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TESTING OF EVACUATION SYSTEM MODELS IN ICE-COVERED WATER WITH WAVES

D. Sudom[1], E. Kennedy[2], T. Ennis[2], A. Simoes Re[2], and G. W. Timco[1]
[1]Canadian Hydraulics Centre
National Research Council of Canada
Ottawa, ON K1A 0R6 Canada
[2]Institute for Ocean Technology
National Research Council of Canada
St. John's, NF A1B 3T5 Canada

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ABSTRACT

A series of experiments was carried out to study the navigability of three evacuation lifeboat designs in a variety of environmental conditions. The test series investigated the combined effects of ice and waves on the lifeboats. Three different hull designs representing current lifeboats were modelled at a scale of 1:13. The variables in the test program included the hull design, level of power to the model, ice concentration, wave period and model launch direction. The lifeboat had to meet pass/fail criteria, which depended on whether the model could make way in a given environmental condition. Overall, the models were able to make way in most cases. Compared to previous evacuation model test series, the models in the present tests were better able to navigate the given conditions. When travelling with the wave direction, the model could always make way. When travelling into the waves, the models all had some difficulty in several tests; especially those at higher wave frequencies and higher ice concentrations. The results provide further insight into the viability of evacuation lifeboat systems in ice-covered water conditions.

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TESTING OF EVACUATION SYSTEM MODELS IN ICE-COVERED WATER WITH WAVES

1. INTRODUCTION

The incorporation of escape-evacuation-rescue (EER) systems on offshore structures is an important aspect of platform design. These systems need to take into account not only a wide range of possible hazards and structure design, but also a wide range of environmental conditions. Moreover, conventional lifeboats are often the primary means of evacuation from offshore structures. While these vessels may be satisfactory in open-water conditions, the question arises as to their capabilities in ice-covered water. In these situations, the lifeboat must be able to withstand potential conditions with higher loading and limited navigability, compared to open water.

Lifeboats similar to the models tested in this study would only be used for offshore evacuation in a limited range of pack ice conditions, not in fast ice. Factors that will affect lifeboat performance in ice-covered water include the ice concentration, thickness and strength, the prevalence of land-fast or pack ice conditions, the presence of waves and the physical features of the ice. In order to evaluate the effectiveness of an evacuation system, or a part thereof, these factors must be taken into account in the design and operation of an EER system (see, for example, Poplin et al., 1998a and 1998b; Wright et al., 2003).

The presence of both ice and waves surrounding an offshore platform could occur off of the Eastern coast of Canada (the Grand Banks region), where offshore development is presently occurring. In this region, pack ice could potentially surround an offshore platform, and certainly the wave climate in this region is known to be severe. There are additional implications that make the study of lifeboat performance in ice and waves important. In the event of an emergency with toxic fumes or smoke plumes, it could become necessary for a lifeboat to travel in a specific direction, for example, upwind of the compromised structure. However, upwind is often also updrift (that is, into the waves). For these reasons, it is important to investigate the manoeuvrability of a vessel in both ice and waves, and to define the wave and ice conditions in which vessel movement is possible.

2. PROJECT OBJECTIVES AND SCOPE

The project objectives were a continuation and expansion of those of two previous test series (Simões Ré et al, 2003; Barker et al, 2004). In the first series of tests, the performance of a conventional hull design in ice was investigated, with various ice concentrations, piece sizes, ice thicknesses and with two different power capabilities. The aim was to determine performance boundaries of the lifeboat in these varying conditions. In the second test series, waves were added to some of the previous test configurations to study the effect of waves on lifeboat performance in ice. The wave period, in model scale, was either a "storm" condition of 1.0 seconds or a "swell" condition of 1.67 s.

The present test series investigated three lifeboat designs: a conventional model (IOT 544), a free fall model (IOT 609), and a Mad Rock Polar Haven model (IOT 681). The models were scaled to 1:13. Table 1 shows the scaling factors for a variety of the test parameters. The characteristics that were varied in the tests were the wave period, ice concentration, launch direction, and power to the boat. The main tests were done at 7 and 9 tenths ice concentration, and the ice sheet thickness varied from 25 to 30 mm.

The wave parameters were first determined for conditions without ice. The wave height was kept constant at 0.1 m (model scale). The wave periods used, in model scale, were 1.0, 1.25, 1.43, and 1.67 seconds. These values were chosen for two reasons: (1) they are representative of moderate conditions in the Grand Banks region offshore Canada, and (2) they are at the limit of the capabilities of the wave machine in the ice tank at Canadian Hydraulics Centre.

Table 1 Modelling Laws for the Physical Model Tests; $\lambda = 13$

Property	Scale by	Model value	Full-Scale Value
Wave Period	$\lambda^{1/2}$	1.0 s / 1.25 s / 1.43 s / 1.67 s	3.6 s / 4.5 s / 5.2 s / 6.0 s
Wave Length	λ	1.54 m / 2.27 m / 2.79 m / 3.47 m	20.2 m / 29.5 m / 36.3 m / 45.0 m
Ice Thickness	λ	Range: 25 mm to 30 mm	0.33 m to 0.39 m
Lifeboat Mass	λ^3	IOT 544: 5.404 kg IOT 609: 5.028 kg IOT 681: 4.650 kg	11873 kg 11047 kg 10216 kg
Lifeboat Length	λ	IOT 544 and 681: 0.769 m IOT 609: 0.865 m	10 m 11.25 m

The tests investigated three launch directions: the model facing into the waves (referred to as 0° Minus), away from the waves (0° Plus), or parallel to the waves (90°). For the tests in which the lifeboat was launched 90° to the direction of wave travel, the model had to turn to face into the waves and try to make headway in that direction. The launch direction was varied in order to study how well the model could make headway into the waves or how effectively it could be propelled when traveling with the waves.

The ice thicknesses investigated ranged from 25 to 30 mm in model scale. Piece size was randomly generated, in order to reflect a natural ice regime.

The effects of power to the model were also investigated in the present test program. The models were tested at power level P1 (approximately 3.1 m/s or 6 knots), and with additional power (P2). The value for power level P2 was slightly different for each lifeboat and are discussed in Section 3.4.

During several runs, the effect of using the coxswain view was investigated. In these tests, the operator attempted to drive the model using the boat view only.

Several other variables that were not intended to be investigated as part of the test program are likely to influence lifeboat performance. These variables include the ice floe size and the performance of the beaches or wave absorbers.

3. TEST SET-UP

3.1 Test Facility

The tests were performed in the ice tank at the NRC Canadian Hydraulics Centre (CHC) in Ottawa (Pratte and Timco, 1981). Previous tests were held at the NRC Institute for Ocean Technology (IOT) (Simões Ré et al, 2003; Simões Ré et al, 2002), however the IOT ice tank is not able to accommodate a wave machine. The CHC tank, which is 21 m long by 7 m wide and 1.2 m deep, has a removable gate that facilitates access by a loader for moving the wave machines into the ice tank, and is housed in a large insulated room equipped with loading bay doors. The room can be cooled to an air temperature of -20°C. By varying the room's air temperature, ice sheets can be grown, tempered or melted. Spanning the ice tank is a carriage that can travel the length of the tank. The carriage is driven through two helical-cut rack and pinion gears, and is designed for loads up to 50 kN with a speed range from 3 to 650 mm/s. The evacuation system was mounted onto the main carriage. A small service carriage also spans the tank and this was used to mount wave gauges for sampling purposes. A photograph of the tank is shown in Figure 1.

Figure 1 Ice tank at the Canadian Hydraulics Centre.

3.2 Ice

3.2.1 Model Ice Characteristics

PG/AD model ice was used for this test series. This model ice is based on the EG/AD/S model ice developed at NRC in Ottawa (Timco 1986). PG/AD model ice represents well, on a reduced scale, the flexural strength, uni-axial compressive strength, confined compressive strength and failure envelope of sea ice. In addition, there is reasonable scaling of the strain modulus, fracture toughness and density. The paper by Timco (1986) gives details of the mechanical properties of the model ice.

3.2.2 Ice Sheet Preparation

The thickness of the ice was adjusted by selecting an appropriate freezing time to produce the desired thickness. The strength of the ice can be adjusted by altering the time allowed for warming-up the ice. Three ice sheets were used for the test series at 5, 7 and 9 tenths concentration. Each ice sheet was used for a full day of testing. It was intended that the ice sheet be grown to 50 mm, however problems adjusting the cooling system meant that the ice sheets were grown to about 25 to 30 mm thickness.

The first ice sheet, at approximately 5/10^{ths} concentration, was used as a test sheet but the results are analysed here. The second ice sheet was made to 7/10^{ths} concentration. After testing the model lifeboats at this concentration, it was seen that the boats were travelling fairly easily through the ice and wave conditions. For the third day of testing, it was decided that a higher ice concentration (9/10^{ths}) should be used in order to obtain more useful results from the experiment.

In order to achieve the desired concentration of ice in the tank, large sheets of rigid insulation were laid across the tank prior to freezing. For example, at 7/10^{ths} concentration, 30 percent of the water's surface was covered with sheets of insulation (Figure 2).

Figure 2 Preparing an ice sheet. Rigid insulation covers the water surface in order to control the concentration of ice in the tank.

On the morning of testing the temperature in the ice tank chamber was raised to hover around 2°C. The rigid sheets of insulation were removed, and staff randomly broke the ice using rakes and hoes in order to break up the ice sheet into floes. The photo in Figure 3 is an example of a broken ice sheet, shown with lifeboat model IOT 609 (length of 0.865 m). The average ice piece size is approximately 0.2 m. Figure 4 shows some example floe sizes used during one test day.

Figure 3 Piece size distribution after breaking up an ice sheet.

Figure 4 Example piece size.

The effects of ice strength were not investigated, as the focus of the testing was the manoeuvrability of the models in ice with a wave regime. Unlike previous tests that investigated the performance of the model in ice (but without waves), the ice strength was not monitored during the present test series, as there was no undisturbed ice that was suitable for performing flexural tests after the wave machines had been turned on. The ice was initially significantly stronger than a correctly-scaled ice sheet. However, in this case the higher strength implies that floe splitting would not occur if the vessel hit a floe. By the end of each test day, approximately six or seven hours after testing began, the ice was considerably weaker.

3.3 Waves

In this test series, the objective was to examine some moderate wave scenarios that may exist in the Grand Banks region offshore Canada.

3.3.1 Wave Generation

The water depth for all tests was 0.6 m. Wave generation was achieved using a computer-controlled portable wave machine. Sophisticated wave generation software permits the simulation of natural sea states as defined by parametric or measured spectra or by measured wave records.

The wave machines were operated at 0.6, 0.7, 0.8, or 1.0 Hz, corresponding to a model wave period of 1.67, 1.43, 1.25, or 1.0 seconds.

3.3.2 Wave Absorption

In order to absorb wave energy in the ice tank, Progressive Wave Absorbers were placed at the opposite end of the ice tank from the wave machines. This patented type of wave absorber was developed at the CHC in the 1980's, and is now used in several other offshore modelling basins and towing tanks around the world. The performance of the absorber depends on its length, and on the porosities of the constituent galvanized metal sheets. In larger model basins, the absorbers' performance is quite good, with reflection coefficients in the order of 2-6%. In the ice tank, while no measurement of the absorption of the wave energy was made, it was not anticipated that a much larger level of reflection would be observed. More details about the performance of the wave absorbers can be found in Jamieson and Mansard (1987).

In order to help prevent ice from freezing onto the wave absorbers, pieces of rigid insulation were inserted between the absorbers before the temperature of the ice tank was lowered to grow the ice sheet. Reducing the amount of ice on the absorbers ensured their good performance.

3.4 Evacuation Systems

The lifeboat models were lowered into the water using an aluminum square tubing angle with a quick release snap shackle on the model end. The intent was to look at the sail-away phase and not at the lowering and splash down. Earlier experiments used a modelled twin falls deployment system. For the present tests, the model was lowered to the water/ice surface and released from the hook. The sail-away phase was operated from the carriage above the ice tank. At the end of each test, the lifeboat was driven to the edge of the tank, where it was physically removed, inspected, and then reconnected to the launching system. A photograph of the IOT 630 model being deployed with the launching system is shown in Figure 5.

Figure 5 Lifeboat model with launching system

3.4.1 Conventional TEMPSC Design (IOT 544)

The conventional lifeboat model used in the present study was similar to that used in the previous evacuation test series at CHC (Barker et al., 2004). One main difference was the implementation of a new drive system, explained further in Section 4.3. A summary of the model's main features is presented here. The model had a scale of 1:13 and was representative of a 10 m long 80-person totally enclosed motor propelled survival craft (TEMPSC). In model scale the vessel was 0.769 m long with a mass of 5.4 kg, representing a full complement of evacuees. A photograph of the model is shown in Figure 6, with scale drawings in Figure 7.

The IOT 544 model was equipped with a four-bladed propeller of 38 mm diameter, an active rudder, an electric motor and shaft, rechargeable batteries, and a radio transmitter. A wireless video camera was mounted in the coxswain's position. This provided a view that the vessel operator would have during an actual evacuation.

The model was tested at two different levels of power. Power level P1, at 2600 rpm, corresponded to 1.2 Newton bollard pull and a model speed of 0.86 m/s or 1.7 knots. The vessel was also tested with additional power P2 at 3700 rpm, corresponding to 2.7 Newton bollard pull and a speed of 1.1 m/s (2.1 knots).

Figure 6 IOT 544 lifeboat model

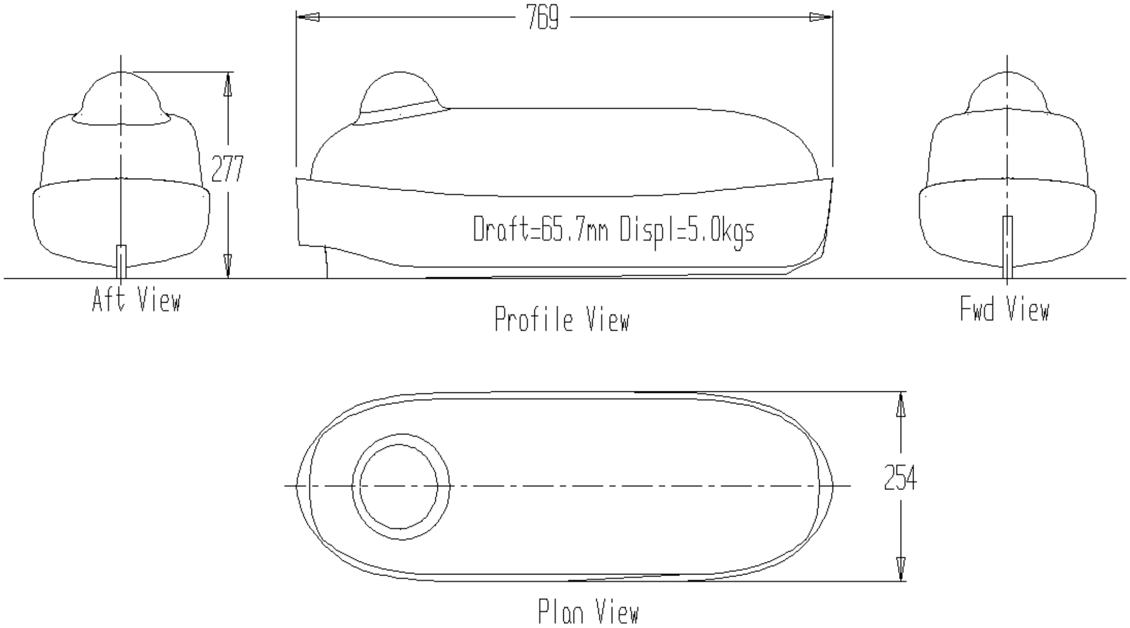


Figure 7 Scale drawings of the IOT 544 lifeboat model

3.4.2 Free fall TEMPSC design (IOT 609)

The IOT 609 model had a scale of 1:13 and was representative of a 11.25 m long lifeboat with an 80-person capacity. The model vessel was 0.865 m long, and was tested for a full complement of evacuees (model mass of 5.03 kg). A photograph of the IOT 609 model is shown in Figure 8. Scale drawings of the model are shown in Figure 9. The model had a four-bladed propeller with 70 mm diameter, an active rudder, an electric motor and shaft, rechargeable batteries, a wireless video camera and a radio transmitter.

The IOT 609 model was tested with two different levels of power. Power level P1 was at 2500 rpm, corresponding with 1.0 Newton bollard pull and a speed of 0.86 m/s (1.7 knots). The vessel was also tested with additional power (P2) at 3700 rpm, corresponding to 2.4 Newton bollard pull and a speed of 1.1 m/s (2.2 knots).

Figure 8 IOT 609 lifeboat model

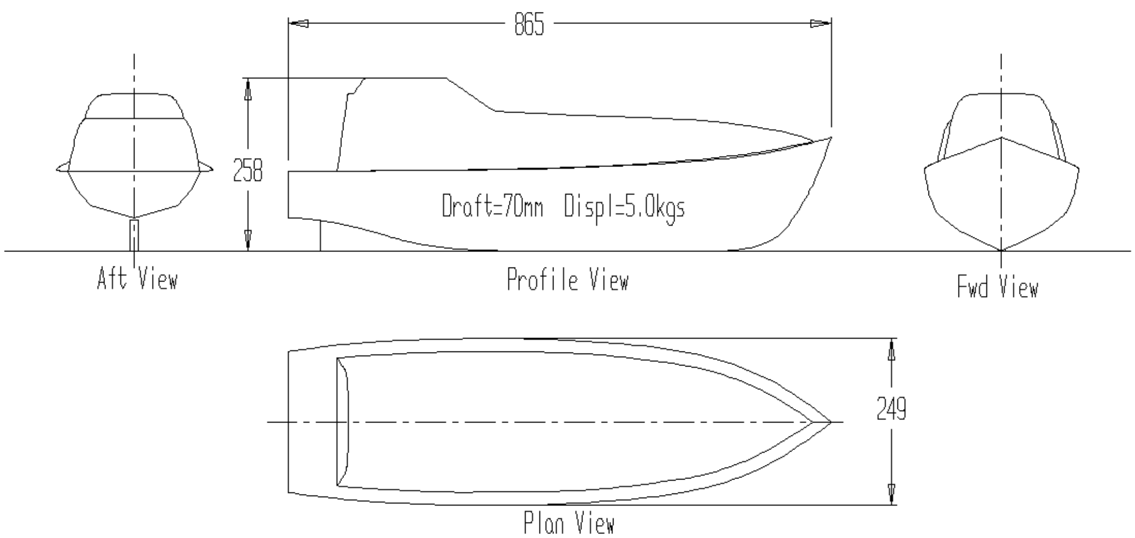


Figure 9 Scale drawings of IOT 609 model

3.4.3 Mad Rock TEMPSC design (IOT 681)

The Polar Haven line of TEMPSCs from Mad Rock Marine Solutions are designed to have a higher performance in ice covered waters and severe environmental conditions. A higher power engine coupled with a high torque propeller were used to provide better manoeuvring characteristics in the above mentioned water conditions. A forward placed coxswain station allows the pilot better visibility of ice and debris. The model is designed for roll reduction and ice protection for the propeller, and a forward placed ice knife helps to prevent the hull from beaching upon ice during transport through ice floes. A photograph of the IOT 681 lifeboat model tested during this study is shown Figure 10, with scale drawings shown in Figure 11.

The IOT 681 model had a scale of 1:13, representing a 10m long lifeboat with a capacity of 64 people. In model scale, the vessel was 0.769 m long and ballasted to a mass of 4.65 kg, representing a full complement of evacuees. The propeller for the model lifeboat was 70 mm in diameter with 3 blades. Like the other designs, the IOT 681 model had a steerable nozzle, an electric motor and shaft, rechargeable batteries, a wireless video camera and a radio transmitter.

The IOT 681 TEMPSC model was tested with two different levels of power. Power level P1, at 2300 rpm, corresponded to 1.19 Newton bollard pull and a speed of 0.86 m/s (1.7 knots). The vessel was also tested with additional power P2 at 3700 rpm, corresponding to 3.45 Newton bollard pull and a speed of 1.1 m/s (2.2 knots).

