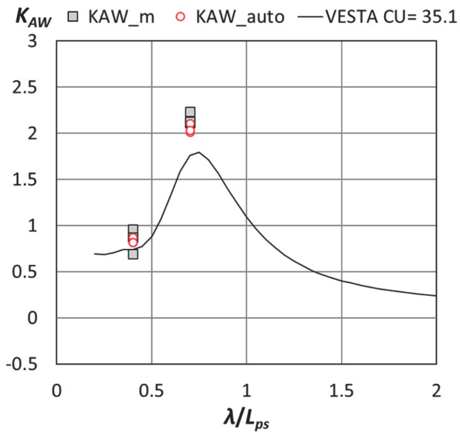
By the comparison of results, it is found that results of the automated measurement system are quantitatively equivalent to those of the conventional manual measurement. Since the measured time series data are basically stable, it is assumed that the difference in analyzed values depending on the analysis range is small. From the comparison between Figs. 7 and 8 and Figs. 9 and 10, the analysis range of the conventional measurement system is shorter than that of the automated measurement system. In the conventional measurement system, the analysis range is chosen manually by involving the stable part of measured time series, thus the last part for λ/L_{ps} = 0.4 of head waves is not involved since the amplitude of encountered waves are start to decrease. While, the last part is slightly included for the analysis in the automated measurement system. However the analysis range is longer and the number of waves is larger than the conventional measurement system. Therefore the added resistance in waves obtained by the mean value and the amplitude of time series data is equivalent to that by the conventional measurement system. For λ/L_{ps} = 0.4 of oblique waves, the analysis range is similar for both measurement systems, it is natural that the obtained added resistance in waves is equivalent.

From 3 test results for the same wave condition, higher or equivalent repeatability has been obtained by the automated measurement system compared to the conventional manual system. For example, in λ/L_{ps} = 0.4 of bow waves, the difference between the maximum value and the minimum values of KAW_auto is 0.05 while that of KAW_m is 0.27. In oblique waves, the dispersion of measured data by the single system is comparably large in both for the automated measurement system and for the conventional manual system. As shown in Figs. 7 and 8, the amplitude of measured data of the resistance is larger in oblique waves than that in head waves. The effect of the measured difference on the averaged value is larger in case the amplitude of the measured time series is larger. Therefore the experimental error on the added resistance in waves tends to be larger in oblique waves.

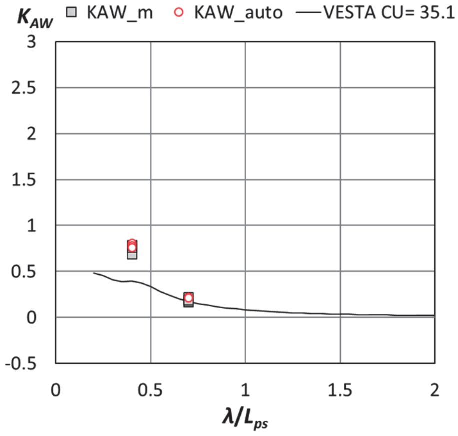
From verification tests, obtained results by the automated measurement system are found to be equivalent to those by the conventional measurement system, and the repeatability of results has been confirmed.



