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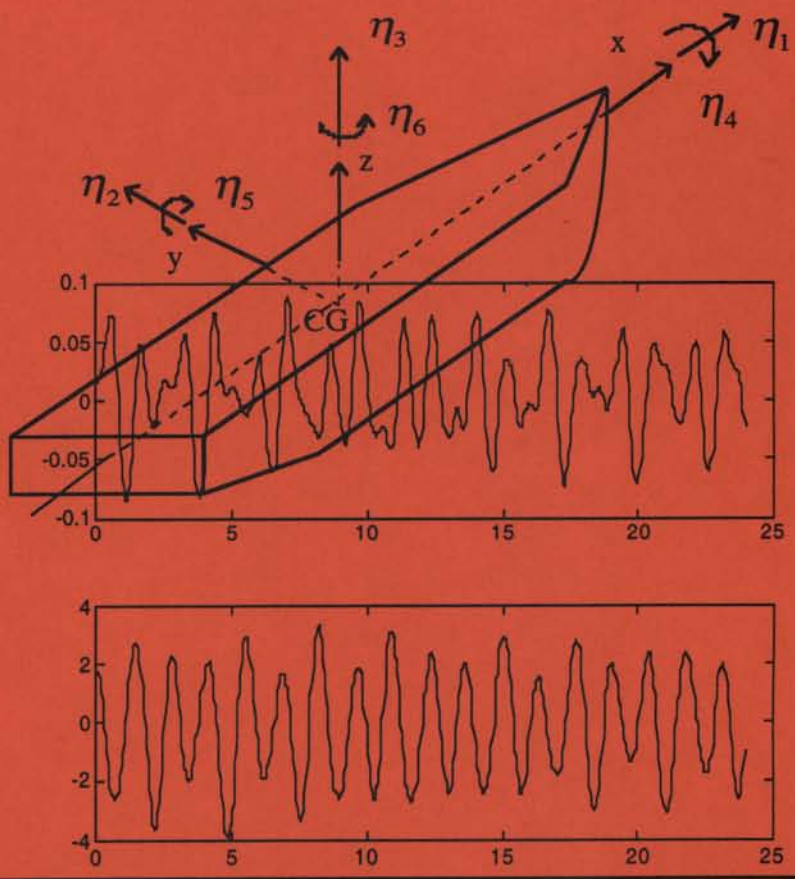
Model Seakeeping Experiments Presented in the Time-Domain to Facilitate Validation of Computational Tools

by

Karl Garme



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Model Seakeeping Experiments Presented in the Time-Domain to Facilitate Validation of Computational Tools

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Abstract

The purpose of *Model Seakeeping Experiments Presented in the Time-Domain to Facilitate Validation of Computational Tools* has been to put together a well-arranged bank of model measurements, useful as a reference material in the validation procedure of real-time simulation models.

The work reports on seakeeping experiments on a model of an 11300 tonne ro-ro vessel. All information is at hand: hull geometry, model condition, test set-up, procedures and time series of the measured quantities.

The time series, together with the hull geometry, is stored on CD-ROM. The printed part of the work reports on the test set-up, procedures and post-processing, and gives a catalogue with overall data on each test. Experiments were performed in regular, irregular and short-crested waves at two speeds, corresponding to five and 15 knots, with relative heading varied around the clock. The wave systems were modelled by regular waves with amplitude corresponding to one-three metre and of irregular waves with significant wave height of five metre. For each test, the waves are described by an analytical expression. Those wave equations describing the wave elevation in time and space, can be used as sea environment when comparing the measurements with time-domain simulations.

The recorded data are from measurements of wave elevation, global and local motion, velocity and acceleration. Each of the 110 tests are described by time series recorded from 18 measurement channels.

Thanks to the generality of the tests and the accessibility of hull geometry and time series, the work should be useful not only as reference in cases of validation, but also to illustrate the dynamic behaviour of ships in the education of naval architects.

Contents

Introduction

Motion modelling in the time domain has, thanks to decreased computer cost, become an accessible approach for studying ship behaviour. Often, it is advantageous to study the actual wave-hull interaction, and not just its effect on the motion in statistical terms. However, mathematical models need to be verified by experiments that are well defined in time and space with respect to ship motions and wave elevation.

This report and the adherent time series, on the model test of an 11300 tonne ro-ro vessel, is meant as a tool to verify mathematical time domain models describing ship motions in waves. The time series reflect on a number of issues in ship hydrodynamics, such as loss of stability in quartering waves, roll motion in head sea and situations of linear and non-linear motion. This make the time series not only useful in verification but also in the education of naval architects where traditionally the time domain is omitted when ship motion is discussed. In the time domain, important dynamic aspects can be studied, such as phase shift between different degrees of freedom, stability problems in waves, and wave crest propagation along the ship versus ship motion.

To enable a comparison with real-time simulation models, the experiments were made in simple, mathematically describable seas:

- regular waves - relative wave direction varied around the clock, two speeds
- irregular waves - relative wave direction varied around the clock, two speeds
- short-crested seas - relative wave direction: bow and quartering, two speeds
- regular waves - following and quartering; tests to create roll resonance phenomena

The test material consists of 110 tests where model behaviour and waves are represented by the time series from 18 measurement channels. Characteristic data of the time series from each of the tests, is collected in a catalogue together with reference to the CD-ROM where all time series are stored. The report introduces a method to create an analytical wave equation based on measured data. Such an equation can be used as wave model to real-time simulation codes. In the catalogue, a wave equation is given for each test.

To give a complete picture of the model test, the report opens with a description of the experiment, a discussion on the measurement signals and wave equation, followed by the test catalogue.

1 Experimental equipment and procedures

1.1 Ship model –geometry and condition

The model is a 1:35 scale model of a 135 m, 11300 tonne ro-ro vessel. It is self-propelled by two propellers. Model heading is controlled by means of two rudders joined together and moved by a servo engine. The propeller and rudder arrangements and the model bow section are shown in figure 1.1.

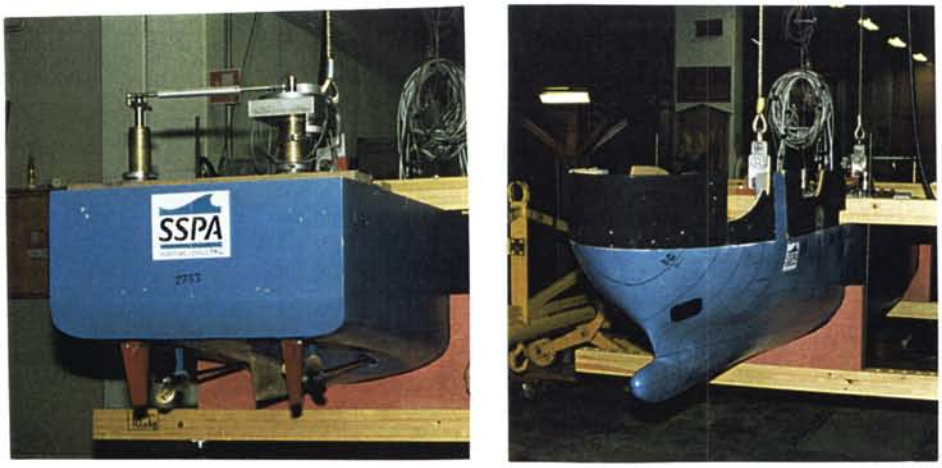


Figure 1.1. Propeller and rudder arrangements, and model bow.

The model condition, i.e. main particulars, floating condition, dynamic properties and basin characteristics, are shown in table 1.1. This condition is valid for all tests except test #130-#134 where the model had a heel angle of approximately 3° to facilitate parametric excitation in roll, (section 3.5).

Table 1.1. Main particulars of the model and test condition

		Comment:
Scale factor	35	
Displacement	263 kg	Measured
Lpp	3.86 m	
Beam in waterline	0.69 m	
Draught	0.157 m	
Block coefficient	0.628	
LCG	-0.105 m	Origin at L/2, positive direction forward
VCG	0.349 m	Distance above keel
KM	0.393 m	
GM	0.044 m	Calculated from heel tests, see section 1.4.
Radius of inertia, roll	0.298 m	Calculated from decay test, see section 1.4.
Radius of inertia, pitch	1.069 m	Assumed equal to the yaw radius of inertia.
Radius of inertia, yaw	1.069 m	Calculated by the method of bifilar suspension.
Natural period, roll	2.75 s	Calculated from decay test, see section 1.4.
Trim at zero speed	0°	Model at even keel
Heel	0° and 3°	3° in test #130-#134
Water depth in test basin	2.55 m	Measured
Water temperature	16.5° C	Measured

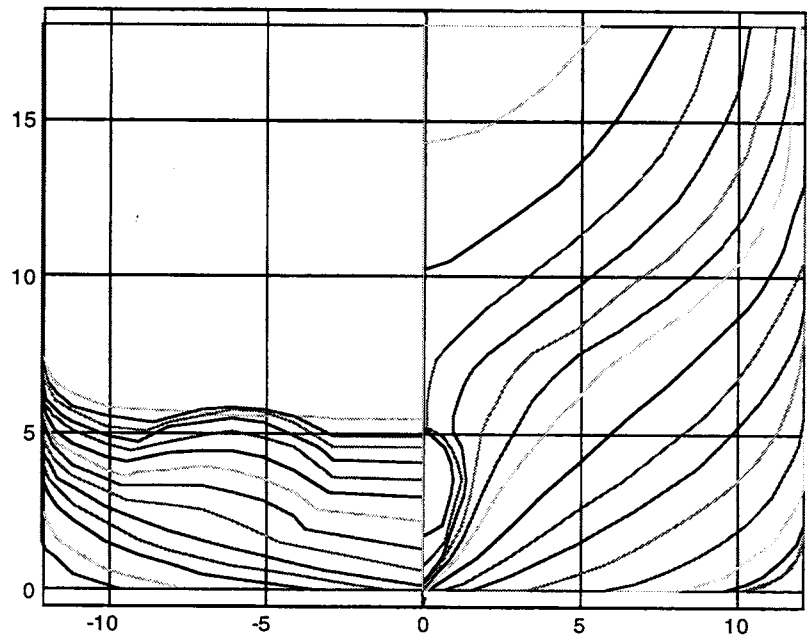


Figure 1.2. Body plan of the full-scale ro-ro vessel.

The coordinates defining the hull geometry are stored on the CD-ROM, file *HullGeometry*. The geometry file consists of 31 equidistant frames. Frame number one is located 3.75 m aft of the after perpendicular. The origin of the coordinate system in which the hull geometry is expressed is located where the keel line and the after perpendicular coincide, (figure 1.3).

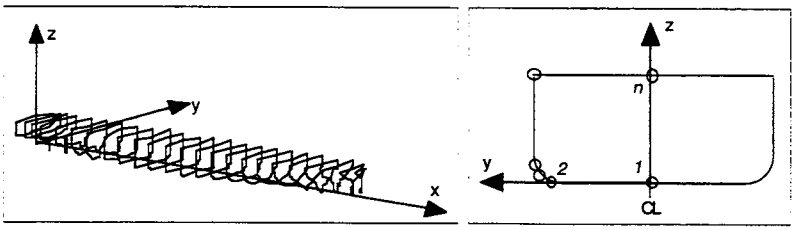


Figure 1.3. The coordinate system in which the hull geometry is defined.

The system is a right-hand system with positive x-direction towards the bow, positive y-direction portwise and consequently positive z-direction, upwards. This coordinate system could be translated to the model fix xyz-system defined in figure 1.7 (section 1.3), by the longitudinal and vertical distance between the origins of the two systems.

The hull geometry file is a text-file which lists the hull sections, number one being the stern section and number 31 the foremost. The structure of the file is shown below with the extract from the file reproduced in italics. The points defining the frames follow the hull clockwise, starting at the lowest point at centreline and ending at top centreline, see figure 1.3. Thus, the hull sections are given as the port half.

**KTHRoRoModel*	ship "name"
135	length between perpendiculars
31	number of frames
1	frame number 1
-3.375	x position of frame number 1
13	number of points defining frame number 1
0 5.4	point no. 1, y coordinate and z coordinate separated by a space
2.9 5.4	point no. 2, " " " " " "
3.6 5.5	.
6.1 5.5	.
7.6 5.6	.
9.1 5.7	.
10.1 5.8	.
11.1 6.2	.
11.7 6.5	.
12 7.0	.
12.1 7.5	.
12.1 18	.
0 18	point no. 13
2	frame number 2
0	x position of frame number 2
14	number of points defining frame number 2
0 4.9	point no. 1, y coordinate and z coordinate separated by a space
2.8 4.9	.
4.1 5.5	.
.	.
.	.

.	.
31	frame number 31
141.75	x position of frame number 31
10	number of points defining frame number 31
0 14.3	point no. 1, y coordinate and z coordinate separated by a space
0.4 14.35	.
0.8 14.4	.
1.8 14.7	.
2.4 15	.
3.1 15.5	.
3.9 16.2	.
4.7 17	.
5.6 18	.
0 18	point no. 10

Each line ends with a "return "-sign.

The hull geometry file is a text-file created in Macintosh environment. The file can easily be transformed to PC-format, for instance through opening it in a text editor for the Power Macintosh and save to disk on a suitable PC-format.

1.2 Test set-up

The principal test set-up is shown in figure 1.4. The size of the basin at the SSPA Maritime Dynamics Laboratory, is 88x40 metre. The water depth during the experiments was 2.55 metre. The basin is equipped with two single-flap wavemakers.

Signal communication with the model was provided for by cables between the model and a carriage above the model following its motion.

The self-propelled model, free to move in all six degrees of freedom, was connected to the carriage by a jointed light-weight arm recording the motion. The arm is assumed not to have any influence on the model motions. By means of this arm, the translations and rotations of the model, relative to a fixed point on the carriage, were measured. This information together with knowledge of the global position, x, y and ψ, of the carriage was used to determine the global quantities of the model: position, course angle and velocity, as well as model motion.

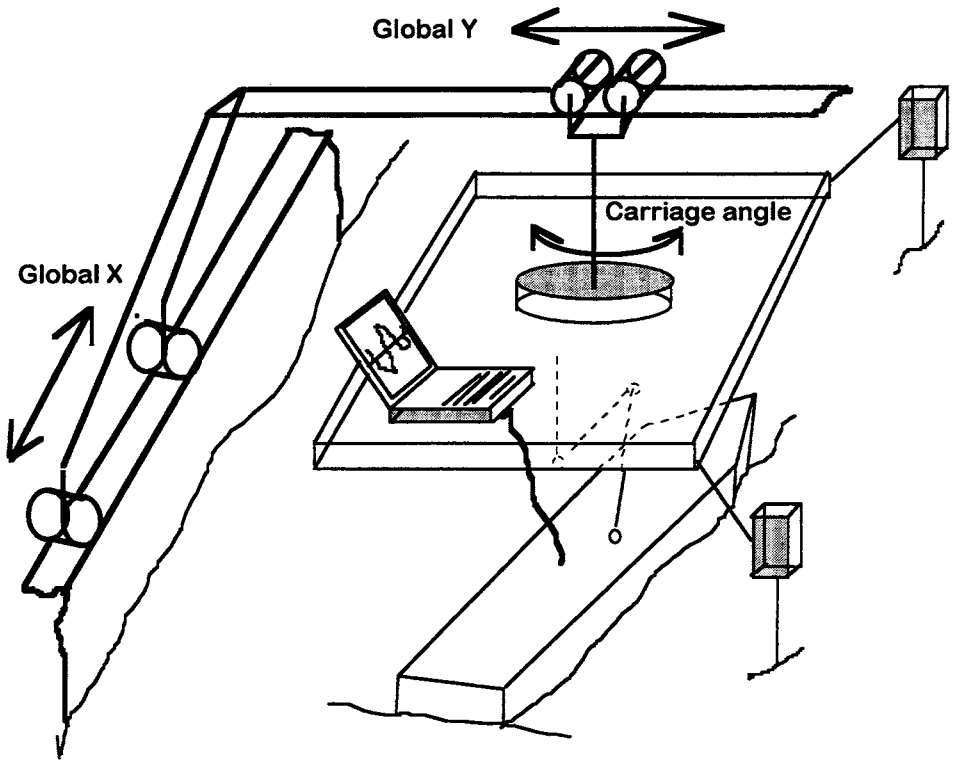


Figure 1.4. Schematic sketch of the test set-up.

The motion control system of the carriage uses the displacements of the arm in the horizontal plane as feedback information to keep the carriage above the model, i.e. minimising the measuring arm deflection. Consequently, the model motions controlled by engines and rudders dictate the path of the carriage and the model motions are in no way influenced by the carriage.

Data was acquired by two independent measurement systems: the standard stationary system at the SSPA Maritime Dynamics Laboratory, and a portable system developed at the Division of Naval Architecture, KTH, (Rinder 1995). Both systems recorded the wave height gauges and an analogue reference signal dropping from 2 to 0 volts as the model was released and the stationary system began to measure. Model motion quantities were measured by both the systems through independent gauges. Global position and motion were recorded by the

stationary system. The motion measuring unit in the portable system was a Seatex MRU-6. This unit processes measurements and delivers digital signals. Besides digital information, four analogue signals can be read from the gauge. The wave elevation was measured by means of two Denshi Co Ltd., VC-502. For gauge performance, see appendix 1.

The portable measurement system stored digital signals as 25 Hz sampled time series. Analogue signals were sampled with 50 Hz. All signals measured by the stationary system were stored with 25 Hz sample frequency.

The position of the MRU-6, the point where the measuring arm was attached to the model and the points where the wave height meters were attached to the carriage are given by table 1.2. The reference point *carriage zero* in table 1.2 is a fixed point of the carriage. When the model is at even keel with no heel and the deflection of the measuring arm is zero in the direction parallel to global x and y, then *carriage zero* will lie on a vertical axis through the centreline of the model at L/2.

Table 1.2. Motion gauges and wave height meter position.

Gauge	Reference/origin	x [m]	y [m]	z [m]	
MRU	CG	0.633	0	0.141	at all tests
Measuring arm	CL at L/2	----------	----------	----------	at all tests
Wave height meter 1	carriage zero	2.215	-2.360	----------	at all tests
Wave height meter 2	carriage zero	-2.310	-2.225	----------	at test 21-84
Wave height meter 2	carriage zero	2.295	2.233	----------	at test 86-120
Wave height meter 2	carriage zero	-2.310	-2.228	----------	at test 121-134

The positions of the wave height meters have been chosen to minimise disturbance from wave systems induced by the model motion. The wave height meter position and relative wave direction are sketched in figure 1.5.

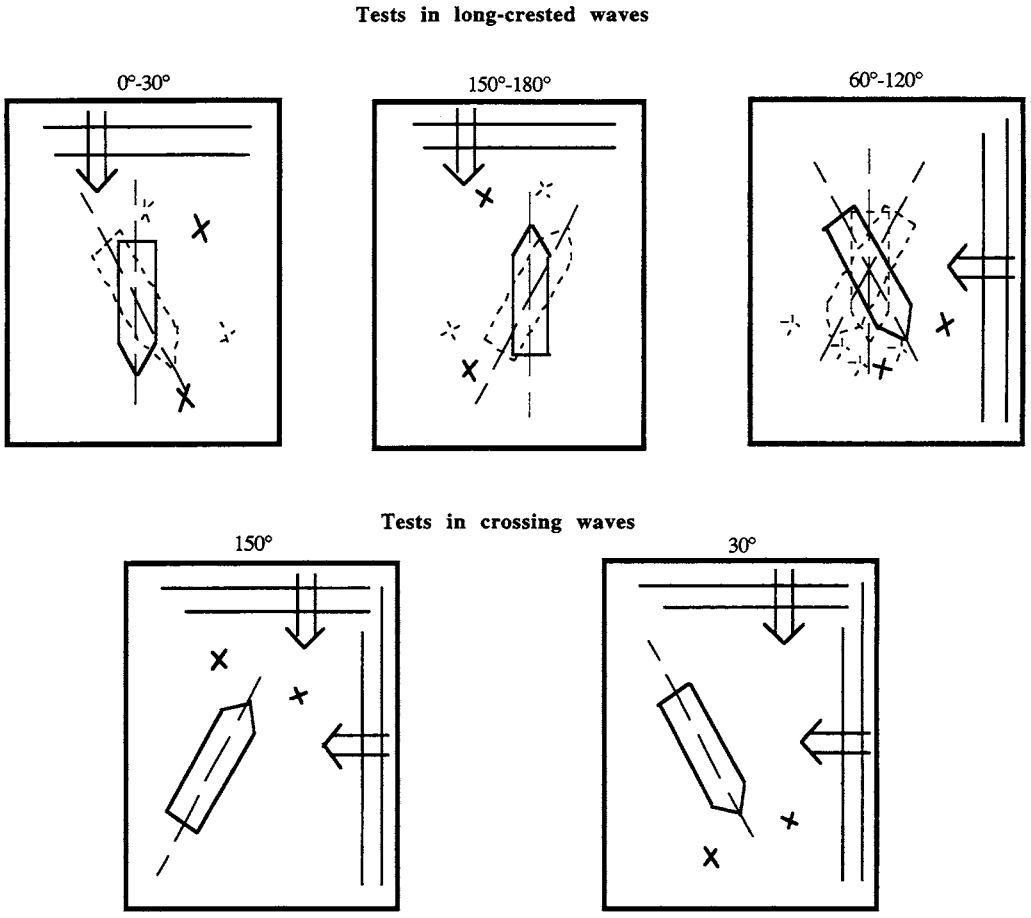


Figure 1.5. Wave height meter position and wave generator used for tests with different relative wave direction.

1.3 Coordinate systems

Three coordinate systems are used as reference for the motion measurements. A basin-fixed reference frame, (figure 1.6), is used to describe global position and motion. Model motions are described by the differences, in six degrees of freedom, between a coordinate system following the mean position of the model and a model-fixed coordinate system, (figure 1.7).

The basin-fixed coordinate system defines global position, that is position of the centre of gravity of the model vessel, the centre of the carriage following the model, the position of wave

height meters and the wave surface. The origin of the coordinate system is the basin mid-point. Positive direction of angle, ψ, is clockwise. In figure 1.6 the rudder angle, δ, is defined as positive toward port.

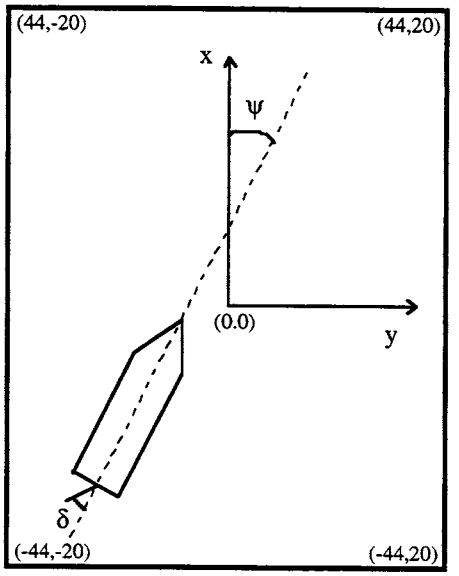


Figure 1.6 Global reference frame.

The model motions are defined as the deviations , η_1 - η_6, from the xyz-coordinate system with the origin in the mean position of the centre of gravity. The xyz-system is a right-hand system with the x-axis positive in the mean direction of the model heading, y-axis positive in the mean port direction and z-axis positive upwards.

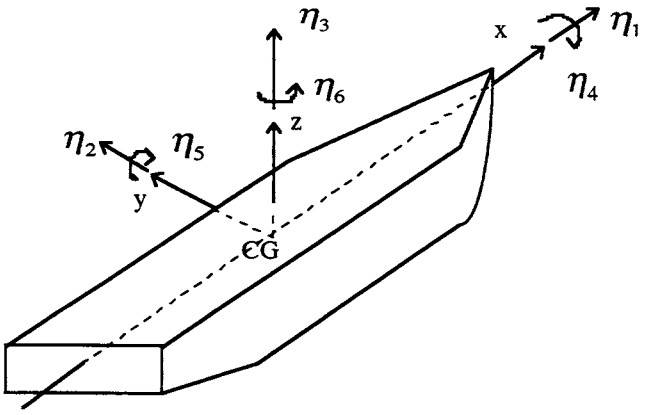


Figure 1.7. Coordinate systems used for describing model motions.

The three translatory degrees of freedom are: η_1 -surge, η_2 -sway, η_3 -heave and the rotational degrees of freedom are: η_4 -roll, η_5 -pitch, η_6 -yaw, (figure 1.7).

Wave direction relative to the model is defined by the angle, β, in figure 1.8. In long-crested waves, consequently, β=180° corresponds to head sea, β=90° to waves in athwartships and β=0° to following waves. From this, the frequency of encounter can be derived, resulting in the expression

$$\omega_e = \omega - \frac{V \cdot \omega^2}{g} \cos\beta \qquad (1.1)$$

where ω is the wave frequency, V the model forward velocity and g the acceleration of gravity.

For the tests where the waves are composed of wave systems propagating from two directions (90° displaced), the model course is defined according to figure 1.8b). Head wave direction could of course be chosen as either of the two but is, in the presentation of the tests in point, chosen to be the global x-direction, (section 3.4).

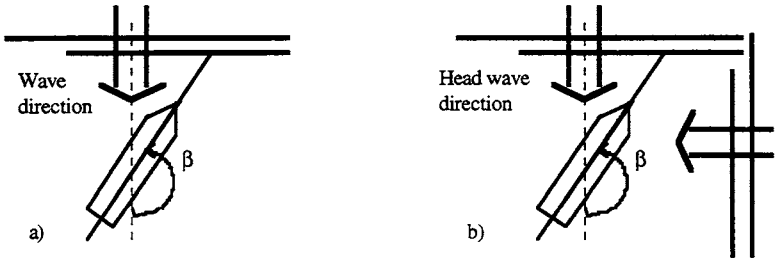


Figure 1.8. a) and b) β defining model course in long-crested and short-crested (crossing) waves respectively.

1.4 Calibration procedures, decay and inclining test

The wave height meters were tested over the measurement domain. The vertical position of the carriage, to which the gauges were attached, was varied and the wave height gauges measured the distance to the water surface. The results are shown in figure 1.9. The line referred to as *exact distance* has an accuracy of ± 0.5 mm. For details about the wave height meter calibration, with measurements made by both the stationary and portable measurement system, consult appendix 2.

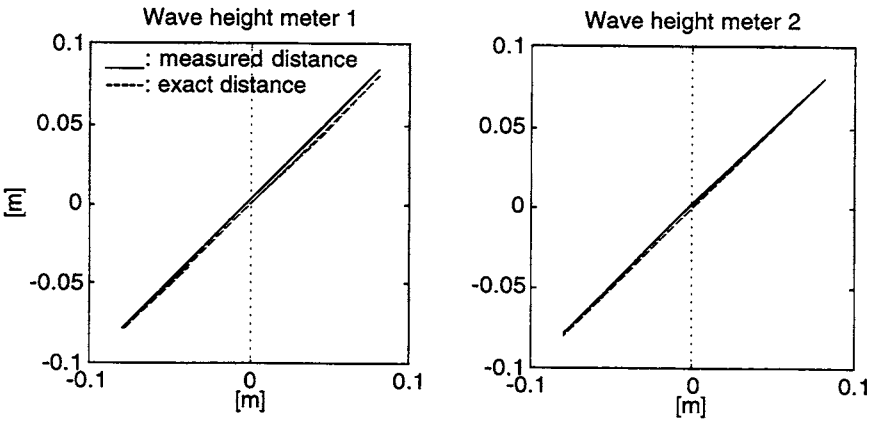


Figure 1.9. Calibration of wave height gauge, portable measurement system.

As a daily routine, one reference measurement was made after starting the systems and waiting for the equipment to become warm; warming-up is important, at least concerning the MRU-6. The reference was: calm water, free model with zero speed. This daily routine gave no indication of systematic errors or fluctuation in system performance. The result from the reference measurement is shown in appendix 2.

Irregular waves were modelled by a simplified P-M spectrum characterised by five-metre significant wave height and a significant period of nine seconds. The characteristics correspond to 0.143 meter and 1.52 seconds in model scale. This spectrum was modelled by three wave components:

$$\zeta_1 = 0.020 \cdot \sin(2.07 \cdot t)$$
$$\zeta_2 = 0.037 \cdot \sin(3.25 \cdot t)$$
$$\zeta_3 = 0.027 \cdot \sin(4.44 \cdot t)$$

Reference measurements of the irregular wave system were performed by generating the wave spectrum by one wave maker at a time. In each case the time series were measured and the significant values determined from the spectrum, (table 1.3). The significant wave height $H_{1/3}$ is calculated as four times the standard deviation of the corresponding time series. T is the average wave period.

Table 1.3. Wave spectrum reference measurement.

Wave maker	Measure time	Min	Mean	Max.	$H_{1/3}$	T
short side	60.8 s	-0.085 m	0.000 m	0.081 m	0.140 m	2.07 s
long side	60.3 s	-0.081 m	0.000 m	0.084 m	0.147 m	1.93 s

The accuracy of the quantities measured by the SSPA stationary measurement system are ±0.5 mm for translatory model motion, ±0.2° for model rotation, ±1 mm for global position and ±0.1° for angle of the carriage. The quantities measured with the portable system i.e. the MRU-6 signals are accurate to ±0.3° for rotation, ±0.3°/s for rotation velocity and ±0.01m/s² for linear acceleration. For details on the MRU-6, see appendix 1.

1.4.1 Preparatory tests and measurements

The model was weighed and its yaw radius of gyration determined by the method of bifilar suspension. The water depth and water temperature were noted.

An inclining test were performed to establish the metacentric height. A 2.5 kg weight was moved from the centre-line to 0.12 meter to starboard and port respectively. The results are shown in table 1.4.

The measured heel angles result in: GM=0.044 m.

Table 1.4. Results from heel test.

Measuring system	Weight displ. y=-0.12	Weight displ. y=0.12
Portable	1.50°	-1.46°
Stationary	1.51°	-1.46°

A roll decay test was performed; the time series is shown in figure 1.10. The test is stored on the CD-ROM as file: *RollDecay*. From the measurement, the neutral frequency in roll is determined to 2.75 s.

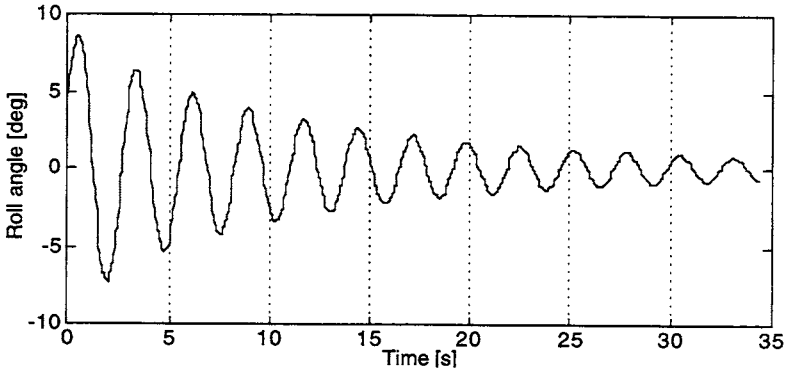


Figure 1.10. Time series of roll decay test.

All model characteristics are summarised in table 1.1, section 1.1.

2 Evaluation and presentation of measurements

The time series of the quantities measured with the two different systems have been synchronised and transformed to the coordinate systems defined in section 1.3. In the synchronisation process it became clear that the measurements made by the stationary and portable system are in remarkably good agreement. Occasional, the time series contained dummy values, i.e, extreme unphysical peak values during one sample. Sequences of time series with dummy values have been removed.

In section 2.2 the measured signals are presented in a table where each signal is referred to valid coordinate system, unit, post-processing and position in the measurement matrix stored on the CD-ROM.

For each test, an equation describing the wave system has been calculated. The idea with such an equation is to obtain an analytical expression possible to use as sea input to real-time simulations of the experiments. The principle on which the equation is based, is discussed in section 2.3. The coefficients used in the equations given for each test in the test catalogue in section 3 are not necessarily the optimal choice. The reader can easily perform the calculation on the time series if a better representation of the waves is preferred. All necessary information is given in section 2.3 and by the time series.

2.1 Synchronisation of signals

Measurement data were collected from three sources: the stationary system, digital output from the MRU-6, and digital signals from the A/D-converter having analogue MRU-6 signals and analogue wave height meter signals as input. Those three sources were between each other displaced in time.

Thanks to the common signals, a measurement-start-indicating signal and the two wave height meter signals, the time difference between the stationary system and the A/D-converter input of the portable system could be found. The displacement in time between the digital MRU-6 input and the A/D-converter input of the portable system was determined by utilising the roll and pitch signals, registered from the digital and the analogue output of the MRU-6.