Figure 10 Mad Rock lifeboat model

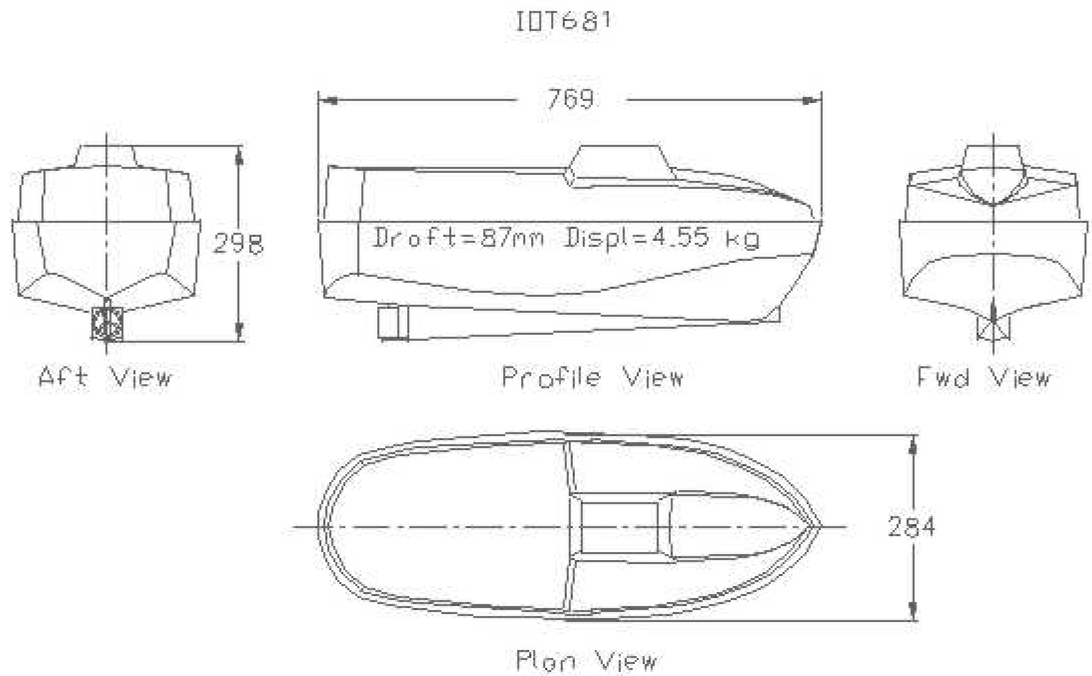


Figure 11 Scale drawings of the IOT 681 lifeboat

4. INSTRUMENTATION

The instrumentation used to collect data during the test series was as follows:

For the lifeboats:

- Three accelerometers recording longitudinal, lateral and vertical accelerations
- Three rate gyros monitoring roll, pitch and yaw
- Motor controller
- Boat-mounted video camera
- Radio transmitter

For the ice tank:

- Three pressure sensors
- Two overhead video cameras to track X-Y position of model

Note that only the pressure sensor and overhead video data were analysed for this study. All analog sensors were calibrated before the start of the experiments. Some of these systems are described in further detail below.

4.1 Wave Data Acquisition

The intent for this series was not to continually monitor the wave conditions, but rather to attempt to reproduce realistic wave climates. The wave height and periods used in this test series were based on un-damped values, that is, with no ice. Because of the dampening effect of pack ice on waves, an attempt was made to measure the wave heights that occurred during testing.

For the last series of tests at the CHC, two capacitance-type wave probes were used to measure wave heights. Protective coverings made of wire mesh were constructed in order to prevent ice from directly interacting with the probes. It was not always possible to prevent this occurrence however, and by the end of the test program, ice was routinely becoming stuck in the protective cages (Barker et al., 2004).

For the present test series, three pressure sensors (P1, P2, and P3) were used to measure wave heights. Since the sensors are submersible, ice impacts are not an issue. The sensors were located along the centreline of the tank, with sensors P1 and P3 located 4.5 m from the wave generator, and sensor P2 located 5.16 m from the wave generator.

Two different types of pressure sensors were used for measuring wave height in the experiments. Sensors P1 and P2 were Motorola MPX2050 Series devices. The accuracy over the calibration range for wave elevations of 0 m to 0.4 m was approximately ± 0.084% for P1 and ± 0.79% for P2. Sensor P3 was a Druck PDCR1830 Series depth-sensing transducer with ± 0.1% accuracy. Photographs of the two types of pressure sensors are shown in Figure 12 and Figure 13. The sensors were mounted on supports to keep them approximately 10 cm above the floor of the test basin.

The calibration information for the pressure sensors is presented in Appendix A. The probes were sampled at a rate of 40 Hz. The data acquisition system was controlled using GEDAP software developed by CHC. The data from each test were stored in a single binary data file.

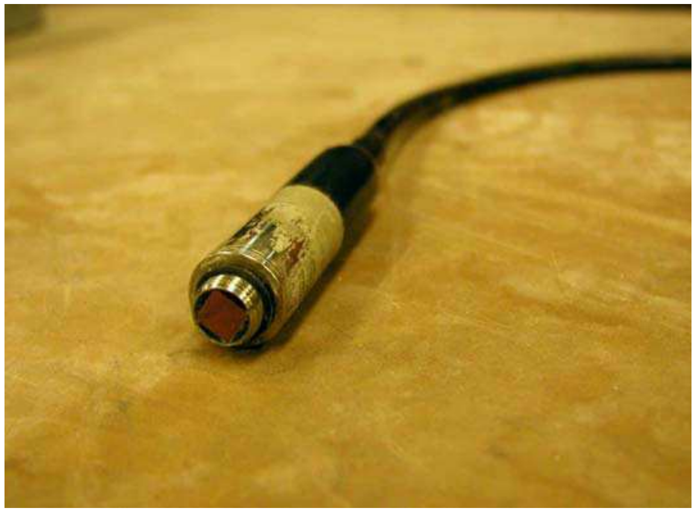


Figure 12 Druck pressure sensor

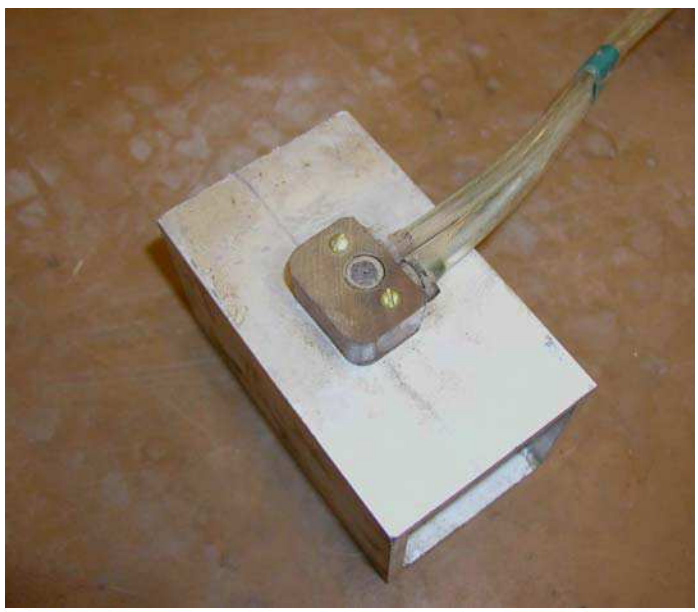


Figure 13 Motorola pressure sensor, mounted on square aluminum tubing support

4.2 TEMPSC Data Acquisition

A newly developed 16-channel 16-bit resolution data acquisition system was implemented for this round of testing at CHC. It was set up to sample 12 channels at a rate of 320 Hz. See Table 2 for channel list and range.

Table 2 TEMPSC data acquisition system channels

Channel	Device	Range
1	Surge Acceleration	10 g
2	Sway Acceleration	10 g
3	Heave Acceleration	8 g
4	Roll Rate	300 deg/sec
5	Pitch Rate	300 deg/sec
6	Yaw Rate	300 deg/sec
7	RPM	0 - 4000
8	Not used	N/A
9	Battery voltage	0 - 25 Volts
10	Battery current	0 - 3 Amps
11	Rudder angle	+/- 30 Deg
12	Not used	N/A

The data was digitized on board the model and transmitted via a 433Mhz radio link to the data logging software on a computer outside the ice tank. The transmit protocol, with its error checking and an advanced receiver design, had an average data capture rate with over 99% effectiveness. This radio system has proven to be reliable in cold and wet environments as well as in areas with multiple metal structures.

The sensors used to acquire acceleration and rates were small capacitive micro-machined units featuring low power consumption. The RPM sensor was a non-contact magnetic-type unit that also outputs direction. The motor voltage supply level came from a resistor network and the drive motor current was derived from a sensor that used a high-side current-sense amplifier across an internal resistor. The rudder angle was derived from a mechanically coupled potentiometer that is powered by a precision voltage reference.

4.3 TEMPSC Remote Control and Drive Systems

The control system was newly developed for this series of tests, replacing the hand held "hobby unit" that was used in the previous evacuation model tests at CHC.

The new design allowed for interfacing with the PC-based controller software. This software enabled each model to be operated with its unique set of calibrated command inputs, and the data file saved for future testing. Another benefit was the quick change over from one model to the next, each sharing the common control system hardware. The software also provided a more realistic and advanced form of human interface that includes a joystick and steering wheel. The control link was achieved through a wireless radio transmitter at 2.4 GHz using "Blue tooth" encoding.

The drive systems on all three models were also updated to include a 44-watt motor with a programmable integrated controller. This gave the models reverse capability and excellent RPM control, both of which were lacking in the previous version. The implementation of this new drive motor was made possible by both the newly developed controller design and the utilization of lithium ion battery technology. This new lighter, higher energy battery allowed the use of a heavier motor and increased the running times between charges. The rudder was actuated by a programmable digital servo, allowing the operator to program the maximum slew rate, range of travel and centre position of the rudder.

4.4 Co-ordinate Systems

4.4.1 Basin Co-ordinates

For the test basin, the co-ordinate system was right-handed. The positive X-axis is defined as up the tank towards the wave absorbers, the Y-axis is defined as the direction perpendicular to the carriage, and the Z-axis is upwards. This is illustrated in Figure 14. Figure 15 is an illustration of the launch directions.

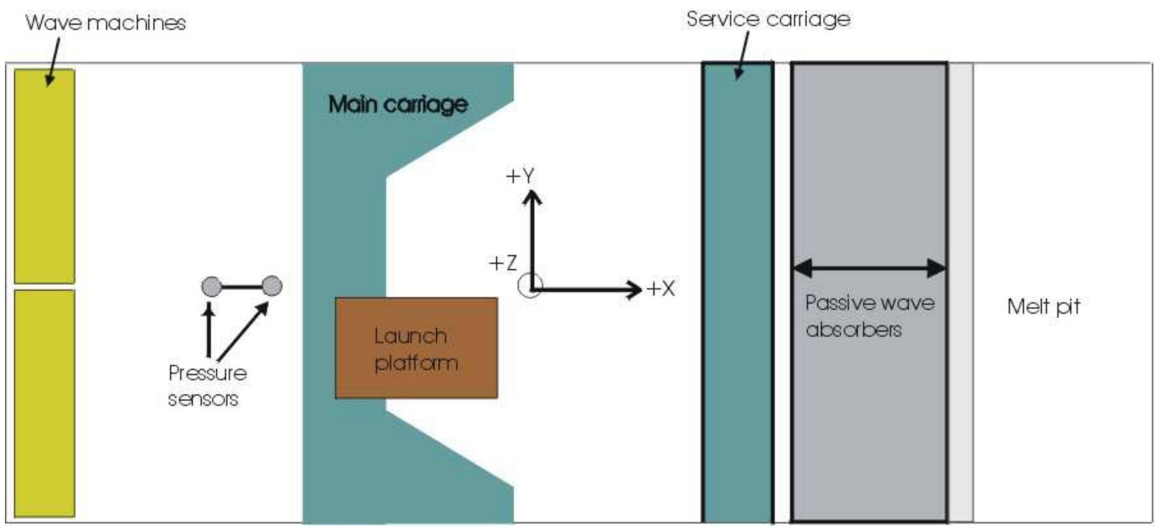


Figure 14 Sketch of ice tank set-up and basin co-ordinate system

4.4.2 TEMPSC Co-ordinates

Each TEMPSC model had a fixed system, with the origin at the aft of the keel along the centre line. This right-handed coordinate system is fixed to the TEMPSC and moves with it. It defines the location of equipment in the TEMPSC, the location of the release mechanisms, the wireless camera position and the accelerometers. Further details about this system were provided in a previous study (Simões Ré et al, 2003). The motion pack was located close to the centre of gravity within the TEMPSC models.

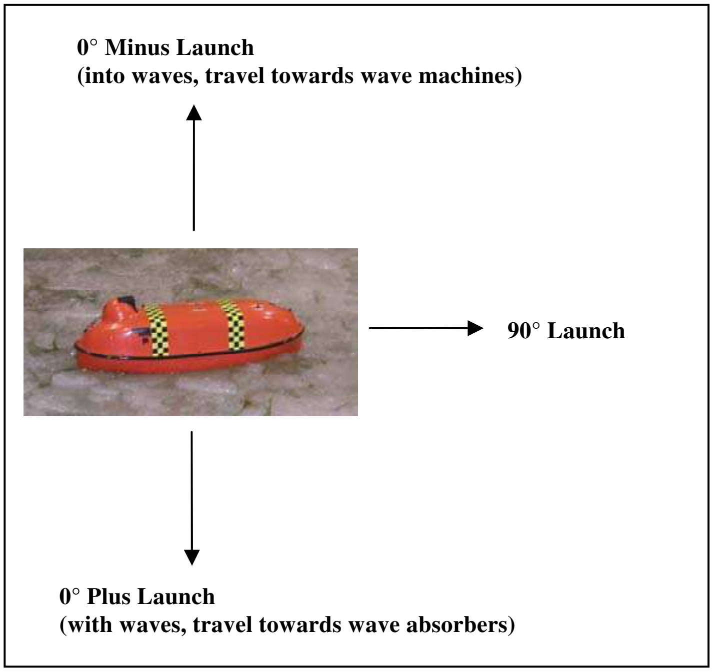


Figure 15 Illustration of launch directions

4.5 Video

Two video cameras were mounted over the test area of the ice tank. The purpose of mounting the cameras in this manner was to use the resulting videos to track the x-y movement of the lifeboat. The cameras were spaced such that a total travel distance of approximately 5.5 m was covered by the two cameras combined. The field of view of the cameras was such that the entire width of the ice tank could not be covered. If the lifeboat drifted or was propelled a wide distance off the centerline of the tank, the lifeboat could no longer be observed by the cameras and this portion of the vessel track would be lost. Also, if the lifeboat was pushed under the service carriage by the waves it was no longer visible to the cameras. Some video data was also collected from a tripod-mounted camera at one end of the ice tank. However, this data is suitable for qualitative analysis only (whether the model met the pass/fail criteria), not x-y positioning.

The video camera located onboard the TEMPSC had, in previous tests, been used by the lifeboat operator to provide the same view as the TEMPSC coxswain. For the present test series, as in the 2003 test series at CHC, the operator chose to operate the TEMPSC lifeboat from atop the main carriage in the ice tank. The lifeboat was navigated by looking down on it, rather than using the view from the on-board camera. The on-board camera view was insufficient for navigating in waves and ice. This decision is discussed further in Section 7.

5. TEST PROGRAM

5.1 Test Methodology

The test methodology was similar to the previous test series, and proceeded as follows:

- The test configuration was set according to the matrix.
- The lifeboat was lowered to water level
- The lifeboat data acquisition was started, followed by the lifeboat video.
- The overhead video recording was started.
- The pressure sensor data acquisition was started.
- The wave machines were initiated with the appropriate drive signal.
- After a manual signal was received, the deployment started. Half way between the lifeboat launching rest position and the water surface, the lifeboat propulsion system was started remotely. The deployment start coincided with the start of the wave machines as much as possible.
- The launching mechanism released the lifeboat into the water. The vessel operator exercised the rudder control remotely during the lifeboat sail away to the safe zone.
- After the TEMPSC either reached the safe zone or it could not travel any further, the wave machines and other data acquisition systems were stopped.
- After completion of the test, the members of the project team started preparation for the next run. The lifeboat was manoeuvred to the edge of the tank, where it was lifted out and reconnected to the launch system.
- The ice in the tank was raked back across the tank to re-cover the water surface.
- The time between test runs was approximately 10 minutes when all events ran smoothly.

5.2 Test Matrix

The complete test matrix consisted of testing three ice sheets. A total of 126 tests were performed. Table 3 shows the 106 tests that were the primary focus of the laboratory program. Tests not included in Table 3 are those that were performed with no power or in still water. Details of all of the tests for the conventional (IOT 544), free fall (IOT 609), and Mad Rock (IOT 681) lifeboat models are shown in Table 4, Table 5, and Table 6 respectively. Tests were named as in the example below. A full explanation of the test names may be found in Appendix B.

CO_5_06_0MINUS_P1

CO	conventional lifeboat model (IOT 544)
5	ice concentration in tenths [5/10^{ths}]
06	wave frequency in Hz [0.6 Hz]
0MINUS	launch direction [0 minus, or into waves]
P1	power level

Testing was done at three different ice concentrations, as discussed previously. The first sheet of ice was mainly used for preliminary testing purposes but several tests at the 0-minus heading (launching into the waves) were carried out. Results from these tests are included here. Since there were several variables to be tested, there was not enough time to perform all tests more than once.