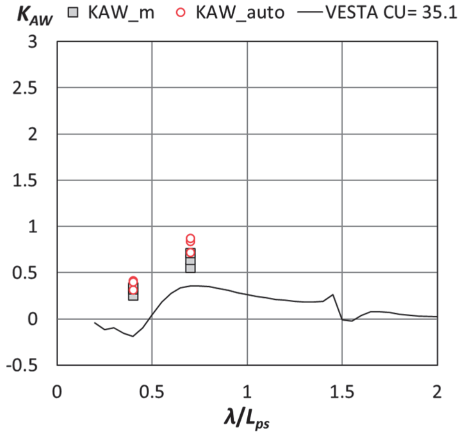
(a) Head waves



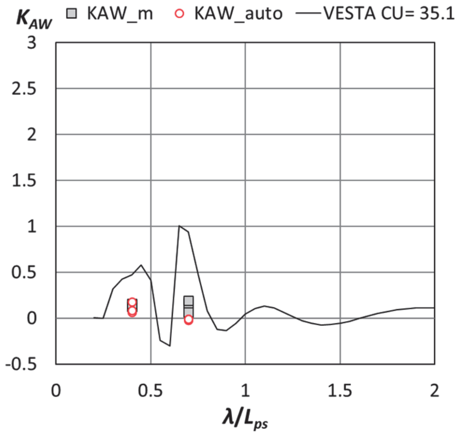
(b) Bow waves



(c) Beam waves

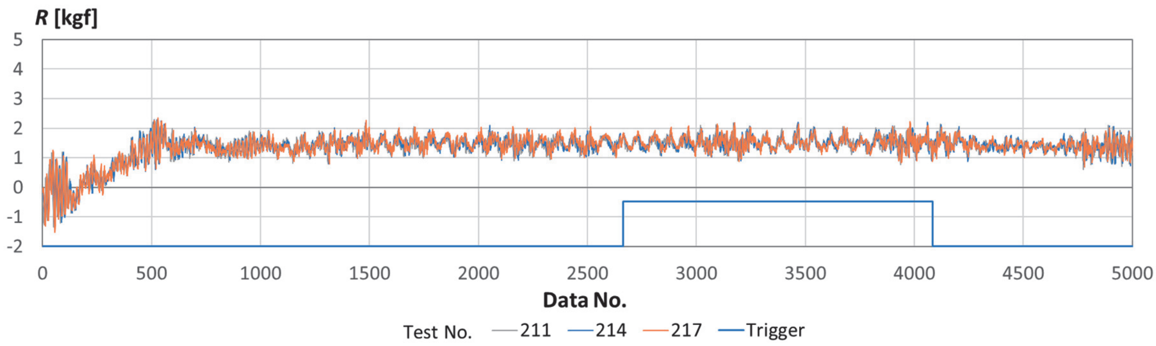


(d) Oblique waves

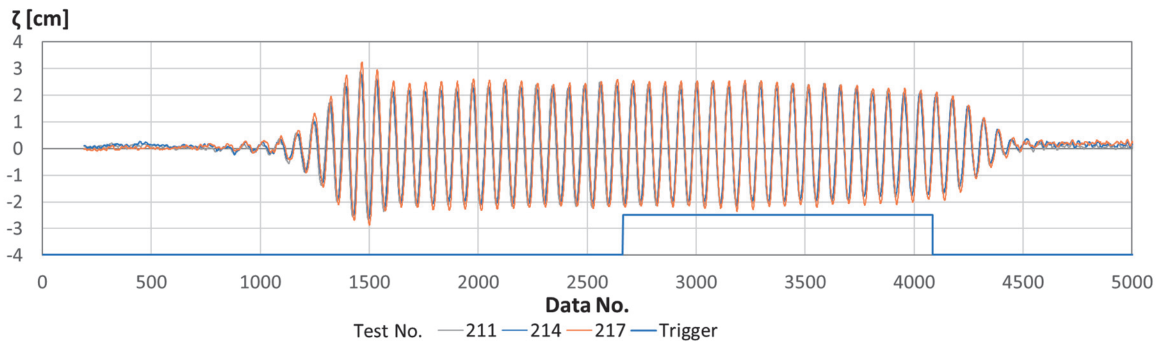


(e) Following waves

Fig. 6 Frequency response of the added resistance in waves for DTC (F_r = 0.157).

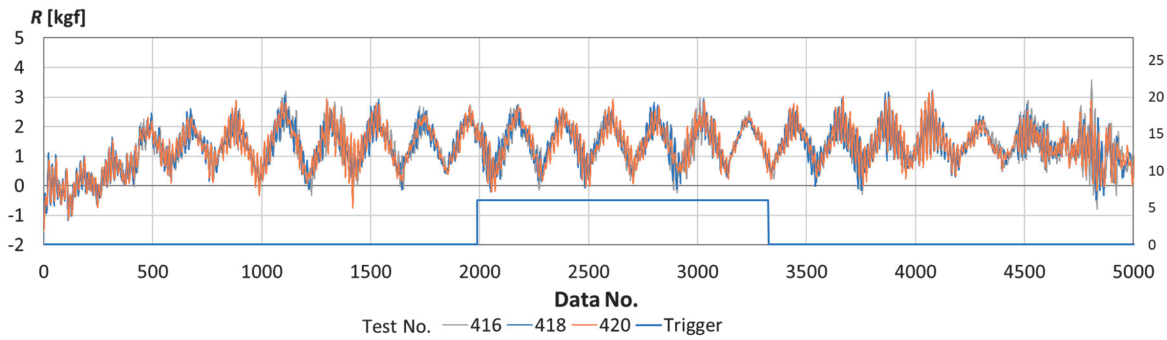


(a) Longitudinal forces acted on a ship model.