The synchronisation is correct to the level of half a sample, corresponding to 20 ms, which is of the order of magnitude of a twenty-fifth of a typical model motion period.

Figure 2.1 shows an example of the compared signals when synchronisation has been performed. This example is representative to all test files stored on the CD-ROM.

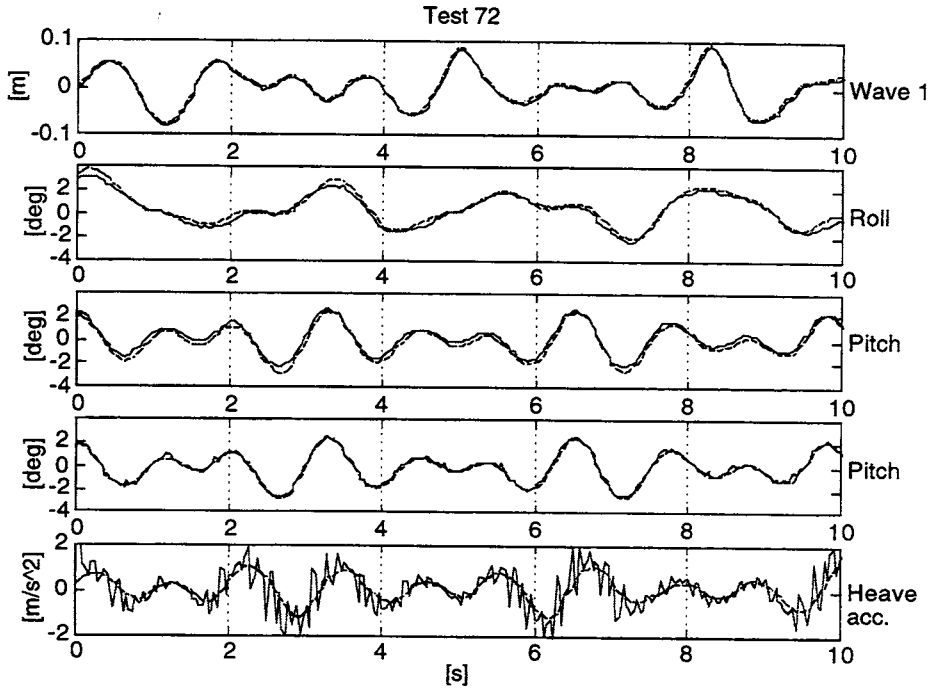


Figure 2.1. The figure is an example of a plot made for all tests to illustrate that the synchronisation has been successful. In all graphs except the fourth, signals from the stationary system are represented by a dotted line. The first graph from above shows the signal from wave height meter 1 collected by the stationary and portable system respectively. In the second and third graph, roll and pitch signals are shown, measured by the stationary system as deflection of the measurement arm and by the portable system as digital MRU-6 signal. The fourth graph shows analogue and digital MRU-6 pitch signals collected at different input ports by the portable system. The last graph shows the heave acceleration signal from the MRU-6 and the heave signal from the stationary system, twice differentiated.

2.2 Signals representing model motion and waves

The measurements are presented on the CD-ROM as one binary file per test. The files are named KTHTest** (** indicating a test number).
A test file contain a **x19 matrix (** indicating total number of samples) in which each column represent a measured channel. The columns are defined in table 2.1.

Table 2.1. Measured quantities, their units and frame of reference, post processing and reference to column in measurement matrix stored on file.

Column	Quantity	Post processing
1	TIME [s]	
2	WAVE 1 [m] positive upwards	Stored as a 25 Hz time series, orig. 50 Hz. Divided by 100 to dim [m]
3	WAVE 2 [m] positive upwards	Stored as a 25 Hz time series, orig. 50 Hz. Divided by 100 to dim [m]
	Model data	
4	Global x-position [m] x coordinate defined in fig. 1.6	measurement-0.105 cos(heading]
5	Global y-position [m] y coordinate defined in fig. 1.6	measurement-0.105 sin(heading]
6	Heading [deg] Ψ coordinate defined in fig. 1.6	Correcting to coordinate system by: 180° or 270°-measurement depending on which wave maker that were used.
7	Forward Velocity [m/s] in x direction defined in fig. 1.7	Stored as 25 Hz time series, originally 5 Hz
8	Surge Acceleration [m/s^2] in η_1 direction defined in fig. 1.7	
9	Port Velocity [m/s] in y direction defined in fig. 1.7	Stored as 25 Hz time series, originally 5 Hz, sign changed
10	Sway Acceleration [m/s^2] in η_2 direction defined in fig. 1.7	sign changed
11	Heave* [m] η_3 coordinate defined in fig. 1.7	* Vertical displacement of a point at (0.105,0,0) sign changed
12	Heave Acceleration [m/s^2] in η_3 direction defined in fig. 1.7	sign changed

13	Roll [deg] η_4 coordinate defined in fig. 1.7	
14	Pitch [deg] η_5 coordinate defined in fig. 1.7	sign changed
15	Yaw Velocity [deg/s] in η_6 direction defined in fig. 1.7	sign changed
	Carriage data	
16	Carriage Angle [1] Ψ coordinate defined in fig. 1.6	From measurements of model pos. and displacements of the measure arm.
17	Carriage-x [m] x coordinate defined in fig. 1.6	
18	Carriage-y [m] y coordinate defined in fig. 1.6	
	Model data	
19	Rudder Angle [deg] δ coordinate defined in fig. 1.6	

All measurements are stored as 25 Hz sampled time series. Table 2.1 indicates any post-processing of the original signal, besides time synchronisation.

The global x- and y-position has been transformed to the model-fixed coordinate system. To make a minimum of changes to the original signals the heave signal, channel 11, corresponds to vertical motion of a point in the centre-line 0.105 m fore of the centre of gravity. Equation 2.1 transforms channel 11 to the xyz-system defined in figure 1.7.

$$\eta_3 = \mathrm{M}(:,11) - 0.105 \cdot \mathrm{M}(:,14) \cdot \frac{\pi}{180} \qquad (2.1)$$

where M(:,11) and M(:,14) refers to the measurement matrix column 11 and 14, representing heave and pitch motion respectively (MATLAB notification).

The heading and carriage angles are, as an effect of their definition (section 1.3), discontinuous at ± 180°. This is noticeable in some of the tests in head sea.

The signals describing the carriage motion are of interest since the wave height meters are rigidly attached to the carriage. Thus, this information is necessary when evaluating the wave system.

2.3 Wave equation

To carry out time domain simulation the wave elevation, relative to the model in time and space, has to be known. The idea with a wave equation, is to give an analytical expression describing the modelled waves, that could be used as input to time domain simulation of the model motion.

The modelled wave systems were: regular long-crested waves, irregular long-crested waves built up by wave components of three different frequencies and short-crested waves created by letting two long-crested systems coincide at right angles. The crossing waves were either a regular wave meeting a three-component irregular system or two three-component irregular systems. The frequencies were chosen in the domain of roll, pitch and heave resonance.

The vertical position of the water surface is assumed to be describable by a series of cosine and sine functions. One-directional long-crested waves propagating in negative global x-direction is described by equation 2.2 and, crossing waves by equation 2.3.

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x) \qquad (2.2)$$

$$\begin{aligned}\zeta(x,y,t) = &\sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x) \\ &+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)\end{aligned} \qquad (2.3)$$

The variables x, y and t refer to global position and time, the constants ω and k are frequency and corresponding wave number and constants a, b, c and d controls wave component amplitude.

The amplitude coefficients, a ,b, c and d, are determined by means of the wave height measurement. An equation for each sample of a test can be formulated. Considering a complete test, we obtain an over-determined system of equations with the coefficients a and b or a, b, c and d as the unknown variables. The coefficients can be determined as the solution to a least squares problem.

This procedure gives the wave elevation at all points of the basin at all instances. Due to the least squares method being a linear method, it is likely to believe that the accuracy of the wave equation is better close to the wave height meter than far away from it, but since the model

always is in the vicinity of the point of measurement the wave equation can be used to describe the environment of model action.

The calculation procedure is very simple. The signals of carriage global position and angle, together with the knowledge of the wave height meter position relative to the *carriage zero* (defined in section 1.3), enables us to determine global position of the wave height meter as a time series. This calculation is performed by the expression:

$$\begin{pmatrix} \text{Wavex} \\ \text{Wavey} \end{pmatrix} = \begin{pmatrix} x + xW \cdot \cos\psi - yW \cdot \sin\psi \\ y + xW \cdot \sin\psi + yW \cdot \cos\psi \end{pmatrix} \qquad (2.4)$$

where x, y and ψ refers to carriage -x, -y and carriage angle, see table 2.1. xW and yW is the coordinates of the wave height meter, see table 1.2.

When the global wave height meter position is determined the wave elevation at a certain position at a certain time instant is known, thus ζ, x, y and t are known for every sample of the test. What is left, to be able to construct the over-determined system of equations, is to choose frequencies, ω, and the corresponding wave numbers, k.

The approach is to choose the same frequencies as are input to the wavemakers. Each wave system contains one, or a combination of, the wave frequencies: 2.07, 3.25 and 4.44 rad/s. The waves actually created in the basin are not this exact with respect to frequency. Frequency variation can of course be the effect of the accuracy of the wave maker but is also an effect of the waves not being fully linear. To capture small frequency variations, wave components with frequencies $\omega \pm d\omega$ are added. In case of regular waves this results in three frequencies modelling the wave system. In irregular waves the number of frequencies has to be chosen for each test individually. To many frequencies gives an inadequate least squares solution. In each case regular, irregular or crossing seas the measured signal should be compared to the one calculated by the equation to determine whether the solution is adequate or not.

Wave numbers are determined for each frequency, taking the basin depth into account, according to the linear potential solution of water waves, (equation 2.4).

$$k = \frac{\omega^2}{g \tanh(kh)} \qquad (2.4)$$

where ω is the frequency, g the acceleration of gravity, k the wave number and h the basin depth equal to 2.55 m.

All information to the over-determined system of equations is now determined. Multiply both sides from the right with the transpose of the system matrix and solve the quadratic system for the unknown amplitude parameters a and b or a, b, c and d.

An important question is how big part of the wave height measurement to use in the wave equation calculation. If the wave system is strongly dispersiv, unstable in frequency, it could be advantageous to cut the measurement in sequences and to determine one wave equation to each sequence. On the other hand for complicated wave systems, irregular waves or crossing wave systems, a rather long time series is necessary, for the system of equations to catch the pattern of the wave elevation.

2.3.1 Examples of wave equations

• Regular long-crested waves

The regular wave system of test 23 is calculated with equation 2.2 and the coefficients in table 2.2. The wave height meter signal and the corresponding calculated one is shown in figure 2.2.

Table 2.2. Wave equation coefficients for test 23.

n	1	2	3
a	-0.0068	0.0138	0.0320
b	-0.0118	0.0208	0.0397
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

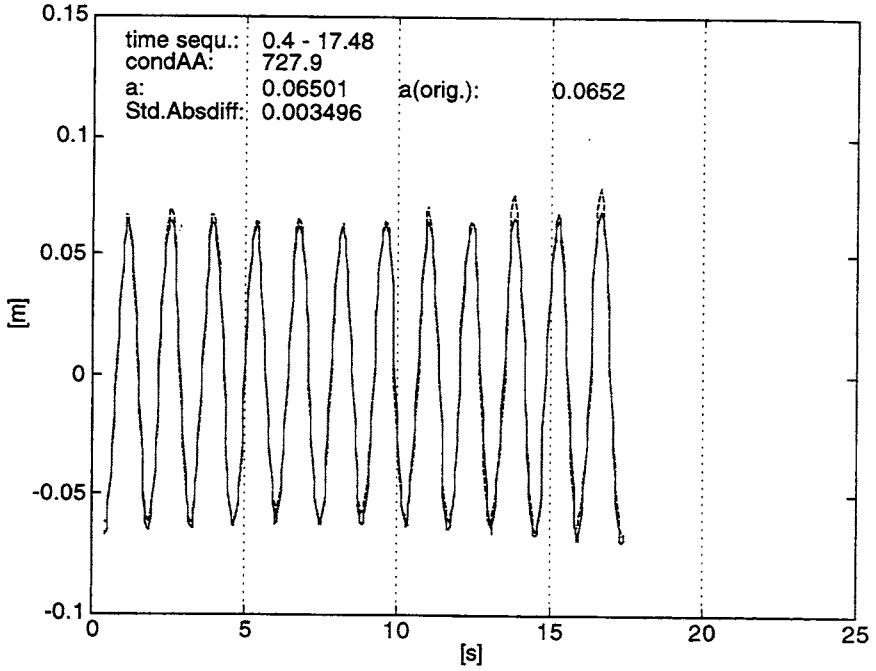


Figure 2.2. Comparison of measured and calculated signal. The original measured signal is drawn with a dotted line.

• Irregular long-crested waves

Table 2.3 gives the coefficients used by equation 2.2 to calculate the irregular waves in test 66. The wave height meter signal and the corresponding calculated one is shown in figure 2.3. Figure 2.4 shows a part of the water surface, at one time instant, calculated with the wave equation.

Table 2.3. Wave equation coefficients for test 66.

n	1	2	3	4	5	6	7	8	9
a	-0.0025	-0.0166	0.0052	0.0048	-0.0414	-0.0017	0.0051	0.0054	0.0010
b	-0.0067	0.0242	-0.0010	0.0016	-0.0108	0.0008	0.0004	-0.0250	-0.0031
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

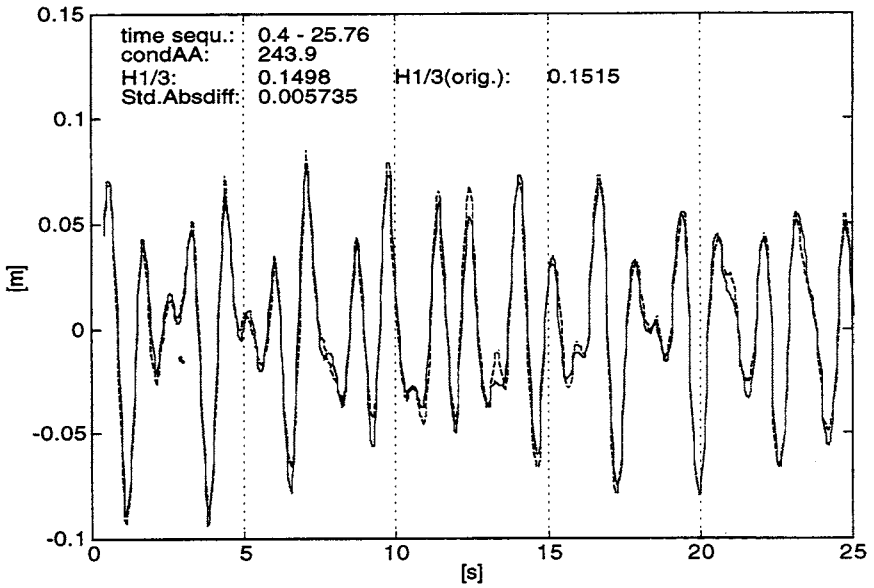


Figure 2.3. Comparison of measured and calculated signal. The original measured signal is drawn with a dotted line.

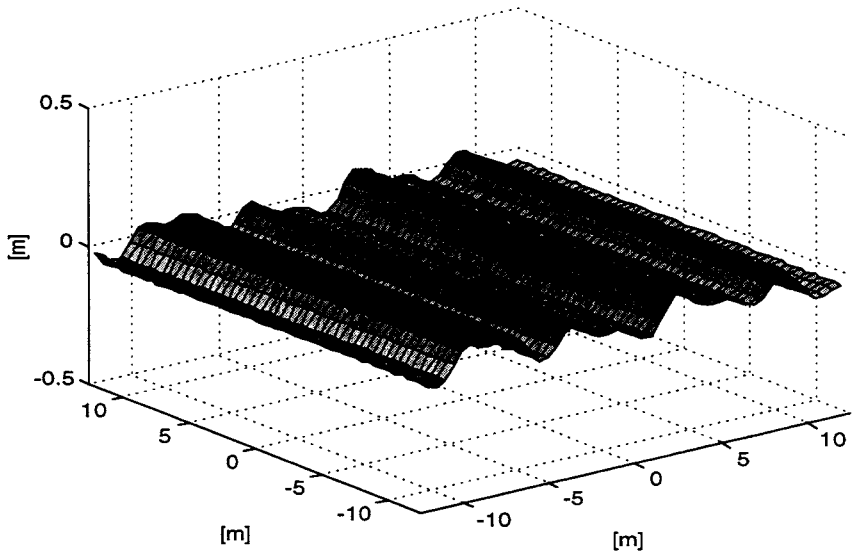


Figure 2.4. Example of the water surface elevation at one time instant of test 66, calculated with nine frequencies modelling the three-component spectrum.

• Two directional seas

A wave system, built-up by a regular wave meeting a three-component wave system at right angles, is defined by equation 2.3 with the coefficients in table 2.4. The wave height meter signal and the corresponding calculated one, is shown in figure 2.5. In figure 2.6 a part of the water surface at one time instant is plotted.

Table 2.4. Wave equation coefficients for test 90.

n/m	1	2	3/1	4/2	5	6	7
a	0.0147	0.0104	-0.0018	-0.0005	-0.0038	-0.0038	-0.0009
b	-0.0103	-0.0068	0.0194	0.0002	0.0020	-0.0216	0.0012
c			0.0104	-0.0069			
d			0.0026	-0.0412			
ω	2.0700	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.5077	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

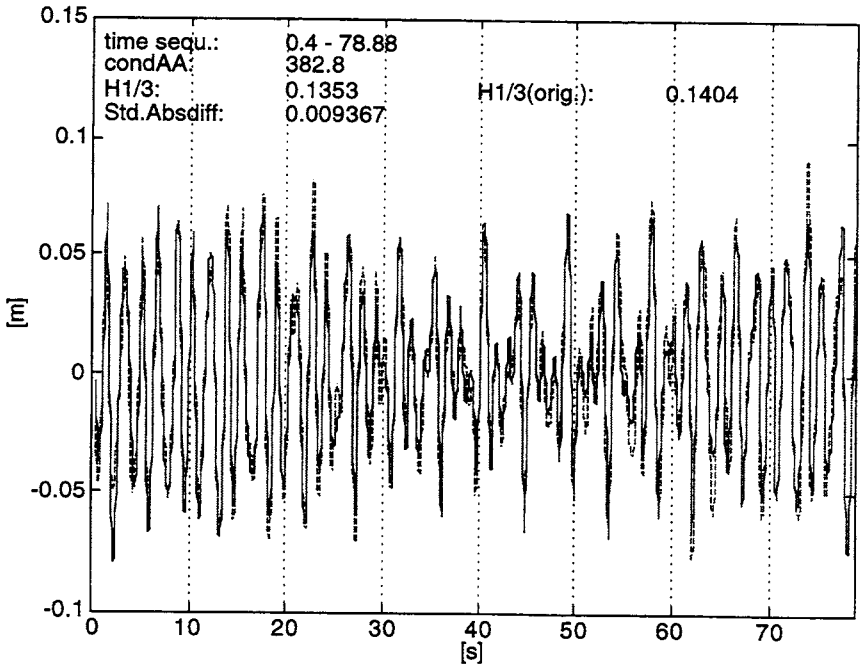


Figure 2.5. Comparison of measured and calculated signal, original signal dotted.

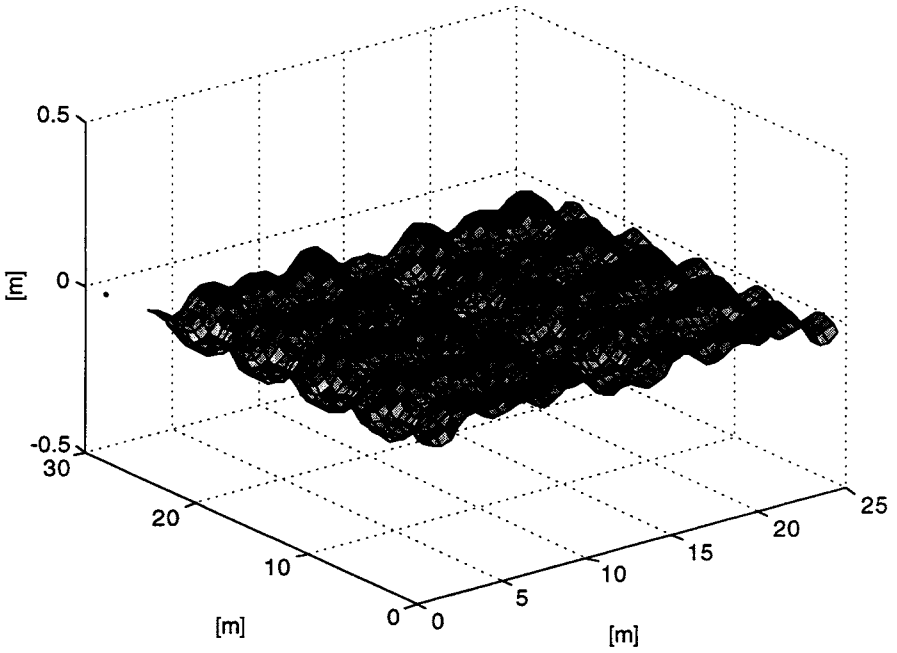


Figure 2.6. Example of the water surface elevation at one time instant of test 90, calculated with equation 2.3 with seven frequencies modelling the three-component spectrum and two frequencies modelling the crossing regular wave.

The last example on a calculated wave elevation, is of a wave pattern created of two crossing three-component wave systems. Table 2.5 gives the coefficients related to equation 2.3. The wave height meter signal and the corresponding calculated one together with an instant picture of the water surface is plotted in figure 2.7.

Table 2.5. Wave equation coefficients for test 112.

n/m	1	2	3	4	5	6
a	0.0209	0.0036	-0.0313	0.0018	0.0156	-0.0005
b	0.0033	0.0103	0.0227	0.0033	-0.0024	0.0003
c	0.0149	-0.0042	-0.0115	-0.0068	-0.0176	-0.0019
d	0.0112	0.0006	0.0320	-0.0012	0.0319	-0.0009
ω	2.0700	3.2000	3.2500	3.3000	4.4400	4.4900
k	0.5077	1.0536	1.0852	1.1175	2.0097	2.0552

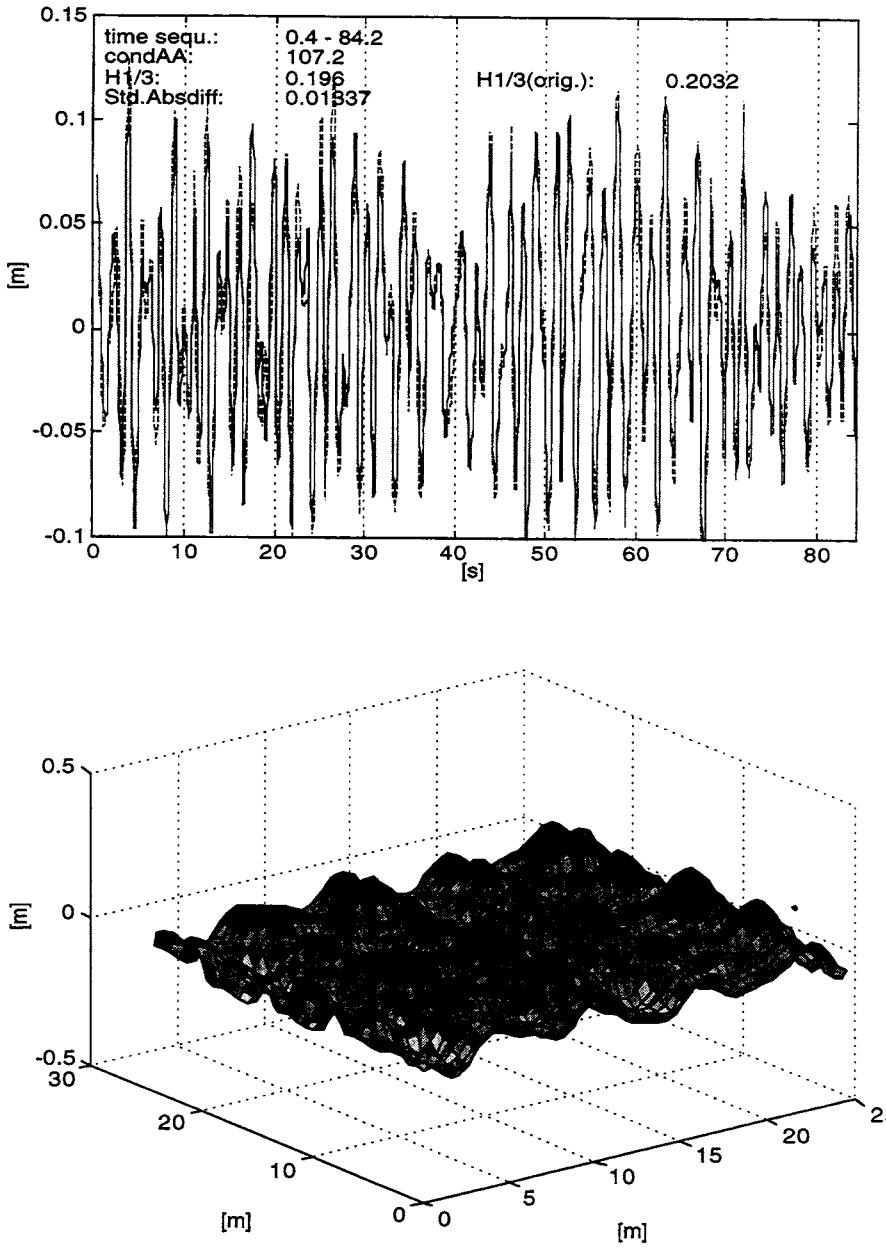


Figure 2.7. Upper graph: comparison of measured and calculated signal, measured signal dotted. Lower graph: example of the water surface elevation at one time instant, calculated with equation 2.3 with six frequencies modelling each of the two crossing three-component wave systems.

3 Test-catalogue: overall results and references to data files

This set of experimental data consists of 56 tests in regular long-crested waves, 21 tests in long-crested irregular waves and 34 tests in seas of crossing wave systems. Each of the tests are stored on files named: *KTHTest* followed by a number.

The test matrices, with measurement signals as columns, see section 2.2, are saved as binary files by means of the program MATLAB (The Math Works inc.) in Macintosh environment. The binary format is memory efficient and can be opened by other programs than MATLAB and in other environments than the Macintosh.

The first two signs of a KTHTest-file are integers, 16-bits, giving the size, number of rows and columns, of the measurement matrix. After the two integers follow the measurement matrix as floating point values, 16-bits.

The test files can be read by the following MATLAB function:

```
%--- Open and read a KTHTest** binary file
% --- Output: filename
%           m- number of samples (rows of measurement matrix M)
%           n- number of channels (columns of M)
%           M- measurement matrix
function[filename,m,n,M]=OpenKTHTestfile()
[filename, path]=uigetfile('', 'Choose KTHTest file:');
fname=[path, filename];
theFID=fopen(fname,'r');

%           --- Reads data
[m,count]=fread(theFID,[1,1],'long');
[n,count]=fread(theFID,[1,1],'long');
[M,count]=fread(theFID,[m,n],'float');

%           --- Close file
status=fclose(theFID);
```

3.1 Introduction to the catalogue

Although all measurements are saved to file, overall information about the tests still is considered valuable to have in print. Hopefully the following sections will be helpful to the user of this test material.

The tests are grouped as follow:

- Tests in regular waves -section 3.2
- Tests in irregular waves -section 3.3
- Tests in crossing waves -section 3.4
- Tests in following regular waves -section 3.5

The reason to separate the first and fourth group, both being tests in regular waves, is the general character of the first, whereas the tests in following waves are performed to excite phenomena related to the roll eigenfrequency of the model. Tests in the first group are performed at two speeds and with relative course angle varied around the clock with an increment of 30°. The tests in irregular waves are, like the first group, made at two model speeds and at the same course angles as in regular waves with the exception of the 60° case. This condition was excluded to keep the time schedule in the laboratory. In group three, seas are combined by regular waves meeting a three-component irregular wave system at right angles or two irregular systems meeting at right angles. The model velocity was as for group one and two but course angle, relative to the defined head wave direction, was limited to bow-sea, 150°, and quartering seas, 30°.

The following sections, (3.2-3.5), are arranged as a catalogue with overall data corresponding to each test. The sections, grouped above, are divided into sub-sections, (see contents). The first page of each sub-section describes the test situation with respect to model speed, heading and the wave environment. Speed and heading are given as mean-, minimum-, maximum value and standard deviation. The wave system is characterised by frequency and amplitude in case of regular waves and significant wave height when irregular waves are modelled. Amplitude is calculated as the square root of two, times the standard deviation of the wave height measurement, and significant wave height as four times the standard deviation of the wave height measurement. For the tests in regular waves these statistical data are supplemented by transfer functions showing heave, pitch and roll response of the measurements relative to strip calculations. The strip calculations are made with the code MacSkepps (KTH, div. Naval Architecture). The MacSkepps code is based on the strip-theory formulated by Salvesen, Tuck & Faltinsen (1970).

The page summarising the tests of each group, gives a picture of how well the model managed to keep speed and course in the present seas and, for regular waves, how close to linear theory model motions were. After the summarising page each individual test is presented on one page each. Each model run is described by a wave equation and by statistical data for each of the measurement channels. The wave equation is given as an analytical expression with matching coefficients collected in a table next to the equation. As a measure on the agreement of the measured wave elevation and the elevation obtained by the equation, is wave amplitude or significant wave height, depending on type of wave system. The standard deviation of the difference between the measured time series and the calculated one is also given, intended as a measure on the quality of the wave equation. The coefficients for use in the wave equation has been calculated with data from the wave height meter judged the least influenced by model created waves.

Information on the 18 measure channels are given, like the data on the summarising page, as mean-, minimum- and maximum value. The given value of deviation is based on standard deviation of the measured time series. The four expressions below are used in the catalogue.

- $4 \cdot$std -used as definition of significant double amplitude
- $2 \cdot$std - used as definition of significant amplitude
- $\sqrt{2} \cdot$std - used as definition of amplitude
- std - used when non of the above are considered adequate

The statistical data given in the catalogue are calculated by means of standard MATLAB functions, used on the time series with the first and last 10 samples removed. Consequently the values will of course differ if a smaller part of the time series is considered.

Note that channel six, model heading, and channel 16 carriage angle are, through their definition, discontinuous at 180° and π respectively, i.e. in head sea.

3.2 Tests in regular waves

3.2.1 Heading 180°, speed 1.3 m/s

Table 3.1. In the table, *freq.* refers to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
22	1.32	0.83	1.71	0.090	-179.5	-180.0	-179.2	0.15	2.07	0.060
23	1.02	0.93	1.17	0.060	-179.4	-179.6	-179.1	0.12	3.25	0.065
24	1.36	1.25	1.47	0.052	-179.4	-179.8	-179.1	0.14	3.25	0.058
25	1.34	1.27	1.41	0.047	-179.1	-179.9	-178.4	0.41	4.44	0.082
26	1.37	1.29	1.41	0.035	-157.3	-180.0	180.0	85.91	4.44	0.062
27	1.32	1.25	1.38	0.034	-179.4	-179.7	-179.2	0.14	2.07	0.030
28	1.37	1.30	1.44	0.032	-179.4	-179.7	-179.2	0.12	3.25	0.031
29	1.31	1.27	1.37	0.025	-179.4	-179.7	-179.2	0.10	3.25	0.029
30	1.36	1.33	1.37	0.012	-179.5	-180.0	-179.2	0.24	4.44	0.028
31	1.33	1.15	1.51	0.106	-179.5	-179.8	-179.2	0.12	2.07	0.095
32	0.91	0.74	1.09	0.092	-167.1	-180.0	180.0	65.78	3.25	0.082
33	1.41	1.28	1.54	0.069	-179.6	-179.9	-179.3	0.17	3.25	0.085
34	1.33	1.24	1.45	0.065	-108.1	-180.0	180.0	143.0	4.44	0.095

Note the discontinuous heading signal in test 26, 32 and 34.