Table 3 Main test matrix

Launch direction (degrees)	Nominal ice concentration (tenths)	Number of tests performed for each lifeboat		
		IOT 544	IOT 609	IOT 681
0-	5	8	6	6
	7	5	5	6
	9	9	9	9
0+	5	-	-	-
	7	-	-	-
	9	2	2	3
90	5	-	-	-
	7	7	6	7
	9	4	5	7

Table 4 Expanded details for the complete test matrix for the IOT 544 lifeboat model

Test #	Test Name	Date	Nominal Ice Concentration (tenths)	Launch Direction (degrees)	Power (P1/P2)	Nominal Wave Height (m)	Nominal Wave Frequency (Hz)
CO_0	CO_test1	18-May-05	5	0-	P1 then P2	-	-
1	CO_5_06_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.6
2	CO_5_06_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.6
3	CO_5_07_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.7
4	CO_5_07_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.7
5	CO_5_08_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.8
6	CO_5_08_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.8
CO_A	CO_TESTA	18-May-05	5	0-	P1	-	-
CO_B	CO_TESTB	18-May-05	5	0-	P2	-	-
7	CO_5_10_0MINUS_P1	18-May-05	5	0-	P1	0.1	1.0
8	CO_5_10_0MINUS_P2	18-May-05	5	0-	P2	0.1	1.0
21	CO_7_06_0MINUS_P1	20-May-05	7	0-	P1	0.1	0.6
22	CO_7_08_0MINUS_P1	20-May-05	7	0-	P1	0.1	0.8
23	CO_7_08_0MINUS_P2	20-May-05	7	0-	P2	0.1	0.8
24	CO_7_10_0MINUS_P1	20-May-05	7	0-	P1	0.1	1.0
25	CO_7_10_0MINUS_P2	20-May-05	7	0-	P2	0.1	1.0
26	CO_7_06_90_P1	20-May-05	7	90	P1	0.1	0.6
27	CO_7_06_90_P2	20-May-05	7	90	P2	0.1	0.6
28	CO_7_08_90_P1	20-May-05	7	90	P1	0.1	0.8
29	CO_7_08_90_P2	20-May-05	7	90	P2	0.1	0.8
30	CO_7_08_90_P2A	20-May-05	7	90	P2	0.1	0.8
31	CO_7_10_90_P2	20-May-05	7	90	P2	0.1	1.0
32	CO_7_10_90_P1	20-May-05	7	90	P1	0.1	1.0
57	CO_9_06_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.6
58	CO_9_06_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.6
59	CO_9_08_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.8
60	CO_9_08_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.8
61	CO_9_07_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.7
62	CO_9_07_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.7
63	CO_9_10_0MINUS_P1	25-May-05	9	0-	P1	0.1	1.0
64	CO_9_10_0MINUS_P2	25-May-05	9	0-	P2	0.1	1.0
65	CO_9_06_0PLUS_P1	25-May-05	9	0+	P1	0.1	0.6
66	CO_9_08_0PLUS_P1	25-May-05	9	0+	P1	0.1	0.8
CO_C	CO_9_CALM_P1	25-May-05	9	0-	P1	-	-
CO_D	CO_9_CALM_P2	25-May-05	9	0-	P2	-	-
67	CO_9_08_90_P1	25-May-05	9	90	P1	0.1	0.8
68	CO_9_10_90_P2	25-May-05	9	90	P2	0.1	1.0
69	CO_9_08_90_P1A	25-May-05	9	90	P1	0.1	0.8
70	CO_9_08_0MINUS_P1A	25-May-05	9	0-	P1	0.1	0.8
71	CO_9_06_90_P1	25-May-05	9	90	P1	0.1	0.6
72	CO_9_10_0PLUS_NP	25-May-05	9	0+	-	0.1	1.0

Table 5 Expanded details for the complete test matrix for the IOT 609 lifeboat model

Test #	Test Name	Date	Nominal Ice Concentration (tenths)	Launch Direction (degrees)	Power (P1/P2)	Nominal Wave Height (m)	Nominal Wave Frequency (Hz)
9	FF_5_06_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.6
10	FF_5_06_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.6
11	FF_5_08_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.8
12	FF_5_08_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.8
13	FF_5_10_0MINUS_P1	18-May-05	5	0-	P1	0.1	1.0
14	FF_5_10_0MINUS_P2	18-May-05	5	0-	P2	0.1	1.0
FF_A	FF_TESTA	18-May-05	5	0-	P1	-	-
FF_B	FF_TESTB	18-May-05	5	0-	P2	-	-
33	FF_7_06_0MINUS_P1	20-May-05	7	0-	P1	0.1	0.6
34	FF_7_08_0MINUS_P1	20-May-05	7	0-	P1	0.1	0.8
35	FF_7_08_0MINUS_P2	20-May-05	7	0-	P2	0.1	0.8
36	FF_7_10_0MINUS_P1	20-May-05	7	0-	P1	0.1	1.0
37	FF_7_10_0MINUS_P2	20-May-05	7	0-	P2	0.1	1.0
38	FF_7_06_90_P1	20-May-05	7	90	P1	0.1	0.6
39	FF_7_06_90_P2	20-May-05	7	90	P2	0.1	0.6
40	FF_7_08_90_P1	20-May-05	7	90	P1	0.1	0.8
41	FF_7_08_90_P2	20-May-05	7	90	P2	0.1	0.8
42	FF_7_10_90_P1	20-May-05	7	90	P1	0.1	1.0
43	FF_7_10_90_P2	20-May-05	7	90	P2	0.1	1.0
FF_C	FF_7_CALM_0MINUS_P1	20-May-05	7	0-	P1	-	-
FF_D	FF_7_CALM_0MINUS_P2	20-May-05	7	0-	P2	-	-
73	FF_9_06_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.6
74	FF_9_06_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.6
75	FF_9_08_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.8
76	FF_9_08_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.8
77	FF_9_07_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.7
78	FF_9_07_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.7
79	FF_9_10_0MINUS_P1	25-May-05	9	0-	P1	0.1	1.0
80	FF_9_10_0MINUS_P2	25-May-05	9	0-	P2	0.1	1.0
81	FF_9_06_90_P1	25-May-05	9	90	P1	0.1	0.6
82	FF_9_08_90_P1	25-May-05	9	90	P1	0.1	0.8
83	FF_9_08_90_P2	25-May-05	9	90	P2	0.1	0.8
84	FF_9_10_90_P2	25-May-05	9	90	P2	0.1	1.0
FF_E	FF_9_CALM_P2	25-May-05	9	0-	P2	-	-
FF_F	FF_9_CALM_P1	25-May-05	9	0-	P1	-	-
85	FF_9_08_90_P1	25-May-05	9	90	P1	0.1	0.8
86	FF_9_10_0MINUS_P1A	25-May-05	9	0-	P1	0.1	1.0
87	FF_9_06_0PLUS_P1	25-May-05	9	0+	P1	0.1	0.6
88	FF_9_08_0PLUS_P1	25-May-05	9	0+	P1	0.1	0.8
89	FF_9_10_0PLUS_NP	25-May-05	9	0+	-	0.1	1.0

Table 6 Expanded details for the complete test matrix for the IOT 681 lifeboat model

Test #	Test Name	Date	Nominal Ice Concentration (tenths)	Launch Direction (degrees)	Power (P1/P2)	Nominal Wave Height (m)	Nominal Wave Frequency (Hz)
15	MR_5_06_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.6
16	MR_5_06_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.6
17	MR_5_08_0MINUS_P1	18-May-05	5	0-	P1	0.1	0.8
18	MR_5_08_0MINUS_P2	18-May-05	5	0-	P2	0.1	0.8
19	MR_5_10_0MINUS_P1	18-May-05	5	0-	P1	0.1	1.0
20	MR_5_10_0MINUS_P2	18-May-05	5	0-	P2	0.1	1.0
MR_A	MR_TESTA**	18-May-05	5	0-	P1	-	-
MR_B	MR_TESTB**	18-May-05	5	0-	P2	-	-
44	MR_7_06_0MINUS_P1	20-May-05	7	0-	P1	0.1	0.6
45	MR_7_08_0MINUS_P1	20-May-05	7	0-	P1	0.1	0.8
46	MR_7_08_0MINUS_P2	20-May-05	7	0-	P2	0.1	0.8
47	MR_7_10_0MINUS_P1	20-May-05	7	0-	P1	0.1	1.0
48	MR_7_10_0MINUS_P1A	20-May-05	7	0-	P1	0.1	1.0
49	MR_7_10_0MINUS_P2	20-May-05	7	0-	P2	0.1	1.0
50	MR_7_06_90_P1	20-May-05	7	90	P1	0.1	0.6
51	MR_7_06_90_P2	20-May-05	7	90	P2	0.1	0.6
52	MR_7_08_90_P1	20-May-05	7	90	P1	0.1	0.8
53	MR_7_08_90_P2	20-May-05	7	90	P2	0.1	0.8
54	MR_7_10_90_P1	20-May-05	7	90	P1	0.1	1.0
55	MR_7_10_90_P1A	20-May-05	7	90	P1	0.1	1.0
56	MR_7_10_90_P2	20-May-05	7	90	P2	0.1	1.0
MR_C	MR_7_CALM_0MINUS_P1	20-May-05	7	0-	P1	-	-
MR_D	MR_7_CALM_0MINUS_P2	20-May-05	7	0-	P2	-	-
90	MR_9_06_0PLUS_P1	25-May-05	9	0+	P1	0.1	0.6
91	MR_9_08_0PLUS_P1	25-May-05	9	0+	P1	0.1	0.8
92	MR_9_10_0PLUS_NP	25-May-05	9	0+	-	0.1	1.0
93	MR_9_06_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.6
94	MR_9_06_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.6
95	MR_9_08_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.8
96	MR_9_08_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.8
97	MR_9_07_0MINUS_P1	25-May-05	9	0-	P1	0.1	0.7
98	MR_9_07_0MINUS_P2	25-May-05	9	0-	P2	0.1	0.7
99	MR_9_10_0MINUS_P1	25-May-05	9	0-	P1	0.1	1.0
100	MR_9_10_0MINUS_P2	25-May-05	9	0-	P2	0.1	1.0
101	MR_9_06_90_P1	25-May-05	9	90	P1	0.1	0.6
102	MR_9_08_90_P1	25-May-05	9	90	P1	0.1	0.8
103	MR_9_10_90_P2	25-May-05	9	90	P2	0.1	1.0
MR_E	MR_9_CALM_P2	25-May-05	9	0-	P2	-	-
MR_F	MR_9_CALM_P1	25-May-05	9	0-	P1	-	-
104	MR_9_10_0MINUS_P2A	26-May-05	9	0-	P2	0.1	1.0
105	MR_9_06_90_P1A	26-May-05	9	90	P1	0.1	0.6
106	MR_9_08_90_P1A	26-May-05	9	90	P1	0.1	0.8
107	MR_9_10_90_P2	26-May-05	9	90	P2	0.1	1.0
108	MR_9_10_90_P2A	26-May-05	9	90	P2	0.1	1.0
109	MR_9_06_0PLUS_P1A	26-May-05	9	0+	P1	0.1	0.6

6. RESULTS

A complete summary of the results of the test program for the three lifeboat designs (conventional, free fall and Mad Rock) may be found in Appendices C, D and E, respectively. These appendices contain tables of data that summarize the pass/fail results for each test as well as the x-y plots of the vessel's travel path. Appendix H shows some general photographs from the tests.

As with the previous tests in ice, successful runs were defined as those for which the TEMPSC was able to launch and then sail away a set distance through the broken ice. Each test in this series was given a pass or fail grade based on whether the boat made it to a distance of 5.0 boat lengths from its launch point target. This corresponds to a full-scale distance of 50 m for the conventional (IOT 544) and Mad Rock (IOT 681) models, and 56 m for the free fall (IOT 609) model.

6.1 Video Analysis

The overhead video was recorded on VHS tapes for the first day of testing, and on DVD for the remaining test days. The VHS videos were converted from analog to digital video. The video logs for all tests are found in Appendix F.

Once the videos had been screened, the video segment for each test was recorded in digital format and exported as an .avi file. The video was not slowed down to convert it to full-scale time. These .avi files were then used in a program called VideoPoint Capture, allowing a specific number of frames to be selected for analysis. Typically 5 to 10 frames were determined to be sufficient for x-y plotting purposes. The digital video files were then compressed and saved. Finally, the compressed files were opened in VideoPoint 2.5. The x-y axes were rotated for each file, since the cameras were not perfectly aligned with the tank. The path of the vessel was then traced using the digital tracking capabilities of this program. For each frame, a point on the vessel had to be highlighted. Each point was represented by a set of x-y coordinates and the corresponding time. This data was exported to Excel and plotted as a representation of the path of the motion of the model.

The data manipulation in Excel was fairly straightforward. A correction was made to the data for each test before plotting. The two overhead cameras were positioned such that the vessel traveled from one camera's field of view into the other. The fields of view of the two cameras overlapped, so the two sets of data had to be superimposed and then made into one continuous data set. Also, the plotting order of the points from camera A and camera B depended on the direction of travel of the vessel. For motion in the positive direction (i.e. with the waves) data from camera B had to be listed before camera A and for a negative vessel direction (into the waves) data points for camera A were plotted before camera B. An example of a typical output plot is shown in Figure 16. The coloured, dotted lines indicate the location of 2.5, 5.0 and 7.5 boat lengths of travel distance. The red diamond indicates the launch location. Note that the direction of travel indicates the intended direction for the lifeboat, either into or with the waves, not the direction that the lifeboat may have ended up traveling.

The fields of view captured by the two cameras corresponded to a viewable length of about 5.5 m (equivalent to about 7.1 boat lengths for the IOT 544 and IOT 681 models, or 6.3 boat lengths for the IOT 609 model). The limited number of frames selected for analysis in VideoPoint sometimes meant that the entire path of the vessel was not captured. In addition, part of the view was often blocked by the main service carriage from which the vessel was launched. Thus, for some tests the boat did not appear to quite meet the 5.0 boat length distance required for a 'pass'. Most of these tests were obviously actually 'passes'. If a test was questionable, the video taken from the end of the tank could be examined.

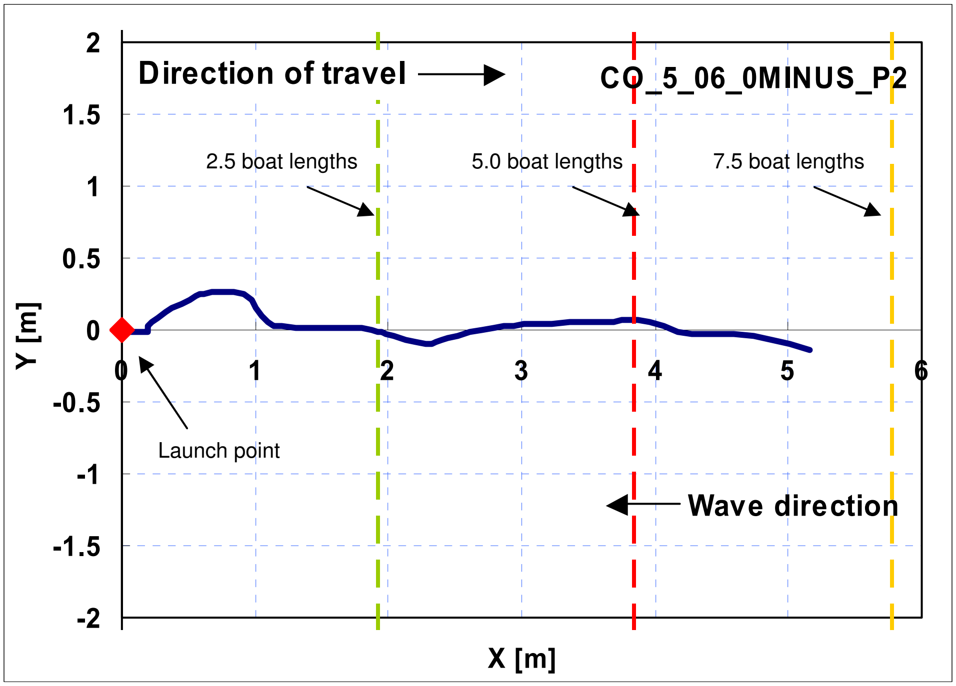


Figure 16 Example x-y output from video analysis. Note that the direction of travel is the intended direction, which not always necessarily the heading the vessel achieved.

6.2 Pressure Sensor Data Analysis

An example of wave analysis for one test is shown in Figure 17. Plots of the analysed pressure sensor data can be found in Appendix E.

In the 2003 evacuation test series, the wave probe readings were unreliable because the ice routinely jammed the protective cages surrounding the wave probes. Where good readings were obtained, the storm wave heights were generally much lower than the 0.1 m nominal height, with values ranging from 0.01 m to 0.04 m. The swell readings, by contrast, were much higher than the nominal wave height, often almost three times as large. This could be due to the generation of standing waves in the ice tank under swell conditions (Barker et al., 2004).

In the present test series, most values for maximum wave height were closer to the 0.1m nominal wave height, although on average all were higher than the nominal height. The average maximum wave heights were quite high for the 1-second period swell waves (1.0 Hz) at 5/10^{ths}

and 7/10ths ice concentration. Table 7 illustrates the differences between the average maximum wave heights for various ice conditions.

Table 7 Average maximum wave heights (m) for various conditions in the ice tank

Wave frequency	Ice concentration		
	5/10ths	7/10ths	9/10ths
0.6 Hz	0.148	0.116	0.120
0.7 Hz	0.154	-	0.121
0.8 Hz	0.179	0.165	0.157
1.0 Hz	0.232	0.243	0.167

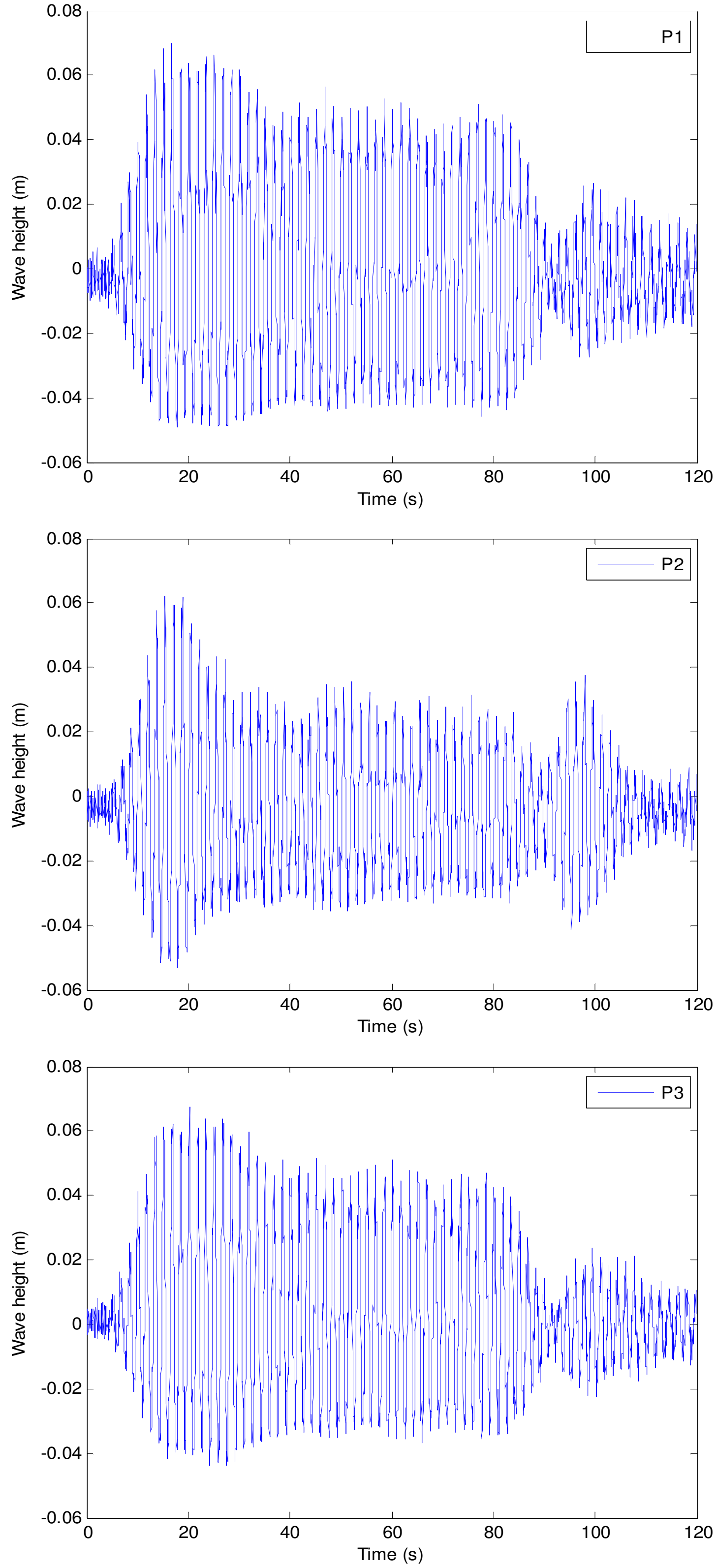


Figure 17 Example of wave analysis for three pressure sensors (P1, P2, and P3) used to determine wave heights for test no. 71 (CO_9_06_90_P1).

7. DISCUSSION

7.1 Effect of Waves and Ice Combined

Table 8 shows the results for tests in the main test matrix (those indicated in Table 4, 5 and 6). In the table, an "F" indicates a fail while a "P" indicates a pass. These grades are preceded by the number of tests in that configuration that received that grade. The pass criterion was that the vessel reaches a distance of 5.0 boat lengths in the intended direction of travel. Results with an asterisk (*) indicate that overhead video data was missing for one or more tests. Where available, video taken from the end of the tank was used to assess whether the vessel had a probable pass or fail.

Table 8 Results for the main test matrix; pass/fail criterion set at 5.0 boat-lengths

Launch direction (degrees)	Nominal ice concentration (tenths)	Grade for each lifeboat [Pass or Fail]		
		IOT 544	IOT 609	IOT 681
0-	5	7P 1F*	6P	6P
	7	4P 1F	5P	6P
	9	8P 1F	9P	8P 1F**
0+	5	-	-	-
	7	-	-	-
	9	2P	2P	2P*
90	5	-	-	-
	7	7P	6P	6P*
	9	3P 1F	4P 1F	4P 3F**

* missing overhead video analysis for one or more tests
** failure may be due to rudder problems in at least one test

The lifeboat models each had difficulty getting through the waves and ice for some tests. The average test duration for a 'pass' using the 5 boat length criteria is approximately 30 seconds. Therefore a duration of 40 seconds was chosen (somewhat arbitrarily) as a cut-off value for pass/fail in Table 9. In model scale, this corresponds to an average speed of approximately 0.13 m/s. The full-scale lifeboat speed would be approximately 0.36 m/s, which is quite slow. For open water transit in calm conditions, the model vessels should travel at about 0.86 m/s (3.1 m/s in full-scale).

A test was considered a 'fail' if the boat took more than 40 seconds to reach 5 boat lengths. This method of analysis gives some indication of which factors may cause navigational problems for the vessels.