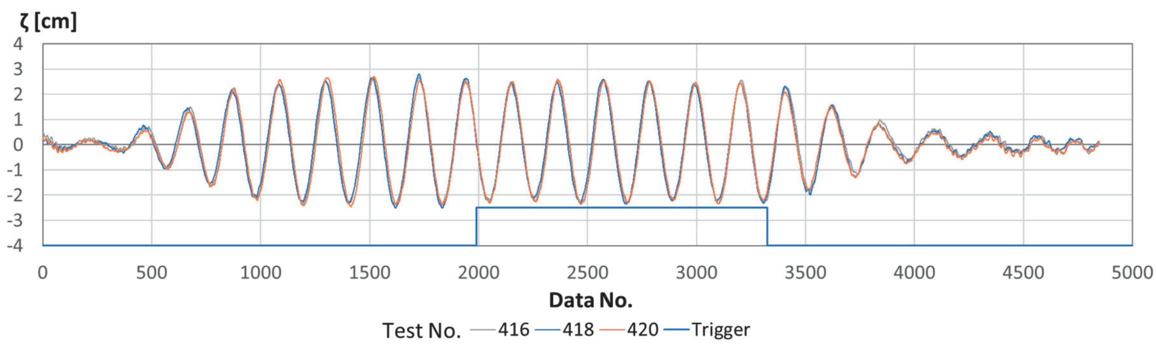


(b) Wave height

Fig. 7 Time series of measured data by the automated measurement system (λ/L_{ps} = 0.4, Head waves).

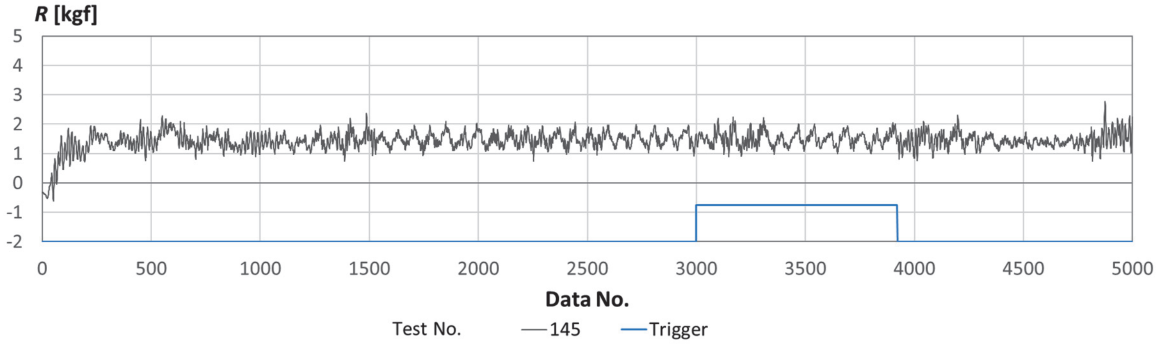


(a) Longitudinal forces acted on a ship model.

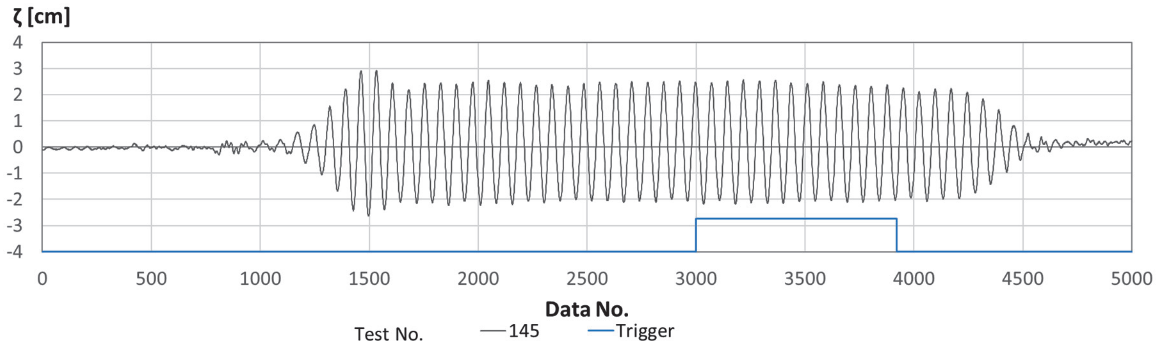


(b) Wave height

Fig. 8 Time series of measured data by the automated measurement system (λ/L_{ps} = 0.4, Oblique waves).

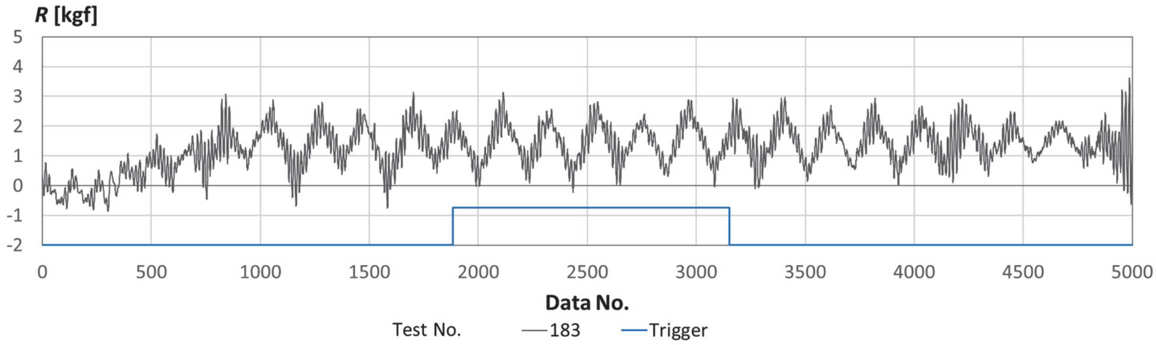


(a) Longitudinal forces acted on a ship model.