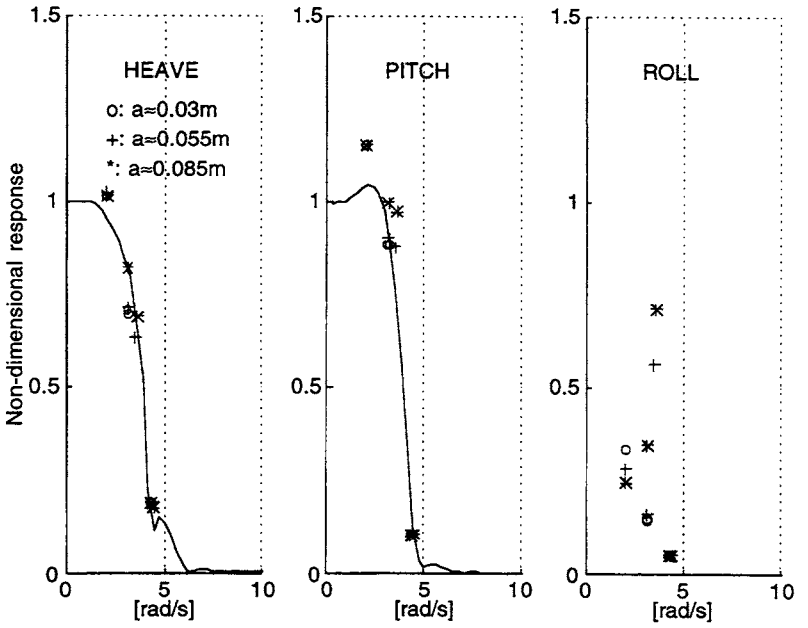
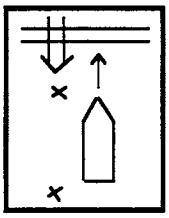


Figure 3.1. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970). Note the non-linear roll response.

Test no 22



The 29.4 seconds measurement is stored on file: *KTHTest22.*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0164	-0.0437	-0.0104
b	0.0139	-0.0583	-0.0009
ω	2.0200	2.0700	2.1200
k	0.4903	0.5077	0.5256

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0599	0.0589	0.0072

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.060	0.073	0.059	
Wave2	-0.001	-0.063	0.072	0.054	

	mean	min	max	std	comment
Heading	-179.461	-179.970	-179.200	0.155	
Forward vel.	1.322	0.827	1.712	0.090	
Surge acc.	-0.032	-0.381	0.312	0.212	
Port vel.	-0.005	-0.016	0.007	0.005	
Sway acc.	0.000	-0.056	0.065	0.021	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.075	0.064	0.060	
Heave acc.	0.034	-0.486	0.542	0.412	

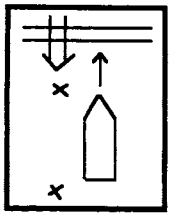
	mean	min	max	sqrt(2)*std	comment
Roll	0.074	-0.669	0.782	0.482	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.076	-2.191	2.345	1.975	

	mean	min	max	std	comment
Yaw vel.	-0.023	-0.359	0.337	0.163	

	mean	min	max	std	comment
Rudder angle	-0.012	-0.590	0.548	0.240	

Test no 23



The 26.2 seconds measurement is stored on file: *KTHTest23*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0068	0.0138	0.0320
b	-0.0118	0.0208	0.0397
ω.	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0652	0.0650	0.0035

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.066	0.079	0.065	
Wave2	-0.001	-0.079	0.092	0.077	

	mean	min	max	std	comment
Heading	-179.414	-179.650	-179.080	0.123	
Forward vel.	1.025	0.926	1.170	0.060	
Surge acc.	-0.026	-0.522	0.429	0.306	
Port vel.	-0.006	-0.022	0.021	0.008	
Sway acc.	-0.002	-0.102	0.077	0.031	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.001	-0.045	0.044	0.041	
Heave acc.	0.039	-0.618	0.650	0.550	

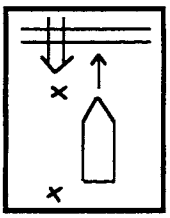
	mean	min	max	sqrt(2)*std	comment
Roll	-0.076	-4.158	4.034	2.291	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.016	-3.892	3.701	3.521	

	mean	min	max	std	comment
Yaw vel.	0.017	-1.305	0.965	0.361	

	mean	min	max	std	comment
Rudder angle	-0.102	-1.097	0.485	0.353	

Test no 24



The 31.0 seconds measurement is stored on file: *KTHTest 24*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0058	-0.0074	0.0105
b	-0.0041	0.0109	0.0507
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0584	0.0582	0.0033

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.059	0.070	0.057	
Wave2	-0.004	-0.069	0.067	0.056	

	mean	min	max	std	comment
Heading	-179.424	-179.810	-179.100	0.141	
Forward vel.	1.357	1.255	1.469	0.052	
Surge acc.	-0.036	-0.476	0.338	0.248	
Port vel.	-0.005	-0.016	0.007	0.004	
Sway acc.	0.002	-0.049	0.062	0.018	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.003	-0.048	0.043	0.041	
Heave acc.	0.033	-0.768	0.752	0.696	

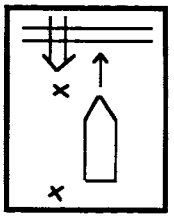
	mean	min	max	sqrt(2)*std	comment
Roll	-0.077	-0.803	0.990	0.574	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.169	-3.795	3.352	3.213	

	mean	min	max	std	comment
Yaw vel.	0.003	-0.574	0.618	0.237	

	mean	min	max	std	comment
Rudder angle	-0.027	-0.991	0.675	0.307	

Test no 25



The 23.8 seconds measurement is stored on file: *KTHTest24*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based. on signal from wave height meter no. 1

n	1	2	3
a	-0.0051	0.0170	0.0029
b	0.0012	-0.0393	-0.0448
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0825	0.0820	0.0061

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.081	0.098	0.076	
Wave2	-0.001	-0.110	0.151	0.104	

	mean	min	max	std	comment
Heading	-179.068	-179.910	-178.420	0.410	
Forward vel.	1.340	1.273	1.407	0.047	
Surge acc.	-0.032	-0.245	0.091	0.082	
Port vel.	-0.004	-0.028	0.024	0.016	
Sway acc.	-0.004	-0.120	0.091	0.039	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.022	0.017	0.015	
Heave acc.	0.040	-1.197	1.134	0.899	

	mean	min	max	sqrt(2)*std	comment
Roll	0.020	-0.644	0.812	0.431	

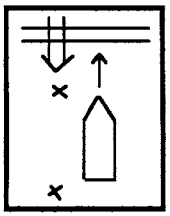
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.126	-1.462	0.916	0.893	

	mean	min	max	std	comment
Yaw vel.	-0.041	-1.184	0.915	0.417	

	mean	min	max	std	comment
Rudder angle	-0.396	-2.151	1.560	0.657	

Test no 26

The 26.6 seconds measurement is stored on file: *KTHTest26*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0066	-0.0149	0.0134
b	-0.0009	0.0137	0.0517
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0625	0.0622	0.0040

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.064	0.076	0.058	
Wave2	-0.001	-0.096	0.109	0.077	

	mean	min	max	std	comment
Heading	-157.330	-179.980	179.990	85.912	discontin.
Forward vel.	1.366	1.293	1.412	0.035	
Surge acc.	-0.037	-0.193	0.075	0.062	
Port vel.	-0.004	-0.022	0.014	0.011	
Sway acc.	-0.002	-0.089	0.060	0.029	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.019	0.013	0.011	
Heave acc.	0.045	-0.989	0.896	0.699	

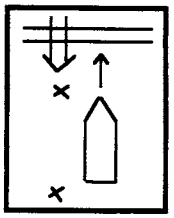
	mean	min	max	sqrt(2)*std	comment
Roll	0.004	-0.603	0.454	0.345	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.066	-1.076	0.827	0.663	

	mean	min	max	std	comment
Yaw vel.	-0.043	-0.802	0.660	0.314	

	mean	min	max	std	comment
Rudder angle	-0.190	-1.476	1.581	0.577	

Test no 27



The 31.0 seconds measurement is stored on file: *KTHTest27*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0089	-0.0329	-0.0015
b	-0.0024	-0.0124	-0.0013
ω	2.0200	2.0700	2.1200
k	0.4903	0.5077	0.5256

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0297	0.0293	0.0036

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.031	0.038	0.029	
Wave2	-0.001	-0.034	0.031	0.026	

	mean	min	max	std	comment
Heading	-179.400	-179.740	-179.170	0.143	
Forward vel.	1.315	1.252	1.377	0.034	
Surge acc.	-0.038	-0.228	0.149	0.106	
Port vel.	-0.003	-0.015	0.004	0.004	
Sway acc.	-0.004	-0.036	0.032	0.013	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.040	0.028	0.030	
Heave acc.	0.037	-0.198	0.269	0.200	

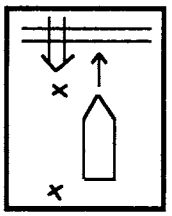
	mean	min	max	sqrt(2)*std	comment
Roll	0.117	-0.370	0.542	0.287	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.041	-1.201	1.224	0.978	

	mean	min	max	std	comment
Yaw vel.	-0.015	-0.298	0.300	0.107	

	mean	min	max	std	comment
Rudder angle	-0.044	-0.401	0.359	0.171	

Test no 28



The 33.4 seconds measurement is stored on file: *KTHTest28*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0063	-0.0156	0.0313
b	-0.0011	-0.0046	0.0270
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0309	0.0308	0.0018

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.033	0.037	0.030	
Wave2	-0.002	-0.032	0.026	0.016	

	mean	min	max	std	comment
Heading	-179.403	-179.680	-179.210	0.115	
Forward vel.	1.371	1.298	1.439	0.032	
Surge acc.	-0.030	-0.268	0.158	0.123	
Port vel.	-0.003	-0.010	0.005	0.004	
Sway acc.	-0.003	-0.029	0.029	0.011	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.029	0.020	0.021	
Heave acc.	0.045	-0.417	0.441	0.374	

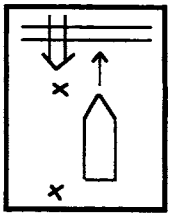
	mean	min	max	sqrt(2)*std	comment
Roll	0.047	-0.378	0.435	0.269	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.030	-2.059	1.808	1.653	

	mean	min	max	std	comment
Yaw vel.	-0.012	-0.442	0.438	0.171	

	mean	min	max	std	comment
Rudder angle	-0.054	-0.675	0.506	0.217	

Test no 29



The 34.2 seconds measurement is stored on file: *KTHTest29*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0012	-0.0053	0.0318
b	-0.0030	0.0046	-0.0111
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0294	0.0293	0.0019

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.030	0.036	0.029	
Wave2	-0.003	-0.034	0.025	0.024	

	mean	min	max	std	comment
Heading	-179.425	-179.680	-179.240	0.104	
Forward vel.	1.315	1.268	1.367	0.025	
Surge acc.	-0.032	-0.270	0.163	0.122	
Port vel.	-0.003	-0.011	0.006	0.003	
Sway acc.	-0.003	-0.030	0.024	0.010	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.028	0.018	0.020	
Heave acc.	0.043	-0.370	0.409	0.333	

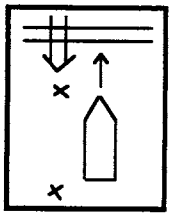
	mean	min	max	sqrt(2)*std	comment
Roll	0.045	-0.270	0.524	0.269	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.022	-1.956	1.759	1.586	

	mean	min	max	std	comment
Yaw vel.	-0.001	-0.380	0.349	0.150	

	mean	min	max	std	comment
Rudder angle	-0.032	-0.527	0.527	0.192	

Test no 30



The 31.4 seconds measurement is stored on file: *KTHTest30*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0047	-0.0116	0.0288
b	-0.0013	0.0019	0.0192
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0282	0.0281	0.0016

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.033	0.036	0.029	
Wave2	-0.002	-0.039	0.033	0.028	

	mean	min	max	std	comment
Heading	-179.530	-179.960	-179.240	0.237	
Forward vel.	1.356	1.333	1.374	0.012	
Surge acc.	-0.034	-0.111	0.050	0.035	
Port vel.	-0.002	-0.014	0.009	0.006	
Sway acc.	0.001	-0.032	0.036	0.013	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.006	-0.014	0.004	0.006	
Heave acc.	0.041	-0.471	0.494	0.341	

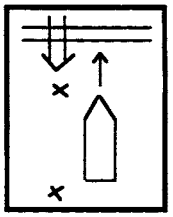
	mean	min	max	sqrt(2)*std	comment
Roll	0.042	-0.237	0.366	0.161	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.047	-0.416	0.615	0.361	

	mean	min	max	std	comment
Yaw vel.	-0.005	-0.406	0.454	0.153	

	mean	min	max	std	comment
Rudder angle	-0.052	-0.738	0.717	0.305	

Test no 31



The 18.2 seconds measurement is stored on file: *KTHTest31*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	0.0187	0.0256	
b	0.0713	0.0127	
ω	2.0700	2.1200	
k	0.5077	0.5256	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0946	0.0935	0.0080

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.099	0.112	0.093	
Wave2	-0.002	-0.101	0.113	0.087	

	mean	min	max	std	comment
Heading	-179.460	-179.810	-179.250	0.121	
Forward vel.	1.331	1.151	1.506	0.106	
Surge acc.	-0.063	-0.557	0.475	0.338	
Port vel.	-0.005	-0.019	0.009	0.007	
Sway acc.	0.004	-0.052	0.065	0.030	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.104	0.102	0.096	
Heave acc.	0.039	-0.817	0.772	0.653	

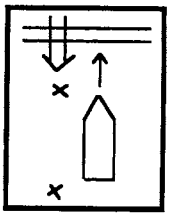
	mean	min	max	sqrt(2)*std	comment
Roll	0.103	-0.921	1.167	0.663	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.149	-3.364	3.336	3.131	

	mean	min	max	std	comment
Yaw vel.	-0.003	-0.593	0.399	0.226	

	mean	min	max	std	comment
Rudder angle	-0.139	-0.570	0.401	0.244	

Test no 32



The 14.2 seconds measurement is stored on file: *KTHTest32*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	-0.0076	0.0888	
b	0.0048	-0.0020	
ω	3.2500	3.3000	
k	1.0852	1.1475	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0825	0.0822	0.0040

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.080	0.094	0.083	
Wave2	0.002	-0.099	0.122	0.099	

	mean	min	max	std	comment
Heading	-167.098	-180.000	179.990	65.776	discontin.
Forward vel.	0.911	0.743	1.091	0.092	
Surge acc.	-0.024	-0.695	0.604	0.448	
Port vel.	-0.012	-0.039	0.024	0.013	
Sway acc.	-0.004	-0.208	0.156	0.058	

	mean	min	max	sqrt(2)*std	comment
Heave	0.001	-0.056	0.062	0.057	
Heave acc.	0.057	-0.843	0.794	0.707	

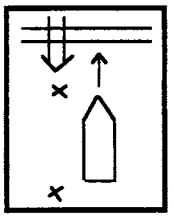
	mean	min	max	sqrt(2)*std	comment
Roll	-0.234	-5.419	5.761	3.742	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.123	-5.399	5.124	5.101	

	mean	min	max	std	comment
Yaw vel.	0.056	-1.701	1.824	0.725	

	mean	min	max	std	comment
Rudder angle	-0.094	-1.077	0.739	0.412	

Test no 33



The 21.4 seconds measurement is stored on file: *KTHTest33*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0147	-0.0173	-0.0768
b	0.0015	-0.0037	0.0246
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0851	0.0847	0.0058

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.088	0.104	0.085	
Wave2	-0.004	-0.084	0.090	0.069	

	mean	min	max	std	comment
Heading	-179.616	-179.940	-179.260	0.166	
Forward vel.	1.406	1.280	1.537	0.069	
Surge acc.	-0.046	-0.672	0.489	0.387	
Port vel.	-0.011	-0.031	0.007	0.009	
Sway acc.	-0.003	-0.117	0.116	0.044	

	mean	min	max	sqrt(2)*std	comment
Heave	0.002	-0.071	0.077	0.070	
Heave acc.	0.034	-1.284	1.191	1.237	

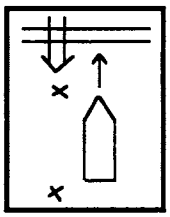
	mean	min	max	sqrt(2)*std	comment
Roll	-0.020	-2.017	2.920	1.838	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.714	-6.171	4.863	5.267	

	mean	min	max	std	comment
Yaw vel.	-0.022	-1.365	1.306	0.509	

	mean	min	max	std	comment
Rudder angle	0.012	-0.993	0.718	0.377	

Test no 34



The 25.0 seconds measurement is stored on file: *KTHTest34*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0012	0.0588	0.0360
b	0.0088	-0.0265	-0.0048
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0951	0.0945	0.0075

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.092	0.113	0.091	
Wave2	0.000	-0.118	0.157	0.120	

	mean	min	max	std	comment
Heading	-108.099	-179.990	180.000	143.054	discontin.
Forward vel.	1.333	1.241	1.446	0.065	
Surge acc.	-0.036	-0.373	0.121	0.107	
Port vel.	-0.013	-0.044	0.034	0.022	
Sway acc.	-0.001	-0.135	0.130	0.044	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.024	0.020	0.016	
Heave acc.	0.033	-1.398	1.457	1.029	

	mean	min	max	sqrt(2)*std	comment
Roll	0.091	-1.337	0.935	0.554	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.235	-2.076	0.946	1.093	

	mean	min	max	std	comment
Yaw vel.	0.028	-1.001	1.180	0.462	

	mean	min	max	std	comment
Rudder angle	-0.323	-1.817	1.162	0.757	

3.2.2 Heading 180°, speed 0.44 m/s

Table 3.2. In the table, *freq.* refers to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
35	0.43	0.27	0.60	0.085	-134.9	-180.0	180.0	118.0	2.07	0.065
36	0.45	0.35	0.55	0.066	55.6	-180.0	180.0	170.6	3.25	0.065
37	0.24	0.18	0.30	0.030	179.0	177.9	179.6	0.47	4.44	0.076
38	0.53	0.47	0.58	0.028	179.7	179.7	179.9	0.05	4.44	0.051
39	0.39	0.37	0.42	0.015	179.1	178.6	179.5	0.26	4.44	0.048

Note the discontinuous heading signal in test 35 and 36. This is due to the definition of heading, see section 1.1. Test 37-39 were interrupted due to strong roll motion, an effect of parametric excitation.

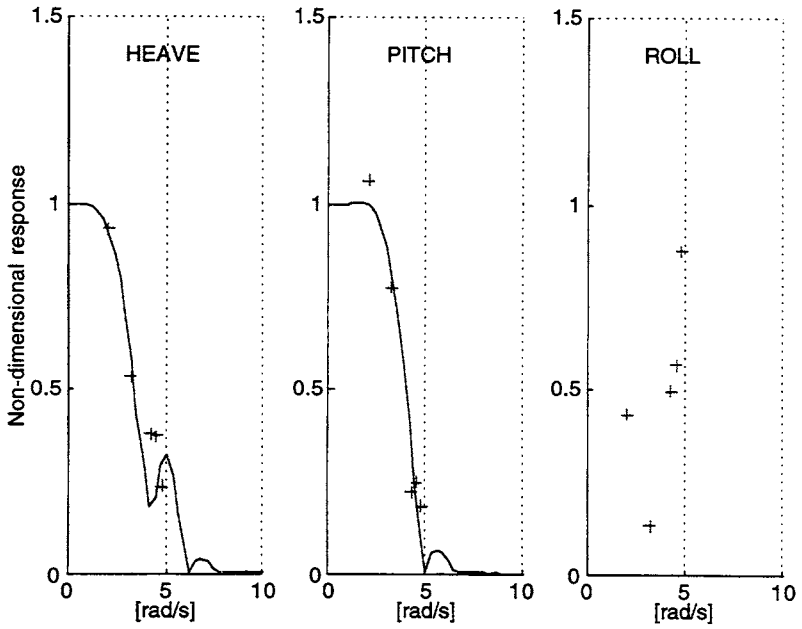
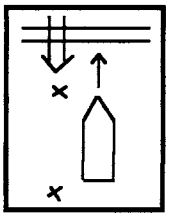


Figure 3.2. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970). Note the non-linear roll response, in test 37-39 an effect of parametric excitation.

Test no 35

The 42.2 seconds measurement is stored on file: *KTHTest35*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0046	0.0312	0.0086
b	0.0047	-0.0506	-0.0053
ω	2.0200	2.0700	2.1200
k	0.4903	0.5077	0.5256

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0647	0.0638	0.0076

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	-0.001	-0.079	0.084	0.064	
Wave2	-0.001	-0.081	0.074	0.064	

	mean	min	max	std	comment
Heading	-134.910	-180.000	179.990	118.027	discontin.
Forward vel.	0.427	0.266	0.597	0.085	
Surge acc.	0.001	-0.359	0.393	0.225	
Port vel.	-0.007	-0.020	0.008	0.006	
Sway acc.	-0.001	-0.043	0.039	0.018	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.001	-0.072	0.068	0.060	
Heave acc.	0.037	-0.345	0.417	0.289	

	mean	min	max	sqrt(2)*std	comment
Roll	0.039	-1.485	1.648	0.803	

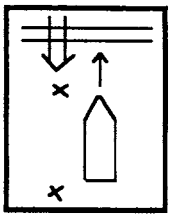
	mean	min	max	sqrt(2)*std	comment
Pitch	0.219	-2.121	2.748	1.991	

	mean	min	max	std	comment
Yaw vel.	0.020	-0.505	0.442	0.202	

	mean	min	max	std	comment
Rudder angle	-0.448	-2.366	1.394	0.892	

Test no 36

The 31.8 seconds measurement is stored on file: *KTHTest36*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0037	0.0026	-0.0478
b	0.0040	-0.0093	-0.0371
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0647	0.0645	0.0035

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.067	0.072	0.064	
Wave2	-0.002	-0.062	0.064	0.055	

	mean	min	max	std	comment
Heading	55.611	-179.990	180.000	170.629	discontin.
Forward vel.	0.450	0.354	0.550	0.066	
Surge acc.	-0.003	-0.448	0.444	0.300	
Port vel.	-0.015	-0.022	-0.004	0.004	
Sway acc.	-0.001	-0.051	0.040	0.017	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.001	-0.038	0.038	0.034	
Heave acc.	0.039	-0.422	0.340	0.323	

	mean	min	max	sqrt(2)*std	comment
Roll	0.041	-0.679	0.899	0.519	

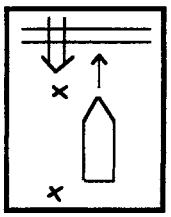
	mean	min	max	sqrt(2)*std	comment
Pitch	0.210	-2.907	3.578	3.059	

	mean	min	max	std	comment
Yaw vel.	0.063	-0.608	0.624	0.280	

	mean	min	max	std	comment
Rudder angle	0.751	-1.711	2.873	1.059	

Test no37

The 9.0 seconds measurement is stored on file: *KTHTest37*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0651		
b	0.0362		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0759	0.0745	0.0082

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.006	-0.070	0.099	0.073	
Wave2	-0.001	-0.067	0.082	0.068	

	mean	min	max	std	comment
Heading	179.026	177.930	179.610	0.474	
Forward vel.	0.239	0.181	0.298	0.030	
Surge acc.	-0.016	-0.220	0.139	0.113	
Port vel.	-0.009	-0.076	0.045	0.028	
Sway acc.	0.006	-0.207	0.243	0.074	

	mean	min	max	sqrt(2)*std	comment
Heave	0.002	-0.019	0.021	0.017	
Heave acc.	0.047	-0.507	0.748	0.549	

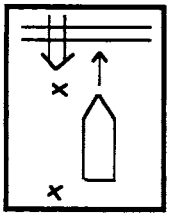
	mean	min	max	sqrt(2)*std	comment
Roll	-0.906	-14.549	10.607	7.597	par. exitation

	mean	min	max	sqrt(2)*std	comment
Pitch	0.176	-1.591	1.819	1.548	

	mean	min	max	std	comment
Yaw vel.	-0.161	-1.250	0.587	0.355	

	mean	min	max	std	comment
Rudder angle	2.015	-0.106	5.070	1.258	

Test no 38



The 13.4 seconds measurement is stored on file: *KTHTest38*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0016	-0.0676	
b	0.0315	0.0078	
ω	4.3900	4.4400	
k	1.9647	2.0097	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0514	0.0507	0.0051

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.053	0.067	0.050	
Wave2	0.002	-0.071	0.077	0.065	

	mean	min	max	std	comment
Heading	179.743	179.660	179.850	0.053	
Forward vel.	0.529	0.467	0.578	0.028	
Surge acc.	-0.015	-0.156	0.120	0.081	
Port vel.	-0.009	-0.043	0.009	0.013	
Sway acc.	-0.000	-0.114	0.089	0.035	

	mean	min	max	sqrt(2)*std	comment
Heave	0.001	-0.019	0.020	0.019	
Heave acc.	0.026	-0.651	0.819	0.682	

	mean	min	max	sqrt(2)*std	comment
Roll	0.059	-4.265	4.860	2.867	par. exitation

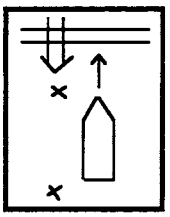
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.019	-1.414	1.287	1.268	

	mean	min	max	std	comment
Yaw vel.	0.003	-0.339	0.358	0.159	

	mean	min	max	std	comment
Rudder angle	0.749	-0.317	1.500	0.372	

Test no 39

The 11.0 seconds measurement is stored on file: *KTHTest39*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0262	0.0921	
b	-0.0370	0.0068	
ω	4.3900	4.4400	
k	1.9647	2.0097	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0483	0.0480	0.0039

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.050	0.055	0.049	
Wave2	-0.000	-0.063	0.066	0.062	

	mean	min	max	std	comment
Heading	179.145	178.560	179.490	0.258	
Forward vel.	0.395	0.371	0.417	0.015	
Surge acc.	-0.016	-0.183	0.125	0.095	
Port vel.	-0.012	-0.054	0.007	0.014	
Sway acc.	-0.005	-0.140	0.075	0.037	

	mean	min	max	sqrt(2)*std	comment
Heave	0.001	-0.019	0.020	0.018	
Heave acc.	0.042	-0.573	0.757	0.618	

	mean	min	max	sqrt(2)*std	comment
Roll	0.169	-5.036	6.366	3.255	par. exitation

	mean	min	max	sqrt(2)*std	comment
Pitch	0.051	-1.449	1.475	1.384	

	mean	min	max	std	comment
Yaw vel.	-0.040	-0.602	0.374	0.214	

	mean	min	max	std	comment
Rudder angle	1.512	0.274	3.374	0.741	

3.2.3 Heading 150°, speed 1.30 m/s

Table 3.3. In the table, *freq.* refers to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
40	1.34	1.24	1.45	0.061	150.3	149.6	150.9	0.32	2.07	0.055
41	1.39	1.32	1.45	0.037	149.5	148.9	150.0	0.29	3.25	0.055
42	1.30	1.22	1.40	0.045	149.4	148.9	149.9	0.26	3.25	0.058
43	1.07	0.99	1.27	0.068	147.5	145.8	149.1	1.00	4.44	0.055
44	1.37	1.33	1.41	0.021	148.6	147.4	150.2	0.93	4.44	0.056

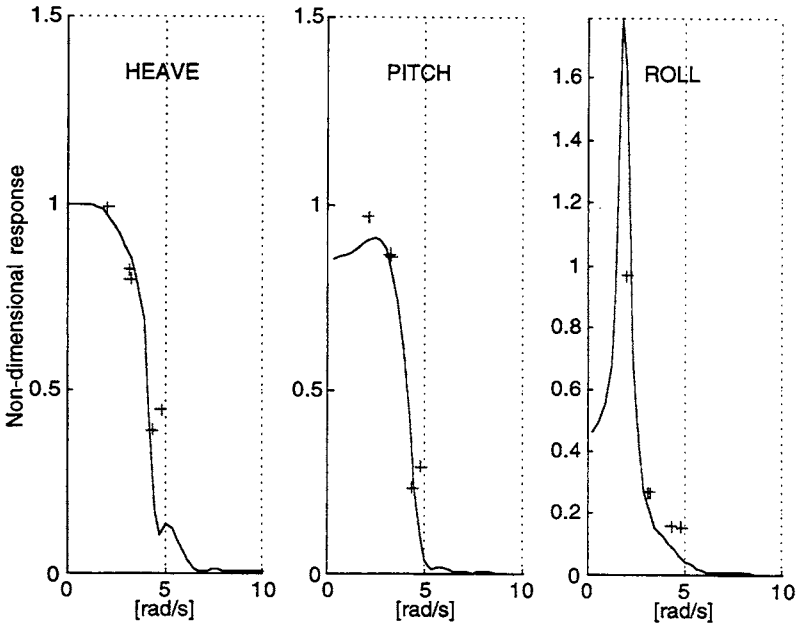
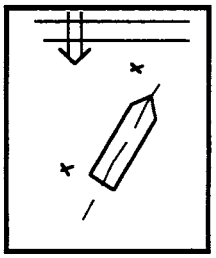


Figure 3.3. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970). The roll motion indicates non-linear behaviour at the resonance frequency.