Table 9 Results for the main test matrix; pass/fail criteria set at 5.0 boat-lengths and test duration of 40 seconds

Launch direction (degrees)	Nominal ice concentration (tenths)	Grade for each lifeboat [Pass or Fail]		
		IOT 544	IOT 609	IOT 681
0-	5	6P 2F*	5P 1F	5P 1F
	7	4P 1F	5P	5P 1F
	9	5P 4F	7P 2F	7P 2F**
0+	5	-	-	-
	7	-	-	-
	9	2P	2P	2P*
90	5	-	-	-
	7	4P 3F	4P 2F	5P 1F*
	9	1P 3F	2P 3F	4P 3F**

* missing overhead video analysis for one or more tests
** failure may be due to rudder problems in at least one test

7.2 Navigation of Lifeboat Models

The test results for the lifeboats were determined using pass/fail criteria of (a) reaching a distance of 5.0 boat lengths; and (b) reaching this distance within 40 seconds. Results are plotted for each model – IOT 544 (Figure 18 and Figure 19), IOT 609 (Figure 20 and Figure 21), and IOT 681 (Figure 22 and Figure 23). The tests included in the plots are those in which the vessel attempted into travel into the wave direction (from a launch heading of either 0 degrees or 90 degrees to the wave direction). Tests in which the vessel was traveling with the waves (0 plus) were excluded.

There were not any major differences in the navigational capabilities of the three boats. The conventional lifeboat had more difficulty meeting the pass criteria than the IOT 609 and IOT 681 vessels. The IOT 681 model had some mechanical problems during two tests, which may have prevented the model from being able to achieve a 'pass'. In tests 103 and 108, the IOT 681 model rudder was not operating properly. These tests were both at 9/10^{ths} ice concentration with 1.0 Hz wave frequency.

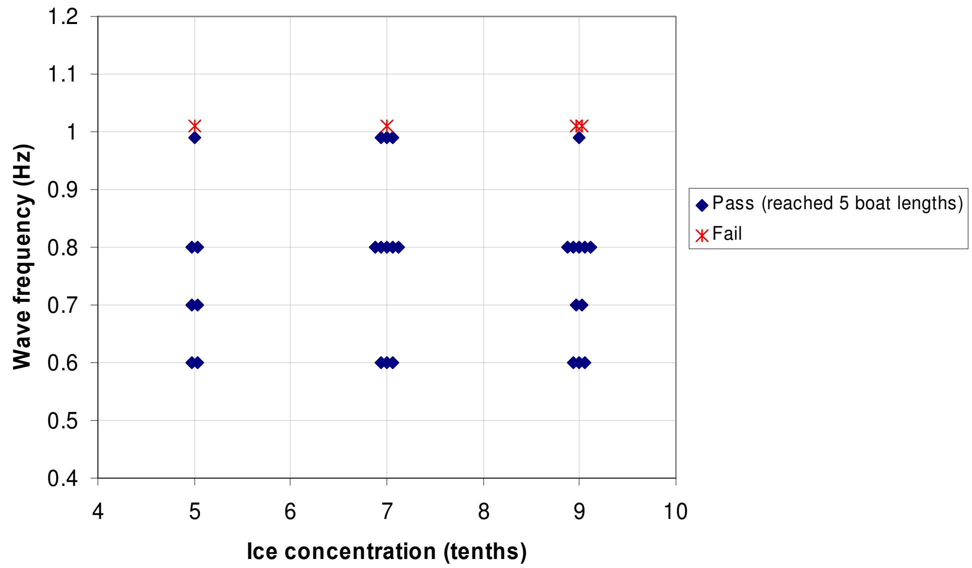


Figure 18 IOT 544 test results; pass/fail criterion set at 5.0 boat-lengths

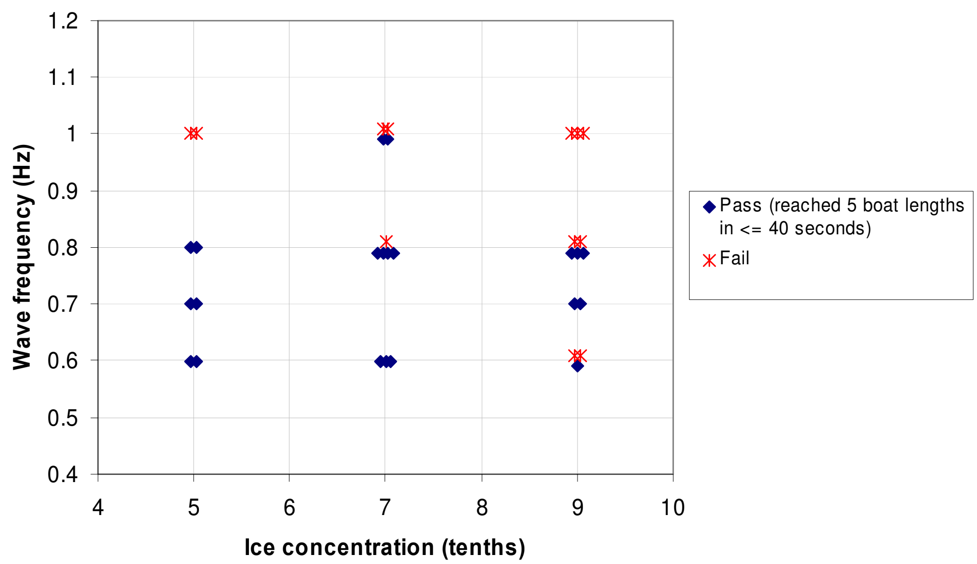


Figure 19 IOT 544 test results; pass/fail criteria set at 5.0 boat-lengths and test duration of 40 seconds

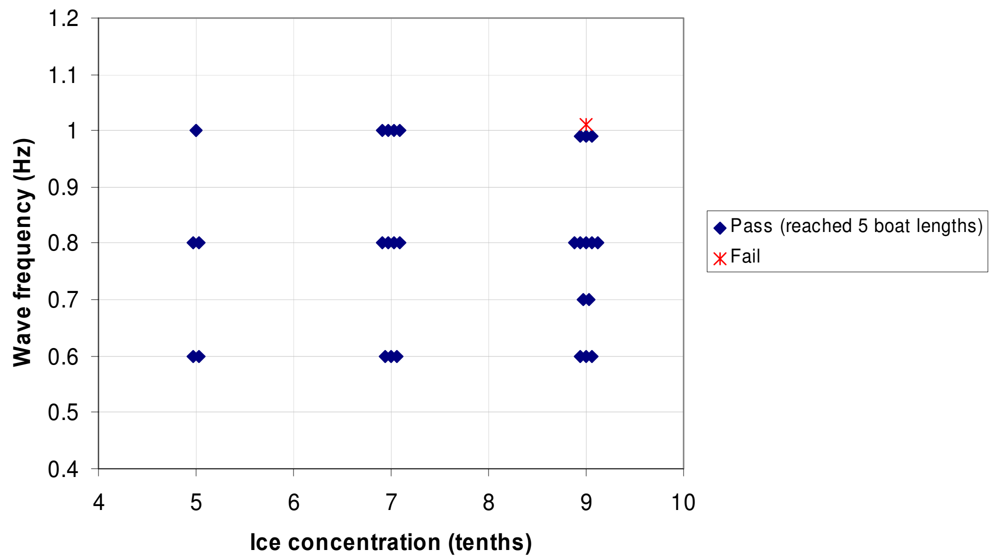


Figure 20 IOT 609 test results; pass/fail criterion set at 5.0 boat-lengths

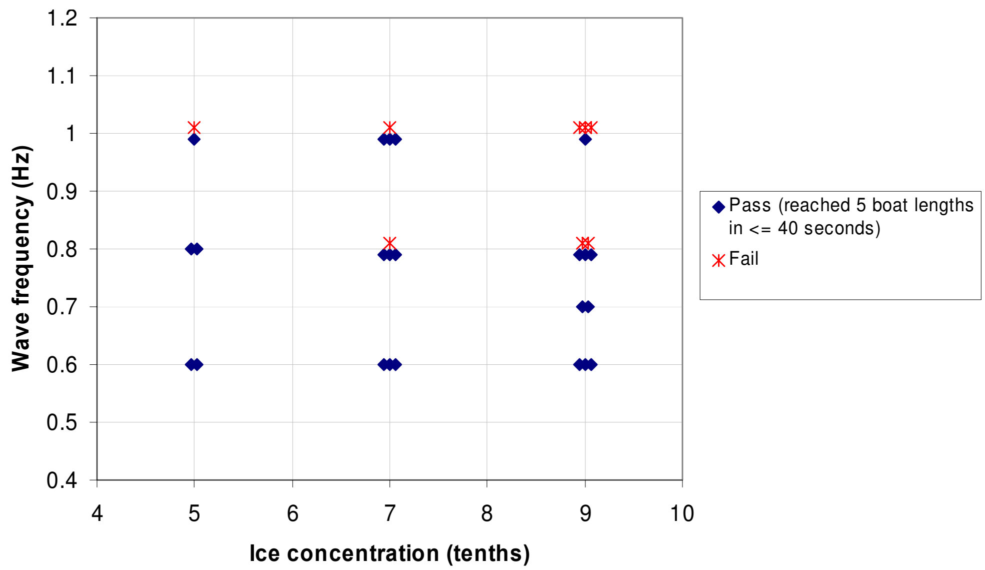


Figure 21 IOT 609 test results; pass/fail criteria set at 5.0 boat-lengths and test duration of 40 seconds

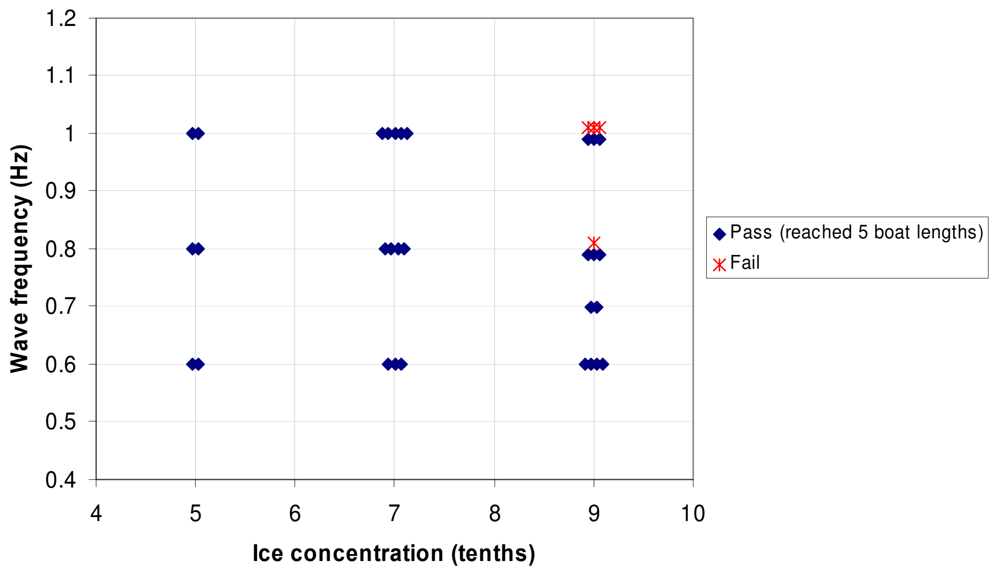


Figure 22 IOT 681 test results; pass/fail criterion set at 5.0 boat-lengths

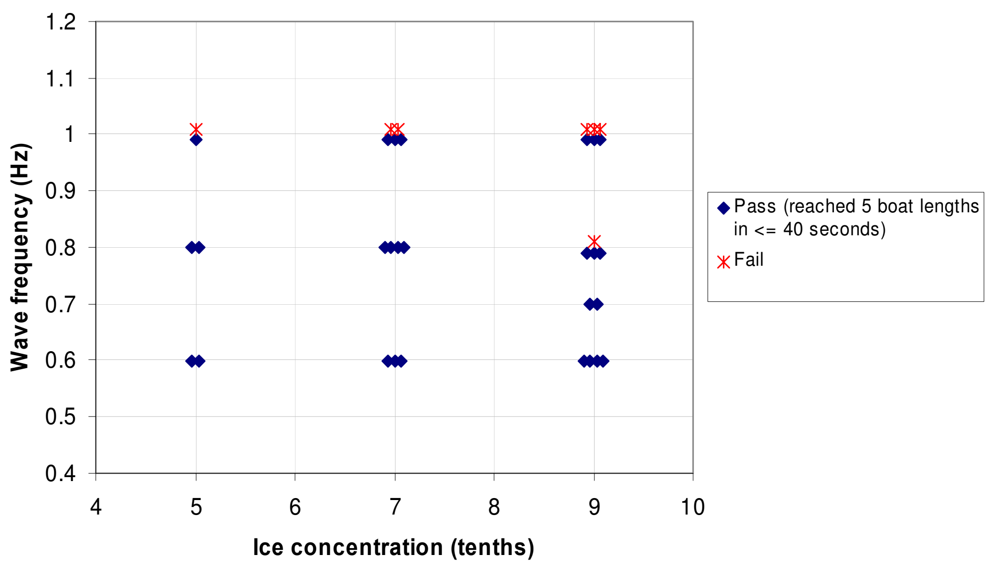
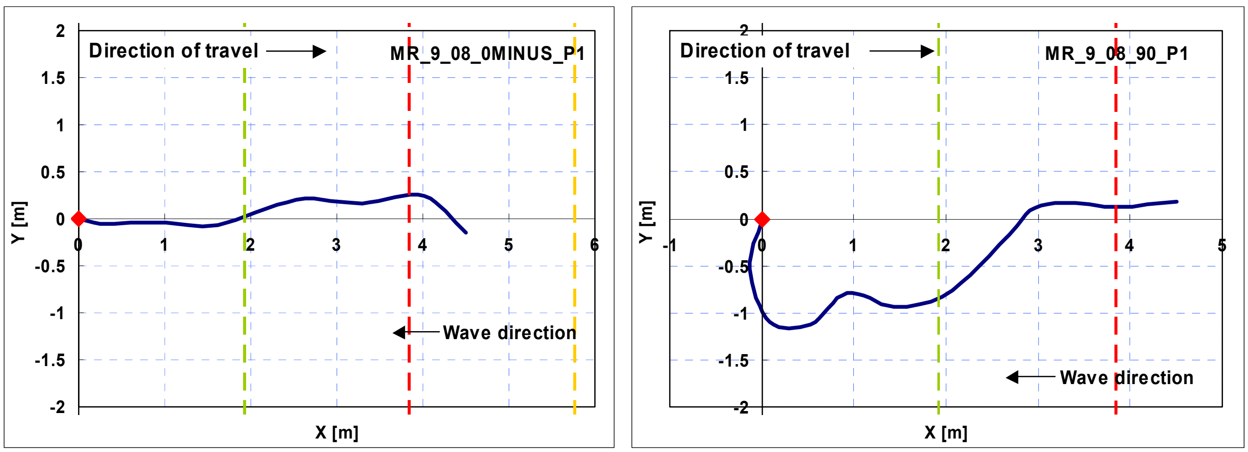


Figure 23 IOT 681 test results; pass/fail criteria set at 5.0 boat-lengths and test duration of 40 seconds

7.3 Effect of Launch Direction

When travelling with the waves (0 plus heading), the model always achieved the safe distance from the start point, and was helped along by the waves. In attempting to travel into the waves (0 minus), the equivalent safe distance in the other direction was usually achieved. For the 90° launch tests, all vessels had some difficulty meeting the pass criteria at 9/10^{ths} ice concentration and high frequency waves. Figure 24 shows the IOT 681 model's path for two tests with the same conditions but with different launch headings. Launching the vessel at 90 degrees generally increased the length of time necessary for the lifeboat to reach a set distance, since the lifeboat had to turn to face into the wave direction without being pushed back by the waves and ice.

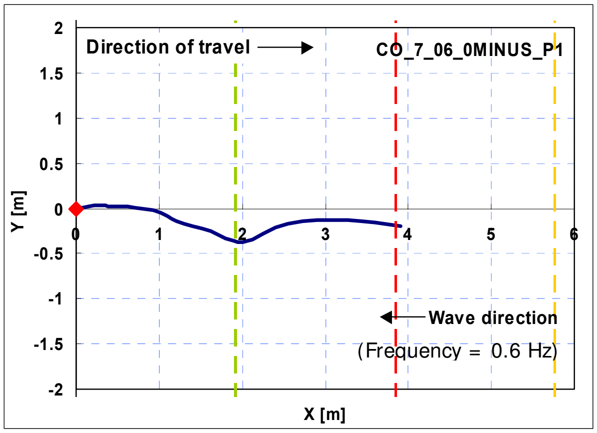


(a) Time = 24 seconds (b) Time = 34 seconds

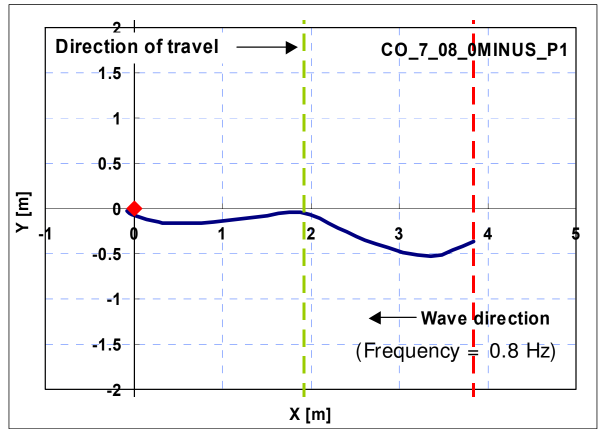
Figure 24 IOT 681 lifeboat tests at 9/10^{ths} ice concentration, wave frequency of 0.8 Hz, power level P1 (6 knots), and launch direction of (a) 0 degrees; (b) 90 degrees

7.4 Effect of Wave Frequency on Lifeboat Performance

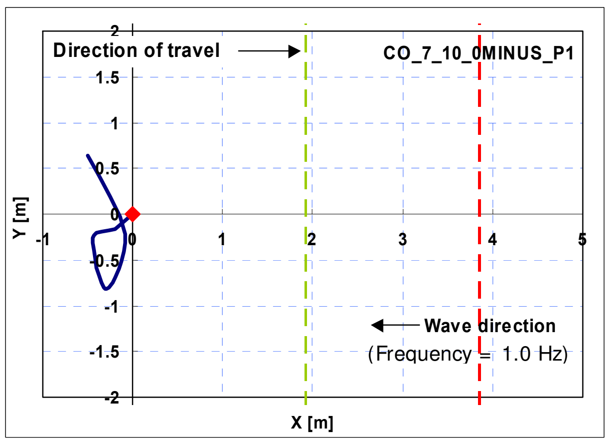
A higher wave frequency (i.e. shorter wave period) generally caused an increase in the time necessary for the lifeboat to travel the specified distance. The IOT 544 lifeboat model was able to pass 5.0 boat lengths in all but four tests – these four 'fails' were all tests at the highest wave frequency. An example of three tests with the IOT 544 model in which the wave frequency was varied is shown in Figure 25.



(a) Time = 19 seconds



(b) Time = 28 seconds



(c) Time = 28 seconds

Figure 25 IOT 544 lifeboat model tests at 0 minus heading, 7/10ths ice concentration, power level P1, and wave frequency of (a) 0.6 Hz; (b) 0.8 Hz; (c) 1.0 Hz.

For the IOT 609 lifeboat, the model failed to reach the 5.0 boat length criterion for only one test. This test was performed at the highest wave frequency, 1.0 Hz. For all other tests, when other variables were held constant, the time taken to reach 5.0 boat lengths increased when wave frequency was increased.

For the IOT 681 model, three of the four tests in which the lifeboat failed to reach 5.0 boat lengths were tests carried out at the highest wave frequency. It is noted that this model experienced some mechanical difficulties, which may have prevented the lifeboat from performing properly in two of the tests that appeared to be 'fails'.

7.5 Effect of Power Level on Lifeboat Performance

As mentioned, the effect of varying the power to the boats was also investigated in this test program. The models were each tested at two different power levels. The speeds and bollard pull corresponding to each power level varied slightly for each vessel, as explained in Section 3.4. Table 10 compares the power levels and corresponding force, rpm, and speed for each of the vessels.