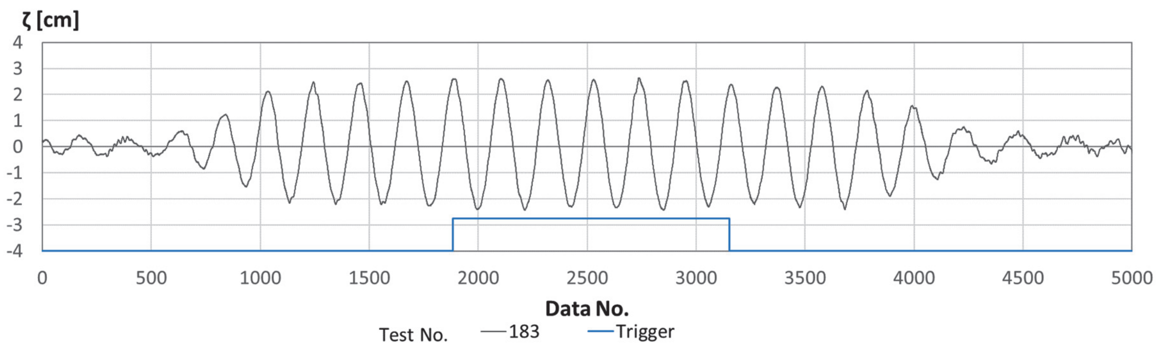


(b) Wave height

Fig. 9 Time series of measured data by the conventional measurement system (λ/L_{ps} = 0.4, Head waves).



(a) Longitudinal forces acted on a ship model.



(b) Wave height

Fig. 10 Time series of measured data by the conventional measurement system (λ/L_{ps} = 0.4, Oblique waves).

5. Conclusions

The automated measurement system for Actual Sea Model Basin at NMRI for the experiment of the added resistance in regular waves has been developed by the sequential system combines the towing carriage, wave generator, measurement device, recording device and analysis system. The arrangement of the system and the flow for the sequential tests are described. By the verification tests with the DTC container ship in regular waves, obtained results by the automated measurement system are found to be equivalent to those by the conventional manual system and the repeatability of results has been confirmed.

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References

1) K. Tanizawa, M. Ueno, H. Taguchi, T. Fujiwara, H. Miyazaki, H. Sawada and Y. Tsukada: The Actual Sea Model Basin, Papers of National Maritime Research Institute, Vol. 10, No. 4 (2010), pp. 343-382. (in Japanese)
2) M. Ueno, H. Miyazaki, H. Taguchi, Y. Kitagawa, Y. Tsukada: Model experiment reproducing an incident of fast ferry. Journal of Marine Science and Technology, Vol.18 No.2, (2013), pp.192-202.
3) M. Ikehata, N. Nagamatsu, K. Hayasaki, A. Kokumai and S. Watanabe: On System for Automatic Tank Test (SATT) of Akashi Ship Model Basin, Journal of the Kansai Society of Naval Architects, Japan, Vol. 155 (1974), pp. 133-149 (in Japanese)
4) A. Yazaki, T. Sagae, Y. Tsukino, S. Hoshino, H. Sumiyoshi, H. Kiyono and T. Sakai: Computer aided tank test systems if the Shipbuilding Research Center of Japan, Journal of the Society of Naval Architects of Japan, Vol 131 (1972), pp. 43-52. (in Japanese)
5) H. Shimoda, H. Kawashima, Y. Ichinose and M. Tsujimoto: Advanced Tank Testing Technology, Papers of National Maritime Research Institute, Vo. 20, No. 4 (2020). (in Japanese)
6) T. Hamada and K. Hoshino: Replacement of the towing carriage driving system of 400m towing tank with AC motor and introduction of automatic tank test system, Proceeding of the research society of the ship performance in actual seas, pw74-9.
7) O. Moctar, V. Shigunov and T. Zorn: Duisburg Test Case: Post-Panamax Container Ship for Benchmarking, Ship Technology Research, Vol 59-3(2012), pp. 50-64.
8) M. Tsujimoto, N. Sogihara, M. Kuroda and A. Sakurada: Ship Performance Simulator in Actual Seas -VESTA-, Papers of National Maritime Research Institute, Vo. 15, No. 4 (2018). (in Japanese)
9) ITTC: ITTC Recommended Procedures and Guidelines 7.8-02 07-02.1 (2017).