Test no 40



The 23.8 seconds measurement is stored on file: *KTHTest40*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0150	0.0148	0.0096
b	-0.0026	-0.0196	0.0428
ω	2.0200	2.0700	2.1200
k	0.4903	0.5077	0.5256

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0551	0.0547	0.0050

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.000	-0.071	0.081	0.058	
Wave2	-0.002	-0.072	0.068	0.052	

	mean	min	max	std	comment
Heading	150.266	149.550	150.890	0.315	
Forward vel.	1.343	1.239	1.452	0.061	
Surge acc.	-0.050	-0.337	0.257	0.176	
Port vel.	-0.005	-0.082	0.064	0.036	
Sway acc.	-0.006	-0.163	0.124	0.078	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.006	-0.073	0.063	0.057	
Heave acc.	0.042	-0.543	0.572	0.388	

	mean	min	max	sqrt(2)*std	comment
Roll	0.086	-2.091	2.148	1.621	

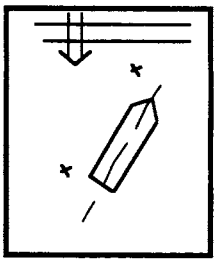
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.023	-2.077	2.133	1.619	

	mean	min	max	std	comment
Yaw vel.	-0.028	-1.514	1.296	0.719	

	mean	min	max	std	comment
Rudder angle	0.159	-1.645	1.624	0.858	

Test no 41

The 23.0 seconds measurement is stored on file: *KTHTest41*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0247	0.0188	-0.0448
b	-0.0008	0.0014	-0.0279
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0552	0.0550	0.0031

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.057	0.066	0.052	
Wave2	-0.005	-0.047	0.031	0.025	

	mean	min	max	std	comment
Heading	149.489	148.880	150.000	0.292	
Forward vel.	1.390	1.323	1.454	0.037	
Surge acc.	-0.049	-0.425	0.312	0.228	
Port vel.	-0.027	-0.050	0.003	0.011	
Sway acc.	-0.005	-0.196	0.266	0.129	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.052	0.046	0.043	
Heave acc.	0.049	-0.766	0.748	0.676	

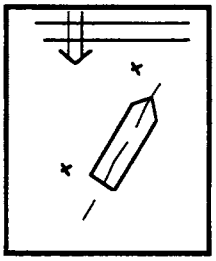
	mean	min	max	sqrt(2)*std	comment
Roll	0.098	-1.271	1.283	0.875	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.153	-3.271	3.097	2.828	

	mean	min	max	std	comment
Yaw vel.	0.064	-2.342	2.535	1.403	

	mean	min	max	std	comment
Rudder angle	0.864	-1.750	3.563	1.563	

Test no 42



The 23.4 seconds measurement is stored on file: *KTHTest42*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0245	0.0187	-0.0347
b	-0.0065	0.0051	-0.0432
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0584	0.0583	0.0031

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.060	0.068	0.055	
Wave2	-0.005	-0.067	0.062	0.045	

	mean	min	max	std	comment
Heading	149.389	148.900	149.910	0.258	
Forward vel.	1.304	1.225	1.396	0.045	
Surge acc.	-0.045	-0.442	0.334	0.246	
Port vel.	-0.029	-0.053	0.010	0.012	
Sway acc.	-0.003	-0.209	0.286	0.137	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.053	0.047	0.044	
Heave acc.	0.052	-0.749	0.724	0.658	

	mean	min	max	sqrt(2)*std	comment
Roll	0.031	-1.162	1.143	0.896	

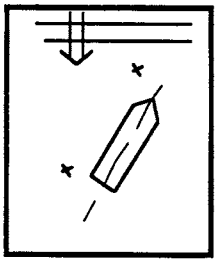
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.099	-3.342	3.161	2.949	

	mean	min	max	std	comment
Yaw vel.	0.056	-2.445	2.761	1.497	

	mean	min	max	std	comment
Rudder angle	1.025	-1.792	4.070	1.660	

Test no 43

The 25.4 seconds measurement is stored on file: *KTHTest43*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0558	0.0592	-0.0632
b	-0.0314	0.0666	-0.0174
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0555	0.0552	0.0041

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.061	0.072	0.055	
Wave2	-0.002	-0.067	0.077	0.056	

	mean	min	max	std	comment
Heading	147.512	145.840	149.100	0.997	
Forward vel.	1.068	0.994	1.274	0.068	
Surge acc.	-0.040	-0.246	0.180	0.104	
Port vel.	-0.094	-0.133	-0.045	0.019	
Sway acc.	-0.004	-0.265	0.237	0.124	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.002	-0.030	0.030	0.025	
Heave acc.	0.037	-1.190	1.175	0.958	

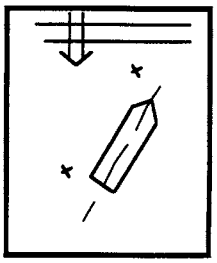
	mean	min	max	sqrt(2)*std	comment
Roll	0.084	-1.527	1.410	0.984	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.150	-2.573	1.984	1.860	

	mean	min	max	std	comment
Yaw vel.	0.118	-2.167	2.773	1.196	

	mean	min	max	std	comment
Rudder angle	3.374	0.422	7.043	1.552	

Test no 44



The 20.6 seconds measurement is stored on file: *KTHTest44*

Wave equation

$$\zeta(x,y,t) = \sum_{n=i}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0238	0.0137	-0.0475
b	-0.0660	0.0991	-0.0572
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0565	0.0562	0.0042

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.059	0.072	0.055	
Wave2	-0.002	-0.067	0.074	0.050	

	mean	min	max	std	comment
Heading	148.580	147.390	150.160	0.928	
Forward vel.	1.368	1.327	1.407	0.021	
Surge acc.	-0.049	-0.220	0.102	0.086	
Port vel.	-0.092	-0.129	-0.057	0.016	
Sway acc.	0.000	-0.241	0.215	0.123	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.029	0.025	0.021	
Heave acc.	0.034	-1.271	1.103	0.962	

	mean	min	max	sqrt(2)*std	comment
Roll	0.178	-1.873	1.596	1.017	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.266	-2.305	1.450	1.515	

	mean	min	max	std	comment
Yaw vel.	0.162	-1.698	2.406	0.971	

	mean	min	max	std	comment
Rudder angle	2.215	-0.506	4.955	1.365	

3.2.4 Heading 120°, speed 1.30 m/s

Table 3.4. In the table, *freq.* refers to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
45	1.34	1.24	1.44	0.053	120.3	119.0	121.4	0.64	2.07	0.050
46	1.41	1.31	1.49	0.042	120.4	117.6	121.5	0.96	3.25	0.052
47	1.32	1.21	1.40	0.042	121.0	120.2	122.0	0.38	3.25	0.055
48	1.30	1.25	1.36	0.025	117.9	116.0	119.0	0.57	4.44	0.056

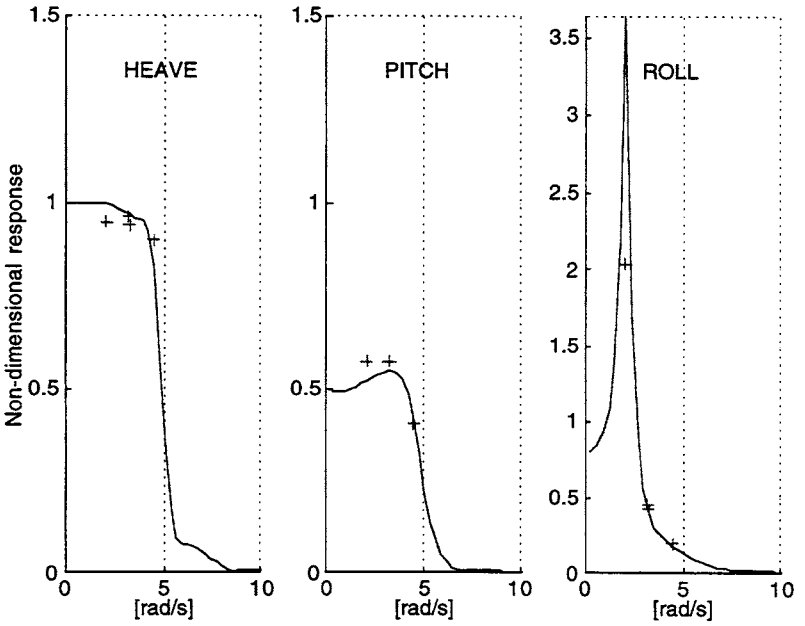
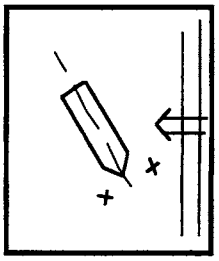


Figure 3.4. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970). The roll motion indicates non-linear behaviour at the resonance frequency.

Test no 45



The 21.8 seconds measurement is stored on file: *KTHTest45*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0135	-0.0154	
b	0.0372	-0.0026	
ω	2.0700	2.1200	
k	0.5077	0.5256	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0504	0.0493	0.0065

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.000	-0.062	0.069	0.053	
Wave2	-0.001	-0.061	0.062	0.052	

	mean	min	max	std	comment
Heading	120.307	119.000	121.370	0.636	
Forward vel.	1.342	1.236	1.439	0.053	
Surge acc.	-0.072	-0.256	0.163	0.095	
Port vel.	-0.002	-0.187	0.193	0.106	
Sway acc.	0.001	-0.289	0.256	0.138	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.070	0.057	0.050	
Heave acc.	0.040	-0.440	0.522	0.322	

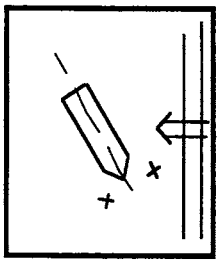
	mean	min	max	sqrt(2)*std	comment
Roll	-0.083	-3.587	3.949	3.147	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.148	-1.449	1.432	0.890	

	mean	min	max	std	comment
Yaw vel.	0.305	-1.388	2.313	0.934	

	mean	min	max	std	comment
Rudder angle	0.429	-2.467	2.994	1.239	

Test no 46



The 22.2 seconds measurement is stored on file: *KTHTest46*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0260	0.0346	0.0086
b	-0.0146	0.0494	-0.0824
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0525	0.0519	0.0053

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.054	0.063	0.053	
Wave2	-0.001	-0.058	0.059	0.049	

	mean	min	max	std	comment
Heading	120.362	117.610	121.490	0.958	
Forward vel.	1.413	1.308	1.494	0.042	
Surge acc.	-0.053	-0.333	0.265	0.179	
Port vel.	-0.006	-0.172	0.148	0.097	
Sway acc.	-0.008	-0.422	0.393	0.247	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.003	-0.061	0.051	0.051	
Heave acc.	0.030	-0.737	0.882	0.722	

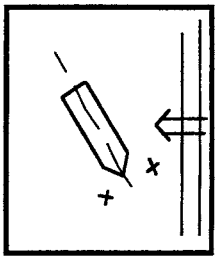
	mean	min	max	sqrt(2)*std	comment
Roll	-0.028	-2.847	3.014	1.447	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.092	-2.147	2.136	1.887	

	mean	min	max	std	comment
Yaw vel.	0.180	-3.151	3.536	1.847	

	mean	min	max	std	comment
Rudder angle	0.274	-3.816	5.377	2.224	

Test no 47



The 23.0 seconds measurement is stored on file: *KTHTest47*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0023	0.0265	-0.0781
b	0.0251	-0.0450	0.0140
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0547	0.0544	0.0042

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.059	0.064	0.055	
Wave2	-0.004	-0.056	0.051	0.046	

	mean	min	max	std	comment
Heading	121.013	120.240	122.020	0.375	
Forward vel.	1.318	1.210	1.401	0.042	
Surge acc.	-0.047	-0.345	0.267	0.190	
Port vel.	-0.010	-0.198	0.151	0.102	
Sway acc.	-0.002	-0.401	0.425	0.255	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.060	0.053	0.052	
Heave acc.	0.056	-0.730	0.807	0.705	

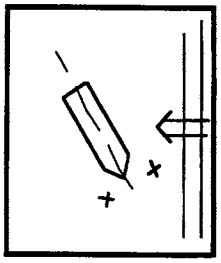
	mean	min	max	sqrt(2)*std	comment
Roll	-0.012	-1.772	3.052	1.403	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.068	-2.261	2.189	1.979	

	mean	min	max	std	comment
Yaw vel.	0.036	-3.082	3.362	1.915	

	mean	min	max	std	comment
Rudder angle	-0.394	-4.470	3.310	2.123	

Test no 48



The 23.8 seconds measurement is stored on file: *KTHTest48*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0169	-0.0319	-0.0188
b	-0.0070	-0.0017	0.0511
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0555	0.0550	0.0049

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.002	-0.059	0.070	0.055	
Wave2	0.001	-0.061	0.069	0.054	

	mean	min	max	std	comment
Heading	117.863	115.970	118.980	0.571	
Forward vel.	1.305	1.253	1.360	0.025	
Surge acc.	-0.038	-0.303	0.244	0.163	
Port vel.	-0.105	-0.223	0.022	0.066	
Sway acc.	-0.007	-0.526	0.618	0.324	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.002	-0.055	0.054	0.050	
Heave acc.	0.046	-1.411	1.177	1.213	

	mean	min	max	sqrt(2)*std	comment
Roll	1.131	-1.317	3.889	1.180	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.172	-3.012	2.784	2.547	

	mean	min	max	std	comment
Yaw vel.	0.206	-4.700	5.696	2.684	

	mean	min	max	std	comment
Rudder angle	2.736	-1.708	6.747	2.122	

3.2.5 Heading 90°, speed 1.30 m/s

Table 3.5. In the table, *freq.* referes to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
49	1.31	1.26	1.36	0.020	91.0	90.1	92.5	0.54	2.07	0.053
50	1.32	1.25	1.37	0.029	91.1	90.0	94.1	1.22	3.25	0.055
51	1.43	1.32	1.47	0.031	90.9	90.1	92.6	0.60	4.44	0.055
52	1.30	1.26	1.32	0.013	91.3	90.4	93.0	0.67	4.44	0.056

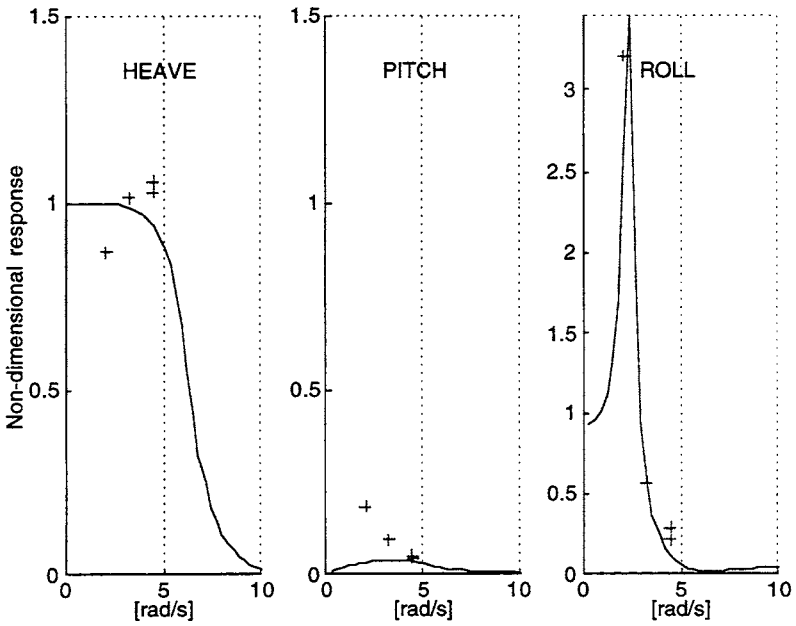
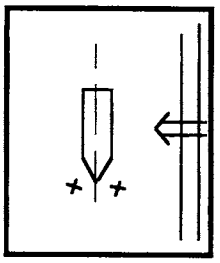


Figure 3.5. Measurments ploted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970).

Test no 49

The 39.0 seconds measurement is stored on file: *KTHTest49*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0324	-0.0419	-0.0291
b	0.0233	-0.0370	0.0228
ω	2.0200	2.0700	2.1200
k	0.4903	0.5077	0.5256

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0526	0.0520	0.0055

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.069	0.061	0.056	
Wave2	-0.002	-0.063	0.053	0.050	

	mean	min	max	std	comment
Heading	91.046	90.140	92.460	0.542	
Forward vel.	1.312	1.256	1.362	0.020	
Surge acc.	-0.033	-0.096	0.047	0.034	
Port vel.	-0.005	-0.312	0.327	0.189	
Sway acc.	0.006	-0.493	0.290	0.232	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.059	0.057	0.049	
Heave acc.	0.039	-0.352	0.360	0.251	

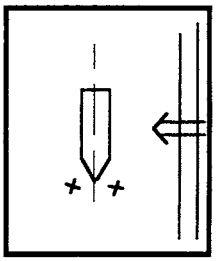
	mean	min	max	sqrt(2)*std	comment
Roll	0.011	-6.195	5.919	5.260	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.071	-0.250	0.640	0.293	

	mean	min	max	std	comment
Yaw vel.	-0.036	-0.581	0.771	0.276	

	mean	min	max	std	comment
Rudder angle	-0.286	-2.256	0.780	0.626	

Test no 50



The 38.2 seconds measurement is stored on file: *KTHTest50*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0027	-0.0339	0.0721
b	-0.0148	0.0207	0.0324
ω	3.2000	3.2500	3.3000
k	1.0536	1.0852	1.1175

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0547	0.0543	0.0045

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.055	0.064	0.054	
Wave2	-0.002	-0.056	0.062	0.052	

	mean	min	max	std	comment
Heading	91.068	89.980	94.120	1.215	
Forward vel.	1.324	1.253	1.373	0.029	
Surge acc.	-0.036	-0.125	0.034	0.032	
Port vel.	-0.010	-0.288	0.198	0.134	
Sway acc.	0.005	-0.522	0.514	0.316	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.064	0.055	0.055	
Heave acc.	0.039	-0.626	0.744	0.614	

	mean	min	max	sqrt(2)*std	comment
Roll	-0.062	-2.907	4.349	1.898	

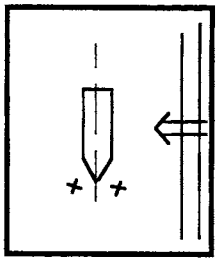
	mean	min	max	sqrt(2)*std	comment
Pitch	0.044	-0.548	0.522	0.297	

	mean	min	max	std	comment
Yaw vel.	-0.090	-1.448	1.522	0.432	

	mean	min	max	std	comment
Rudder angle	-0.224	-4.786	1.075	1.324	

Test no 51

The 34.2 seconds measurement is stored on file: *KTHTest51*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0034	-0.0245	0.0684
b	-0.0033	0.0050	0.0297
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0553	0.0551	0.0038

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.061	0.067	0.055	
Wave2	-0.001	-0.058	0.060	0.049	

	mean	min	max	std	comment
Heading	90.948	90.100	92.640	0.600	
Forward vel.	1.427	1.319	1.468	0.031	
Surge acc.	-0.038	-0.116	0.039	0.029	
Port vel.	-0.044	-0.254	0.157	0.118	
Sway acc.	0.006	-0.790	0.705	0.477	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.073	0.066	0.058	
Heave acc.	0.041	-1.520	1.397	1.160	

	mean	min	max	sqrt(2)*std	comment
Roll	0.217	-3.408	4.602	1.704	

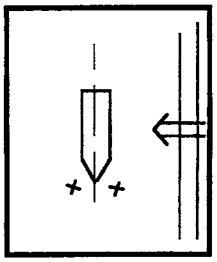
	mean	min	max	sqrt(2)*std	comment
Pitch	0.019	-0.601	0.540	0.285	

	mean	min	max	std	comment
Yaw vel.	-0.075	-1.608	1.255	0.547	

	mean	min	max	std	comment
Rudder angle	-0.141	-3.142	1.202	0.809	

Test no 52

The 36.6 seconds measurement is stored on file: *KTHTest52*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0054	-0.0212	0.0554
b	0.0015	-0.0088	0.0463
ω	4.3900	4.4400	4.4900
k	1.9647	2.0097	2.0552

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0555	0.0552	0.0039

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.056	0.072	0.056	
Wave2	-0.002	-0.053	0.056	0.043	

	mean	min	max	std	comment
Heading	91.263	90.380	93.000	0.665	
Forward vel.	1.298	1.260	1.319	0.013	
Surge acc.	-0.035	-0.119	0.025	0.029	
Port vel.	-0.048	-0.253	0.135	0.117	
Sway acc.	0.008	-0.794	0.711	0.479	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.071	0.066	0.058	
Heave acc.	0.043	-1.421	1.467	1.156	

	mean	min	max	sqrt(2)*std	comment
Roll	0.198	-2.144	3.611	1.239	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.043	-0.403	0.569	0.267	

	mean	min	max	std	comment
Yaw vel.	-0.084	-1.529	1.147	0.562	

	mean	min	max	std	comment
Rudder angle	-0.155	-2.910	1.265	0.860	

3.2.6 Heading 60°, speed 1.30 m/s

Table 3.6. In the table, *freq.* refers to the control signal sent to the wave maker and *ampl.* to the amplitude determined from the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
53	1.31	1.18	1.44	0.067	60.6	58.5	62.2	0.90	2.07	0.054
54	1.30	1.11	1.54	0.114	61.5	59.8	64.4	1.13	3.25	0.055
55	1.24	1.08	1.41	0.085	62.9	60.8	65.3	1.08	4.44	0.055

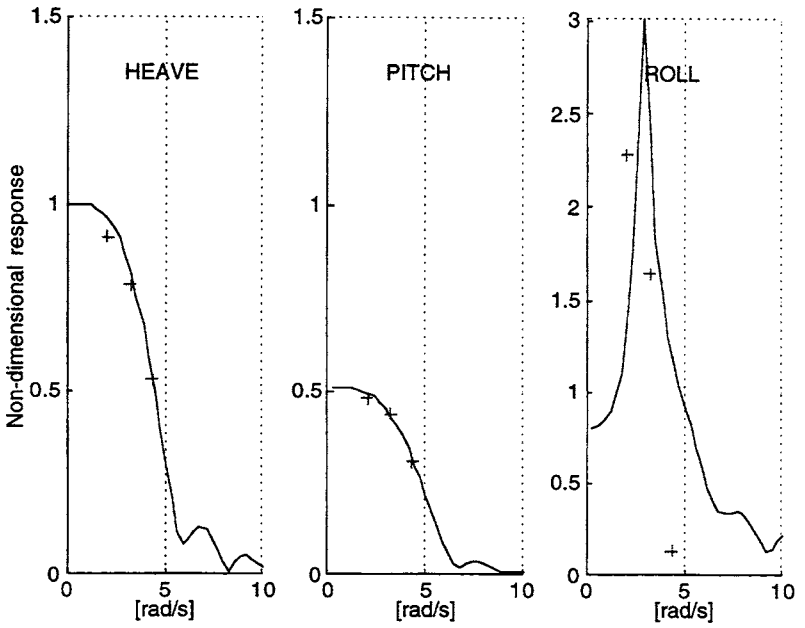
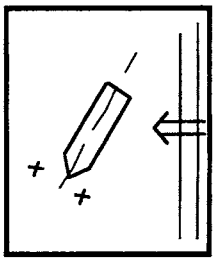


Figure 3.6. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970).

Test no 53



The 24.6 seconds measurement is stored on file: *KTHTest53*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0001	0.0124	
b	-0.0420	-0.0060	
ω	2.0700	2.1200	
k	0.5077	0.5256	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0542	0.0533	0.0068

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.000	-0.068	0.067	0.056	
Wave2	-0.002	-0.061	0.063	0.054	

	mean	min	max	std	comment
Heading	60.617	58.470	62.170	0.897	
Forward vel.	1.308	1.175	1.441	0.067	
Surge acc.	-0.062	-0.255	0.113	0.092	
Port vel.	-0.013	-0.269	0.245	0.161	
Sway acc.	0.003	-0.333	0.299	0.155	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.065	0.062	0.051	
Heave acc.	0.044	-0.319	0.325	0.186	

	mean	min	max	sqrt(2)*std	comment
Roll	0.087	-5.837	4.029	3.672	

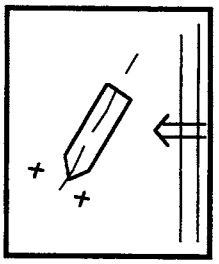
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.107	-1.180	0.885	0.782	

	mean	min	max	std	comment
Yaw vel.	0.075	-2.273	2.463	1.181	

	mean	min	max	std	comment
Rudder angle	0.477	-3.057	4.449	1.723	

Test no 54

The 24.2 seconds measurement is stored on file: *KTHTest54*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0077	-0.0220	
b	-0.0045	0.0549	
ω	3.2500	3.3000	
k	1.0852	1.1175	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0551	0.0540	0.0050

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	-0.001	-0.057	0.065	0.056	
Wave2	-0.002	-0.072	0.070	0.059	

	mean	min	max	std	comment
Heading	61.535	59.850	64.410	1.130	
Forward vel.	1.296	1.107	1.538	0.114	
Surge acc.	-0.050	-0.333	0.242	0.175	
Port vel.	-0.019	-0.230	0.191	0.132	
Sway acc.	0.005	-0.290	0.301	0.189	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.049	0.043	0.043	
Heave acc.	0.045	-0.333	0.385	0.314	

	mean	min	max	sqrt(2)*std	comment
Roll	0.054	-6.073	6.538	5.584	

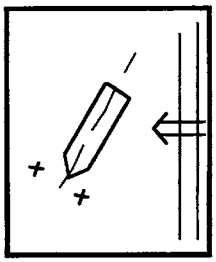
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.009	-1.713	1.761	1.501	

	mean	min	max	std	comment
Yaw vel.	-0.027	-4.110	3.775	2.488	

	mean	min	max	std	comment
Rudder angle	-0.362	-6.431	4.765	3.141	

Test no 55

The 24.6 seconds measurement is stored on file: *KTHTest55*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0322	0.0024	
b	0.0529.	-0.1154	
ω	4.3900	4.4400	
k	1.9647	2.0097	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0554	0.0544	0.0069

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.000	-0.063	0.073	0.055	
Wave2	0.004	-0.064	0.078	0.053	

	mean	min	max	std	comment
Heading	62.867	60.780	65.300	1.077	
Forward vel.	1.241	1.076	1.410	0.085	
Surge acc.	-0.039	-0.378	0.345	0.221	
Port vel.	-0.053	-0.270	0.154	0.127	
Sway acc.	-0.006	-0.487	0.495	0.274	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.002	-0.038	0.038	0.029	
Heave acc.	0.037	-0.637	0.546	0.382	

	mean	min	max	sqrt(2)*std	comment
Roll	0.450	-1.511	1.570	0.854	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.024	-2.070	2.581	1.946	

	mean	min	max	std	comment
Yaw vel.	0.037	-7.195	7.544	4.448	

	mean	min	max	std	comment
Rudder angle	-1.931	-9.889	5.272	3.878	

3.2.7 Heading 30°, speed 1.30 m/s

Table 3.7. In the table, *freq.* refers to the control signal sent to the wave maker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
56	1.33	0.87	1.81	0.267	32.1	30.7	33.7	0.78	2.07	0.060
57	1.28	0.86	1.82	0.280	30.3	28.7	31.9	0.84	2.07	0.062
58	1.30	0.76	1.84	0.334	30.8	29.0	33.3	1.05	3.25	0.048
59	1.22	1.03	1.42	0.120	31.4	29.1	33.2	1.08	4.44	0.050

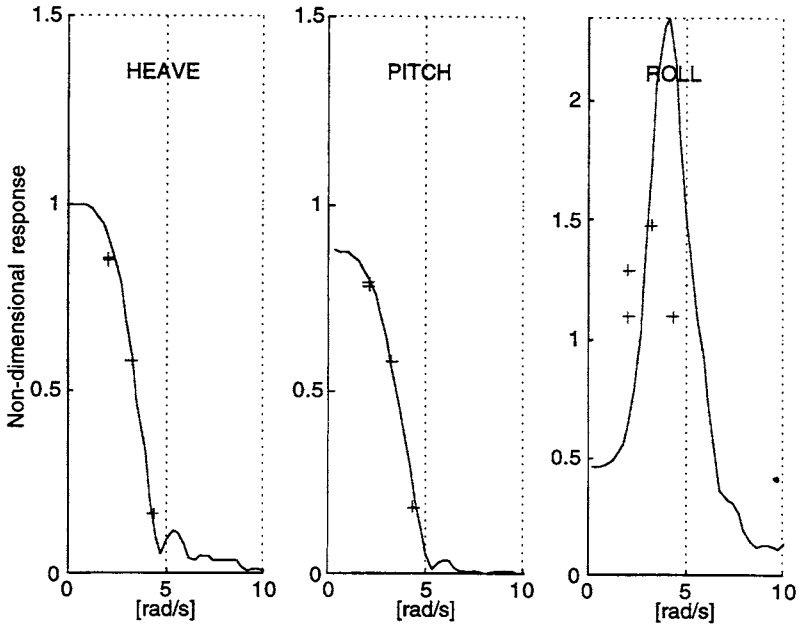
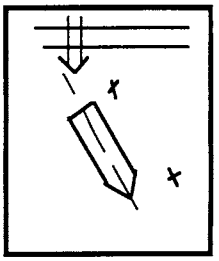


Figure 3.7. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970). The roll motion indicates non-linear behaviour.

Test no 56



The 24.2 seconds measurement is stored on file: *KTHTest56*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0557	0.0205	
b	0.0074	-0.0274	
ω	2.0700	2.1200	
k	0.5077	0.5256	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0601	0.0595	0.0058

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.007	-0.061	0.079	0.057	
Wave2	-0.002	-0.067	0.070	0.058	

	mean	min	max	std	comment
Heading	32.091	30.690	33.700	0.775	
Forward vel.	1.331	0.869	1.810	0.267	
Surge acc.	-0.061	-0.327	0.218	0.159	
Port vel.	-0.003	-0.192	0.197	0.109	
Sway acc.	-0.007	-0.170	0.146	0.092	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.065	0.059	0.049	
Heave acc.	0.045	-0.127	0.211	0.118	

	mean	min	max	sqrt(2)*std	comment
Roll	0.083	-2.278	2.409	1.838	

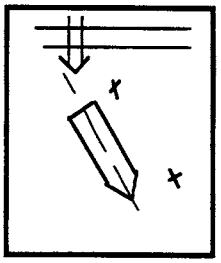
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.063	-1.626	1.537	1.324	

	mean	min	max	std	comment
Yaw vel.	0.215	-1.784	2.245	1.121	

	mean	min	max	std	comment
Rudder angle	-0.188	-0.274	-0.126	0.035	

Test no 57

The 23.8 seconds measurement is stored on file: *KTHTest57*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0272	-0.0226	
b	0.0301	-0.0091	
ω	2.0700	2.1200	
k	0.5077	0.5256	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0616	0.0613	0.0048

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.009	-0.061	0.084	0.058	
Wave2	-0.002	-0.064	0.077	0.059	

	mean	min	max	std	comment
Heading	30.291	28.690	31.910	0.836	
Forward vel.	1.284	0.857	1.820	0.280	
Surge acc.	-0.051	-0.325	0.259	0.160	
Port vel.	0.004	-0.199	0.193	0.105	
Sway acc.	-0.002	-0.172	0.147	0.086	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.005	-0.066	0.064	0.050	
Heave acc.	0.045	-0.171	0.234	0.129	

	mean	min	max	sqrt(2)*std	comment
Roll	-0.087	-3.044	2.635	2.218	

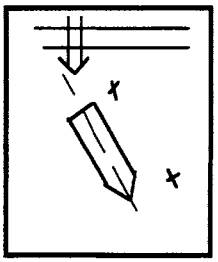
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.044	-1.655	1.786	1.335	

	mean	min	max	std	comment
Yaw vel.	0.050	-2.543	2.103	1.171	

	mean	min	max	std	comment
Rudder angle	0.279	-3.015	3.100	1.642	

Test no 58

The 23.0 seconds measurement is stored on file: *KTHTest58*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0536	-0.0495	
b	-0.0769	0.0855	
ω	3.2500	3.3000	
k	1.0852	1.1175	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0478	0.0465	0.0041

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.012	-0.052	0.065	0.047	
Wave2	-0.006	-0.061	0.072	0.055	

	mean	min	max	std	comment
Heading	30.781	29.000	33.320	1.051	
Forward vel.	1.300	0.761	1.836	0.334	
Surge acc.	-0.062	-0.390	0.271	0.211	
Port vel.	-0.017	-0.148	0.144	0.082	
Sway acc.	-0.013	-0.209	0.141	0.091	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.002	-0.035	0.033	0.028	
Heave acc.	0.036	-0.152	0.240	0.141	

	mean	min	max	sqrt(2)*std	comment
Roll	1.014	-4.475	5.914	4.461	

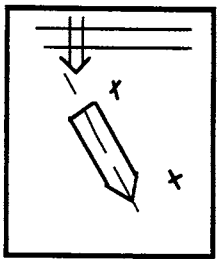
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.096	-1.986	1.849	1.728	

	mean	min	max	std	comment
Yaw vel.	0.101	-3.809	3.607	2.378	

	mean	min	max	std	comment
Rudder angle	-0.295	-5.756	4.681	3.113	

Test no 59

The 27.0 seconds measurement is stored on file: *KTHTest59*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	-0.0146		
b	-0.0455		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0504	0.0478	0.0109

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.011	-0.057	0.065	0.049	
Wave2	0.005	-0.062	0.085	0.055	

	mean	min	max	std	comment
Heading	31.447	29.060	33.230	1.077	
Forward vel.	1.223	1.027	1.418	0.120	
Surge acc.	-0.019	-0.256	0.221	0.115	
Port vel.	-0.053	-0.168	0.077	0.064	
Sway acc.	0.005	-0.262	0.219	0.103	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.003	-0.016	0.012	0.008	
Heave acc.	0.042	-0.233	0.308	0.150	

	mean	min	max	sqrt(2)*std	comment
Roll	-1.418	-7.550	5.790	6.108	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.141	-1.360	1.575	1.016	

	mean	min	max	std	comment
Yaw vel.	-0.028	-4.735	4.573	2.941	

	mean	min	max	std	comment
Rudder angle	-1.129	-7.127	5.124	3.744	

3.2.8 Heading 0°, speed 1.30 m/s

Table 3.8. In the table, *freq.* refers to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed [m/s]				model heading [deg]				wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
60	1.32	0.81	1.80	0.321	0.6	0.3	1.0	0.20	2.07	0.068
61	1.30	0.74	1.86	0.341	0.6	0.2	1.1	0.19	3.25	0.048
62	1.28	1.18	1.42	0.048	0.5	-0.2	1.2	0.30	4.44	0.047

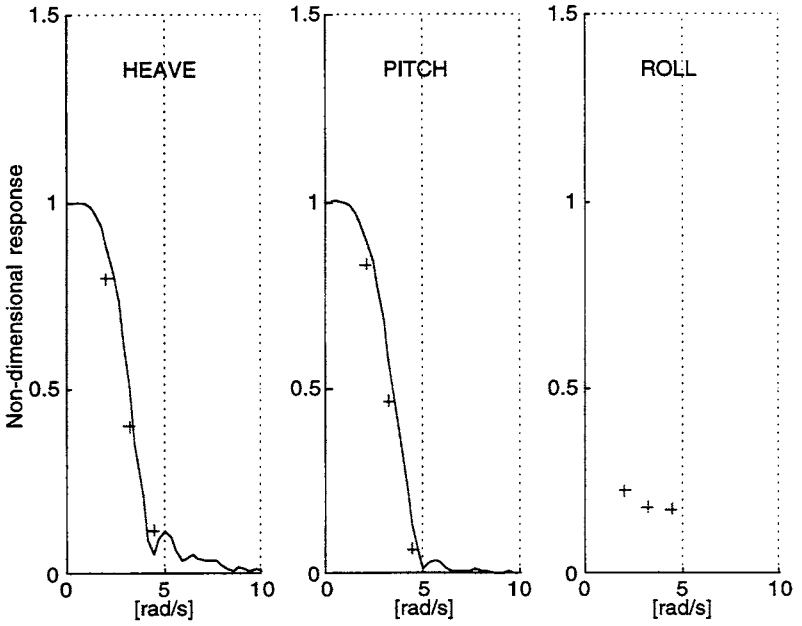
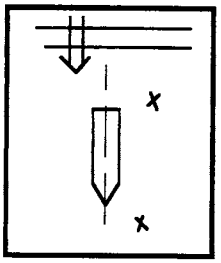


Figure 3.8. Measurements plotted together with transfer functions calculated by the linear strip method code MacSkepps, (KTH, div. Naval Architecture). The code is based on strip theory according to Salvesen, Tuck and Faltinsen (1970).