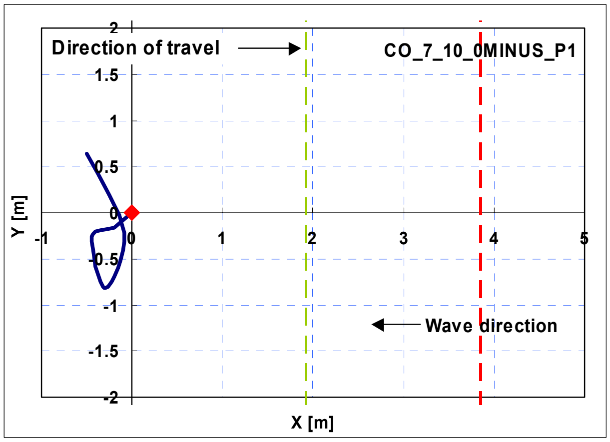
Table 10 Power levels for IOT 544, IOT 609, and IOT 681 models

Model	Speed	Force [Newtons]	RPM	Speed [m/s]
IOT 544	P1	1.20	2600	3.1
IOT 609	P1	1.01	2500	3.1
IOT 681	P1	1.19	2300	3.1
IOT 544	P2	2.70	3700	3.9
IOT 609	P2	2.40	3700	4.1
IOT 681	P2	3.45	3700	4.1

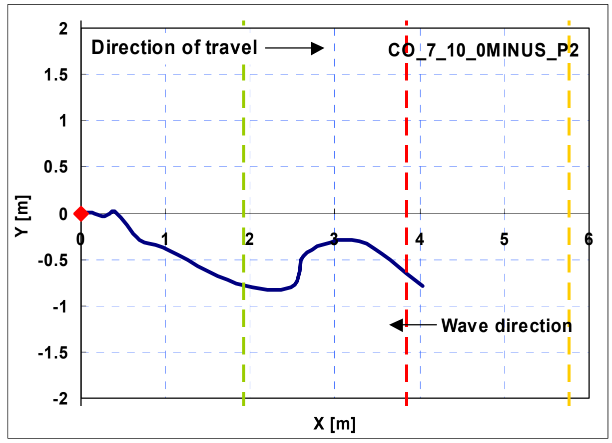
In previous tests series in ice with no waves, an increase in power had little effect on the performance of the lifeboat. However, the additional power in waves and ice does affect the lifeboat's ability to make headway into waves in ice-covered waters. A higher power level generally allowed the lifeboat to traverse the set distance into the wave direction in a shorter time period. This could have repercussions for evacuation procedures where it may be imperative to travel upwind of the structure.

For some of the IOT 544 lifeboat model tests, increasing the power to the boat allowed the model to travel through wave and ice conditions that it would not be able navigate at a lower power level. At the highest wave frequency, with 5/10^{ths} and 7/10^{ths} ice concentration, the IOT 544 boat could not pass the 5.0 boat length requirement. With additional power, the vessel was able to reach 5.0 boat lengths. Figure 26 shows an example of two tests with the same ice and wave climate but different power levels; the model could not make headway without additional power.

At 9/10^{ths} ice concentration, the IOT 544 model managed to eventually make its way to the 5.0 boat length goal at the lower power level. With additional power, the boat was pushed back by the waves and ice and could not make headway. This is an illustration of a situation in which the pass/fail result depends on the ice conditions immediately around the model; i.e. whether there happens to be an open water lead so that the vessel can make headway.



(a) Time = 28 seconds

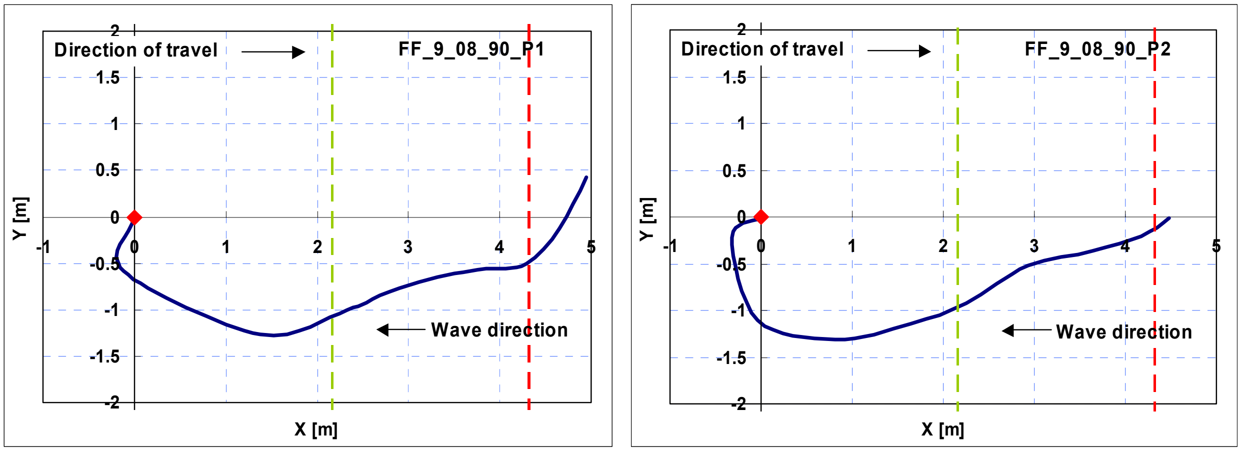


(b) Time = 29 seconds

Figure 26 IOT 544 lifeboat model tests at 0 minus heading, 7/10ths ice concentration, wave frequency of 1.0 Hz, and power level of (a) P1; (b) with additional power, P2.

The IOT 609 model reached 5.0 boat lengths in all tests except one (launching 90 degrees into the highest frequency waves and the highest ice concentration). As with the IOT 544 lifeboat, the IOT 609 model generally took much less time to travel through the wave and ice climate when the vessel was operating at a higher power level. In Figure 27, two tests are shown in which the power level was varied. At the higher power level, the vessel reached the 5.0 boat length mark relatively easily in 30 seconds. At the lower power level, the vessel took nearly 90 seconds. This test was repeated and the vessel took 60 seconds the second time.

In the IOT 681 model tests, as with the other models, operating with additional power decreased the length of time required to travel a set distance into the waves.



(a) Time = 1 min 26 seconds

(b) Time = 30 seconds

Figure 27 IOT 609 lifeboat model tests at 90 degree heading, 9/10ths ice concentration, and wave frequency of 0.8 Hz, and power level of (a) P1; (b) with additional power, P2.

7.6 Navigation with On-board Video System

As mentioned, navigability using the on-board video system was extremely difficult, if not futile, given the wave conditions examined in this test series. It would perhaps have been worthwhile to navigate the TEMPSC models using only the on-board video regardless, given that a TEMPSC operator in the field would have no alternative. However it was almost impossible for the operator to try to pick a path through the floes, as the floes had changed position by the time the ice came into view again, riding down a crest. This is a real operational problem with current TEMPSC designs. In previous test series in ice with no waves, and with waves but no ice, the operator was still able to use the on-board video system to manoeuvre the lifeboat (with some difficulty) around ice floes or in line with a general heading.

7.7 Comparison with Previous Test Programs

For the 2003 evacuation test series (with ice and waves), the TEMPSC had the same hull design as the IOT 544 model in the present test series. In the 2003 tests, the TEMPSC rarely achieved a 'pass' except when the vessel was travelling with the wave direction and being pushed along by the waves. The present test series demonstrated that all three TEMPSC models were generally able to travel through various ice concentration ices at several wave frequencies, whereas in previous tests little or no headway was achieved in similar conditions.

The results for the IOT 544 model can be compared for the 2003 and 2005 test series, with some caution. The model achieved more passes in the 2005 tests, which could be due to several factors including:

- The vessel had additional power for some of the 2005 tests.

- The measured wave heights for the 2003 tests (at wave frequency of 0.625 Hz) were much higher than the nominal wave height, often almost three times as large. This could be due to the generation of standing waves in the ice tank under swell conditions. For the 2005 test series, the wave-absorbing beaches were improved and wave heights were closer to the nominal value.
- The TEMPSC used for the 2005 tests had a new and improved control system and updated drive system.
- The average floe size appeared to be smaller for the 2005 test series, especially after a full day of testing.

8. SUMMARY

A physical model test program was carried out in order to investigate the effect of lifeboat design on the performance in various pack ice and wave conditions. Three different lifeboat hull forms were selected - conventional (IOT 544), free fall (IOT 609), and Mad Rock Polar Haven (IOT 681). The model lifeboats were constructed at a scale of 1:13. The lifeboat had to meet pass/fail criteria, which depended on whether the vessel could make way in a given environmental condition. The models were able to make way in most cases, and generally had relatively good control over the path travelled through the floes, especially at lower wave frequencies. Compared to previous evacuation model tests, the vessels in the present test series were better able to navigate the given conditions. When travelling with the wave direction, the model could always make way. When travelling into the waves, each model had some difficulty in several tests; especially those at higher wave frequencies and higher ice concentrations. As in the 2003 test series, it was not practical to use the on-board video system to navigate the TEMPSC through the ice floes since the floes had changed position by the time they were within the field of view of the on-board video camera, after the model rode up and down a wave.

In Figure 28, the effects of vessel heading, ice concentration and wave climate are summarized.

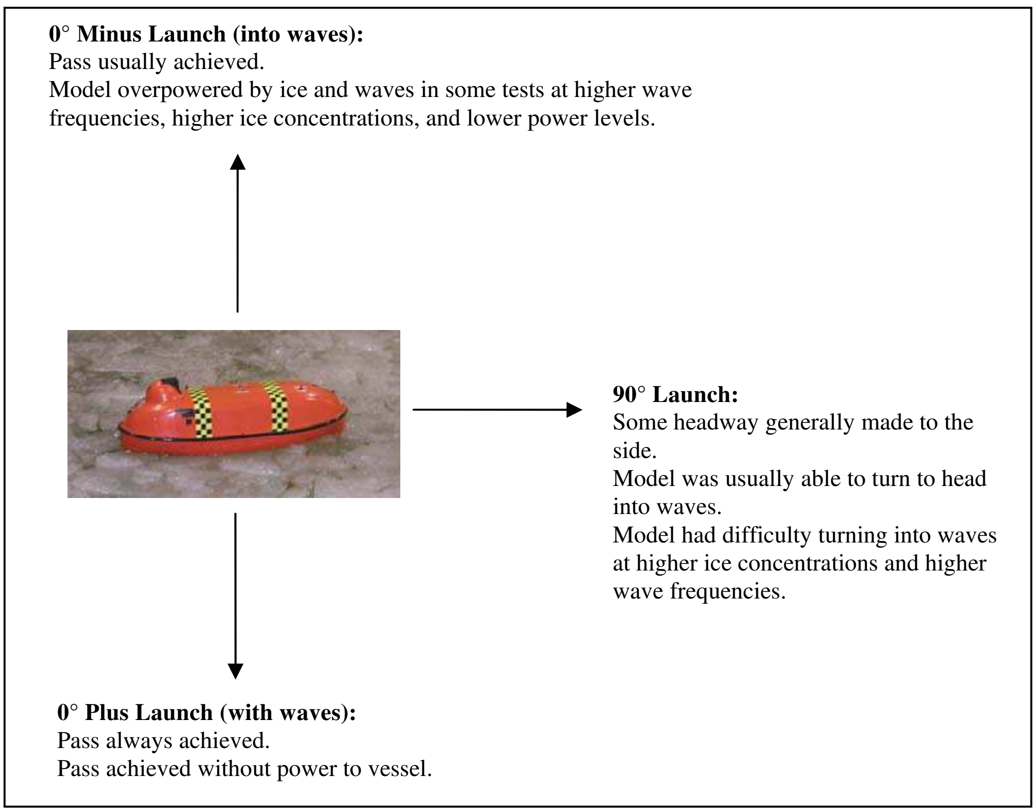


Figure 28 Summary of results

9. ACKNOWLEDGEMENTS

The financial support of the PERD Marine Transportation and Safety Committee is gratefully acknowledged.

The authors would also like to thank the CHC Facility technical staff (S. Lafrance, J. Dazé, J. Zhang and D. Pelletier) who helped with the instrumentation and set-up of the experiments.

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Timco, G.W. (1986) *EG/AD/S: A New Type of Model Ice for Refrigerated Towing Tanks*. Cold Regions Science and Technology, Vol. 12, pp 175-195.

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APPENDIX A CALIBRATED WAVE MACHINE SENSORS

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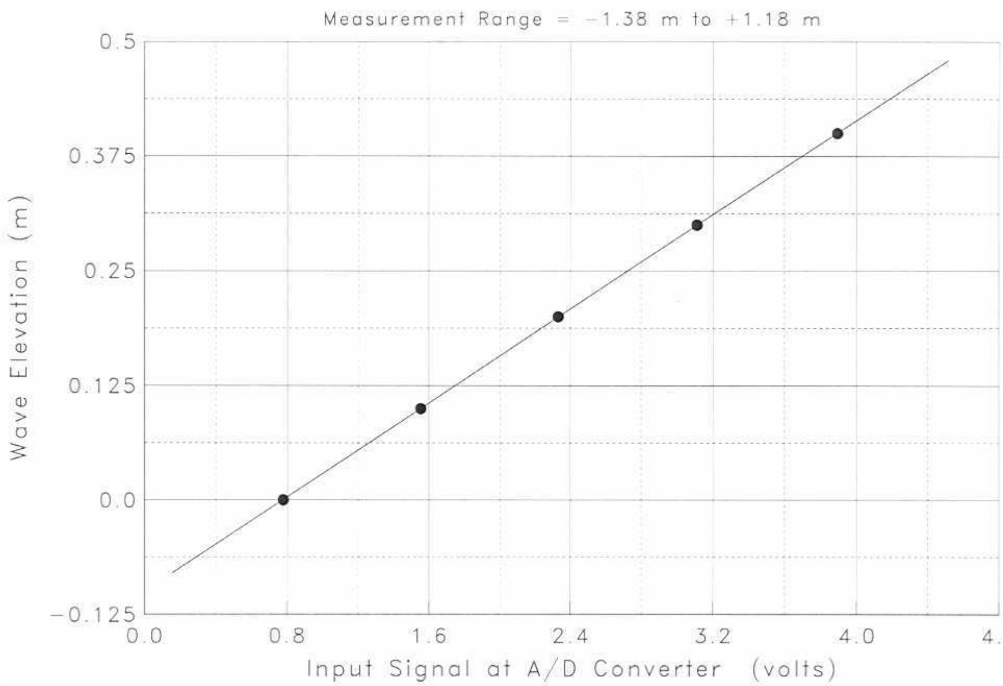
Calibration of PCI6031E Channel 5 09:25 21 April 2005

alibrated by: JD & JZ Calibration Status: NORMAL
roject: Evacuation in Ice Facility: Ice Tank
ensor: P1 Model: MPX2050 / 50kPa Serial No. 1
rogrammable Gain: 1 Plug-In Gain: 1 Filter Frequency: 1.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (m)	Fitted Curve (m)	Error (m)
1	0.778	0.00000	0.00032	0.00032383
2	1.553	0.10000	0.09985	−0.00015237
3	2.331	0.20000	0.19966	−0.00033531
4	3.112	0.30000	0.29984	−0.00016394
5	3.895	0.40000	0.40033	0.00032774
Maximum Error = −0.0838% of Calibration Range				

$$Y = C_0 + C_1 V$$

where $Y(t)$ = Wave Elevation (m)
$V(t)$ = input signal at A/D converter (volts)
C_0 = −0.0994663 m
C_1 = 0.128328 m/volt



Calibration of PCI6031E Channel 6 09:25 21 April 2005

Calibrated by: JD & JZ Calibration Status: NORMAL

Project: Evacuation in Ice Facility: Ice Tank

Sensor: P2 Model: MPX2050 / 50kPa Serial No. 3

Programmable Gain: 1 Plug-In Gain: 1 Filter Frequency: 1.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (m)	Fitted Curve (m)	Error (m)
1	0.875	0.00000	0.00224	0.0022404
2	1.669	0.10000	0.09975	−0.0002450
3	2.460	0.20000	0.19684	−0.0031613
4	3.286	0.30000	0.29835	−0.0016472
5	4.137	0.40000	0.40281	0.0028130
Maximum Error = −0.790% of Calibration Range				

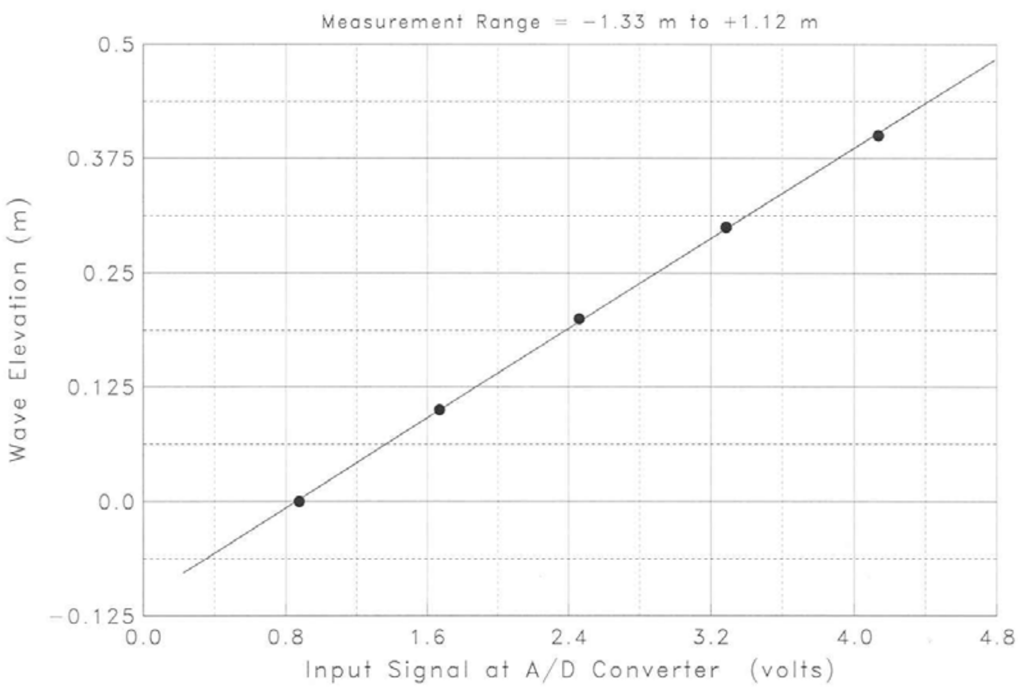
$Y = C_0 + C_1 V$

where $Y(t)$ = Wave Elevation (m)

$V(t)$ = input signal at A/D converter (volts)

$C_0 = -0.105252$ m

$C_1 = 0.122812$ m/volt



Calibration of PCI6031E Channel 7 15:07 27 April 2005

alibrated by: JD & JZ Calibration Status: NORMAL
roject: Evacuation in Ice Facility: Ice Tank
ensor: P3 Model: PCDR1830 Serial No. 74287
rogrammable Gain: 1 Plug-In Gain: 1 Filter Frequency: 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (m)	Fitted Curve (m)	Error (m)
1	−0.242	0.00000	0.00006	0.00005942
2	−1.277	0.10000	0.10002	0.00001636
3	−2.314	0.20000	0.20007	0.00006992
4	−3.344	0.30000	0.29958	−0.00042394
5	−4.387	0.40000	0.40028	0.00027823
Maximum Error = −0.106% of Calibration Range				

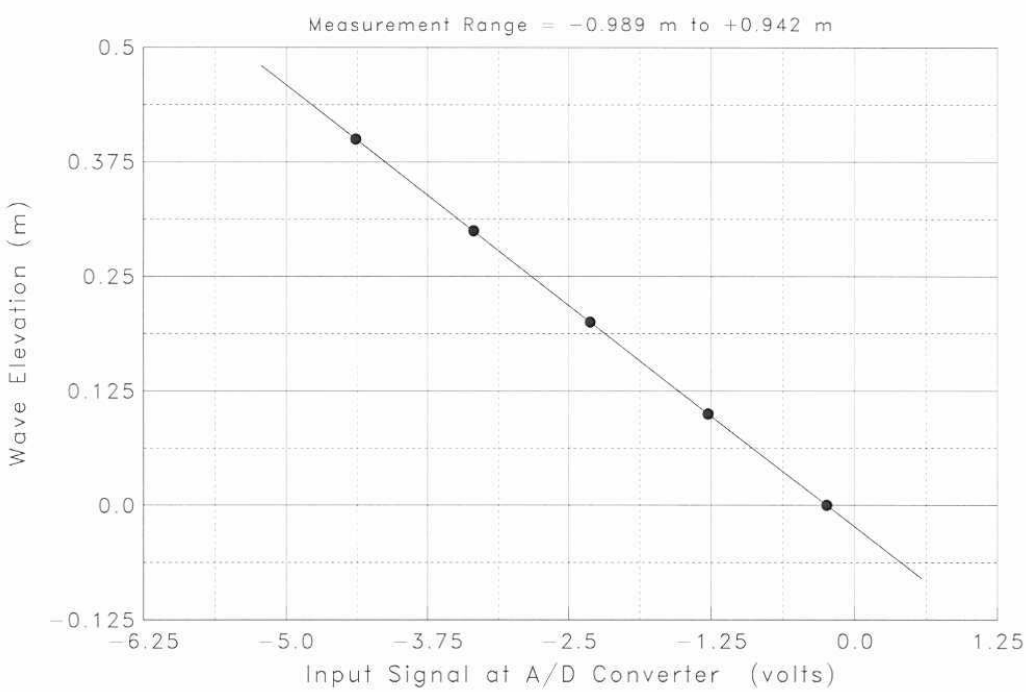
$Y = C_0 + C_1 V$

where $Y(t)$ = Wave Elevation (m)

$V(t)$ = input signal at A/D converter (volts)

$C_0 = -0.0233202$ m

$C_1 = -0.0965508$ m/volt



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APPENDIX B TEST DEFINITIONS

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DEFINITIONS

The tests were named as in the following examples:

CO_5_06_0MINUS_P1
CO conventional lifeboat (IOT 544)
5 ice concentration in tenths [5/10ths]
06 wave frequency in Hz [0.6 Hz]
0MINUS launch direction [0 minus, or into waves]
P1 power level

FF_7_10_0PLUS_P2
FF freefall lifeboat (IOT 609)
7 ice concentration in tenths [7/10ths]
10 wave frequency in Hz [1.0 Hz]
0PLUS launch direction [0 plus, or following waves]
P2 power level

MR_9_08_90_P2
MR Mad Rock lifeboat (IOT 681)
9 ice concentration in tenths [9/10ths]
08 wave frequency in Hz [0.8 Hz]
90 launch direction [90 degrees, or parallel to wave direction]
P2 power level

MR_9_08_90_P2A
A test would be given this name if it were a repetition of test **MR_9_08_90_P2**.