Test no 60



The 37.4 seconds measurement is stored on file: *KTHTest60*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3
a	0.0193	-0.0807	
b	-0.0020	0.0010	
ω	2.0700	2.1200	
k	0.5077	0.5256	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0680	0.0666	0.0081

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.006	-0.068	0.090	0.067	
Wave2	0.002	-0.065	0.079	0.063	

	mean	min	max	std	comment
Heading	0.633	0.280	1.040	0.197	
Forward vel.	1.323	0.811	1.796	0.321	
Surge acc.	-0.029	-0.357	0.265	0.197	
Port vel.	-0.002	-0.059	0.037	0.018	
Sway acc.	-0.002	-0.050	0.066	0.019	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.001	-0.069	0.056	0.054	
Heave acc.	0.037	-0.145	0.259	0.132	

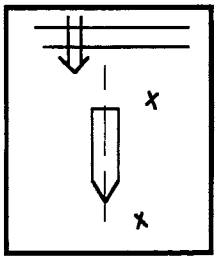
	mean	min	max	sqrt(2)*std	comment
Roll	0.091	-0.558	0.833	0.436	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.074	-1.853	1.826	1.642	

	mean	min	max	std	comment
Yaw vel.	0.044	-0.440	0.543	0.244	

	mean	min	max	std	comment
Rudder angle	-0.076	-0.696	0.506	0.311	

Test no 61



The 37.0 seconds measurement is stored on file: *KTHTest61*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	-0.0840	0.0699	
b	0.0531	-0.0195	
ω	3.2500	3.3000	
k	1.0852	1.1175	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0485	0.0480	0.0049

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.001	-0.064	0.078	0.054	
Wave2	-0.007	-0.060	0.068	0.050	

	mean	min	max	std	comment
Heading	0.637	0.190	1.110	0.189	
Forward vel.	1.301	0.738	1.862	0.341	
Surge acc.	-0.030	-0.321	0.331	0.191	
Port vel.	0.002	-0.028	0.031	0.012	
Sway acc.	-0.001	-0.044	0.051	0.017	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.003	-0.033	0.023	0.021	
Heave acc.	0.039	-0.115	0.230	0.094	

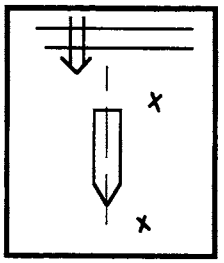
	mean	min	max	sqrt(2)*std	comment
Roll	0.044	-0.935	1.019	0.606	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.069	-1.696	2.170	1.578	

	mean	min	max	std	comment
Yaw vel.	0.001	-0.945	0.953	0.378	

	mean	min	max	std	comment
Rudder angle	-0.117	-1.265	1.097	0.459	

Test no 62



The 37.8 seconds measurement is stored on file: *KTHTest62*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	0.0143	-0.0236	
b	-0.0153	-0.0462	
ω	4.3900	4.4400	
k	1.9647	2.0097	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0466	0.0453	0.0075

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.005	-0.054	0.079	0.048	
Wave2	-0.001	-0.049	0.048	0.040	

	mean	min	max	std	comment
Heading	0.499	-0.210	1.170	0.298	
Forward vel.	1.280	1.184	1.421	0.048	
Surge acc.	-0.035	-0.135	0.055	0.040	
Port vel.	-0.001	-0.025	0.025	0.011	
Sway acc.	-0.000	-0.049	0.059	0.021	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.014	0.006	0.006	
Heave acc.	0.040	-0.272	0.346	0.099	

	mean	min	max	sqrt(2)*std	comment
Roll	0.065	-1.359	1.539	0.977	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.046	-0.556	0.698	0.362	

	mean	min	max	std	comment
Yaw vel.	0.010	-1.752	1.499	0.655	

	mean	min	max	std	comment
Rudder angle	0.014	-1.666	2.193	0.795	

3.3 Tests in irregular waves

The irregular waves were in all cases built up by three regular components of frequencies 2.07, 3.25 and 4.44 rad/s.

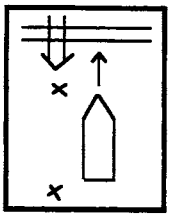
3.3.1 Heading 180°

Table 3.3.1. In column *wave* the significant wave height, $H_{1/3}$, refers to, four times the standard deviation of the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave
no	mean	min	max	std	mean	min	max	std	$H_{1/3}$
63	0.27	0.11	0.43	0.068	-162.9	-180.0	180.0	75.50	0.183
64	0.58	0.41	0.68	0.055	-147.2	-180.0	180.0	102.43	0.141
65	0.51	0.40	0.61	0.047	-147.1	-180.0	180.0	102.27	0.146
66	1.29	1.17	1.38	0.043	-179.4	-179.6	-179.2	0.10	0.152

Test no 63

The 46.2 seconds measurement is stored on file: *KTHTest63*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	0.0005	-0.0099	-0.0008	-0.0044	-0.0256	-0.0026	-0.0061	0.0298	0.0014
b	0.0065	-0.0312	0.0056	-0.0096	0.0492	-0.0048	-0.0050	0.0302	-0.0039
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1834	0.1811	0.0072

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.098	0.116	0.184	
Wave2	-0.002	-0.115	0.108	0.172	

	mean	min	max	std	comment
Heading	-162.905	-180.000	180.000	75.505	discont.
Forward vel.	0.274	0.110	0.435	0.068	
Surge acc.	-0.003	-0.542	0.526	0.260	
Port vel.	-0.005	-0.018	0.005	0.004	
Sway acc.	-0.004	-0.073	0.072	0.024	

	mean	min	max	2*std	comment
Heave	0.001	-0.056	0.056	0.047	
Heave acc.	0.040	-0.502	0.633	0.500	

	mean	min	max	2*std	comment
Roll	0.015	-1.441	1.848	1.297	

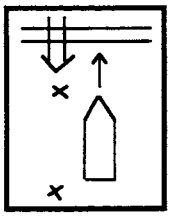
	mean	min	max	2*std	comment
Pitch	0.214	-3.375	4.263	3.649	

	mean	min	max	std	comment
Yaw vel.	-0.004	-0.972	0.558	0.250	

	mean	min	max	std	comment
Rudder angle	0.032	-2.256	2.404	0.820	

Test no 64

The 55.0 seconds measurement is stored on file: *KTHTest64*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0022	0.0127	0.0021	-0.0038	0.0422	0.0028	-0.0049	-0.0034	-0.0026
b	-0.0008	-0.0102	-0.0015	0.0042	0.0184	-0.0049	-0.0016	0.0248	-0.0015
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1409	0.1391	0.0056

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.079	0.092	0.135	
Wave2	-0.002	-0.088	0.099	0.153	

	mean	min	max	std	comment
Heading	-147.244	-180.000	180.000	102.433	
Forward vel.	0.579	0.409	0.684	0.055	
Surge acc.	-0.008	-0.467	0.382	0.193	
Port vel.	-0.006	-0.020	0.014	0.007	
Sway acc.	0.001	-0.075	0.068	0.023	

	mean	min	max	2*std	comment
Heave	0.000	-0.047	0.053	0.042	
Heave acc.	0.039	-0.626	0.634	0.566	

	mean	min	max	2*std	comment
Roll	0.049	-1.297	1.454	1.184	

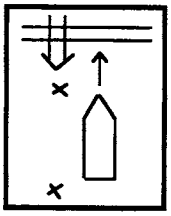
	mean	min	max	2*std	comment
Pitch	0.133	-3.080	3.193	2.830	

	mean	min	max	std	comment
Yaw vel.	0.004	-0.906	0.741	0.274	

	mean	min	max	std	comment
Rudder angle	-0.162	-2.657	2.298	0.880	

Test no 65

The 65.4 seconds measurement is stored on file: *KTHTest65*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0023	0.0139	0.0025	-0.0032	-0.0352	-0.0014	0.0034	0.0037	0.0020
b	-0.0021	0.0150	0.0002	-0.0015	0.0216	-0.0007	0.0018	-0.0248	0.0002
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1465	0.1449	0.0053

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.079	0.104	0.144	
Wave2	-0.002	-0.087	0.088	0.143	

	mean	min	max	std	comment
Heading	-147.130	-180.000	180.000	102.275	discont.
Forward vel.	0.508	0.403	0.611	0.047	
Surge acc.	-0.006	-0.450	0.403	0.194	
Port vel.	-0.007	-0.021	0.012	0.007	
Sway acc.	-0.001	-0.076	0.063	0.022	

	mean	min	max	2*std	comment
Heave	0.000	-0.052	0.052	0.041	
Heave acc.	0.044	-0.595	0.651	0.519	

	mean	min	max	2*std	comment
Roll	0.077	-1.278	1.506	1.128	

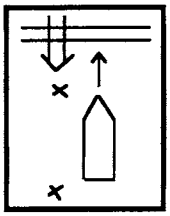
	mean	min	max	2*std	comment
Pitch	0.157	-2.971	3.268	2.803	

	mean	min	max	std	comment
Yaw vel.	-0.007	-0.793	0.813	0.270	

	mean	min	max	std	comment
Rudder angle	-0.323	-2.699	2.088	0.899	

Test no 66

The 38.6 seconds measurement is stored on file: *KTHTest66*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0025	-0.0166	0.0052	0.0048	-0.0414	-0.0017	0.0051	0.0054	0.0010
b	-0.0067	0.0242	-0.0010	0.0016	-0.0108	0.0008	0.0004	-0.0250	-0.0031
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1515	0.1498	0.0057

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.087	0.089	0.148	
Wave2	0.000	-0.102	0.118	0.195	

	mean	min	max	std	comment
Heading	-179.375	-179.580	-179.180	0.097	
Forward vel.	1.291	1.173	1.382	0.043	
Surge acc.	-0.030	-0.464	0.379	0.202	
Port vel.	-0.006	-0.019	0.009	0.005	
Sway acc.	0.000	-0.057	0.050	0.021	

	mean	min	max	2*std	comment
Heave	-0.002	-0.061	0.059	0.050	
Heave acc.	0.040	-0.984	0.890	0.814	

	mean	min	max	2*std	comment
Roll	-0.008	-0.795	1.073	0.693	

	mean	min	max	2*std	comment
Pitch	-0.043	-3.855	3.316	3.420	

	mean	min	max	std	comment
Yaw vel.	-0.014	-0.648	0.693	0.210	

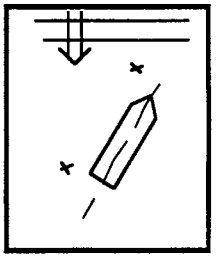
	mean	min	max	std	comment
Rudder angle	-0.044	-0.675	0.485	0.217	

3.3.2 Heading 150°

Table 3.3.2. In column *wave* the significant wave height, $H_{1/3}$, refers to four times the standard deviation of the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave
no	mean	min	max	std	mean	min	max	std	$H_{1/3}$
67	0.44	0.33	0.55	0.048	144.0	140.6	148.9	1.91	0.135
68	1.31	1.23	1.38	0.036	149.7	148.8	150.4	0.40	0.149
69	1.31	1.21	1.38	0.036	150.2	148.7	151.0	0.63	0.148

Test no 67



The 57.0 seconds measurement is stored on file: *KTHTest67*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0006	0.0062	0.0015	0.0002	0.0249	0.0066	0.0200	0.0078	-0.0159
b	-0.0059	0.0144	0.0008	-0.0145	0.0089	0.0025	0.0002	-0.0291	0.0102
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5079	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1347	0.1327	0.0057

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.078	0.095	0.133	
Wave2	-0.001	-0.081	0.082	0.130	

	mean	min	max	std	comment
Heading	143.998	140.580	148.940	1.907	
Forward vel.	0.442	0.326	0.550	0.048	
Surge acc.	-0.004	-0.446	0.449	0.200	
Port vel.	-0.057	-0.141	0.014	0.035	
Sway acc.	0.001	-0.261	0.317	0.119	

	mean	min	max	2*std	comment
Heave	0.001	-0.052	0.058	0.046	
Heave acc.	0.041	-0.591	0.626	0.514	

	mean	min	max	2*std	comment
Roll	-0.053	-4.827	5.308	3.882	

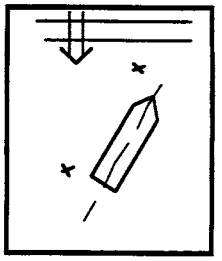
	mean	min	max	2*std	comment
Pitch	0.181	-3.133	3.686	2.963	

	mean	min	max	std	comment
Yaw vel.	0.130	-3.870	4.051	1.635	

	mean	min	max	std	comment
Rudder angle	4.969	-4.618	14.908	4.161	

Test no 68

The 23.8 seconds measurement is stored on file: *KTHTest68*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0157	0.0033	0.0147	0.0260	0.0169	-0.0035	-0.0072	-0.0279	0.0118
b	-0.0157	0.0201	-0.0130	0.0089	-0.0337	0.0163	-0.0088	0.0370	-0.0019
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1494	0.1473	0.0061

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.063	0.102	0.141	
Wave2	-0.005	-0.084	0.066	0.125	

	mean	min	max	std	comment
Heading	149.666	148.820	150.400	0.403	
Forward vel.	1.313	1.229	1.381	0.036	
Surge acc.	-0.047	-0.429	0.301	0.183	
Port vel.	-0.040	-0.078	-0.002	0.017	
Sway acc.	0.005	-0.176	0.315	0.104	

	mean	min	max	2*std	comment
Heave	-0.002	-0.058	0.053	0.050	
Heave acc.	0.036	-1.038	0.850	0.863	

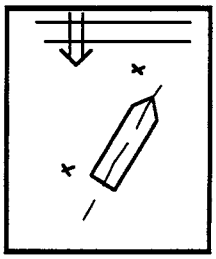
	mean	min	max	2*std	comment
Roll	0.194	-2.253	2.027	2.195	

	mean	min	max	2*std	comment
Pitch	-0.135	-3.141	3.028	3.046	

	mean	min	max	std	comment
Yaw vel.	-0.072	-2.452	2.790	1.199	

	mean	min	max	std	comment
Rudder angle	0.882	-1.918	4.130	1.327	

Test no 69



The 23.8 seconds measurement is stored on file: *KTHTest69*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	0.0026	-0.0217	0.0276	0.0316	0.0019	0.0042	-0.0050	0.0262	-0.0058
b	-0.0304	0.0337	-0.0025	0.0038	-0.0324	0.0204	0.0103	0.0212	-0.0037
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1475	0.1459	0.0055

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.003	-0.075	0.086	0.140	
Wave2	-0.004	-0.083	0.087	0.133	

	mean	min	max	std	comment
Heading	150.212	148.700	150.970	0.634	
Forward vel.	1.312	1.210	1.380	0.036	
Surge acc.	-0.046	-0.369	0.339	0.184	
Port vel.	-0.041	-0.091	0.003	0.018	
Sway acc.	0.002	-0.263	0.298	0.109	

	mean	min	max	2*std	comment
Heave	-0.003	-0.051	0.055	0.049	
Heave acc.	0.036	-1.070	0.901	0.846	

	mean	min	max	2*std	comment
Roll	0.263	-3.157	4.254	3.879	

	mean	min	max	2*std	comment
Pitch	-0.130	-3.356	3.108	3.037	

	mean	min	max	std	comment
Yaw vel.	0.102	-3.003	2.681	1.217	

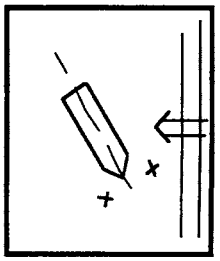
	mean	min	max	std	comment
Rudder angle	0.892	-2.002	5.563	1.447	

3.3.3 Heading 120°

Table 3.3.3. In column wave the significant wave height, $H_{1/3}$, refers to four times the standard deviation of the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave
no	mean	min	max	std	mean	min	max	std	$H_{1/3}$
70	0.50	0.36	0.61	0.047	118.8	115.0	121.6	1.24	0.137
71	1.30	1.21	1.37	0.039	120.4	119.5	121.1	0.30	0.148
72	1.31	1.21	1.41	0.037	120.3	119.5	121.2	0.33	0.150

Test no 70



The 76.6 seconds measurement is stored on file: *KTHTest70*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	0.0025	0.0139	-0.0026	0.0023	-0.0114	0.0013	-0.0029	-0.0129	0.0027
b	-0.0002	-0.0133	0.0032	0.0011	-0.0372	-0.0012	-0.0030	0.0191	0.0005
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1370	0.1324	0.0088

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.070	0.087	0.138	
Wave2	-0.003	-0.083	0.087	0.136	

	mean	min	max	std	comment
Heading	118.799	114.980	121.610	1.242	
Forward vel.	0.499	0.359	0.614	0.047	
Surge acc.	-0.013	-0.446	0.407	0.180	
Port vel.	-0.039	-0.323	0.203	0.106	
Sway acc.	-0.009	-0.579	0.565	0.228	

	mean	min	max	2*std	comment
Heave	-0.000	-0.075	0.076	0.062	
Heave acc.	0.041	-0.855	0.811	0.713	

	mean	min	max	2*std	comment
Roll	0.314	-9.526	6.260	4.982	

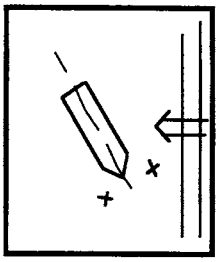
	mean	min	max	2*std	comment
Pitch	0.114	-2.995	3.216	2.635	

	mean	min	max	std	comment
Yaw vel.	0.186	-4.631	4.457	2.071	

	mean	min	max	std	comment
Rudder angle	0.953	-7.797	14.329	4.483	

Test no 71

The 25.8 seconds measurement is stored on file: *KTHTest71*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6			
a	0.0078	-0.0002	-0.0258	0.0003	-0.0005	0.0062			
b	-0.0233	0.0087	-0.0236	-0.0022	-0.0029	0.0301			
ω	2.0700	2.1200	3.2500	3.3000	4.3900	4.4400			
k	0.5077	0.5256	1.0852	1.1175	1.9647	2.0097			

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1485	0.1452	0.0075

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.080	0.084	0.148	
Wave2	-0.005	-0.090	0.082	0.126	

	mean	min	max	std	comment
Heading	120.430	119.530	121.080	0.300	
Forward vel.	1.305	1.214	1.374	0.039	
Surge acc.	-0.044	-0.402	0.308	0.155	
Port vel.	-0.041	-0.252	0.142	0.086	
Sway acc.	-0.002	-0.497	0.510	0.225	

	mean	min	max	2*std	comment
Heave	-0.003	-0.075	0.073	0.066	
Heave acc.	0.041	-1.176	1.102	1.101	

	mean	min	max	2*std	comment
Roll	0.536	-2.223	2.974	2.355	

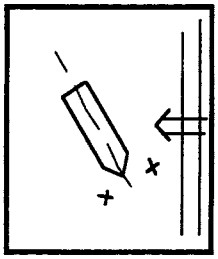
	mean	min	max	2*std	comment
Pitch	-0.089	-2.960	2.715	2.644	

	mean	min	max	std	comment
Yaw vel.	0.051	-4.930	4.611	1.959	

	mean	min	max	std	comment
Rudder angle	0.577	-4.425	4.720	1.859	

Test no 72

The 24.6 seconds measurement is stored on file: *KTHTest72*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6			
a	-0.0275	0.0097	-0.0258	-0.0053	0.0021	0.0146			
b	-0.0112	0.0026	0.0142	-0.0072	-0.0001	0.0229			
ω	2.0700	2.1200	3.2500	3.3000	4.3900	4.4400			
k	0.5077	0.5256	1.0852	1.1175	1.9647	2.0097			

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1501	0.1467	0.0079

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.075	0.094	0.146	
Wave2	-0.007	-0.087	0.053	0.117	

	mean	min	max	std	comment
Heading	120.310	119.520	121.150	0.328	
Forward vel.	1.311	1.207	1.406	0.037	
Surge acc.	-0.044	-0.364	0.292	0.153	
Port vel.	-0.037	-0.249	0.170	0.091	
Sway acc.	-0.009	-0.535	0.557	0.229	

	mean	min	max	2*std	comment
Heave	-0.004	-0.081	0.070	0.067	
Heave acc.	0.045	-1.249	1.222	1.114	

	mean	min	max	2*std	comment
Roll	0.558	-3.101	3.863	3.119	

	mean	min	max	2*std	comment
Pitch	-0.088	-3.000	2.862	2.618	

	mean	min	max	std	comment
Yaw vel.	0.037	-5.099	4.419	2.002	

	mean	min	max	std	comment
Rudder angle	0.725	-3.667	5.816	1.944	

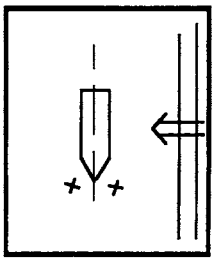
3.3.4 Heading 90°

Table 3.3.4. In column wave the significant wave height, $H_{1/3}$, refers to four times the standard deviation of the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave
no	mean	min	max	std	mean	min	max	std	$H_{1/3}$
73	0.54	0.45	0.60	0.028	91.4	89.8	92.4	0.50	0.142
74	1.37	1.32	1.42	0.024	91.0	90.5	91.6	0.24	0.147
75	1.33	1.27	1.39	0.026	91.2	90.6	92.1	0.36	0.148

Test no 73

The 96.6 seconds measurement is stored on file: *KTHTest73*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0010	-0.0140	0.0009	-0.0006	-0.0239	-0.0025	0.0007	0.0283	0.0031
b	-0.0004	-0.0108	-0.0009	-0.0009	0.0251	-0.0041	0.0029	-0.0002	-0.0008
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1423	0.1389	0.0077

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.003	-0.073	0.093	0.143	
Wave2	-0.003	-0.082	0.075	0.135	

	mean	min	max	std	comment
Heading	91.414	89.840	92.400	0.505	
Forward vel.	0.540	0.449	0.596	0.028	
Surge acc.	-0.005	-0.114	0.088	0.031	
Port vel.	-0.023	-0.338	0.302	0.128	
Sway acc.	-0.004	-0.948	0.703	0.326	

	mean	min	max	2*std	comment
Heave	-0.001	-0.090	0.086	0.074	
Heave acc.	0.041	-1.121	1.215	1.048	

	mean	min	max	2*std	comment
Roll	0.241	-5.634	5.448	4.506	

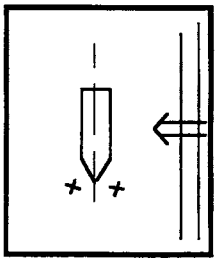
	mean	min	max	2*std	comment
Pitch	0.175	-0.536	0.715	0.429	

	mean	min	max	std	comment
Yaw vel.	0.006	-1.603	1.377	0.428	

	mean	min	max	std	comment
Rudder angle	-0.300	-5.121	3.182	1.361	

Test no 74

The 35.8 seconds measurement is stored on file: *KTHTest74*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0168	0.0144	0.0055	-0.0009	-0.0222	0.0049	-0.0056	-0.0329	0.0217
b	-0.0106	0.0161	-0.0182	-0.0028	-0.0130	-0.0104	-0.0251	0.0701	-0.0115
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1469	0.1449	0.0058

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.078	0.086	0.148	
Wave2	-0.001	-0.079	0.075	0.143	

	mean	min	max	std	comment
Heading	91.045	90.500	91.600	0.240	
Forward vel.	1.367	1.319	1.421	0.024	
Surge acc.	-0.037	-0.113	0.045	0.031	
Port vel.	-0.010	-0.315	0.274	0.128	
Sway acc.	-0.010	-0.721	0.856	0.352	

	mean	min	max	2*std	comment
Heave	-0.006	-0.092	0.075	0.068	
Heave acc.	0.039	-0.834	1.202	0.955	

	mean	min	max	2*std	comment
Roll	0.113	-4.984	5.501	3.921	

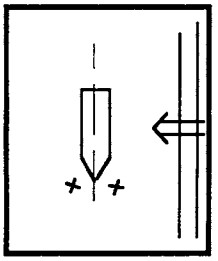
	mean	min	max	2*std	comment
Pitch	0.039	-0.394	0.609	0.414	

	mean	min	max	std	comment
Yaw vel.	-0.014	-0.969	0.922	0.356	

	mean	min	max	std	comment
Rudder angle	0.129	-1.264	1.180	0.420	

Test no 75

The 39.0 seconds measurement is stored on file: *KTHTest75*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	-0.0166	0.0296	0.0029	-0.0027	0.0080	0.0009	0.0004	-0.0017	-0.0027
b	-0.0159	0.0280	-0.0175	-0.0049	0.0404	-0.0003	0.0016	0.0276	-0.0014
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1475	0.1451	0.0062

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.086	0.077	0.148	
Wave2	-0.001	-0.074	0.075	0.139	

	mean	min	max	std	comment
Heading	91.213	90.570	92.110	0.358	
Forward vel.	1.326	1.267	1.389	0.026	
Surge acc.	-0.038	-0.129	0.037	0.035	
Port vel.	-0.016	-0.328	0.274	0.136	
Sway acc.	0.000	-0.729	0.832	0.360	

	mean	min	max	2*std	comment
Heave	-0.005	-0.092	0.075	0.069	
Heave acc.	0.037	-0.948	1.287	0.972	

	mean	min	max	2*std	comment
Roll	0.085	-4.150	4.894	3.902	

	mean	min	max	2*std	comment
Pitch	0.037	-0.534	0.609	0.443	

	mean	min	max	std	comment
Yaw vel.	-0.049	-1.425	1.053	0.409	

	mean	min	max	std	comment
Rudder angle	-0.024	-1.896	1.180	0.561	

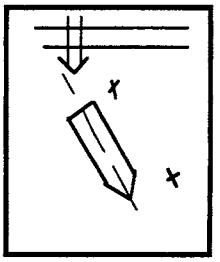
3.3.5 Heading 30°

Table 3.3.5. In column *wave* the significant wave height, $H_{1/3}$, refers to four times the standard deviation of the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave
no	mean	min	max	std	mean	min	max	std	$H_{1/3}$
76	0.46	0.14	0.83	0.154	30.1	26.0	33.5	1.71	0.143
77	0.48	0.15	0.82	0.153	30.6	28.6	32.5	0.82	0.141
78	1.34	0.86	1.76	0.242	31.4	29.9	33.6	0.84	0.156
79	1.31	0.82	1.84	0.239	31.2	29.3	33.9	1.06	0.098
80	1.35	0.85	1.86	0.251	31.7	29.9	33.4	0.84	0.095

Test no 76

The 80.2 seconds measurement is stored on file: *KTHTest76*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	0.0007	0.0046	-0.0016	-0.0032	-0.0204	0.0006	0.0146	-0.0258	-0.0185
b	0.0029	0.0169	-0.0068	-0.0083	-0.0336	0.0025	-0.0244	-0.0104	0.0001
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1428	0.1402	0.0068

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.080	0.108	0.139	
Wave2	-0.002	-0.083	0.077	0.134	

	mean	min	max	std	comment
Heading	30.127	26.050	33.480	1.709	
Forward vel.	0.464	0.145	0.829	0.154	
Surge acc.	-0.005	-0.457	0.459	0.195	
Port vel.	-0.006	-0.133	0.108	0.047	
Sway acc.	-0.003	-0.327	0.304	0.118	

	mean	min	max	2*std	comment
Heave	0.000	-0.044	0.052	0.039	
Heave acc.	0.040	-0.403	0.397	0.333	

	mean	min	max	2*std	comment
Roll	0.390	-3.601	5.868	2.924	

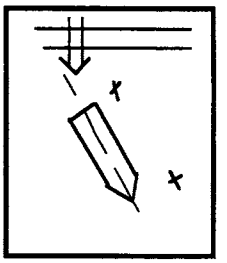
	mean	min	max	2*std	comment
Pitch	0.209	-2.504	3.277	2.438	

	mean	min	max	std	comment
Yaw vel.	-0.017	-4.746	4.272	1.739	

	mean	min	max	std	comment
Rudder angle	-0.183	-10.789	10.852	4.095	

Test no 77

The 79.0 seconds measurement is stored on file: *KTHTest77*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	0.0020	0.0179	-0.0064	-0.0019	-0.0067	0.0024	0.0278	0.0361	-0.0072
b	-0.0004	-0.0036	0.0005	0.0082	0.0395	-0.0009	0.0186	-0.0517	-0.0206
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1408	0.1384	0.0064

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.076	0.099	0.137	
Wave2	-0.001	-0.081	0.090	0.132	

	mean	min	max	std	comment
Heading	30.580	28.570	32.530	0.824	
Forward vel.	0.475	0.147	0.816	0.153	
Surge acc.	0.018	-0.433	0.439	0.190	
Port vel.	-0.010	-0.137	0.094	0.044	
Sway acc.	0.038	-0.221	0.397	0.115	

	mean	min	max	2*std	comment
Heave	0.000	-0.046	0.049	0.039	
Heave acc.	0.039	-0.317	0.470	0.328	

	mean	min	max	2*std	comment
Roll	0.175	-2.796	4.317	2.615	

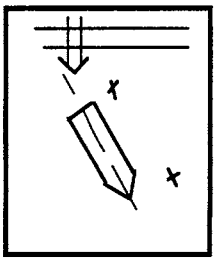
	mean	min	max	2*std	comment
Pitch	0.341	-2.325	2.974	2.357	

	mean	min	max	std	comment
Yaw vel.	0.076	-3.939	3.958	1.749	

	mean	min	max	std	comment
Rudder angle	-1.092	-11.105	9.230	4.263	

Test no 78

The 24.6 seconds measurement is stored on file: *KTHTest78*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3						
a	-0.0116	0.0247	-0.0143						
b	0.0227	-0.0312	-0.0024						
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1559	0.1547	0.0045

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.007	-0.074	0.080	0.133	
Wave2	-0.002	-0.067	0.078	0.124	

	mean	min	max	std	comment
Heading	31.383	29.900	33.560	0.835	
Forward vel.	1.344	0.860	1.759	0.242	
Surge acc.	-0.048	-0.357	0.221	0.146	
Port vel.	-0.018	-0.196	0.132	0.074	
Sway acc.	-0.004	-0.202	0.187	0.084	

	mean	min	max	2*std	comment
Heave	-0.004	-0.045	0.032	0.039	
Heave acc.	0.039	-0.143	0.235	0.167	

	mean	min	max	2*std	comment
Roll	0.363	-5.579	5.730	6.504	

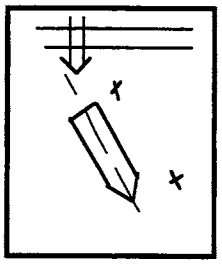
	mean	min	max	2*std	comment
Pitch	-0.041	-1.849	1.481	1.672	

	mean	min	max	std	comment
Yaw vel.	0.215	-3.813	4.487	1.814	

	mean	min	max	std	comment
Rudder angle	-0.331	-6.322	4.109	2.352	

Test no 79

The 25.4 seconds measurement is stored on file: *KTHTest79*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3						
a	0.0049	-0.0301	0.0277						
b	-0.0188	0.0144	0.0089						
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.0985	0.0958	0.0054

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.008	-0.041	0.069	0.100	
Wave2	-0.001	-0.082	0.080	0.154	

	mean	min	max	std	comment
Heading	31.223	29.280	33.940	1.063	
Forward vel.	1.310	0.818	1.836	0.239	
Surge acc.	-0.049	-0.348	0.304	0.153	
Port vel.	-0.014	-0.236	0.168	0.089	
Sway acc.	-0.003	-0.215	0.193	0.094	

	mean	min	max	2*std	comment
Heave	-0.004	-0.042	0.033	0.036	
Heave acc.	0.040	-0.152	0.245	0.178	

	mean	min	max	2*std	comment
Roll	-0.121	-5.659	6.070	5.533	

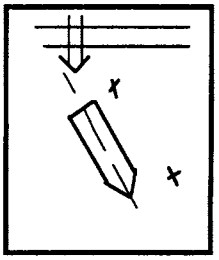
	mean	min	max	2*std	comment
Pitch	-0.046	-1.784	2.049	1.794	

	mean	min	max	std	comment
Yaw vel.	0.035	-4.757	4.631	2.011	

	mean	min	max	std	comment
Rudder angle	-0.130	-6.638	5.036	2.684	

Test no 80

The 24.6 seconds measurement is stored on file: *KTHTest80*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3						
a	0.0121	0.0297	-0.0165						
b	0.0205	0.0079	0.0118						
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.0947	0.0931	0.0042

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.051	0.065	0.104	
Wave2	0.001	-0.076	0.085	0.172	

	mean	min	max	std	comment
Heading	31.710	29.930	33.360	0.836	
Forward vel.	1.348	0.850	1.856	0.251	
Surge acc.	-0.052	-0.365	0.312	0.161	
Port vel.	-0.018	-0.196	0.141	0.081	
Sway acc.	-0.009	-0.178	0.181	0.078	

	mean	min	max	2*std	comment
Heave	-0.004	-0.039	0.035	0.036	
Heave acc.	0.040	-0.255	0.246	0.193	

	mean	min	max	2*std	comment
Roll	0.380	-3.613	5.195	3.772	

	mean	min	max	2*std	comment
Pitch	-0.031	-1.962	2.200	1.915	

	mean	min	max	std	comment
Yaw vel.	0.102	-4.241	4.491	2.099	

	mean	min	max	std	comment
Rudder angle	-0.736	-6.259	4.847	2.651	

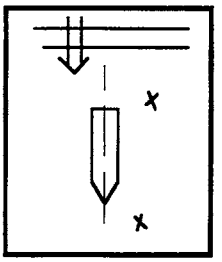
3.3.6 Heading 0°

Table 3.3.6. In column *wave* the significant wave height, $H_{1/3}$, refers to four times the standard deviation of the part of the measurement used to determine the wave equation.

test	model speed				model heading				wave
no	mean	min	max	std	mean	min	max	std	$H_{1/3}$
81	0.45	0.05	0.82	0.172	1.9	-0.4	2.8	0.55	0.146
82	1.32	0.78	1.83	0.250	0.6	0.1	1.1	0.22	0.176
83	1.31	0.76	1.85	0.274	0.5	0.2	0.8	0.16	0.180
84	1.32	0.78	1.86	0.280	0.5	-0.4	0.8	0.22	0.138

Test no 81

The 122.6 seconds measurement is stored on file: *KTHTest81*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3	4	5	6	7	8	9
a	0.0009	-0.0191	0.0044	0.0021	0.0372	-0.0011	-0.0036	-0.0281	0.0061
b	-0.0047	-0.0112	-0.0004	0.0025	0.0005	-0.0029	0.0001	0.0010	0.0011
ω	2.0200	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900
k	0.4903	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1459	0.1431	0.0072

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.091	0.107	0.150	
Wave2	-0.001	-0.084	0.099	0.139	

	mean	min	max	std	comment
Heading	1.871	-0.420	2.830	0.547	
Forward vel.	0.447	0.046	0.817	0.172	
Surge acc.	-0.003	-0.458	0.479	0.199	
Port vel.	0.000	-0.034	0.032	0.012	
Sway acc.	-0.004	-0.077	0.067	0.024	

	mean	min	max	2*std	comment
Heave	-0.001	-0.046	0.044	0.038	
Heave acc.	0.041	-0.336	0.403	0.275	

	mean	min	max	2*std	comment
Roll	0.084	-1.769	1.481	0.933	

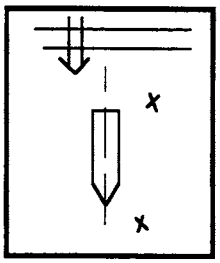
	mean	min	max	2*std	comment
Pitch	0.231	-2.553	3.348	2.462	

	mean	min	max	std	comment
Yaw vel.	-0.009	-0.898	0.780	0.280	

	mean	min	max	std	comment
Rudder angle	-0.774	-4.151	2.128	0.999	

Test no 82

The 34.4 seconds measurement is stored on file: *KTHTest82*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3						
a	0.0185	-0.0070	-0.0297						
b	0.0109	0.0288	0.0153						
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1762	0.1744	0.0058

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.001	-0.076	0.091	0.181	
Wave2	-0.002	-0.065	0.082	0.139	

	mean	min	max	std	comment
Heading	0.634	0.110	1.110	0.222	
Forward vel.	1.316	0.781	1.833	0.250	
Surge acc.	-0.038	-0.310	0.297	0.147	
Port vel.	0.001	-0.034	0.030	0.013	
Sway acc.	-0.001	-0.047	0.045	0.018	

	mean	min	max	2*std	comment
Heave	-0.005	-0.047	0.035	0.036	
Heave acc.	0.042	-0.088	0.194	0.116	

	mean	min	max	2*std	comment
Roll	0.161	-0.794	1.166	0.791	

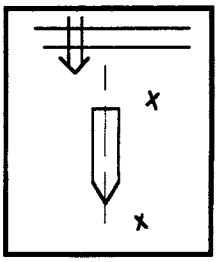
	mean	min	max	2*std	comment
Pitch	0.024	-1.607	1.918	1.688	

	mean	min	max	std	comment
Yaw vel.	-0.007	-1.355	1.165	0.414	

	mean	min	max	std	comment
Rudder angle	-0.138	-1.559	1.433	0.514	

Test no 83

The 38.6 seconds measurement is stored on file: *KTHTest83*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3						
a	0.0145	-0.0429	-0.0314						
b	0.0192	-0.0489	-0.0107						
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1805	0.1768	0.0086

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	-0.001	-0.085	0.086	0.172	
Wave2	-0.002	-0.045	0.052	0.089	

	mean	min	max	std	comment
Heading	0.530	0.170	0.840	0.155	
Forward vel.	1.308	0.757	1.853	0.274	
Surge acc.	-0.035	-0.328	0.291	0.154	
Port vel.	0.001	-0.032	0.033	0.012	
Sway acc.	0.000	-0.046	0.048	0.018	

	mean	min	max	2*std	comment
Heave	-0.004	-0.041	0.032	0.034	
Heave acc.	0.039	-0.131	0.196	0.122	

	mean	min	max	2*std	comment
Roll	0.155	-0.820	1.334	0.851	

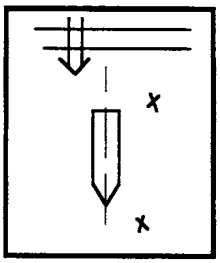
	mean	min	max	2*std	comment
Pitch	0.028	-1.671	1.893	1.808	

	mean	min	max	std	comment
Yaw vel.	-0.006	-0.891	1.002	0.331	

	mean	min	max	std	comment
Rudder angle	0.022	-1.117	1.054	0.391	

Test no 84

The 37.8 seconds measurement is stored on file: *KTHTest84*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	3						
a	-0.0175	0.0339	-0.0049						
b	-0.0105	-0.0107	0.0130						
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Deviation between original signal and equation

meas. sign. wave height [m]	calc. sign. wave height [m]	std of abs.diff. [m]
0.1379	0.1330	0.0082

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.000	-0.060	0.072	0.129	
Wave2	0.002	-0.047	0.039	0.074	

	mean	min	max	std	comment
Heading	0.511	-0.400	0.830	0.219	
Forward vel.	1.323	0.778	1.863	0.280	
Surge acc.	-0.032	-0.351	0.324	0.159	
Port vel.	0.000	-0.031	0.036	0.013	
Sway acc.	-0.002	-0.060	0.044	0.018	

	mean	min	max	2*std	comment
Heave	-0.005	-0.037	0.033	0.034	
Heave acc.	0.041	-0.157	0.211	0.129	

	mean	min	max	2*std	comment
Roll	0.165	-0.878	1.273	0.952	

	mean	min	max	2*std	comment
Pitch	0.078	-1.952	2.231	1.883	

	mean	min	max	std	comment
Yaw vel.	0.016	-0.742	0.811	0.307	

	mean	min	max	std	comment
Rudder angle	0.002	-0.822	0.759	0.361	

3.4 Tests in crossing waves

The crossing seas were built-up by a three-component regular spectrum created at the short side of the basin, and a regular or irregular wave system from the long side.

In the tests three parameters are used to show how the wave equation models the two intersecting wave patterns, *H1/3 x-system* –significant wave height of the system propagating in x-direction, *a (or H1/3) y-system* –amplitude or significant wave height of the system propagating in y-direction, and *wave eq. H1/3* – a value coupled to the above through:

$$4\cdot\sqrt{\left(\frac{H_{1/3}x-\text{system}}{4}\right)^2+\left(\frac{ay-\text{system}}{\sqrt{2}}\right)^2} \text{ or } 4\cdot\sqrt{\left(\frac{H_{1/3}x-\text{system}}{4}\right)^2+\left(\frac{H_{1/3}y-\text{system}}{4}\right)^2}$$

The other three parameters given for each test are the same as for long-crested waves, *meas. H1/3* –significant wave height of the part of the wave height time series used to determine the wave equation, *calc. H1/3* –the corresponding value of the same time series created by the wave equation, and *std. abs. diff.* – the standard deviation of the difference between the original and the calculated time series.

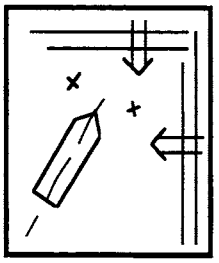
3.4.1 Heading 150°, regular waves crossing irregular

Table 3.4.1. The amplitude value in the column *regular wave* is the calculated value from the determination of the wave equation and the frequency value is the value sent to the wave maker.

test	model speed				model heading				regular wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
87	0.42	0.31	0.54	0.047	142.7	134.6	151.7	4.04	2.07	0.031
88	1.31	1.21	1.41	0.046	149.7	148.7	150.6	0.44	"	0.040
89	1.31	1.20	1.40	0.043	150.0	148.5	151.1	0.75	"	0.035
90	0.38	0.21	0.54	0.072	146.7	141.6	149.7	2.26	3.25	0.040
91	1.35	1.23	1.47	0.051	150.2	148.4	151.5	0.80	"	0.037
92	1.31	1.19	1.42	0.051	150.4	148.6	151.4	0.72	"	0.039
93	0.40	0.15	0.60	0.080	147.7	140.3	160.7	5.22	4.44	0.047
94	1.22	1.10	1.31	0.052	152.3	151.2	153.3	0.48	"	0.040
95	1.27	1.16	1.37	0.047	151.3	149.3	153.0	0.83	"	0.041

Test no 87

The seconds measurement is stored on file: *KTHTest87*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	0.0009		-0.0036	0.0077	-0.0047	0.0049	0.0128	-0.0012	
b	-0.0075		-0.0038	-0.0361	0.0028	-0.0019	0.0109	-0.0049	
c	-0.0019	0.0080							
d	-0.0235	-0.0092							
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1220	0.0310	0.1502	0.1451	0.1374	0.0116

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.087	0.100	0.144	
Wave2	0.001	-0.109	0.127	0.195	

	mean	min	max	std	comment
Heading	142.681	134.600	151.740	4.039	
Forward vel.	0.421	0.313	0.539	0.047	
Surge acc.	-0.003	-0.531	0.475	0.212	
Port vel.	-0.048	-0.122	0.040	0.032	
Sway acc.	0.006	-0.380	0.427	0.146	

	mean	min	max	2*std	comment
Heave	-0.000	-0.081	0.080	0.068	
Heave acc.	0.038	-0.749	0.705	0.566	

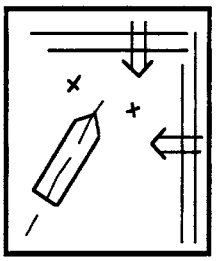
	mean	min	max	2*std	comment
Roll	-0.028	-10.442	10.065	9.301	

	mean	min	max	2*std	comment
Pitch	0.192	-3.722	3.866	3.099	

	mean	min	max	std	comment
Yaw vel.	0.055	-5.498	4.669	1.879	

	mean	min	max	std	comment
Rudder angle	3.721	-7.615	15.440	5.215	

Test no 88



The 24.6 seconds measurement is stored on file: *KTHTest88*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	-0.0048		0.0107	-0.0133	0.0027	-0.0054	-0.0248	0.0056	
b	0.0176		-0.0122	-0.0378	0.0083	0.0011	0.0169	-0.0000	
c	-0.0242	-0.0109							
d	0.0165	0.0053							
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1378	0.0399	0.1781	0.1884	0.1849	0.0091

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.094	0.126	0.185	
Wave2	0.000	-0.089	0.118	0.166	

	mean	min	max	std	comment
Heading	149.685	148.720	150.640	0.437	
Forward vel.	1.310	1.210	1.411	0.046	
Surge acc.	-0.040	-0.454	0.358	0.192	
Port vel.	-0.036	-0.117	0.037	0.040	
Sway acc.	-0.005	-0.336	0.368	0.148	

	mean	min	max	2*std	comment
Heave	-0.004	-0.086	0.084	0.076	
Heave acc.	0.040	-1.095	1.026	0.959	

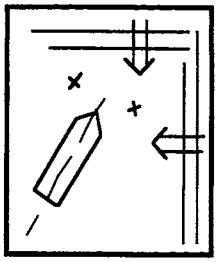
	mean	min	max	2*std	comment
Roll	0.148	-4.424	3.914	4.394	

	mean	min	max	2*std	comment
Pitch	-0.092	-3.385	3.479	3.170	

	mean	min	max	std	comment
Yaw vel.	0.118	-3.609	3.219	1.435	

	mean	min	max	std	comment
Rudder angle	0.828	-2.777	5.364	1.556	

Test no 89



The 25.0 seconds measurement is stored on file: *KTHTest89*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	-0.0100		0.0093	0.0463	-0.0106	-0.0037	-0.0227	0.0015	
b	-0.0148		0.0116	-0.0101	-0.0028	-0.0004	-0.0120	0.0016	
c	0.0237	-0.0009							
d	-0.0189	0.0210							
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1385	0.0347	0.1697	0.1654	0.1617	0.0087

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.002	-0.101	0.115	0.164	
Wave2	0.002	-0.101	0.107	0.178	

	mean	min	max	std	comment
Heading	149.984	148.530	151.050	0.753	
Forward vel.	1.306	1.197	1.405	0.043	
Surge acc.	-0.050	-0.519	0.410	0.191	
Port vel.	-0.036	-0.099	0.025	0.029	
Sway acc.	0.001	-0.260	0.341	0.135	

	mean	min	max	2*std	comment
Heave	-0.005	-0.087	0.100	0.077	
Heave acc.	0.047	-1.156	1.151	0.925	

	mean	min	max	2*std	comment
Roll	0.187	-4.858	5.186	4.518	

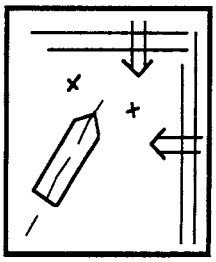
	mean	min	max	2*std	comment
Pitch	-0.155	-4.206	3.347	3.130	

	mean	min	max	std	comment
Yaw vel.	0.102	-3.149	3.363	1.358	

	mean	min	max	std	comment
Rudder angle	1.181	-3.534	5.049	1.677	

Test no 90

The 83.0 seconds measurement is stored on file: *KTHTest90*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	0.0147	0.0104	-0.0018	-0.0005	-0.0038	-0.0038	-0.0009		
b	-0.0103	-0.0068	0.0194	0.0002	0.0020	-0.0216	0.0012		
c			0.0104	-0.0069					
d			0.0026	-0.0412					
ω	2.0700	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900		
k	0.5077	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552		

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1112	0.0405	0.1596	0.1404	0.1353	0.0094

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.074	0.095	0.141	
Wave2	0.000	-0.068	0.069	0.109	

	mean	min	max	std	comment
Heading	146.728	141.600	149.690	2.259	
Forward vel.	0.383	0.212	0.543	0.072	
Surge acc.	-0.001	-0.650	0.635	0.328	
Port vel.	-0.033	-0.169	0.116	0.062	
Sway acc.	0.002	-0.292	0.319	0.137	

	mean	min	max	2*std	comment
Heave	0.001	-0.086	0.099	0.087	
Heave acc.	0.041	-1.049	0.990	0.921	

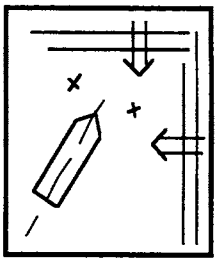
	mean	min	max	2*std	comment
Roll	0.031	-5.757	6.211	4.568	

	mean	min	max	2*std	comment
Pitch	0.175	-4.445	5.190	4.628	

	mean	min	max	std	comment
Yaw vel.	0.083	-3.657	3.016	1.289	

	mean	min	max	std	comment
Rudder angle	4.927	-5.637	14.935	3.826	

Test no 91



The 24.6 seconds measurement is stored on file: *KTHTest91*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	-0.0194	-0.0109	-0.0051	-0.0087	0.0055	0.0027	-0.0067		
b	-0.0014	0.0121	-0.0154	-0.0123	-0.0031	-0.0340	0.0037		
c			0.0019	0.0123					
d			-0.0036	0.0359					
ω	2.0700	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900		
k	0.5077	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552		

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1381	0.0374	0.1740	0.1726	0.1699	0.0072

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.097	0.107	0.173	
Wave2	-0.000	-0.085	0.129	0.179	

	mean	min	max	std	comment
Heading	150.207	148.450	151.490	0.804	
Forward vel.	1.346	1.229	1.469	0.051	
Surge acc.	-0.047	-0.542	0.455	0.206	
Port vel.	-0.029	-0.122	0.053	0.041	
Sway acc.	0.004	-0.438	0.508	0.235	

	mean	min	max	2*std	comment
Heave	-0.004	-0.097	0.078	0.074	
Heave acc.	0.035	-1.366	1.279	1.185	

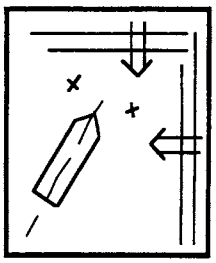
	mean	min	max	2*std	comment
Roll	0.203	-3.370	2.727	2.577	

	mean	min	max	2*std	comment
Pitch	-0.136	-4.238	3.534	3.392	

	mean	min	max	std	comment
Yaw vel.	0.115	-4.404	4.296	1.867	

	mean	min	max	std	comment
Rudder angle	0.862	-3.765	6.374	2.099	

Test no 92



The 23.8 seconds measurement is stored on file: *KTHTest92*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	0.0189	-0.0060	-0.0167	-0.0077	-0.0010	0.0003	0.0064		
b	0.0035	0.0057	-0.0147	-0.0066	-0.0008	0.0325	0.0004		
c			0.0014	-0.0009					
d			-0.0094	0.0450					
ω	2.0700	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900		
k	0.5077	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552		

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1381	0.0390	0.1767	0.1741	0.1714	0.0076

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.114	0.088	0.170	
Wave2	0.000	-0.103	0.106	0.169	

	mean	min	max	std	comment
Heading	150.355	148.550	151.430	0.725	
Forward vel.	1.312	1.186	1.416	0.051	
Surge acc.	-0.051	-0.603	0.431	0.215	
Port vel.	-0.035	-0.106	0.045	0.039	
Sway acc.	0.010	-0.456	0.528	0.230	

	mean	min	max	2*std	comment
Heave	-0.005	-0.100	0.074	0.078	
Heave acc.	0.047	-1.370	1.409	1.215	

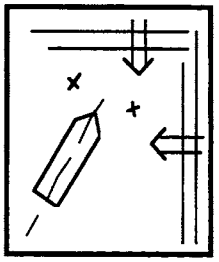
	mean	min	max	2*std	comment
Roll	0.184	-2.521	3.730	3.444	

	mean	min	max	2*std	comment
Pitch	-0.166	-4.172	3.906	3.536	

	mean	min	max	std	comment
Yaw vel.	0.141	-4.725	4.135	1.912	

	mean	min	max	std	comment
Rudder angle	0.622	-3.891	5.743	2.059	

Test no 93



The 84.8 seconds measurement is stored on file: *KTHTest93*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	-0.0132	0.0041	0.0015		0.0170				
b	-0.0109	-0.0365	-0.0001		0.0078				
c				-0.0022	0.0011	0.0200			
d				-0.0049	0.0018	-0.0414			
ω	2.0700	3.2500	3.3000	4.3900	4.4400	4.4900			
k	0.5077	1.0852	1.1175	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1268	0.0470	0.1837	0.1923	0.1815	0.0157

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.102	0.156	0.189	
Wave2	0.001	-0.123	0.141	0.182	

	mean	min	max	std	comment
Heading	147.723	140.310	160.690	5.215	
Forward vel.	0.396	0.146	0.596	0.080	
Surge acc.	-0.005	-0.678	0.615	0.245	
Port vel.	0.029	-0.113	0.151	0.049	
Sway acc.	-0.003	-0.547	0.608	0.227	

	mean	min	max	2*std	comment
Heave	-0.000	-0.073	0.081	0.059	
Heave acc.	0.042	-1.022	1.064	0.837	

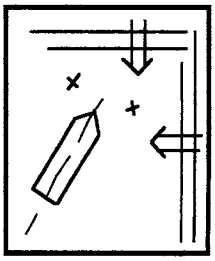
	mean	min	max	2*std	comment
Roll	-0.231	-8.319	6.962	4.653	

	mean	min	max	2*std	comment
Pitch	0.124	-4.733	5.254	3.868	

	mean	min	max	std	comment
Yaw vel.	-0.030	-6.873	7.115	2.902	

	mean	min	max	std	comment
Rudder angle	-0.995	-17.985	16.429	7.065	

Test no 94



The 26.6 seconds measurement is stored on file: *KTHTest94*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	-0.0172	-0.0147	-0.0263	0.0050	0.0161				
b	-0.0064	-0.0098	-0.0081	-0.0029	-0.0207				
c					0.0014	-0.0060			
d					0.0000	0.0394			
ω	2.0700	3.2000	3.2500	3.3000	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.1175	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1414	0.0404	0.1818	0.1899	0.1854	0.0103

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.003	-0.100	0.117	0.186	
Wave2	0.000	-0.084	0.106	0.180	

	mean	min	max	std	comment
Heading	152.256	151.160	153.340	0.482	
Forward vel.	1.221	1.099	1.314	0.052	
Surge acc.	-0.032	-0.622	0.444	0.224	
Port vel.	0.032	-0.063	0.102	0.033	
Sway acc.	0.019	-0.460	0.528	0.242	

	mean	min	max	2*std	comment
Heave	-0.002	-0.089	0.087	0.076	
Heave acc.	0.051	-1.812	1.439	1.655	

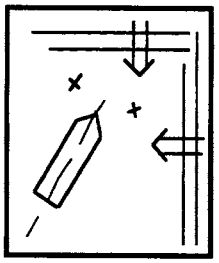
	mean	min	max	2*std	comment
Roll	-0.722	-4.171	2.674	2.833	

	mean	min	max	2*std	comment
Pitch	-0.159	-5.405	4.497	4.181	

	mean	min	max	std	comment
Yaw vel.	-0.031	-5.888	4.761	2.403	

	mean	min	max	std	comment
Rudder angle	-1.015	-5.701	4.081	2.110	

Test no 95



The 25.8 seconds measurement is stored on file: *KTHTest95*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no

	1	2	3	4	5	6	7	8	9
a	-0.0129	-0.0186	-0.0247	0.0091	0.0268				
b	0.0115	-0.0133	0.0036	-0.0078	0.0077				
c					0.0053	0.0321			
d					-0.0030	-0.0168			
ω	2.0700	3.2000	3.2500	3.3000	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.1175	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1397	0.0410	0.1816	0.1864	0.1823	0.0095

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.003	-0.101	0.116	0.188	
Wave2	0.001	-0.108	0.103	0.180	

	mean	min	max	std	comment
Heading	151.296	149.340	152.990	0.834	
Forward vel.	1.274	1.162	1.370	0.047	
Surge acc.	-0.044	-0.548	0.456	0.211	
Port vel.	0.034	-0.054	0.129	0.032	
Sway acc.	0.009	-0.497	0.549	0.245	

	mean	min	max	2*std	comment
Heave	-0.002	-0.077	0.092	0.072	
Heave acc.	0.037	-1.786	1.617	1.590	

	mean	min	max	2*std	comment
Roll	-0.706	-4.622	3.105	2.978	

	mean	min	max	2*std	comment
Pitch	-0.221	-5.073	3.984	3.927	

	mean	min	max	std	comment
Yaw vel.	-0.015	-5.814	5.585	2.545	

	mean	min	max	std	comment
Rudder angle	-1.169	-5.848	3.660	2.193	

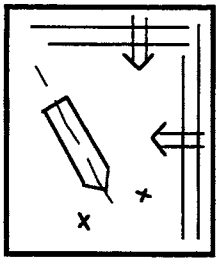
3.4.2 Heading 30°, regular wave crossing irregular

Table 3.4.2. The amplitude value in the column *regular wave* is the calculated value from the determination of the wave equation and the frequency value is the value sent to the wave maker.

test	model speed				model heading				regular wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
96	0.50	0.12	0.89	0.160	31.5	26.8	38.8	3.44	2.07	0.042
97	0.45	0.06	0.89	0.169	34.4	29.0	42.2	3.62	"	0.040
98	1.31	0.84	1.79	0.250	30.3	27.5	33.0	1.37	"	0.042
99	1.30	0.83	1.86	0.247	30.0	26.8	33.9	1.74	"	0.042
100	1.30	0.84	1.73	0.232	30.7	28.8	34.1	0.96	"	0.043
101	0.44	0.02	0.79	0.162	29.5	24.7	36.3	2.87	3.25	0.041
102	0.50	0.11	0.87	0.167	31.4	23.0	37.4	3.91	"	0.039
103	1.28	0.68	1.86	0.274	31.0	28.6	33.8	1.30	"	0.038
104	1.32	0.75	1.90	0.273	30.7	28.6	33.2	1.15	"	0.038
105	1.33	0.93	1.80	0.235	30.9	28.9	32.7	0.87	"	0.036
106	0.33	-0.01	0.72	0.154	27.4	20.1	33.5	3.23	4.44	0.051
107	0.42	0.02	0.86	0.172	29.5	20.2	37.7	4.96	"	0.044
108a	0.46	0.12	0.79	0.151	25.0	17.4	29.9	3.49	"	0.049
108b	0.38	-0.01	0.78	0.177	33.3	26.4	40.3	4.10	"	0.056
109	1.35	0.95	1.85	0.221	29.6	28.1	31.3	0.72	"	0.041
110	1.31	0.88	1.70	0.220	29.3	27.3	31.0	0.71	"	0.041
111	1.29	0.84	1.78	0.247	29.2	27.3	31.1	0.80	"	0.042

Test no 96

The 73.4 seconds measurement is stored on file: *KTHTest96*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	-0.0168		-0.0029	-0.0203	0.0045	-0.0056	0.0162	0.0035	
b	0.0017		-0.0071	-0.0293	0.0054	0.0019	0.0216	0.0020	
c	-0.0293	0.0025							
d	0.0033	-0.0180							
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1314	0.0416	0.1764	0.1805	0.1746	0.0115

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.105	0.124	0.178	
Wave2	0.001	-0.109	0.090	0.156	

	mean	min	max	std	comment
Heading	31.519	26.820	38.790	3.440	
Forward vel.	0.500	0.122	0.886	0.160	
Surge acc.	-0.008	-0.498	0.411	0.194	
Port vel.	-0.007	-0.213	0.199	0.081	
Sway acc.	0.003	-0.371	0.305	0.146	

	mean	min	max	2*std	comment
Heave	-0.001	-0.078	0.069	0.064	
Heave acc.	0.040	-0.543	0.607	0.452	

	mean	min	max	2*std	comment
Roll	0.403	-8.361	10.408	8.605	

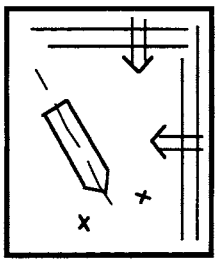
	mean	min	max	2*std	comment
Pitch	0.199	-2.849	2.709	2.418	

	mean	min	max	std	comment
Yaw vel.	-0.122	-4.887	4.963	1.914	

	mean	min	max	std	comment
Rudder angle	-1.001	-12.853	11.969	5.307	

Test no 97

The 82.2 seconds measurement is stored on file: *KTHTest97*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	-0.0135		0.0042	0.0079	-0.0015	0.0018	-0.0169	0.0009	
b	0.0143		-0.0086	-0.0394	0.0031	0.0001	0.0103	0.0018	
c	0.0129	-0.0177							
d	0.0267	-0.0027							
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1328	0.0403	0.1750	0.1811	0.1744	0.0122

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.110	0.130	0.183	
Wave2	0.000	-0.113	0.113	0.164	

	mean	min	max	std	comment
Heading	34.408	28.960	42.200	3.623	
Forward vel.	0.450	0.058	0.888	0.169	
Surge acc.	-0.007	-0.503	0.475	0.207	
Port vel.	-0.019	-0.252	0.162	0.082	
Sway acc.	0.004	-0.467	0.433	0.149	

	mean	min	max	2*std	comment
Heave	-0.001	-0.078	0.082	0.064	
Heave acc.	0.041	-0.587	0.640	0.448	

	mean	min	max	2*std	comment
Roll	0.541	-9.601	10.698	8.686	

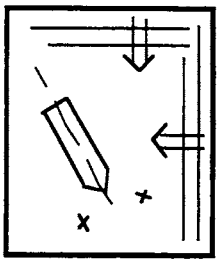
	mean	min	max	2*std	comment
Pitch	0.204	-2.818	3.292	2.583	

	mean	min	max	std	comment
Yaw vel.	-0.041	-5.361	5.202	2.054	

	mean	min	max	std	comment
Rudder angle	-3.422	-19.542	10.770	6.149	

Test no 98

The 25.0 seconds measurement is stored on file: *KTHTest98*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0137	0.0149	-0.0276						
b	-0.0111	0.0326	-0.0102						
c	0.0236								
d	-0.0345								
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1556	0.0418	0.1954	0.1973	0.1940	0.0091

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.007	-0.089	0.093	0.162	
Wave2	-0.001	-0.089	0.098	0.193	

	mean	min	max	std	comment
Heading	30.329	27.450	32.990	1.368	
Forward vel.	1.305	0.837	1.788	0.250	
Surge acc.	-0.050	-0.382	0.351	0.169	
Port vel.	-0.011	-0.261	0.224	0.119	
Sway acc.	-0.012	-0.365	0.330	0.155	

	mean	min	max	2*std	comment
Heave	-0.004	-0.074	0.054	0.063	
Heave acc.	0.037	-0.377	0.463	0.397	

	mean	min	max	2*std	comment
Roll	0.194	-4.759	6.107	5.597	

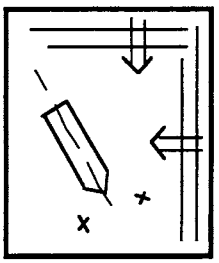
	mean	min	max	2*std	comment
Pitch	-0.052	-2.192	2.519	2.038	

	mean	min	max	std	comment
Yaw vel.	0.174	-4.912	4.196	2.018	

	mean	min	max	std	comment
Rudder angle	-0.201	-6.311	5.112	2.818	

Test no 99

The 24.6 seconds measurement is stored on file: *KTHTest99*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0152	0.0234	-0.0163						
b	0.0013	-0.0283	0.0212						
c	0.0193								
d	-0.0374								
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1689	0.0417	0.2060	0.2214	0.2176	0.0100

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.067	0.084	0.159	
Wave2	-0.003	-0.104	0.107	0.222	

	mean	min	max	std	comment
Heading	29.996	26.750	33.880	1.741	
Forward vel.	1.296	0.826	1.861	0.247	
Surge acc.	-0.043	-0.400	0.373	0.169	
Port vel.	-0.013	-0.238	0.216	0.108	
Sway acc.	-0.009	-0.322	0.318	0.129	

	mean	min	max	2*std	comment
Heave	-0.005	-0.067	0.055	0.057	
Heave acc.	0.037	-0.461	0.500	0.384	

	mean	min	max	2*std	comment
Roll	-0.056	-5.271	5.635	5.130	

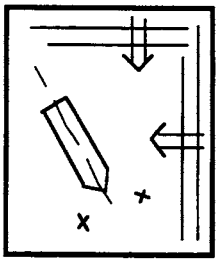
	mean	min	max	2*std	comment
Pitch	-0.028	-2.146	2.626	2.022	

	mean	min	max	std	comment
Yaw vel.	0.222	-5.257	5.206	1.954	

	mean	min	max	std	comment
Rudder angle	-0.012	-7.993	5.785	3.015	

Test no 100

The 25.4 seconds measurement is stored on file: *KTHTest100*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0115	0.0332	-0.0039						
b	0.0083	0.0114	-0.0249						
c	-0.0237								
d	-0.0359								
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1544	0.0429	0.1964	0.2012	0.1986	0.0079