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APPENDIX C ANALYSED TEST RESULTS FOR CONVENTIONAL LIFEBOAT (IOT 544)

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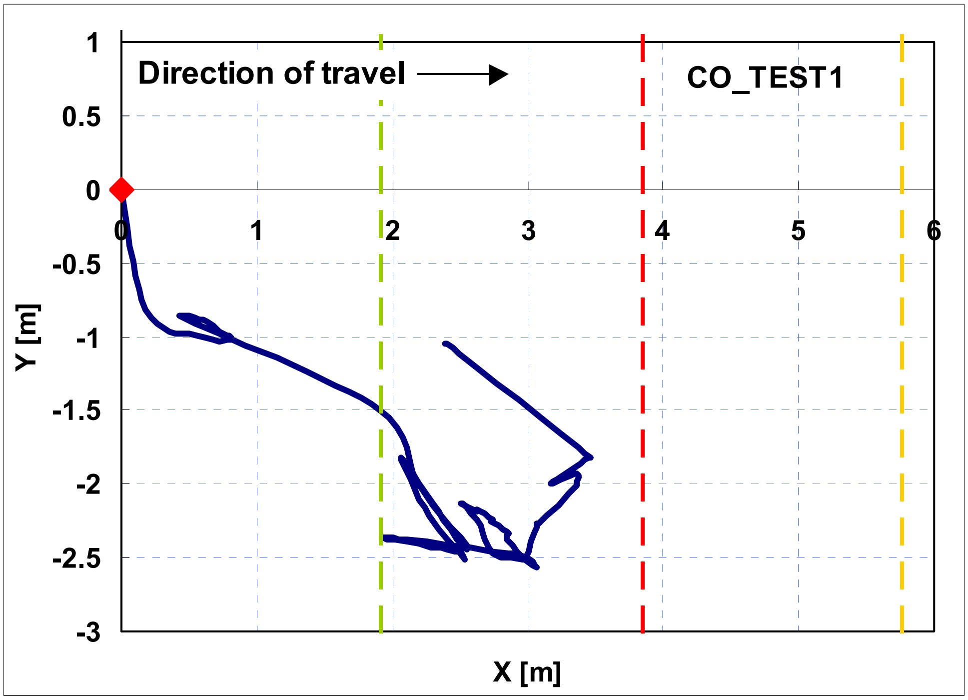
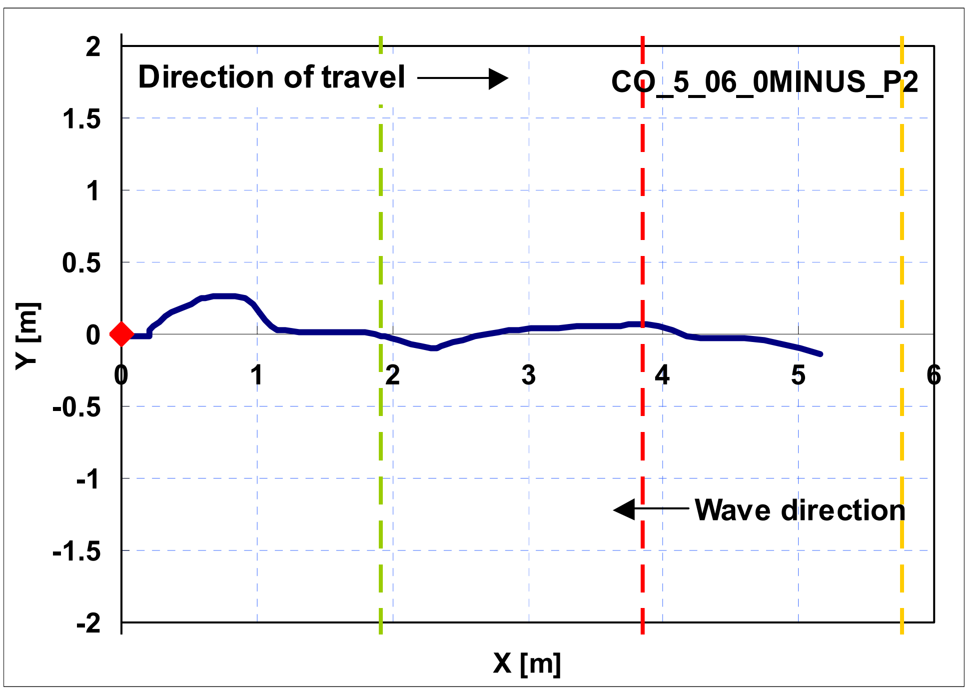
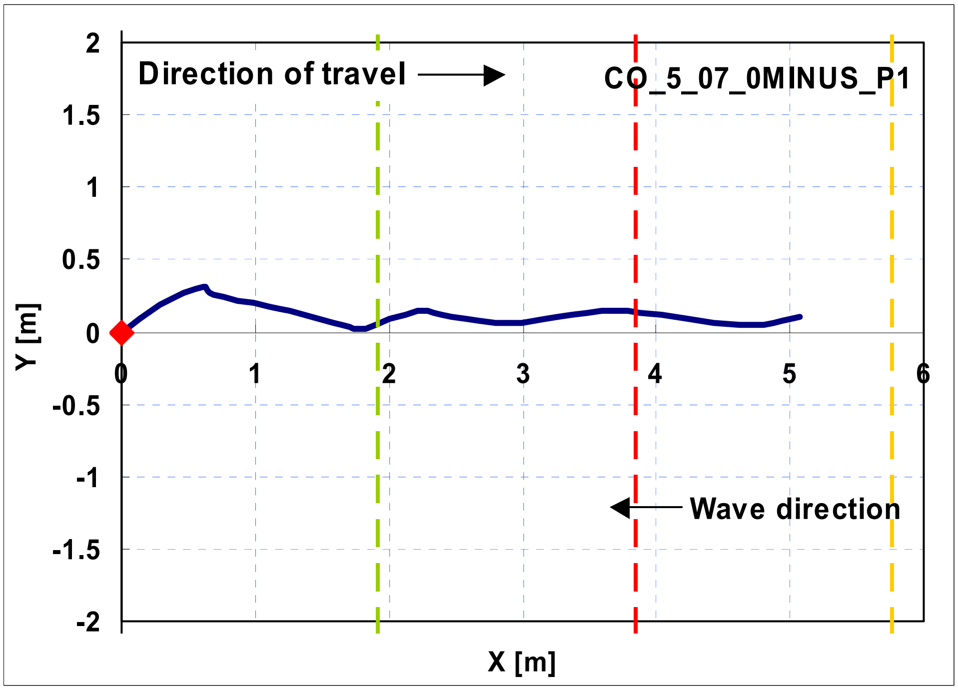
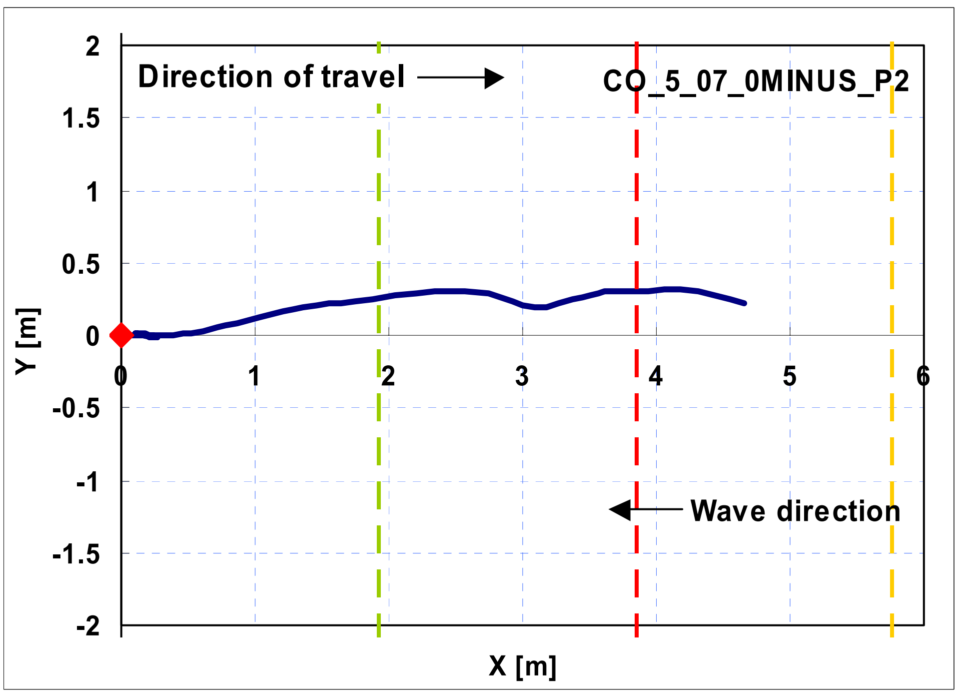
Expanded details for the complete test matrix for the IOT 544 lifeboat

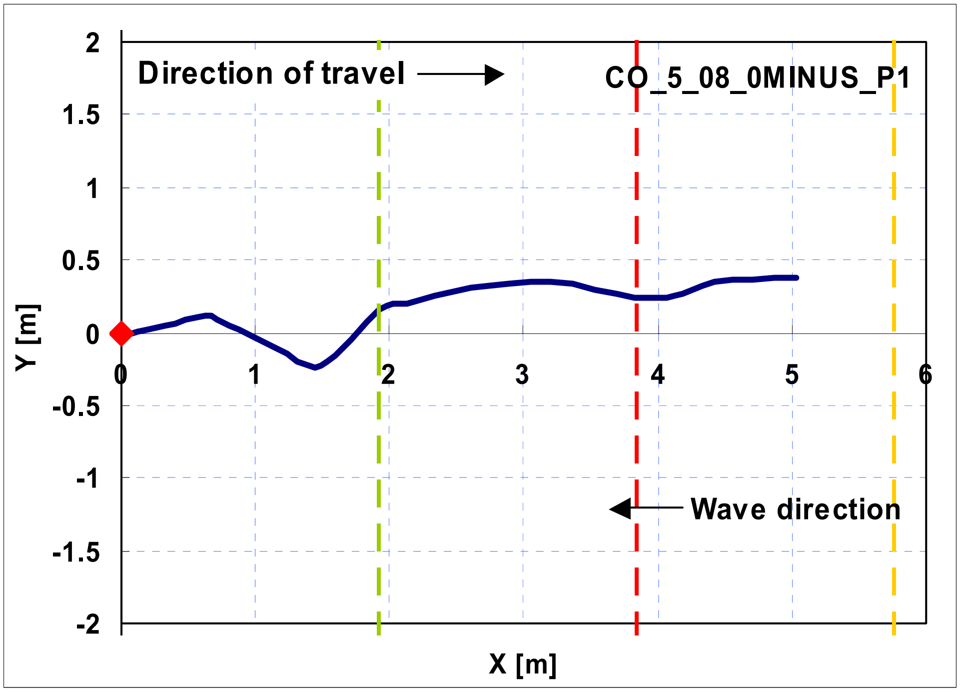
Test Name	Nominal Ice Concentration (tenths)	Nominal Wave Frequency (Hz)	Launch Direction (degrees)	Power (P1/P2)	Test duration (from overhead video)	Pass [5 boat lengths]	Pass [5 boat lengths reached in ≤ 40 seconds]
CO_test1	5	-	0-	P1 then P2	2 min 56 s	Fail	Fail
CO_5_06_0MINUS_P1	5	0.6	0-	P1	N/A	Pass	Pass
CO_5_06_0MINUS_P2	5	0.6	0-	P2	23 s	Pass	Pass
CO_5_07_0MINUS_P1	5	0.7	0-	P1	30 s	Pass	Pass
CO_5_07_0MINUS_P2	5	0.7	0-	P2	13 s	Pass	Pass
CO_5_08_0MINUS_P1	5	0.8	0-	P1	27 s	Pass	Pass
CO_5_08_0MINUS_P2	5	0.8	0-	P2	20 s	Pass	Pass
CO_TESTA	5	-	0-	P1	2 min 44 s	Fail	Fail
CO_TESTB	5	-	0-	P2	46 s	Pass	Fail
CO_5_10_0MINUS_P1	5	1.0	0-	P1	22 s	Fail	Fail
CO_5_10_0MINUS_P2	5	1.0	0-	P2	1 min 2 s	Pass	Fail
CO_7_06_0MINUS_P1	7	0.6	0-	P1	19 s	Pass	Pass
CO_7_08_0MINUS_P1	7	0.8	0-	P1	28 s	Pass	Pass
CO_7_08_0MINUS_P2	7	0.8	0-	P2	18 s	Pass	Pass
CO_7_10_0MINUS_P1	7	1.0	0-	P1	28 s	Fail	Fail
CO_7_10_0MINUS_P2	7	1.0	0-	P2	29 s	Pass	Pass
CO_7_06_90_P1	7	0.6	90	P1	24 s	Pass	Pass
CO_7_06_90_P2	7	0.6	90	P2	16 s	Pass	Pass
CO_7_08_90_P1	7	0.8	90	P1	1 min 4 s	Pass	Fail
CO_7_08_90_P2	7	0.8	90	P2	22 s	Pass	Pass
CO_7_08_90_P2A	7	0.8	90	P2	24 s	Pass	Pass
CO_7_10_90_P2	7	1.0	90	P2	40 s	Pass	Pass
CO_7_10_90_P1	7	1.0	90	P1	1 min	Pass	Fail
CO_9_06_0MINUS_P1	9	0.6	0-	P1	1 min 16 s	Pass	Fail
CO_9_06_0MINUS_P2	9	0.6	0-	P2	N/A	Pass	Pass
CO_9_08_0MINUS_P1	9	0.8	0-	P1	2 min 2 s	Pass	Fail
CO_9_08_0MINUS_P2	9	0.8	0-	P2	24 s	Pass	Pass
CO_9_07_0MINUS_P1	9	0.7	0-	P1	24 s	Pass	Pass
CO_9_07_0MINUS_P2	9	0.7	0-	P2	26 s	Pass	Pass
CO_9_10_0MINUS_P1	9	1.0	0-	P1	1 min 52 s	Pass	Fail
CO_9_10_0MINUS_P2	9	1.0	0-	P2	24 s	Fail	Fail
CO_9_06_0PLUS_P1	9	0.6	0+	P1	20 s	Pass	Pass
CO_9_08_0PLUS_P1	9	0.8	0+	P1	22 s	Pass	Pass
CO_9_CALM_P1	9	-	0-	P1	50 s	Pass	Fail
CO_9_CALM_P2	9	-	0-	P2	16 s	Pass	Pass
CO_9_08_90_P1	9	0.8	90	P1	38 s	Pass	Pass
CO_9_10_90_P2	9	1.0	90	P2	2 s	Fail	Fail
CO_9_08_90_P1A	9	0.8	90	P1	46 s	Pass	Fail
CO_9_08_0MINUS_P1	9	0.8	0-	P1	32 s	Pass	Pass
CO_9_06_90_P1	9	0.6	90	P1	44 s	Pass	Fail
CO_9_10_0PLUS_NP	9	1.0	0+	-	32 s	Pass	Pass


Direction of travel
CO_TEST1
Y [m]
X [m]
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
1
2
3
4
5
6