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.099	0.107	0.167	
Wave2	-0.001	-0.105	0.114	0.198	

	mean	min	max	std	comment
Heading	30.744	28.820	34.120	0.958	
Forward vel.	1.299	0.841	1.732	0.232	
Surge acc.	-0.049	-0.451	0.306	0.166	
Port vel.	-0.016	-0.288	0.185	0.103	
Sway acc.	0.004	-0.405	0.324	0.140	

	mean	min	max	2*std	comment
Heave	-0.004	-0.071	0.066	0.062	
Heave acc.	0.035	-0.458	0.535	0.406	

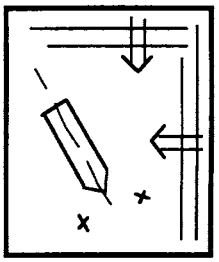
	mean	min	max	2*std	comment
Roll	-0.197	-6.942	7.700	6.506	

	mean	min	max	2*std	comment
Pitch	-0.056	-2.475	2.082	1.997	

	mean	min	max	std	comment
Yaw vel.	-0.060	-5.628	4.038	1.976	

	mean	min	max	std	comment
Rudder angle	-0.422	-7.573	5.574	2.550	

Test no 101



The 84.6 seconds measurement is stored on file: *KTHTest101*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	-0.0037	0.0030	0.0087	0.0326	-0.0059	-0.0079	-0.0066	0.0081	
b	-0.0168	0.0035	0.0022	0.0137	-0.0042	0.0097	-0.0067	0.0029	
c			0.0016	0.0004	-0.0394				
d			-0.0020	-0.0049	-0.0161				
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1384	0.0406	0.1798	0.1919	0.1887	0.0087

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.114	0.122	0.190	
Wave2	0.001	-0.095	0.113	0.172	

	mean	min	max	std	comment
Heading	29.464	24.710	36.340	2.869	
Forward vel.	0.441	0.023	0.788	0.162	
Surge acc.	-0.010	-0.619	0.610	0.234	
Port vel.	-0.019	-0.257	0.225	0.107	
Sway acc.	-0.005	-0.507	0.529	0.228	

	mean	min	max	2*std	comment
Heave	-0.001	-0.079	0.070	0.065	
Heave acc.	0.039	-0.698	0.760	0.653	

	mean	min	max	2*std	comment
Roll	0.508	-6.432	7.429	4.973	

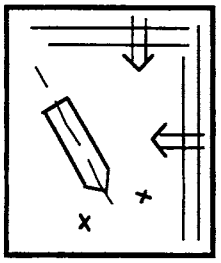
	mean	min	max	2*std	comment
Pitch	0.174	-3.635	4.032	2.978	

	mean	min	max	std	comment
Yaw vel.	0.151	-5.779	6.565	2.239	

	mean	min	max	std	comment
Rudder angle	-0.694	-17.375	16.155	7.081	

Test no 102

The 74.2 seconds measurement is stored on file: *KTHTest102*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0138	-0.0060	0.0118	0.0252	-0.0022	0.0015	-0.0414	-0.0214	
b	-0.0118	0.0024	0.0004	0.0187	-0.0053	-0.0213	-0.0229	0.0038	
c	-0.0049	-0.0185							
d	0.0030	0.0360							
ω	2.0700	2.1200	3.2000	3.2500	3.3000	4.3900	4.4400	4.4900	
k	0.5077	0.5256	1.0536	1.0852	1.1175	1.9647	2.0097	2.0552	

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1259	0.0393	0.1679	0.1602	0.1575	0.0072

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.104	0.113	0.173	
Wave2	0.001	-0.100	0.110	0.159	

	mean	min	max	std	comment
Heading	31.400	22.950	37.440	3.908	
Forward vel.	0.502	0.107	0.875	0.167	
Surge acc.	-0.018	-0.676	0.555	0.273	
Port vel.	-0.012	-0.263	0.232	0.105	
Sway acc.	-0.007	-0.438	0.441	0.183	

	mean	min	max	2*std	comment
Heave	-0.000	-0.077	0.077	0.061	
Heave acc.	0.038	-0.684	0.770	0.585	

	mean	min	max	2*std	comment
Roll	0.747	-3.598	7.343	3.973	

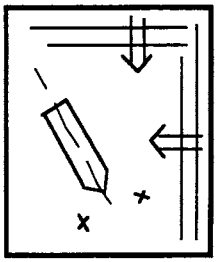
	mean	min	max	2*std	comment
Pitch	0.139	-3.960	3.799	3.494	

	mean	min	max	std	comment
Yaw vel.	0.141	-6.325	6.260	2.855	

	mean	min	max	std	comment
Rudder angle	-2.008	-15.335	14.199	5.912	

Test no 103

The 24.6 seconds measurement is stored on file: *KTHTest103*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0174	-0.0420	-0.0158						
b	0.0098	0.0018	-0.0133						
c		0.0098							
d		-0.0364							
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1384	0.0377	0.1747	0.1844	0.1728	0.0161

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.008	-0.087	0.086	0.158	
Wave2	-0.001	-0.116	0.104	0.180	

	mean	min	max	std	comment
Heading	30.987	28.590	33.830	1.300	
Forward vel.	1.279	0.676	1.858	0.274	
Surge acc.	-0.046	-0.466	0.551	0.232	
Port vel.	-0.020	-0.272	0.230	0.118	
Sway acc.	-0.003	-0.426	0.450	0.215	

	mean	min	max	2*std	comment
Heave	-0.005	-0.070	0.075	0.068	
Heave acc.	0.046	-0.684	0.685	0.770	

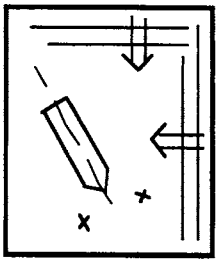
	mean	min	max	2*std	comment
Roll	0.177	-7.678	7.692	6.761	

	mean	min	max	2*std	comment
Pitch	-0.037	-3.059	3.616	3.017	

	mean	min	max	std	comment
Yaw vel.	0.056	-5.118	7.473	2.922	

	mean	min	max	std	comment
Rudder angle	-0.107	-8.162	5.995	3.388	

Test no 104



The 25.4 seconds measurement is stored on file: *KTHTest104*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0128	0.0063	-0.0276						
b	0.0098	0.0441	0.0029						
c		-0.0341							
d		0.0175							
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1436	0.0384	0.1800	0.2033	0.1908	0.0175

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.009	-0.079	0.103	0.171	
Wave2	-0.000	-0.095	0.132	0.200	

	mean	min	max	std	comment
Heading	30.719	28.650	33.200	1.153	
Forward vel.	1.320	0.745	1.897	0.273	
Surge acc.	-0.048	-0.575	0.413	0.229	
Port vel.	-0.023	-0.312	0.172	0.115	
Sway acc.	-0.007	-0.460	0.378	0.213	

	mean	min	max	2*std	comment
Heave	-0.005	-0.084	0.069	0.069	
Heave acc.	0.045	-0.773	0.764	0.815	

	mean	min	max	2*std	comment
Roll	0.167	-4.849	5.811	5.045	

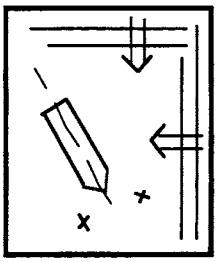
	mean	min	max	2*std	comment
Pitch	-0.054	-3.556	2.990	3.045	

	mean	min	max	std	comment
Yaw vel.	0.146	-7.749	4.691	2.876	

	mean	min	max	std	comment
Rudder angle	-0.255	-7.026	7.446	3.355	

Test no 105

The 24.6 seconds measurement is stored on file: *KTHTest105*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0142	-0.0009	-0.0011						
b	-0.0100	0.0420	-0.0194						
c	-0.0102								
d	0.0340								
ω	2.0700	3.2500	4.4400						
k	0.5077	1.0852	2.0097						

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1593	0.0356	0.1884	0.2021	0.1866	0.0184

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.008	-0.085	0.084	0.160	
Wave2	-0.004	-0.113	0.109	0.204	

	mean	min	max	std	comment
Heading	30.949	28.900	32.710	0.872	
Forward vel.	1.327	0.928	1.800	0.235	
Surge acc.	-0.062	-0.468	0.401	0.198	
Port vel.	-0.015	-0.237	0.271	0.117	
Sway acc.	-0.005	-0.389	0.473	0.219	

	mean	min	max	2*std	comment
Heave	-0.004	-0.080	0.069	0.068	
Heave acc.	0.040	-0.723	0.802	0.805	

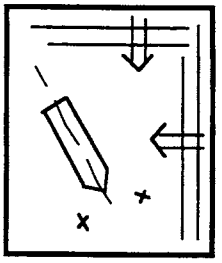
	mean	min	max	2*std	comment
Roll	0.194	-6.459	7.594	7.457	

	mean	min	max	2*std	comment
Pitch	-0.155	-3.008	2.994	2.660	

	mean	min	max	std	comment
Yaw vel.	-0.021	-4.963	4.825	2.264	

	mean	min	max	std	comment
Rudder angle	-0.231	-6.268	5.448	2.725	

Test no 106



The 97.4 seconds measurement is stored on file: *KTHTest106*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	-0.0148	0.0382	0.0015		-0.0205				
b	-0.0132	-0.0137	0.0018		0.0113				
c				0.0067	0.0148	0.0226			
d				0.0052	-0.0023	-0.0504			
ω	2.0700	3.2500	3.3000	4.3900	4.4400	4.4900			
k	0.5077	1.0852	1.1175	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1440	0.0510	0.2038	0.2111	0.2047	0.0128

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.121	0.143	0.209	
Wave2	0.001	-0.102	0.119	0.191	

	mean	min	max	std	comment
Heading	27.353	20.120	33.470	3.230	
Forward vel.	0.327	-0.014	0.716	0.154	
Surge acc.	-0.006	-0.702	0.733	0.280	
Port vel.	-0.070	-0.299	0.133	0.090	
Sway acc.	0.001	-0.572	0.662	0.262	

	mean	min	max	2*std	comment
Heave	0.000	-0.075	0.082	0.061	
Heave acc.	0.041	-0.930	1.056	0.832	

	mean	min	max	2*std	comment
Roll	0.607	-8.417	10.926	7.212	

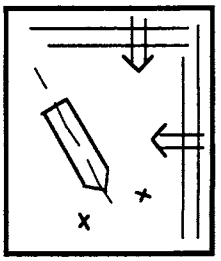
	mean	min	max	2*std	comment
Pitch	0.196	-4.807	5.293	3.977	

	mean	min	max	std	comment
Yaw vel.	0.153	-7.765	7.414	3.010	

	mean	min	max	std	comment
Rudder angle	0.988	-14.493	14.514	7.184	

Test no 107

The 80.8 seconds measurement is stored on file: *KTHTest107*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	-0.0147	-0.0056	0.0011		0.0276				
b	-0.0141	0.0404	0.0002		0.0025				
c				0.0062	0.0023	-0.0474			
d				-0.0015	-0.0140	-0.0109			
ω	2.0700	3.2500	3.3000	4.3900	4.4400	4.4900			
k	0.5077	1.0852	1.1175	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1512	0.0435	0.1949	0.2035	0.1955	0.0140

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.104	0.138	0.204	
Wave2	0.000	-0.116	0.122	0.200	

	mean	min	max	std	comment
Heading	29.501	20.250	37.670	4.964	
Forward vel.	0.424	0.015	0.857	0.172	
Surge acc.	-0.012	-0.627	0.765	0.275	
Port vel.	-0.076	-0.306	0.105	0.089	
Sway acc.	-0.006	-0.514	0.692	0.251	

	mean	min	max	2*std	comment
Heave	-0.000	-0.066	0.076	0.060	
Heave acc.	0.041	-0.922	0.927	0.790	

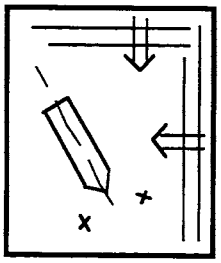
	mean	min	max	2*std	comment
Roll	0.649	-8.463	7.937	5.758	

	mean	min	max	2*std	comment
Pitch	0.126	-4.312	5.499	3.956	

	mean	min	max	std	comment
Yaw vel.	0.156	-7.627	7.821	3.060	

	mean	min	max	std	comment
Rudder angle	3.430	-10.791	18.069	6.298	

Test no 108a



The 48.0 seconds measurement is stored on file: *KTHTest108a*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0028	0.0004	-0.0058	0.0032	0.0156				
b	0.0132	0.0139	-0.0164	-0.0128	0.0091				
c					0.0126	-0.0370			
d					0.0026	-0.0442			
ω	2.0700	3.2000	3.2500	3.3000	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.1175	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1167	0.0488	0.1807	0.1871	0.1818	0.0111

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.107	0.123	0.198	
Wave2	0.001	-0.114	0.105	0.189	

	mean	min	max	std	comment
Heading	25.047	17.390	29.930	3.489	
Forward vel.	0.457	0.125	0.790	0.151	
Surge acc.	-0.009	-0.641	0.550	0.263	
Port vel.	-0.059	-0.271	0.133	0.085	
Sway acc.	-0.004	-0.520	0.596	0.268	

	mean	min	max	2*std	comment
Heave	0.000	-0.064	0.067	0.059	
Heave acc.	0.040	-0.865	1.000	0.869	

	mean	min	max	2*std	comment
Roll	0.699	-8.071	10.541	6.396	

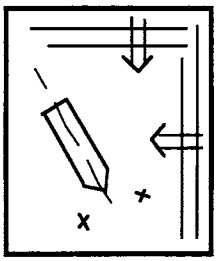
	mean	min	max	2*std	comment
Pitch	0.163	-4.127	4.293	3.725	

	mean	min	max	std	comment
Yaw vel.	0.140	-8.024	6.474	2.916	

	mean	min	max	std	comment
Rudder angle	-0.405	-16.155	18.574	7.819	

Test no 108b

The 37.8 seconds measurement is stored on file: *KTHTest108b*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0177	0.0030	-0.0604	0.0186	-0.0109				
b	-0.0133	-0.0082	0.0036	0.0005	-0.0006				
c					0.0026	-0.0582			
d					-0.0042	-0.0136			
ω	2.0700	3.2000	3.2500	3.3000	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.1175	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1379	0.0560	0.2100	0.2134	0.2092	0.0104

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.125	0.136	0.217	
Wave2	-0.000	-0.106	0.122	0.209	

	mean	min	max	std	comment
Heading	33.288	26.400	40.310	4.101	
Forward vel.	0.380	-0.009	0.779	0.177	
Surge acc.	-0.015	-0.686	0.528	0.281	
Port vel.	-0.093	-0.281	0.110	0.089	
Sway acc.	-0.010	-0.512	0.548	0.239	

	mean	min	max	2*std	comment
Heave	-0.001	-0.076	0.053	0.062	
Heave acc.	0.041	-0.892	0.918	0.772	

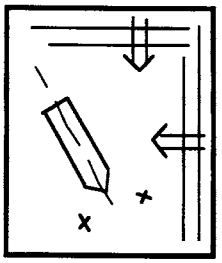
	mean	min	max	2*std	comment
Roll	0.819	-4.857	9.401	5.213	

	mean	min	max	2*std	comment
Pitch	0.097	-4.538	4.180	4.113	

	mean	min	max	std	comment
Yaw vel.	0.319	-7.466	7.112	3.076	

	mean	min	max	std	comment
Rudder angle	9.457	-2.651	22.907	6.170	

Test no 109



The 24.6 seconds measurement is stored on file: *KTHTest109*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0117	0.0211	-0.0174						
b	-0.0191	0.0406	0.0076						
c			0.0037	-0.0430					
d			-0.0003	-0.0087					
ω	2.0700	3.2500	4.4400	4.4900					
k	0.5077	1.0852	2.0097	2.0552					

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1659	0.0407	0.2019	0.2068	0.2035	0.0088

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.086	0.100	0.156	
Wave2	-0.001	-0.112	0.107	0.207	

	mean	min	max	std	comment
Heading	29.609	28.060	31.320	0.725	
Forward vel.	1.350	0.947	1.845	0.221	
Surge acc.	-0.053	-0.391	0.429	0.172	
Port vel.	-0.080	-0.324	0.131	0.090	
Sway acc.	-0.013	-0.524	0.537	0.243	

	mean	min	max	2*std	comment
Heave	-0.004	-0.075	0.069	0.065	
Heave acc.	0.036	-1.187	1.058	1.383	

	mean	min	max	2*std	comment
Roll	0.933	-4.961	5.747	4.745	

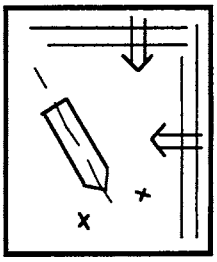
	mean	min	max	2*std	comment
Pitch	-0.212	-3.305	3.528	3.111	

	mean	min	max	std	comment
Yaw vel.	0.208	-5.936	6.039	2.582	

	mean	min	max	std	comment
Rudder angle	1.599	-5.006	7.552	2.503	

Test no 110

The 24.2 seconds measurement is stored on file: *KTHTest110*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0056	-0.0199	0.0267						
b	0.0166	-0.0203	-0.0118						
c			-0.0052	0.0264					
d			-0.0042	0.0381					
ω	2.0700	3.2500	4.4400	4.4900					
k	0.5077	1.0852	2.0097	2.0552					

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1580	0.0408	0.1957	0.1984	0.1943	0.0096

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.093	0.107	0.164	
Wave2	-0.003	-0.105	0.117	0.202	

	mean	min	max	std	comment
Heading	29.275	27.340	31.040	0.713	
Forward vel.	1.305	0.882	1.704	0.220	
Surge acc.	-0.045	-0.417	0.447	0.184	
Port vel.	-0.076	-0.329	0.158	0.092	
Sway acc.	-0.017	-0.514	0.502	0.255	

	mean	min	max	2*std	comment
Heave	-0.003	-0.077	0.071	0.065	
Heave acc.	0.028	-1.277	1.078	1.384	

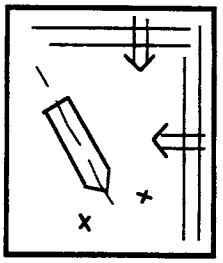
	mean	min	max	2*std	comment
Roll	0.894	-4.064	6.043	4.703	

	mean	min	max	2*std	comment
Pitch	-0.166	-3.351	3.796	3.246	

	mean	min	max	std	comment
Yaw vel.	0.124	-5.587	5.576	2.556	

	mean	min	max	std	comment
Rudder angle	1.920	-5.154	7.909	2.477	

Test no 111



The 24.6 seconds measurement is stored on file: *KTHTest111*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0153	-0.0372	0.0158						
b	0.0117	-0.0123	0.0235						
c			-0.0004	-0.0175					
d			-0.0101	0.0478					
ω	2.0700	3.2500	4.4400	4.4900					
k	0.5077	1.0852	2.0097	2.0552					

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1377	0.0425	0.1828	0.1851	0.1820	0.0084

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.008	-0.114	0.114	0.200	
Wave2	-0.003	-0.111	0.117	0.186	

	mean	min	max	std	comment
Heading	29.152	27.290	31.060	0.797	
Forward vel.	1.285	0.837	1.781	0.247	
Surge acc.	-0.049	-0.452	0.438	0.199	
Port vel.	-0.087	-0.268	0.092	0.086	
Sway acc.	-0.017	-0.521	0.484	0.264	

	mean	min	max	2*std	comment
Heave	-0.002	-0.068	0.070	0.068	
Heave acc.	0.031	-1.365	1.101	1.411	

	mean	min	max	2*std	comment
Roll	1.065	-3.893	5.850	5.128	

	mean	min	max	2*std	comment
Pitch	-0.205	-3.725	3.609	3.417	

	mean	min	max	std	comment
Yaw vel.	0.204	-6.077	6.476	2.902	

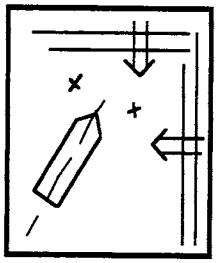
	mean	min	max	std	comment
Rudder angle	1.972	-4.859	9.150	2.845	

3.4.3 Heading 150°, two crossing irregular wave systems

Table 3.4.3.

test	model speed				model heading			
no	mean	min	max	std	mean	min	max	std
112	0.41	0.11	0.63	0.093	145.4	133.4	155.6	5.82
113	1.39	1.26	1.50	0.051	150.6	149.3	152.6	0.84
114	1.30	1.18	1.42	0.053	151.2	149.8	152.6	0.71

Test no 112



The 88.6 seconds measurement is stored on file: *KTHTest112*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no.

	1	2	3	4	5	6	7	8	9
a	0.0209	0.0036	-0.0313	0.0018	0.0156	-0.0005			
b	0.0033	0.0103	0.0227	0.0033	-0.0024	0.0003			
c	0.0149	-0.0042	-0.0115	-0.0068	-0.0176	-0.0019			
d	0.0112	0.0006	0.0320	-0.0012	0.0319	-0.0009			
ω	2.0700	3.2000	3.2500	3.3000	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.1175	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	$H_{1/3}$ y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1366	0.1550	0.2066	0.2032	0.1960	0.0134

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.122	0.135	0.202	
Wave2	0.001	-0.140	0.145	0.203	

	mean	min	max	std	comment
Heading	145.424	133.420	155.580	5.823	
Forward vel.	0.408	0.109	0.632	0.093	
Surge acc.	-0.013	-0.752	0.713	0.289	
Port vel.	0.007	-0.194	0.170	0.068	
Sway acc.	0.003	-0.618	0.586	0.235	

	mean	min	max	2*std	comment
Heave	0.000	-0.100	0.101	0.074	
Heave acc.	0.039	-1.150	1.126	0.805	

	mean	min	max	2*std	comment
Roll	-0.208	-8.853	9.743	7.164	

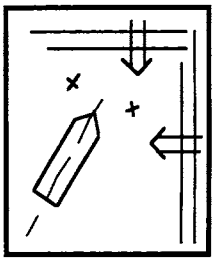
	mean	min	max	2*std	comment
Pitch	0.075	-5.412	5.741	4.308	

	mean	min	max	std	comment
Yaw vel.	0.035	-7.225	7.470	2.603	

	mean	min	max	std	comment
Rudder angle	2.033	-11.118	16.603	5.873	

Test no 113

The 23.8 seconds measurement is stored on file: *KTHTest113*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	0.0172	-0.0002	-0.0124	-0.0021	0.0059	0.0067			
b	-0.0003	0.0070	0.0290	-0.0069	-0.0127	-0.0014			
c	0.0171	-0.0045	0.0056	0.0051	0.0169	-0.0172			
d	0.0082	-0.0029	0.0418	0.0207	-0.0104	0.0151			
ω	2.0700	3.2000	3.2500	4.3900	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	$H_{1/3}$ y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1356	0.1434	0.1974	0.2013	0.1976	0.0097

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.003	-0.108	0.157	0.203	
Wave2	0.000	-0.108	0.151	0.191	

	mean	min	max	std	comment
Heading	150.600	149.320	152.580	0.837	
Forward vel.	1.388	1.264	1.504	0.051	
Surge acc.	-0.052	-0.602	0.550	0.234	
Port vel.	0.001	-0.088	0.132	0.043	
Sway acc.	0.005	-0.647	0.632	0.246	

	mean	min	max	2*std	comment
Heave	-0.005	-0.090	0.107	0.084	
Heave acc.	0.041	-1.781	1.589	1.452	

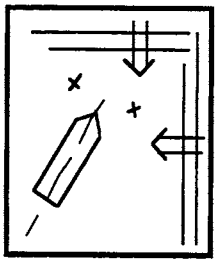
	mean	min	max	2*std	comment
Roll	-0.275	-4.698	5.218	4.525	

	mean	min	max	2*std	comment
Pitch	-0.235	-5.068	3.716	3.934	

	mean	min	max	std	comment
Yaw vel.	-0.080	-6.901	5.393	2.346	

	mean	min	max	std	comment
Rudder angle	0.032	-4.979	5.422	2.201	

Test no 114



The 26.2 seconds measurement is stored on file: *KTHTest114*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 1

	1	2	3	4	5	6	7	8	9
a	0.0180	-0.0047	-0.0330	-0.0012	0.0066	-0.0037			
b	-0.0043	0.0003	-0.0077	0.0099	0.0219	-0.0056			
c	0.0182	0.0046	-0.0421	0.0001	-0.0156	0.0073			
d	0.0004	-0.0060	0.0133	-0.0077	-0.0136	-0.0066			
ω	2.0700	3.2000	3.2500	4.3900	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	$H_{1/3}$ y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1363	0.1458	0.1995	0.2041	0.1999	0.0103

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.131	0.140	0.203	
Wave2	0.001	-0.132	0.132	0.195	

	mean	min	max	std	comment
Heading	151.163	149.810	152.560	0.710	
Forward vel.	1.297	1.178	1.424	0.053	
Surge acc.	-0.048	-0.576	0.462	0.232	
Port vel.	-0.003	-0.123	0.100	0.045	
Sway acc.	0.004	-0.549	0.607	0.255	

	mean	min	max	2*std	comment
Heave	-0.003	-0.116	0.095	0.084	
Heave acc.	0.030	-1.698	1.507	1.409	

	mean	min	max	2*std	comment
Roll	-0.219	-4.500	4.143	2.972	

	mean	min	max	2*std	comment
Pitch	-0.190	-4.547	4.023	3.903	

	mean	min	max	std	comment
Yaw vel.	-0.090	-5.315	7.050	2.484	

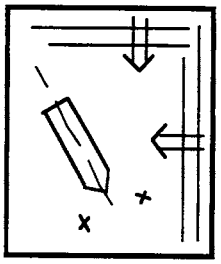
	mean	min	max	std	comment
Rudder angle	-0.171	-5.295	4.768	2.223	

3.4.4 Heading 30°, two crossing irregular wave systems

Table 3.4.4.

test	model speed				model heading			
no	mean	min	max	std	mean	min	max	std
115	0.54	0.11	0.99	0.179	21.3	8.0	32.2	9.79
116	0.44	-0.14	0.82	0.171	27.3	19.0	34.1	3.53
117	0.41	0.02	0.87	0.161	30.8	16.6	42.3	5.38
118	1.33	0.89	2.05	0.245	30.4	28.7	33.2	0.98
119	1.29	0.91	1.66	0.211	29.8	25.0	31.9	1.29
120	1.32	0.88	1.71	0.231	30.1	28.4	32.5	0.84

Test no 115



The 67.4 seconds measurement is stored on file: *KTHTest115*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0170	-0.0352	0.0032	-0.0111	0.0173	0.0015			
b	0.0045	-0.0157	0.0040	0.0152	0.0258	-0.0171			
c	0.0105	-0.0344	-0.0098	0.0061	-0.0099	-0.0016			
d	0.0159	-0.0046	-0.0048	-0.0010	-0.0293	0.0022			
ω	2.0700	3.2500	3.3000	4.3900	4.4400	4.4900			
k	0.5077	1.0852	1.1175	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1285	0.1426	0.1920	0.1892	0.1841	0.0109

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.123	0.148	0.183	
Wave2	0.001	-0.126	0.144	0.196	

	mean	min	max	std	comment
Heading	21.334	8.030	32.180	9.788	
Forward vel.	0.539	0.115	0.991	0.179	
Surge acc.	-0.016	-0.654	0.666	0.258	
Port vel.	-0.017	-0.297	0.285	0.112	
Sway acc.	0.006	-0.696	0.725	0.259	

	mean	min	max	2*std	comment
Heave	-0.001	-0.097	0.095	0.075	
Heave acc.	0.039	-1.191	1.114	0.876	

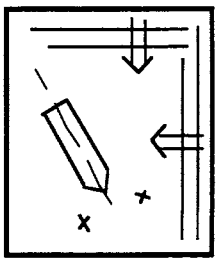
	mean	min	max	2*std	comment
Roll	0.388	-7.850	8.588	6.398	

	mean	min	max	2*std	comment
Pitch	0.120	-4.080	4.733	3.361	

	mean	min	max	std	comment
Yaw vel.	-0.074	-7.646	8.251	2.591	

	mean	min	max	std	comment
Rudder angle	-2.262	-19.008	9.135	5.174	

Test no 116



The 86.2 seconds measurement is stored on file: *KTHTest116*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	0.0140	0.0025	-0.0274	0.0045	0.0114	-0.0042			
b	-0.0114	-0.0023	0.0242	-0.0022	-0.0059	0.0053			
c	0.0186	-0.0031	-0.0052	-0.0040	-0.0265	-0.0005			
d	0.0021	-0.0001	0.0354	-0.0013	0.0205	-0.0039			
ω	2.0700	3.2000	3.2500	4.3900	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1272	0.1470	0.1944	0.1992	0.1938	0.0115

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.005	-0.136	0.168	0.212	
Wave2	0.000	-0.142	0.140	0.201	

	mean	min	max	std	comment
Heading	27.326	18.980	34.060	3.532	
Forward vel.	0.437	-0.141	0.824	0.171	
Surge acc.	-0.011	-0.686	0.795	0.268	
Port vel.	-0.037	-0.414	0.355	0.118	
Sway acc.	-0.003	-0.638	0.731	0.254	

	mean	min	max	2*std	comment
Heave	-0.001	-0.101	0.108	0.074	
Heave acc.	0.041	-1.012	1.155	0.785	

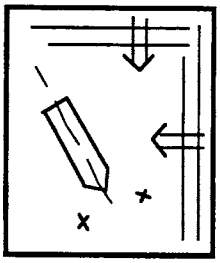
	mean	min	max	2*std	comment
Roll	0.515	-6.305	10.551	5.606	

	mean	min	max	2*std	comment
Pitch	0.154	-4.542	5.737	3.576	

	mean	min	max	std	comment
Yaw vel.	0.006	-7.290	7.999	2.696	

	mean	min	max	std	comment
Rudder angle	-1.367	-13.628	16.181	7.372	

Test no 117



The 94.2 seconds measurement is stored on file: *KTHTest117*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0149	-0.0017	0.0306	-0.0121	-0.0206	0.0010			
b	0.0102	-0.0005	-0.0202	0.0014	0.0131	0.0022			
c	-0.0182	0.0029	0.0093	-0.0002	0.0245	-0.0023			
d	-0.0019	-0.0002	-0.0334	0.0013	-0.0185	0.0059			
ω	2.0700	3.2000	3.2500	4.3900	4.4400	4.4900			
k	0.5077	1.0536	1.0852	1.9647	2.0097	2.0552			

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1274	0.1433	0.1917	0.1960	0.1910	0.0109

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.004	-0.129	0.156	0.206	
Wave2	0.001	-0.137	0.149	0.193	

	mean	min	max	std	comment
Heading	30.798	16.570	42.340	5.380	
Forward vel.	0.408	0.019	0.868	0.161	
Surge acc.	-0.004	-0.832	0.714	0.278	
Port vel.	-0.048	-0.391	0.230	0.112	
Sway acc.	0.005	-0.706	0.731	0.247	

	mean	min	max	2*std	comment
Heave	-0.001	-0.091	0.103	0.072	
Heave acc.	0.041	-0.975	1.192	0.742	

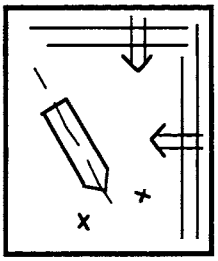
	mean	min	max	2*std	comment
Roll	0.447	-7.957	8.630	5.902	

	mean	min	max	2*std	comment
Pitch	0.198	-5.195	5.082	3.726	

	mean	min	max	std	comment
Yaw vel.	-0.042	-7.235	8.700	2.839	

	mean	min	max	std	comment
Rudder angle	-1.505	-15.252	19.598	8.460	

Test no 118



The 25.8 seconds measurement is stored on file: *KTHTest118*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$
$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0237	0.0076	-0.0391	0.0203					
b	-0.0290	0.0498	0.0111	-0.0175					
c	0.0139	-0.0048	-0.0167	-0.0128					
d	0.0062	0.0082	0.0325	0.0241					
ω	2.0700	2.1200	3.2500	4.4400					
k	0.5077	0.5256	1.0852	2.0097					

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1582	0.1423	0.2128	0.2289	0.2261	0.0088

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.080	0.133	0.172	
Wave2	-0.003	-0.117	0.148	0.225	

	mean	min	max	std	comment
Heading	30.386	28.660	33.200	0.980	
Forward vel.	1.335	0.886	2.049	0.245	
Surge acc.	-0.048	-0.557	0.399	0.213	
Port vel.	-0.045	-0.963	0.832	0.174	
Sway acc.	-0.011	-0.624	0.585	0.243	

	mean	min	max	2*std	comment
Heave	-0.005	-0.100	0.081	0.074	
Heave acc.	0.044	-1.169	1.290	1.081	

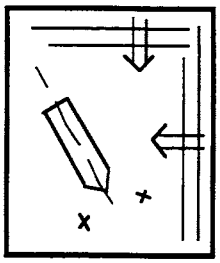
	mean	min	max	2*std	comment
Roll	0.613	-8.052	7.882	6.651	

	mean	min	max	2*std	comment
Pitch	-0.111	-3.787	3.198	3.135	

	mean	min	max	std	comment
Yaw vel.	0.125	-5.479	7.041	2.735	

	mean	min	max	std	comment
Rudder angle	0.199	-8.438	5.759	2.952	

Test no 119



The 25.0 seconds measurement is stored on file: *KTHTest119*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0189	0.0181	0.0365	-0.0217					
b	0.0295	-0.0299	-0.0038	0.0067					
c	-0.0059	-0.0119	0.0234	0.0199					
d	-0.0274	0.0035	-0.0253	-0.0199					
ω	2.0700	2.1200	3.2500	4.4400					
k	0.5077	0.5256	1.0852	2.0097					

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1630	0.1444	0.2178	0.2173	0.2140	0.0086

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.099	0.132	0.191	
Wave2	-0.001	-0.123	0.140	0.214	

	mean	min	max	std	comment
Heading	29.843	25.000	31.910	1.293	
Forward vel.	1.288	0.910	1.660	0.211	
Surge acc.	-0.047	-0.536	0.424	0.203	
Port vel.	-0.056	-0.348	0.221	0.116	
Sway acc.	-0.010	-0.694	0.576	0.253	

	mean	min	max	2*std	comment
Heave	-0.004	-0.085	0.092	0.079	
Heave acc.	0.030	-1.342	1.151	1.118	

	mean	min	max	2*std	comment
Roll	0.442	-6.902	7.654	6.731	

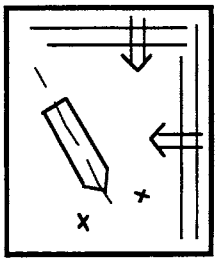
	mean	min	max	2*std	comment
Pitch	-0.145	-3.867	3.558	3.023	

	mean	min	max	std	comment
Yaw vel.	0.334	-6.261	7.935	2.489	

	mean	min	max	std	comment
Rudder angle	0.721	-5.464	9.641	2.727	

Test no 120

The 26.2 seconds measurement is stored on file: *KTHTest120*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_{xn} \cdot t + k_{xn} \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_{xn} \cdot t + k_{xn} \cdot x)$$

$$+ \sum_{m=1}^{M} c_m \cos(\omega_{ym} \cdot t + k_{ym} \cdot y) + \sum_{m=1}^{M} d_m \sin(\omega_{ym} \cdot t + k_{ym} \cdot y)$$

Coefficients based on signal from wave height meter no. 2

	1	2	3	4	5	6	7	8	9
a	-0.0085	0.0018	0.0211	0.0208					
b	0.0078	-0.0133	0.0367	-0.0085					
c	-0.0124	-0.0017	0.0368	-0.0144					
d	-0.0097	-0.0050	0.0114	0.0242					
ω	2.0700	2.1200	3.2500	4.4400					
k	0.5077	0.5256	1.0852	2.0097					

Wave equation characteristics and deviation between original signal and equation

$H_{1/3}$ x-system	a y-system	wave eq. $H_{1/3}$	meas. $H_{1/3}$	calc. $H_{1/3}$	std: abs.diff.
0.1656	0.1485	0.2224	0.2265	0.2227	0.0103

Measurements

	mean	min. ampl.	max. ampl.	4*std	comment
Wave1	0.006	-0.101	0.099	0.183	
Wave2	-0.003	-0.104	0.165	0.221	

	mean	min	max	std	comment
Heading	30.111	28.430	32.540	0.842	
Forward vel.	1.324	0.884	1.708	0.231	
Surge acc.	-0.059	-0.533	0.468	0.215	
Port vel.	-0.050	-0.359	0.184	0.114	
Sway acc.	-0.005	-0.596	0.566	0.242	

	mean	min	max	2*std	comment
Heave	-0.005	-0.093	0.092	0.077	
Heave acc.	0.049	-1.175	1.139	1.111	

	mean	min	max	2*std	comment
Roll	0.304	-7.339	6.751	5.981	

	mean	min	max	2*std	comment
Pitch	-0.187	-3.804	3.517	3.096	

	mean	min	max	std	comment
Yaw vel.	-0.001	-5.880	7.075	2.629	

	mean	min	max	std	comment
Rudder angle	0.620	-6.962	5.928	2.653	

3.5 Tests in following regular waves

Tests in following regular waves with ratio between roll eigen frequency and wave encounter frequency 2, 1 and 0.5.