Direction of travel
CO_5_06_0MINUS_P2
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_5_07_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_5_07_0MINUS_P2
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_5_08_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
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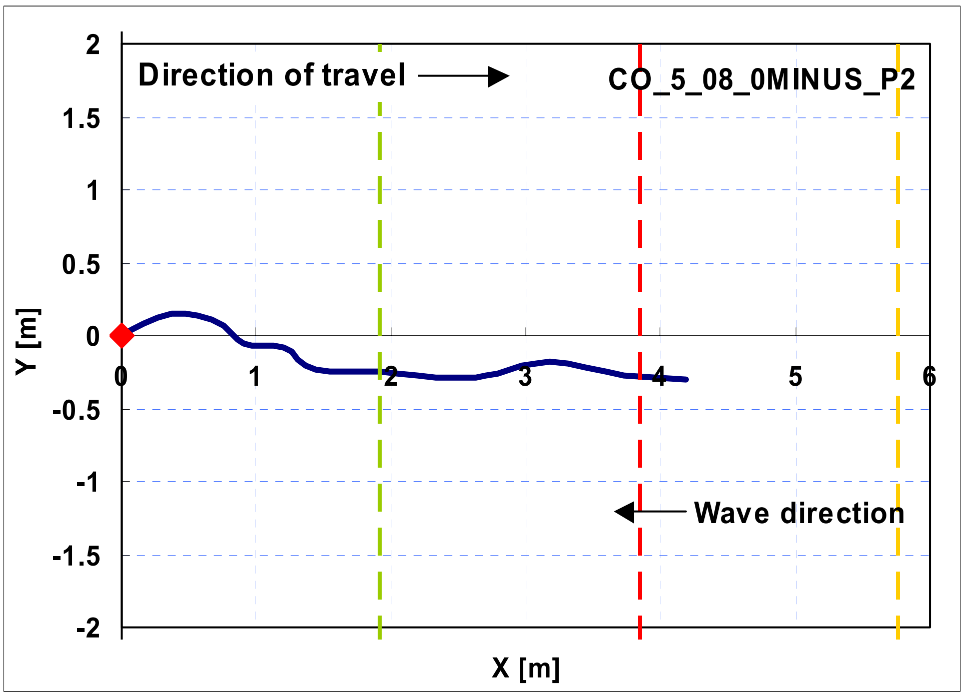
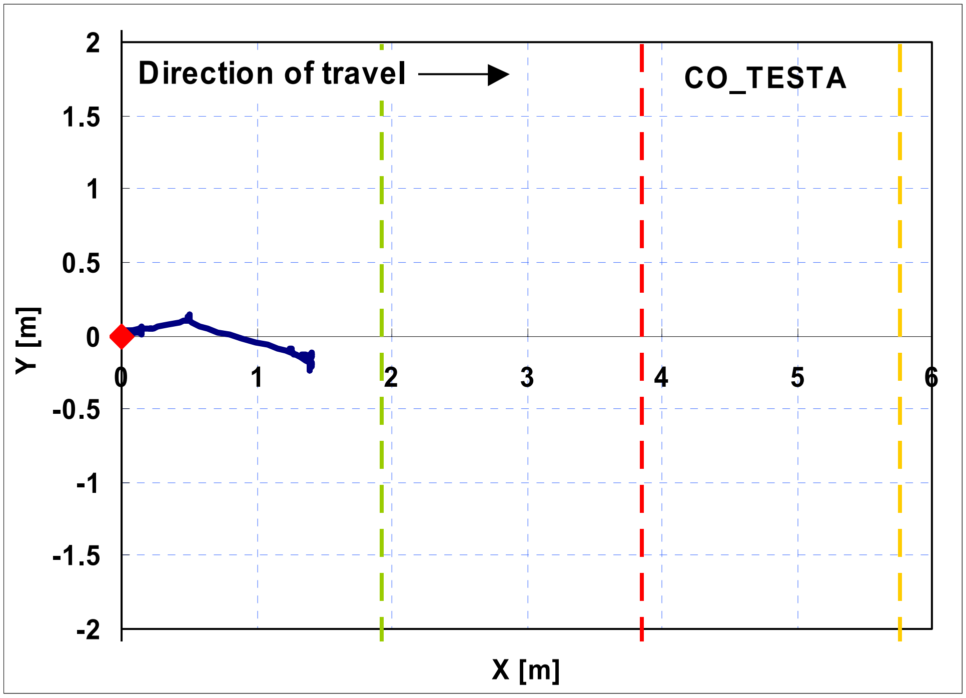
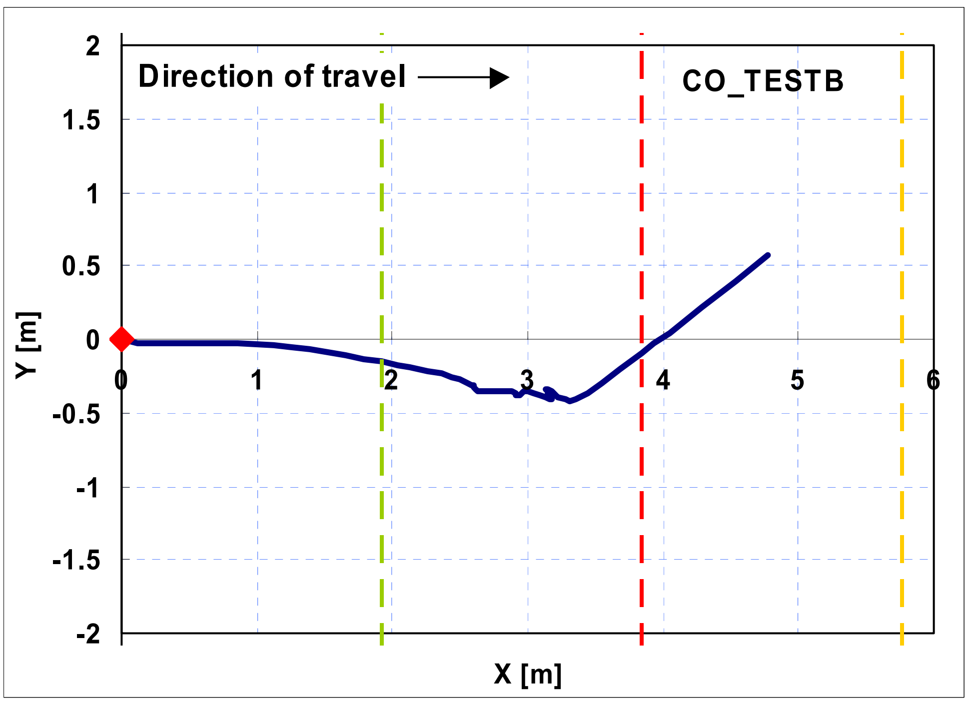
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_5_08_0MINUS_P2
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_TESTA
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_TESTB
Y [m]
X [m]
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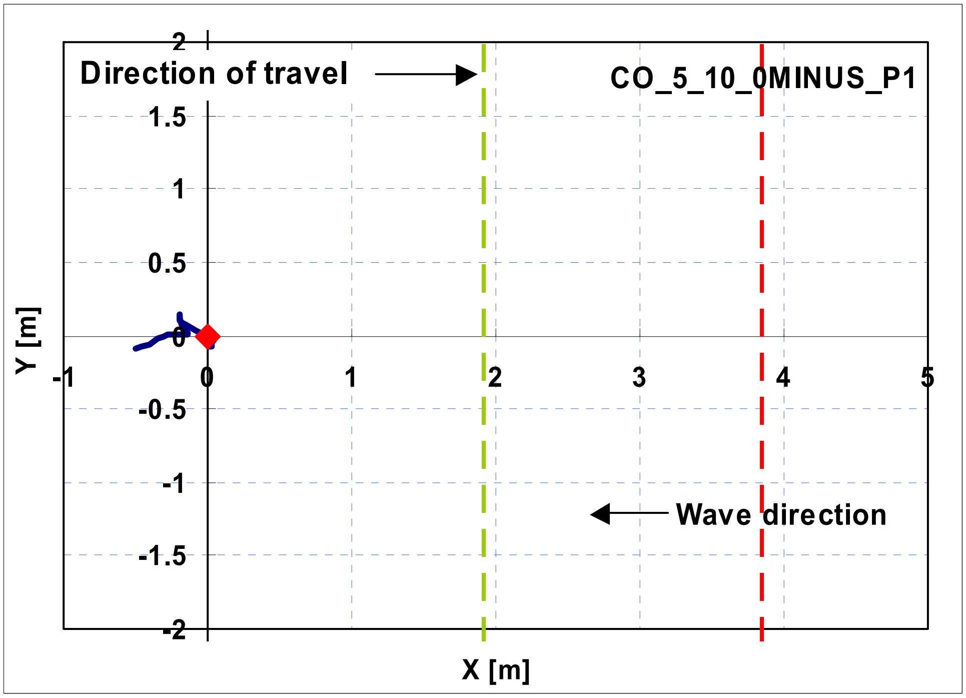
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_5_10_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
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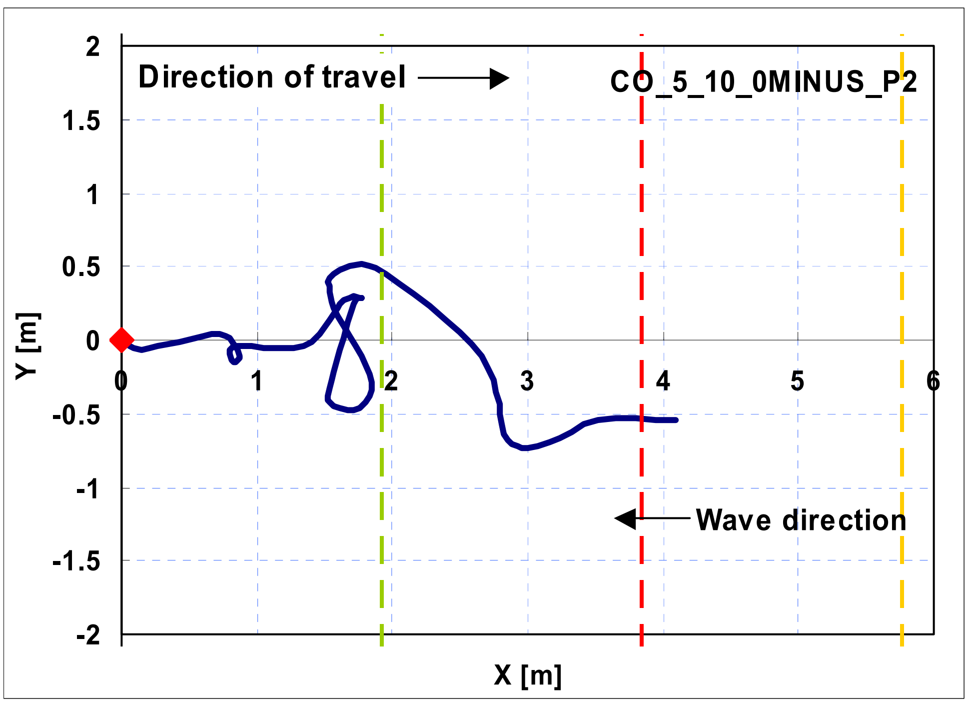
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_5_10_0MINUS_P2
Wave direction
Y [m]
X [m]
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1.5
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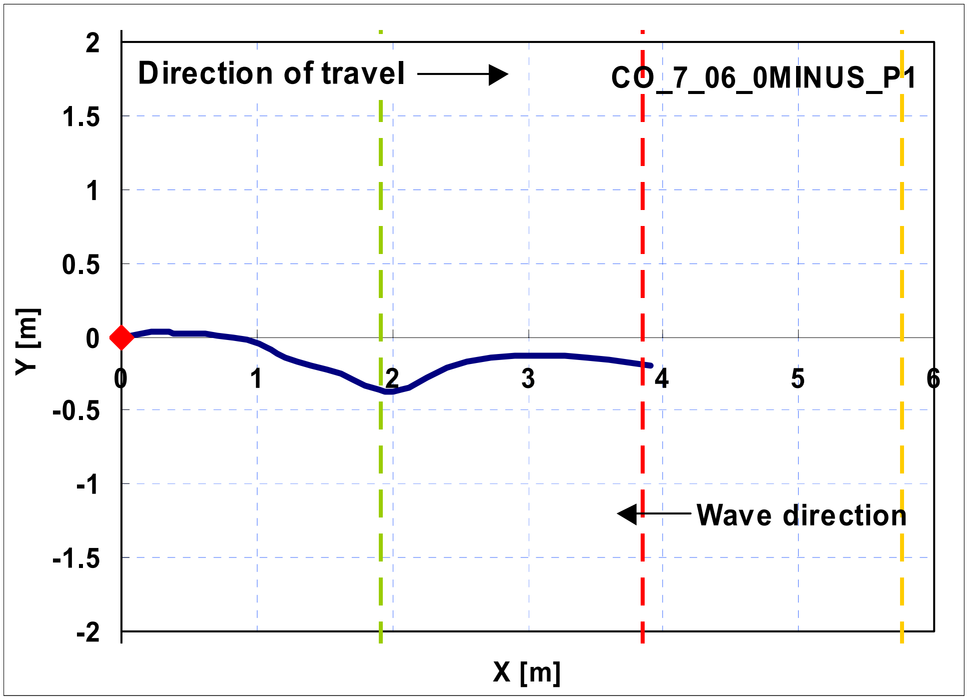
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_7_06_0MINUS_P1
Wave direction
Y [m]
X [m]
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1.5
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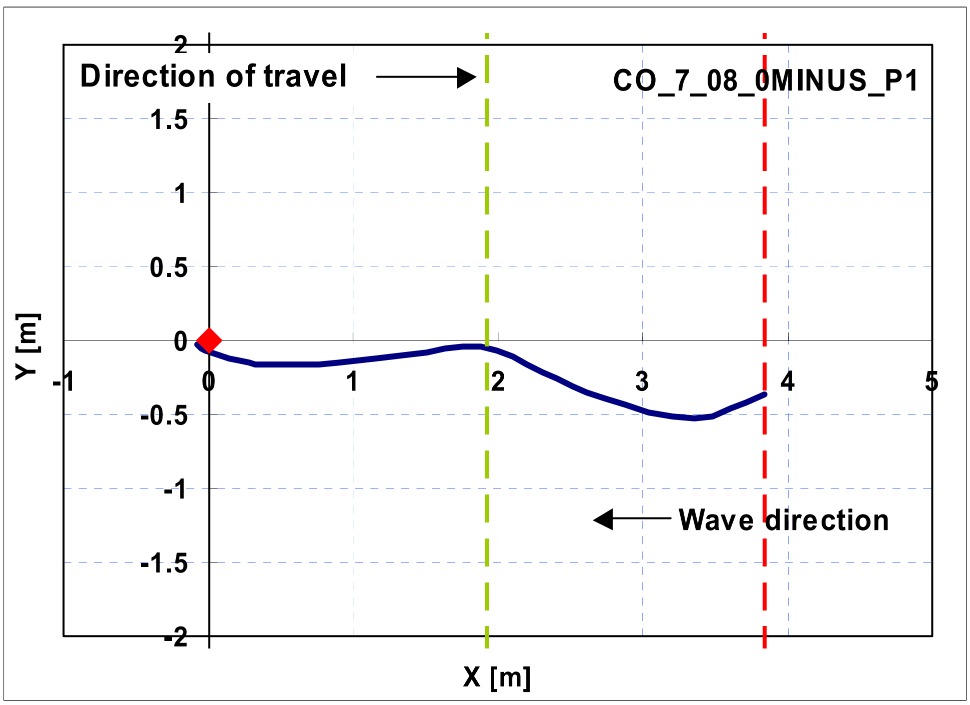
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_7_08_0MINUS_P1
Wave direction
Y [m]
X [m]
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1.5
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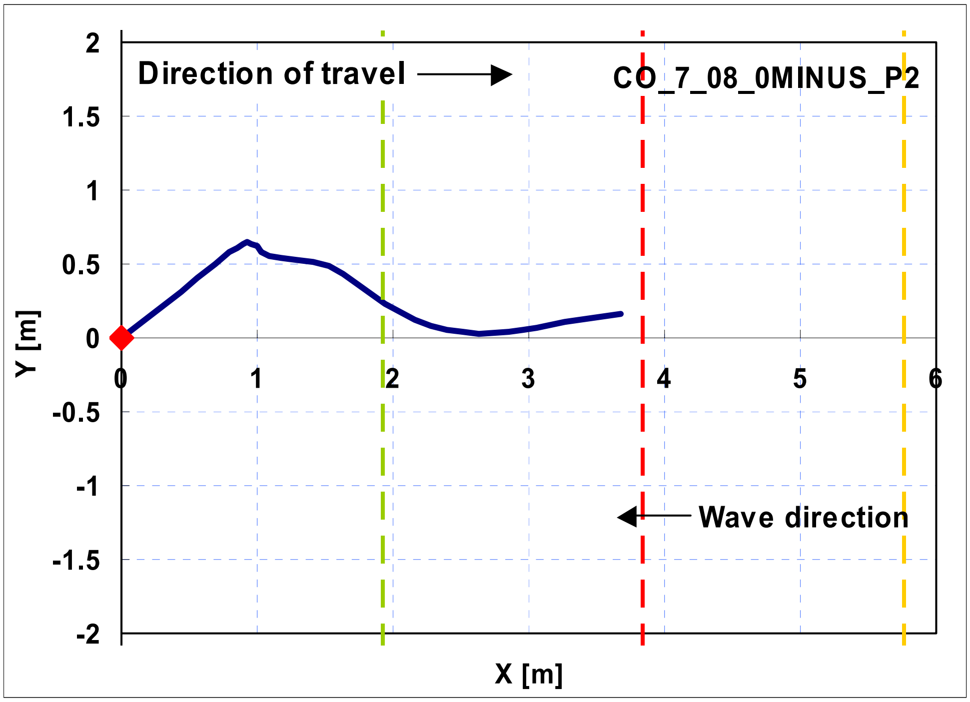
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_08_0MINUS_P2
Wave direction
Y [m]
X [m]
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1.5
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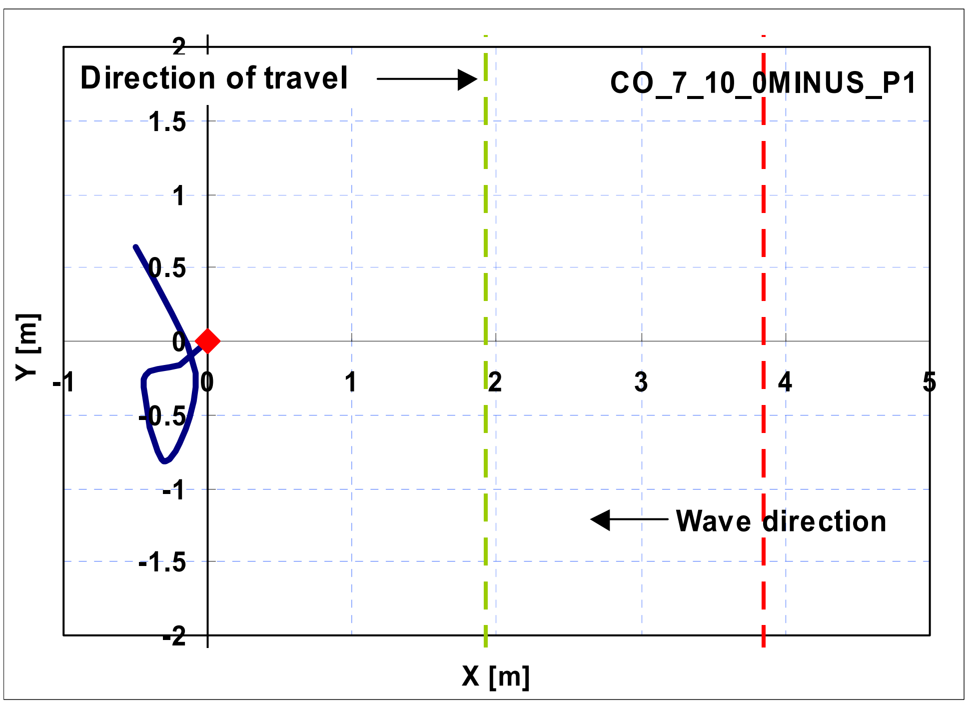