3.5.1 Heading 30°

In those tests the ratio between the roll eigen frequency and the wave excitation frequency is approximately $\omega_0 / \omega_e = 2$.

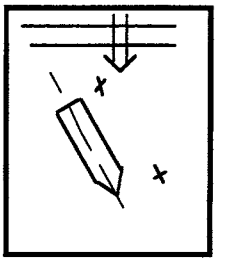
Table 3.5.1. In the table, *freq.* refers to the control signal sent to the wavemaker and *ampl.* to the amplitude determined from the part of the measurement used to calculate the wave equation.

test	model speed				model heading				regular wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
121	1.86	1.70	2.02	0.080	30.7	26.5	35.1	2.84	4.44	0.056
122	1.88	1.74	1.99	0.076	31.1	24.1	35.5	2.97	"	0.056
123	1.96	1.79	2.16	0.096	31.7	26.5	37.7	3.30	"	0.058
124	1.94	1.72	2.15	0.099	31.3	26.7	36.6	3.11	"	0.057
125	1.86	1.52	2.20	0.154	32.1	24.8	38.7	4.14	"	0.085
126	1.86	1.70	2.01	0.094	30.7	22.3	37.7	4.38	"	0.063
127	2.07	1.66	2.42	0.224	30.7	24.0	34.9	2.92	3.81	0.049
128	2.17	1.81	2.54	0.222	30.8	25.9	37.4	3.48	"	0.051
129	2.05	1.69	2.36	0.197	30.1	25.4	34.4	3.02	"	0.048

In test 125 and 126 the roll angle exceed the angle limited by the safety lines attached to the model.

Test no 121

The 15.8 seconds measurement is stored on file: *KTHTest121*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	0.0331		
b	0.0388		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0562	0.0502	0.0132

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.014	-0.062	0.076	0.053	
Wave2	-0.009	-0.084	0.060	0.049	

	mean	min	max	std	comment
Heading	30.653	26.480	35.120	2.839	
Forward vel.	1.859	1.701	2.016	0.080	
Surge acc.	-0.239	-0.445	0.008	0.102	
Port vel.	-0.040	-0.191	0.056	0.067	
Sway acc.	-0.022	-0.259	0.220	0.106	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.011	-0.025	0.002	0.009	
Heave acc.	0.039	-0.189	0.277	0.164	

	mean	min	max	sqrt(2)*std	comment
Roll	2.808	-8.775	13.843	8.240	

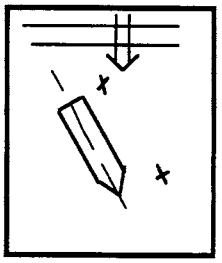
	mean	min	max	sqrt(2)*std	comment
Pitch	-1.181	-2.370	0.598	0.925	

	mean	min	max	std	comment
Yaw vel.	-0.859	-6.549	4.755	3.634	

	mean	min	max	std	comment
Rudder angle	-0.661	-7.848	5.738	4.417	

Test no 122

The 14.2 seconds measurement is stored on file: *KTHTest122*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0427		
b	-0.0329		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0564	0.0527	0.0129

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.011	-0.060	0.068	0.054	
Wave2	-0.012	-0.086	0.051	0.053	

	mean	min	max	std	comment
Heading	31.090	24.150	35.550	2.972	
Forward vel.	1.880	1.737	1.985	0.076	
Surge acc.	-0.104	-0.246	0.031	0.071	
Port vel.	-0.067	-0.191	0.069	0.073	
Sway acc.	-0.007	-0.230	0.189	0.092	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.012	-0.027	0.003	0.009	
Heave acc.	0.041	-0.181	0.269	0.156	

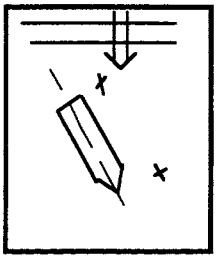
	mean	min	max	sqrt(2)*std	comment
Roll	3.139	-6.699	15.783	7.400	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.427	-1.378	0.351	0.658	

	mean	min	max	std	comment
Yaw vel.	0.952	-5.765	5.644	3.568	

	mean	min	max	std	comment
Rudder angle	-0.926	-7.152	6.603	4.232	

Test no 123



The 15.0 seconds measurement is stored on file: *KTHTest123*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	0.0437		
b	-0.0273		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0584	0.0449	0.0185

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.019	-0.063	0.072	0.055	
Wave2	-0.006	-0.087	0.060	0.050	

	mean	min	max	std	comment
Heading	31.746	26.520	37.680	3.302	
Forward vel.	1.956	1.787	2.160	0.096	
Surge acc.	-0.144	-0.303	-0.002	0.076	
Port vel.	-0.035	-0.208	0.071	0.071	
Sway acc.	-0.049	-0.298	0.169	0.118	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.010	-0.023	0.003	0.009	
Heave acc.	0.037	-0.214	0.289	0.174	

	mean	min	max	sqrt(2)*std	comment
Roll	4.381	-12.495	21.657	12.693	

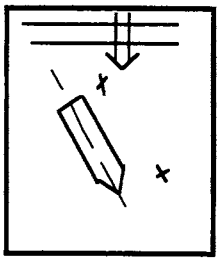
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.621	-1.652	0.192	0.708	

	mean	min	max	std	comment
Yaw vel.	-0.716	-6.878	5.416	3.749	

	mean	min	max	std	comment
Rudder angle	-0.735	-9.029	6.603	4.735	

Test no 124

The 15.0 seconds measurement is stored on file: *KTHTest124*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0357		
b	-0.0345		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0574	0.0419	0.0173

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.020	-0.069	0.066	0.055	
Wave2	-0.003	-0.086	0.062	0.047	

	mean	min	max	std	comment
Heading	31.257	26.710	36.600	3.110	
Forward vel.	1.936	1.722	2.149	0.099	
Surge acc.	-0.135	-0.291	0.020	0.076	
Port vel.	-0.034	-0.211	0.079	0.070	
Sway acc.	-0.035	-0.304	0.196	0.122	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.010	-0.023	0.002	0.009	
Heave acc.	0.042	-0.203	0.267	0.163	

	mean	min	max	sqrt(2)*std	comment
Roll	3.727	-12.562	22.449	13.175	

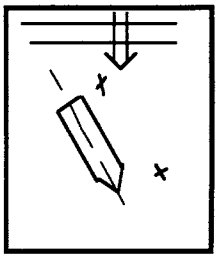
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.555	-1.494	0.326	0.674	

	mean	min	max	std	comment
Yaw vel.	-0.644	-6.108	5.237	3.678	

	mean	min	max	std	comment
Rudder angle	-0.209	-7.152	6.645	4.595	

Test no 125

The 15.0 seconds measurement is stored on file: *KTHTest125*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0387		
b	-0.0503		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0854	0.0607	0.0237

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.026	-0.084	0.117	0.087	
Wave2	0.008	-0.101	0.193	0.096	

	mean	min	max	std	comment
Heading	32.072	24.760	38.730	4.140	
Forward vel.	1.865	1.519	2.198	0.154	
Surge acc.	-0.154	-0.440	0.079	0.140	
Port vel.	-0.065	-0.341	0.139	0.127	
Sway acc.	-0.040	-1.116	1.109	0.214	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.008	-0.026	0.014	0.014	
Heave acc.	0.039	-0.396	0.442	0.239	

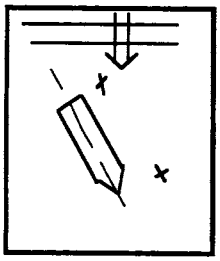
	mean	min	max	sqrt(2)*std	comment
Roll	5.599	-17.752	31.754	16.745	interfered

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.612	-2.389	0.625	1.148	

	mean	min	max	std	comment
Yaw vel.	0.214	-11.356	7.431	5.513	

	mean	min	max	std	comment
Rudder angle	-1.779	-11.940	10.126	6.169	

Test no 126



The 16.2 seconds measurement is stored on file: *KTHTest126*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0249		
b	-0.0549		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0630	0.0567	0.0177

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.014	-0.079	0.102	0.068	
Wave2	0.007	-0.106	0.128	0.085	

	mean	min	max	std	comment
Heading	30.712	22.300	37.720	4.377	
Forward vel.	1.865	1.701	2.011	0.094	
Surge acc.	-0.121	-0.290	0.048	0.096	
Port vel.	-0.080	-0.257	0.102	0.088	
Sway acc.	-0.023	-0.352	0.896	0.142	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.009	-0.028	0.011	0.012	
Heave acc.	0.039	-0.265	0.336	0.188	

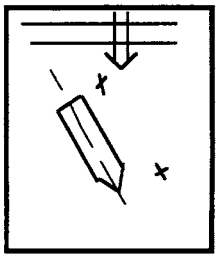
	mean	min	max	sqrt(2)*std	comment
Roll	4.813	-11.166	29.252	12.564	interfered

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.515	-1.576	0.492	0.881	

	mean	min	max	std	comment
Yaw vel.	0.831	-6.921	6.387	3.989	

	mean	min	max	std	comment
Rudder angle	-0.346	-9.113	10.232	5.935	

Test no 127



The 14.2 seconds measurement is stored on file: *KTHTest127*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0135		
b	-0.0480		
ω	3.8100		
k	1.4813		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0486	0.0479	0.0056

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.004	-0.054	0.073	0.056	
Wave2	-0.014	-0.100	0.065	0.071	

	mean	min	max	std	comment
Heading	30.691	24.020	34.880	2.921	
Forward vel.	2.071	1.664	2.420	0.224	
Surge acc.	-0.113	-0.415	0.148	0.174	
Port vel.	-0.046	-0.233	0.111	0.105	
Sway acc.	-0.032	-0.169	0.132	0.063	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.013	-0.027	0.005	0.013	
Heave acc.	0.038	-0.119	0.171	0.083	

	mean	min	max	sqrt(2)*std	comment
Roll	4.453	-11.587	20.846	11.411	

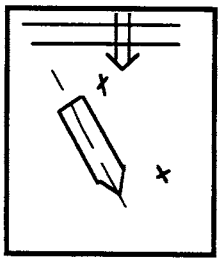
	mean	min	max	sqrt(2)*std	comment
Pitch	-0.547	-2.262	0.850	1.425	

	mean	min	max	std	comment
Yaw vel.	0.961	-5.708	5.868	3.512	

	mean	min	max	std	comment
Rudder angle	-0.413	-5.590	7.806	4.096	

Test no 128

The 12.6 seconds measurement is stored on file: *KTHTest128*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	0.0487		
b	0.0061		
ω	3.8100		
k	1.4813		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0510	0.0446	0.0081

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.013	-0.060	0.078	0.059	
Wave2	-0.004	-0.088	0.064	0.057	

	mean	min	max	std	comment
Heading	30.764	25.920	37.420	3.477	
Forward vel.	2.173	1.813	2.540	0.222	
Surge acc.	-0.179	-0.512	0.146	0.187	
Port vel.	-0.021	-0.186	0.140	0.102	
Sway acc.	-0.039	-0.192	0.080	0.061	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.013	-0.031	0.004	0.012	
Heave acc.	0.039	-0.098	0.183	0.088	

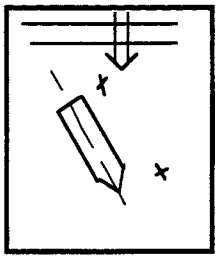
	mean	min	max	sqrt(2)*std	comment
Roll	2.173	-12.514	19.176	10.692	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.867	-2.724	0.875	1.540	

	mean	min	max	std	comment
Yaw vel.	-0.156	-6.671	5.694	3.832	

	mean	min	max	std	comment
Rudder angle	0.112	-8.122	7.088	4.714	

Test no 129



The 13.4 seconds measurement is stored on file: *KTHTest129*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	0.0210		
b	-0.0379		
ω	3.8100		
k	1.4813		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0482	0.0427	0.0072

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.018	-0.059	0.072	0.055	
Wave2	-0.000	-0.097	0.071	0.066	

	mean	min	max	std	comment
Heading	30.143	25.360	34.440	3.023	
Forward vel.	2.049	1.686	2.360	0.197	
Surge acc.	-0.161	-0.424	0.112	0.173	
Port vel.	-0.016	-0.219	0.117	0.096	
Sway acc.	-0.026	-0.204	0.084	0.066	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.012	-0.028	0.001	0.013	
Heave acc.	0.040	-0.093	0.197	0.082	

	mean	min	max	sqrt(2)*std	comment
Roll	2.103	-10.976	16.168	10.614	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.817	-2.368	0.705	1.437	

	mean	min	max	std	comment
Yaw vel.	-0.229	-6.340	5.584	3.498	

	mean	min	max	std	comment
Rudder angle	0.793	-5.253	7.278	4.384	

3.5.2 Heading 0°

The model was heeled portwise approximately 3°. In test 130-1, were the ratio between the roll eigen frequency and the wave excitation frequency $\omega_0/\omega_e=1$, and in test 132-4 $\omega_0/\omega_e=0.5$.

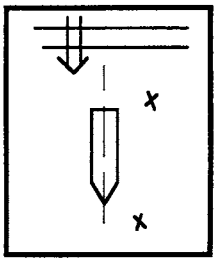
Table 3.5.2. In the table, *freq.* refers to the control signal sent to the wave maker and *ampl.* to the amplitude determined from the measurement used when determining the wave equation.

test	model speed				model heading				regular wave	
no	mean	min	max	std	mean	min	max	std	freq.	ampl.
130	1.10	0.99	1.20	0.055	0.3	-0.5	1.1	0.31	4.44	0.045
131	1.07	0.86	1.27	0.098	0.3	-1.4	1.3	0.60	"	0.074
132	0.30	0.21	0.41	0.035	0.5	-1.1	6.3	1.57	4.96	0.062
133	0.29	0.22	0.34	0.027	-0.5	-2.2	1.9	1.15	"	0.060
134	0.30	0.22	0.37	0.033	-0.3	-2.5	5.5	1.78	"	0.059

In test 134 the auto-pilot was disconnected.

Test no 130

The 46.2 seconds measurement is stored on file: *KTHTest130*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0433		
b	-0.0009		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0450	0.0435	0.0082

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.060	0.071	0.046	
Wave2	-0.001	-0.060	0.067	0.050	

	mean	min	max	std	comment
Heading	0.309	-0.490	1.060	0.314	
Forward vel.	1.104	0.994	1.200	0.055	
Surge acc.	-0.076	-0.221	0.062	0.058	
Port vel.	-0.002	-0.062	0.048	0.025	
Sway acc.	0.025	-0.085	0.127	0.046	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.004	-0.018	0.006	0.005	
Heave acc.	0.041	-0.382	0.507	0.160	

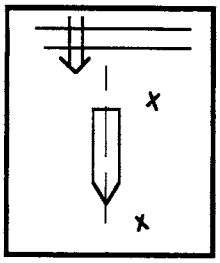
	mean	min	max	sqrt(2)*std	comment
Roll	-2.635	-6.897	1.955	3.407	

	mean	min	max	sqrt(2)*std	comment
Pitch	-0.204	-1.414	0.657	0.534	

	mean	min	max	std	comment
Yaw vel.	-0.613	-1.994	0.702	0.649	

	mean	min	max	std	comment
Rudder angle	0.446	-1.793	2.215	0.918	

Test no 131



The 45.4 seconds measurement is stored on file: *KTHTest131*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1		
a	-0.0099		
b	-0.0663		
ω	4.4400		
k	2.0097		

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0741	0.0667	0.0228

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.000	-0.104	0.137	0.083	
Wave2	0.001	-0.087	0.117	0.073	

	mean	min	max	std	comment
Heading	0.304	-1.390	1.300	0.600	
Forward vel.	1.073	0.860	1.268	0.098	
Surge acc.	-0.039	-0.249	0.204	0.099	
Port vel.	-0.004	-0.101	0.071	0.040	
Sway acc.	0.001	-0.142	0.182	0.071	

	mean	min	max	sqrt(2)*std	comment
Heave	-0.003	-0.019	0.008	0.008	
Heave acc.	0.041	-0.340	0.445	0.164	

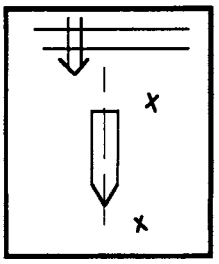
	mean	min	max	sqrt(2)*std	comment
Roll	-2.104	-8.802	5.013	5.402	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.009	-1.294	1.445	0.858	

	mean	min	max	std	comment
Yaw vel.	0.075	-2.087	2.246	0.998	

	mean	min	max	std	comment
Rudder angle	0.401	-2.827	3.397	1.494	

Test no 132



The 33.4 seconds measurement is stored on file: *KTHTest132*

Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	-0.0155	-0.0292	
b	-0.0013	-0.0375	
ω	4.9600	5.0100	
k	2.5078	2.5586	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0622	0.0620	0.0041

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.060	0.078	0.063	
Wave2	0.001	-0.057	0.070	0.052	

	mean	min	max	std	comment
Heading	0.466	-1.090	6.270	1.572	
Forward vel.	0.303	0.210	0.406	0.035	
Surge acc.	-0.004	-0.172	0.169	0.077	
Port vel.	-0.011	-0.258	0.197	0.077	
Sway acc.	0.009	-0.374	0.567	0.141	

	mean	min	max	sqrt(2)*std	comment
Heave	0.000	-0.011	0.009	0.007	
Heave acc.	0.043	-0.238	0.308	0.183	

	mean	min	max	sqrt(2)*std	comment
Roll	-3.432	-28.369	22.101	12.302	

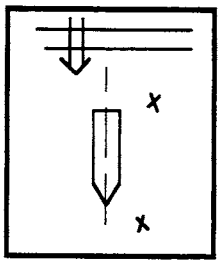
	mean	min	max	sqrt(2)*std	comment
Pitch	0.260	-0.874	1.476	0.728	

	mean	min	max	std	comment
Yaw vel.	0.197	-1.425	2.258	0.638	

	mean	min	max	std	comment
Rudder angle	1.101	-6.856	7.637	3.085	

Test no 133

The 27.8 seconds measurement is stored on file: *KTHTest133*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	-0.0026	0.0012	
b	0.0194	0.0520	
ω	4.9600	5.0100	
k	2.5078	2.5586	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0604	0.0601	0.0040

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.004	-0.060	0.075	0.061	
Wave2	0.000	-0.064	0.070	0.054	

	mean	min	max	std	comment
Heading	-0.547	-2.150	1.920	1.153	
Forward vel.	0.287	0.223	0.344	0.027	
Surge acc.	0.004	-0.145	0.131	0.070	
Port vel.	-0.007	-0.228	0.212	0.111	
Sway acc.	0.010	-0.409	0.398	0.189	

	mean	min	max	sqrt(2)*std	comment
Heave	0.000	-0.010	0.009	0.006	
Heave acc.	0.039	-0.246	0.337	0.178	

	mean	min	max	sqrt(2)*std	comment
Roll	-3.736	-26.462	18.573	16.607	

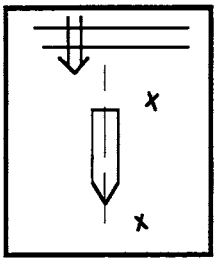
	mean	min	max	sqrt(2)*std	comment
Pitch	0.329	-0.691	1.251	0.637	

	mean	min	max	std	comment
Yaw vel.	0.122	-1.623	1.971	0.664	

	mean	min	max	std	comment
Rudder angle	0.350	-11.329	8.333	3.474	

Test no 134

The 31.0 seconds measurement is stored on file: *KTHTest134*



Wave equation

$$\zeta(x,y,t) = \sum_{n=1}^{N} a_n \cos(\omega_n \cdot t + k_n \cdot x) + \sum_{n=1}^{N} b_n \sin(\omega_n \cdot t + k_n \cdot x)$$

Coefficients based on signal from wave height meter no. 1

n	1	2	
a	-0.0191	-0.0441	
b	0.0071	0.0051	
ω	4.9600	5.0100	
k	2.5078	2.5586	

Deviation between original signal and equation

measured ampl.[m]	calculated ampl. [m]	std of abs.diff. [m]
0.0589	0.0586	0.0041

Measurements

	mean	min. ampl.	max. ampl.	sqrt(2)*std	comment
Wave1	0.003	-0.059	0.073	0.058	
Wave2	0.001	-0.067	0.068	0.053	

	mean	min	max	std	comment
Heading	-0.301	-2.500	5.530	1.781	
Forward vel.	0.301	0.225	0.371	0.033	
Surge acc.	-0.028	-0.186	0.113	0.071	
Port vel.	-0.010	-0.255	0.217	0.129	
Sway acc.	0.012	-0.394	0.519	0.221	

	mean	min	max	sqrt(2)*std	comment
Heave	0.001	-0.010	0.010	0.006	
Heave acc.	0.042	-0.264	0.365	0.189	

	mean	min	max	sqrt(2)*std	comment
Roll	-3.530	-28.868	24.000	19.951	

	mean	min	max	sqrt(2)*std	comment
Pitch	0.160	-0.908	1.048	0.628	

	mean	min	max	std	comment
Yaw vel.	0.233	-1.770	2.885	0.746	

	mean	min	max	std	comment
Rudder angle	–	–	–	–	disconected

Acknowledgement

The seakeeping tests was initiated to cover the demand for experimental data to verify mathematical models at the Division of Naval Architecture, The Royal Institute of Technology (KTH), Stockholm. The project was founded by the National Program for Ship Research in Sweden. The support from SSPA Maritime Consulting, The Swedish Ship Owners Association (SRF) and The Swedish Defence Material Administration (FMV) is greatly appreciated. SSPA for their generous discount on laboratory cost. SRF for lending the model they had produced and made experiments on in 1995 and FMV for lending the portable measurement system.

References

Rinder, *Portabelt mätsystem för fartygs rörelser*, KTH 1995 (in Swedish)
Salvesen, Tuck and Faltinsen, *Ship Motions and Sea Loads*, trans. SNAME, Vol. 78, 1970

Appendix 1 –Gauge data

This appendix summarises the technical data the gauges in the portable system i.e. the motion gauge and the wave height meters.

Motion gauge: Seatex A/S, MRU-6
For details turn to *Seatex Motion Reference Unit, Users Manual, Part I* and *Part II*

Output: 16 digital channels of processed data, max. sampling frequency of 45 Hz, and 4 analogue channels.

Vibration gyro, measures circular velocity i. e. roll, yaw and pitch velocity:

Angular rate range	± 150 deg/s
Angular rate sensor drift	< 10 deg/$\sqrt{h}$
Static error roll, pitch	0.1 deg
Resolution in roll, pitch, yaw	<0.005 deg

Accelerometers, measures linear acceleration i.e. surge, heave and sway acceleration:

Acceleration range	± 30 m/s^2
Noise Level	0.001 m/s^2
Resolution	0.01 m/s^2
Typical dynamic error	2% of max. value

Wave height meter: Denshi Kogyo Co. Ltd., VC-502
For details turn to *Servo Needle Type Wave-Height Meter Instruction Manual VC-502*

Measuring range	0±200 mm
Non-linearity	± 0.1 % FS
Resolution	0.005 mm
Response	1.75 m/s
Drift	±0.01 % FS/°C

Appendix 2 –Calibration and reference measurements

The wave height meters were tested over the measurement domain. The vertical position of the carriage, to which the gauges were attached, were varied and the distance to the water surface measured. Wave height meter 1 indicated plus 1 mm in the negative domain and plus 2.5-4.5 mm from 0 to 80 mm. Wave height meter 2 indicated plus 0.5-1.5 mm in the hole domain. The standard deviation were for all measurements less than 0.5 mm. Results are shown in table A2.1. The column refereed to as *Ref. value* s is accurate to ± 0.5 mm.

Table A 2.1. Wave height meter calibration , all data in metre.

	Ref. value	Stationary system		Portable system	
	-0.0400	Wave height 1	Wave height 2	Wave height 1	Wave height 2
Mean		-0.042	-0.041	-0.039	-0.039
Max.		-0.042	-0.040	-0.038	-0.038
Min.		-0.043	-0.041	-0.040	-0.039
std.		0.000	0.000	0.000	0.000
	-0.0800				
Mean		-0.082	-0.080	-0.079	-0.079
Max.		-0.082	-0.080	-0.079	-0.079
Min.		-0.083	-0.081	-0.080	-0.080
std.		0.000	0.000	0.000	0.000
	0.0005				
Mean		0.000	0.000	0.003	0.002
Max.		0.001	0.001	0.004	0.003
Min.		0.000	0.000	0.002	0.001
std.		0.000	0.000	0.000	0.000
	0.0405				
Mean		0.042	0.040	0.045	0.042
Max.		0.042	0.041	0.046	0.042
Min.		0.041	0.040	0.044	0.041
std.		0.000	0.000	0.000	0.000

	0.0805				
Mean		0.081	0.080	0.084	0.081
Max.		0.082	0.080	0.085	0.081
Min.		0.081	0.079	0.083	0.080
std.		0.000	0.000	0.000	0.000
	0.00005				
Mean		0.000	0.000	0.003	0.001
Max.		0.000	0.001	0.004	0.002
Min.		0.000	0.000	0.002	0.000
std.		0.000	0.000	0.000	0.000

The results from the daily reference measurement are shown in table A2.2. The table gives information on the digital channels from the MRU-6 and the analogue wave height signals. Those are the channels from the portable measurement system stored for each test on the CD-ROM. The #-sign followed by a number, refers to the tests performed after the reference measurement were made.

Table A2.2. Data on the reference measurement. Channels of the portable measurement system. Signs are changed on signals: *pitch, yaw vel, sway acc,* and *heave acc* to fit the coordinate system defined in figure 1.7.

960103 #17-30	roll [°]	pitch [°]	yaw vel. [°/s]	surge acc. [m/ss]	sway acc [m/ss]	heave acc [m/ss]	wave 1 [m]	wave 2 [m]
Mean	0.058	0.216	-0.002	0.000	0.000	0.040	0.001	0.000
Max.	0.078	0.224	0.027	0.004	0.004	0.043	0.004	0.000
Min.	0.039	0.206	-0.030	-0.002	-0.004	0.037	0.000	-0.001
std.	0.009	0.004	0.011	0.001	0.002	0.001	0.001	0.000
960104 #31-67								
Mean	0.143	-0.363	-0.109	-0.098	-0.015	0.032	0.002	-0.001
Max.	0.203	-0.254	-0.074	-0.078	-0.006	0.036	0.005	0.001
Min.	0.105	-0.461	-0.143	-0.117	-0.028	0.027	-0.001	-0.003
std.	0.027	0.056	0.012	0.001	0.006	0.001	0.001	0.001

960105 #68-84								
Mean	0.155	0.197	0.007	0.000	0.000	0.040	0.004	-0.002
Max.	0.187	0.204	0.031	0.003	0.006	0.044	0.005	-0.001
Min.	0.136	0.191	-0.030	-0.003	-0.006	0.037	0.002	-0.003
std.	0.011	0.003	0.012	0.001	0.002	0.001	0.000	0.000
960108 #86-111								
Mean	0.054	0.143	0.024	-0.010	0.001	0.034	0.003	0.001
Max.	0.119	0.160	0.056	-0.005	0.011	0.043	0.006	0.002
Min.	-0.009	0.131	-0.021	-0.014	-0.008	0.026	0.001	-0.001
std.	0.031	0.006	0.016	0.001	0.004	0.003	0.001	0.000
960109 #112-120								
Mean	0.005	0.185	0.000	0.000	0.000	0.040	0.003	0.001
Max.	0.022	0.192	0.022	0.002	0.006	0.043	0.006	0.002
Min.	-0.010	0.179	-0.022	-0.004	-0.005	0.036	0.001	0.000
std.	0.008	0.002	0.008	0.001	0.002	0.001	0.001	0.000
960109 #121-134								
Mean	-2.853	0.229	-0.008	0.002	-0.009	0.040	0.003	0.001
Max.	-2.841	0.234	0.042	0.005	-0.005	0.044	0.004	0.002
Min.	-2.868	0.224	-0.048	-0.002	-0.013	0.037	0.000	0.000
std.	0.007	0.002	0.023	0.001	0.002	0.001	0.001	0.000

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