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_7_10_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
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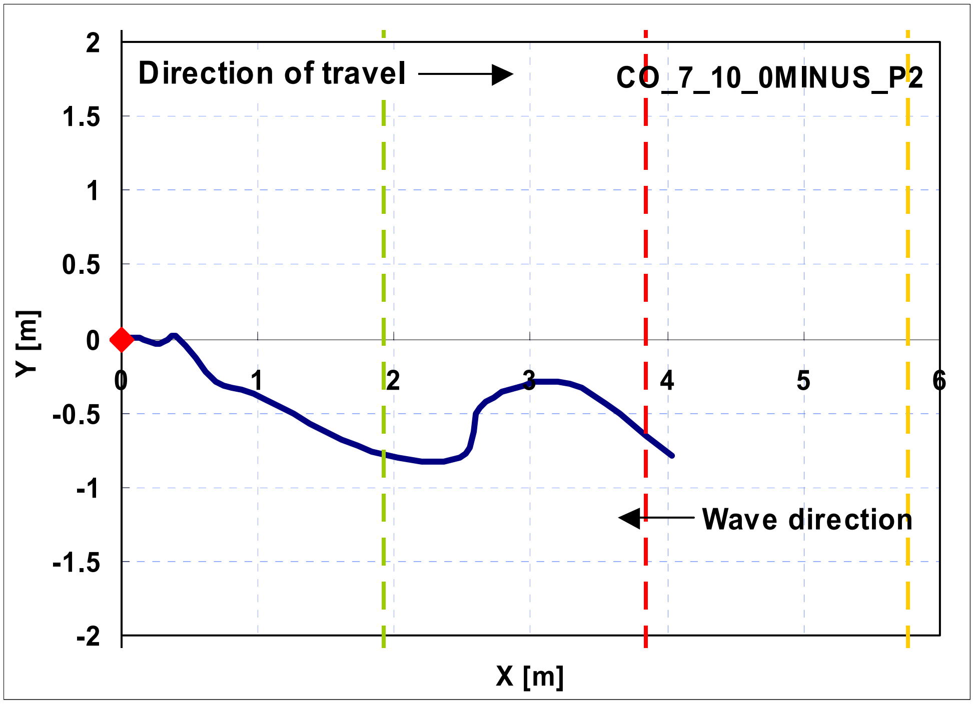
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_10_0MINUS_P2
Wave direction
Y [m]
X [m]
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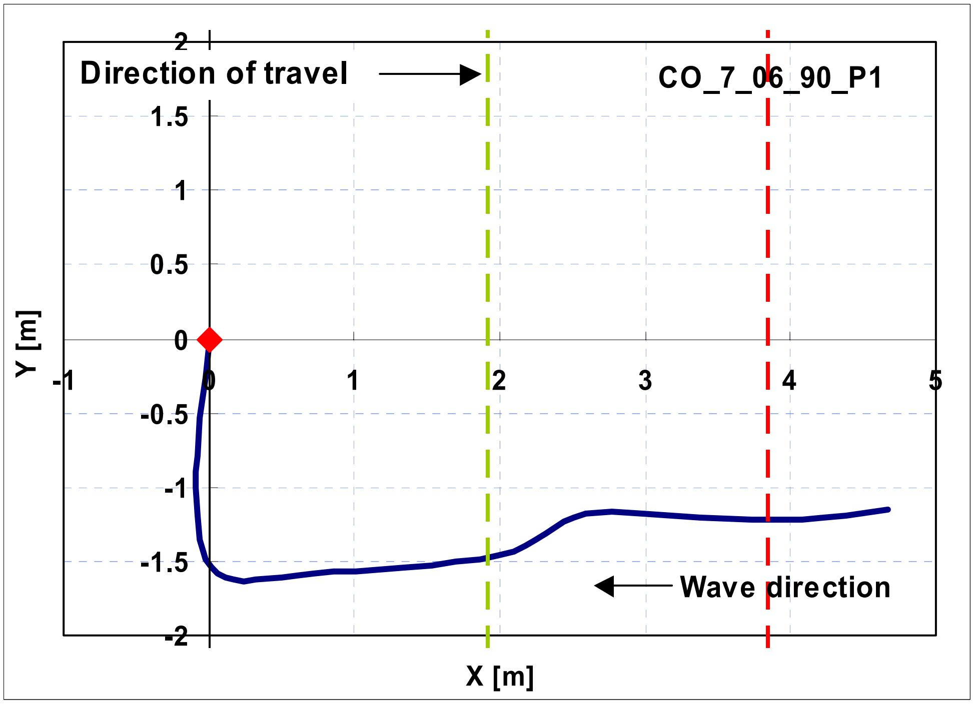
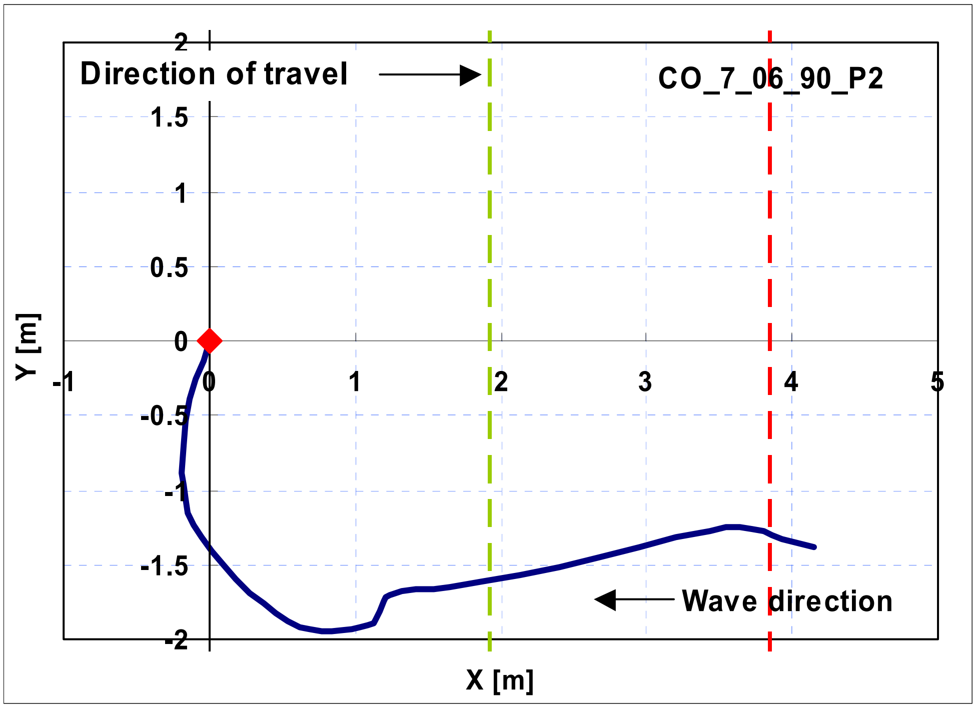
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_7_06_90_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_06_90_P2
Wave direction
Y [m]
X [m]
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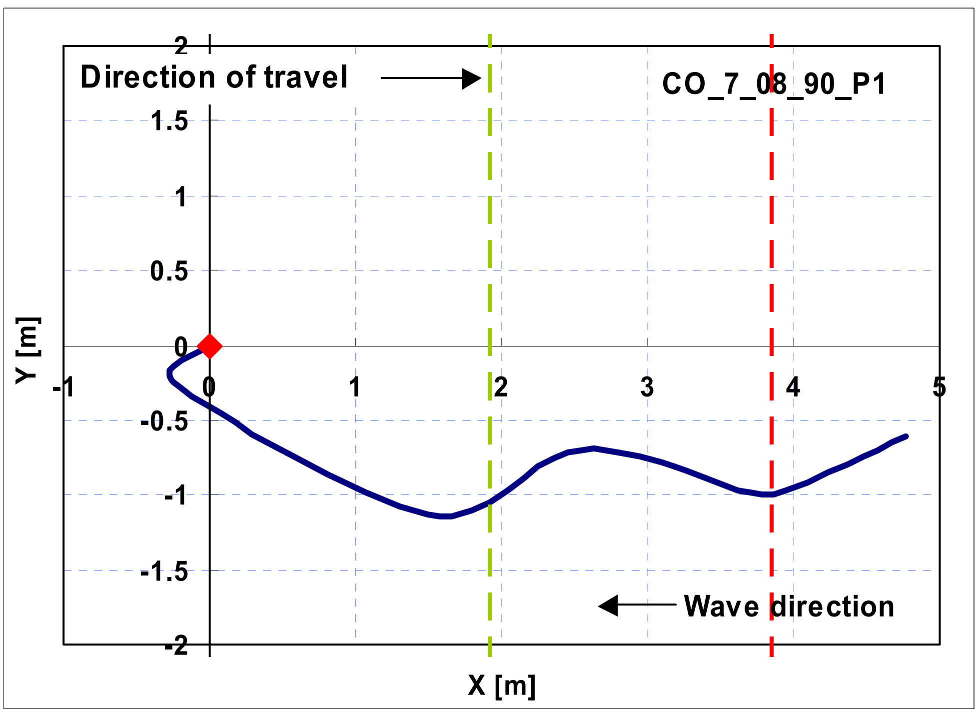
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_08_90_P1
Wave direction
Y [m]
X [m]
2
1.5
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0.5
0
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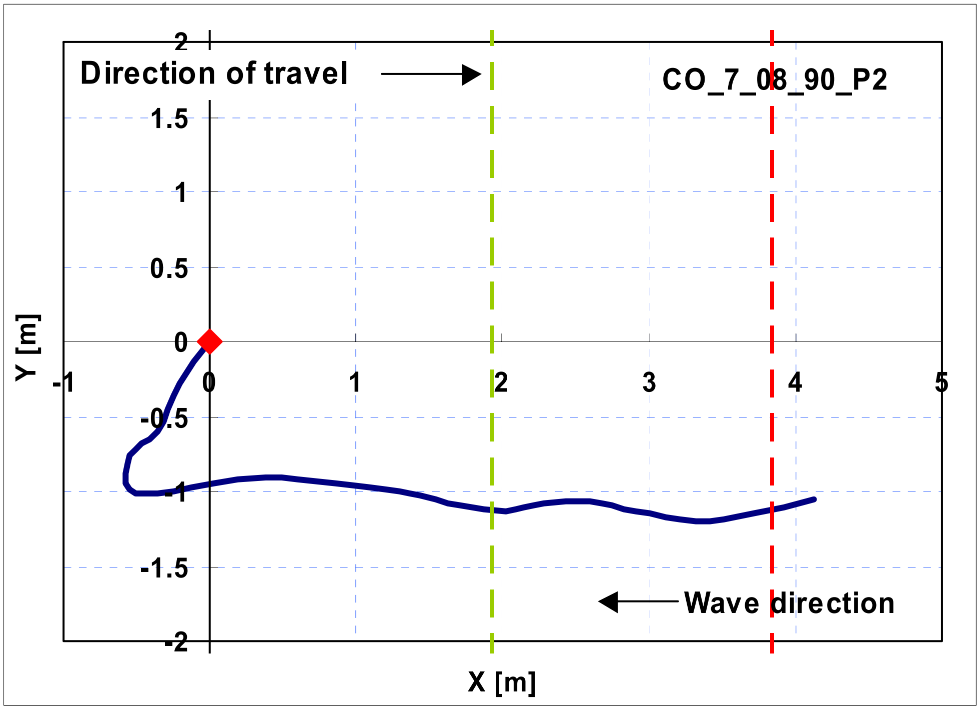
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_08_90_P2
Wave direction
Y [m]
X [m]
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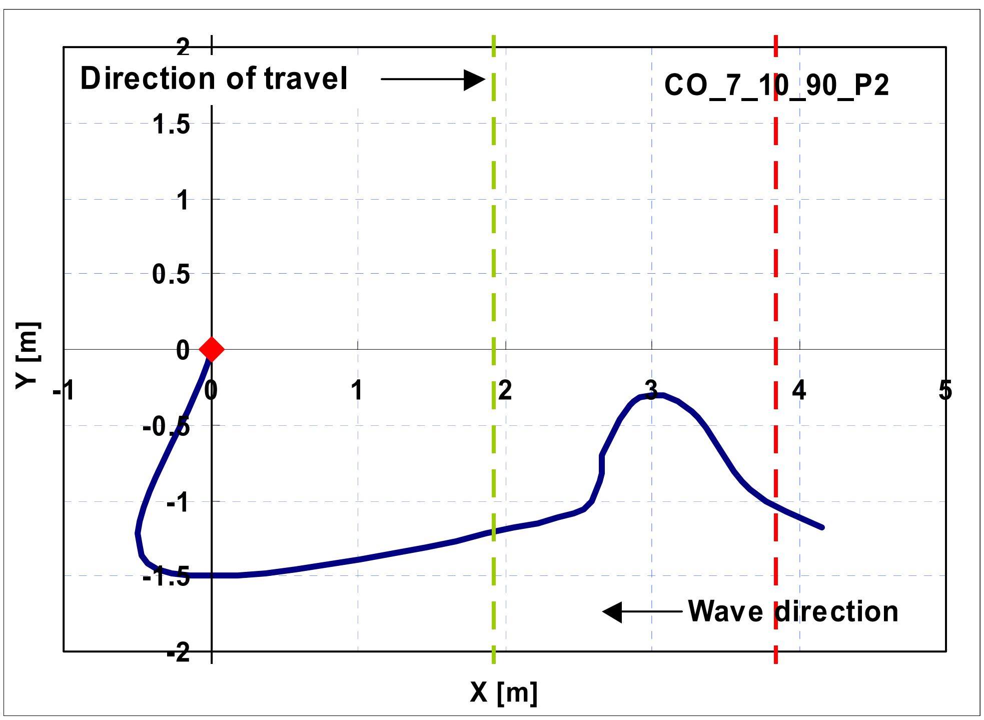
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_10_90_P2
Wave direction
Y [m]
X [m]
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1.5
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0.5
0
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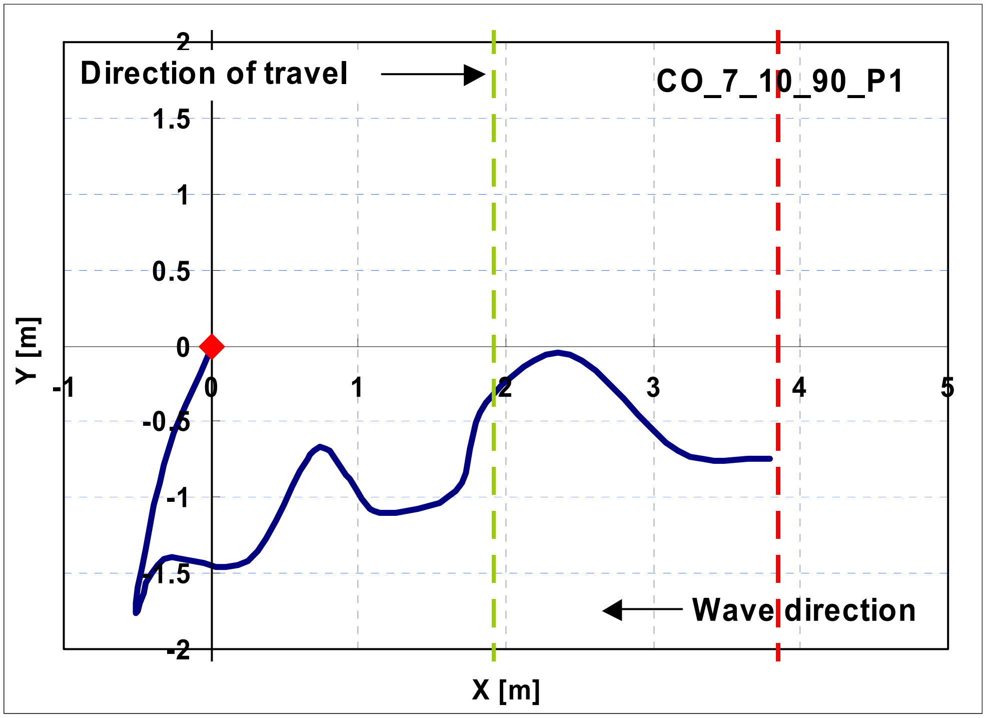
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_7_10_90_P1
Wave direction
Y [m]
X [m]
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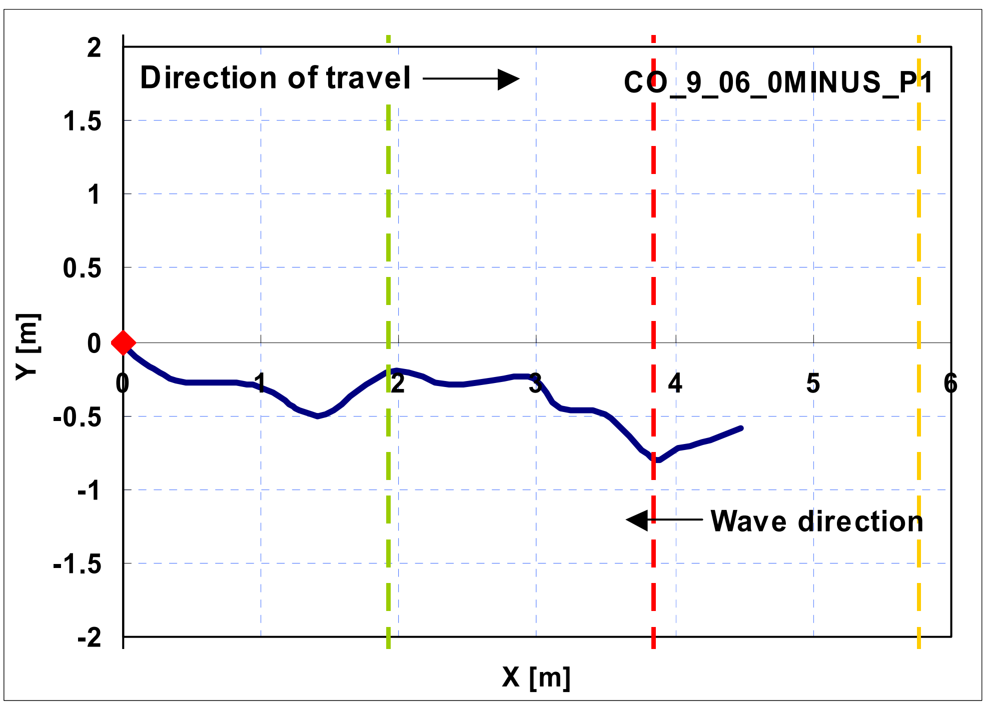
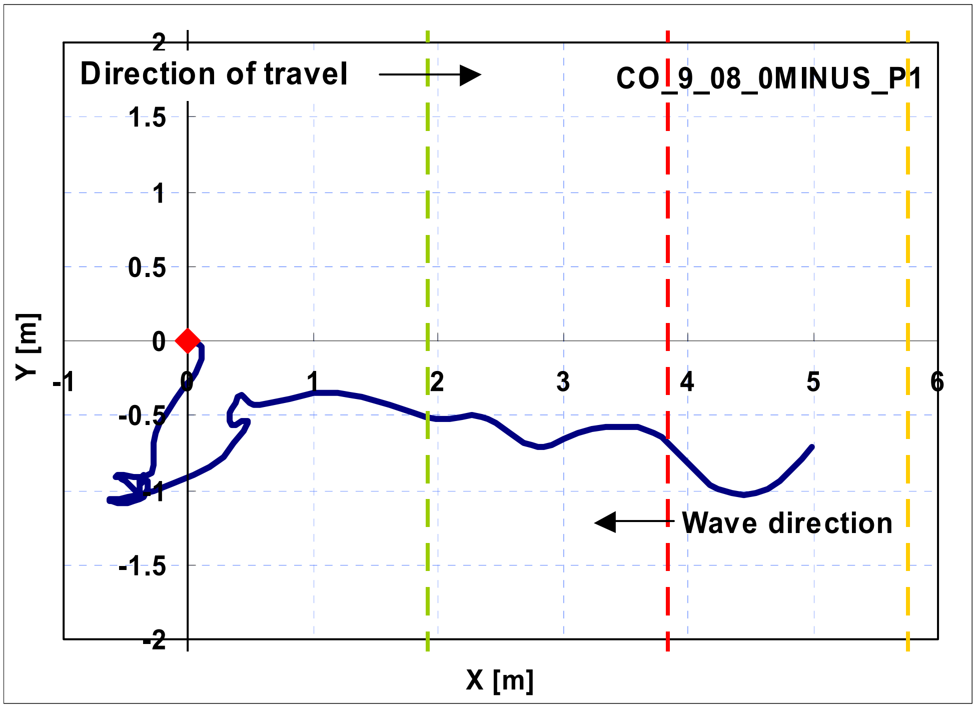
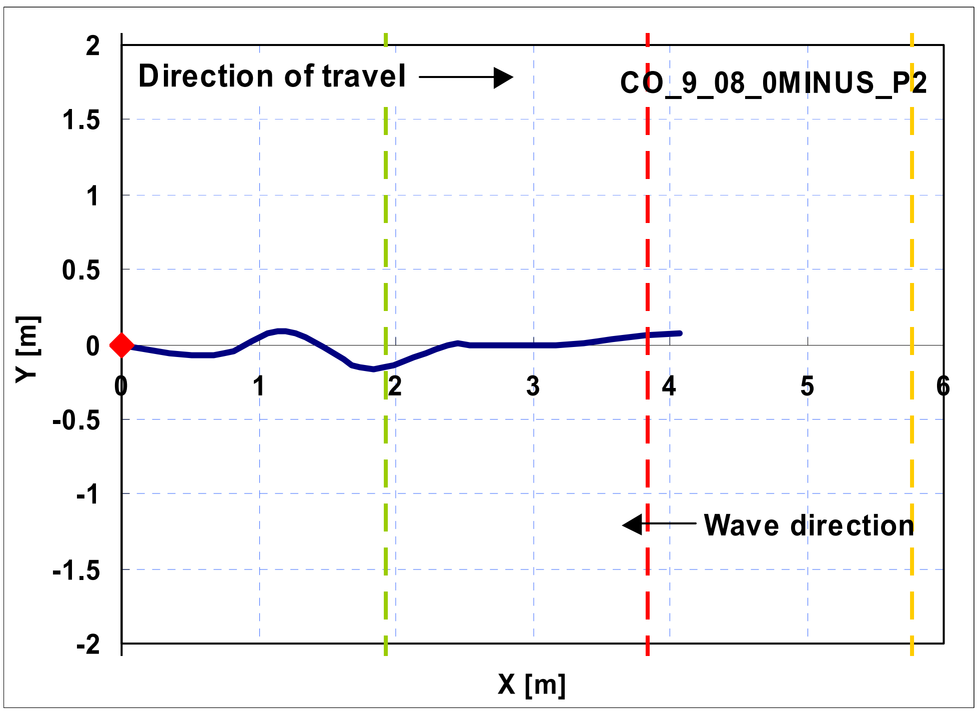
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_9_06_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_9_08_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5
6


Direction of travel
CO_9_08_0MINUS_P2
Wave direction
Y [m]
X [m]
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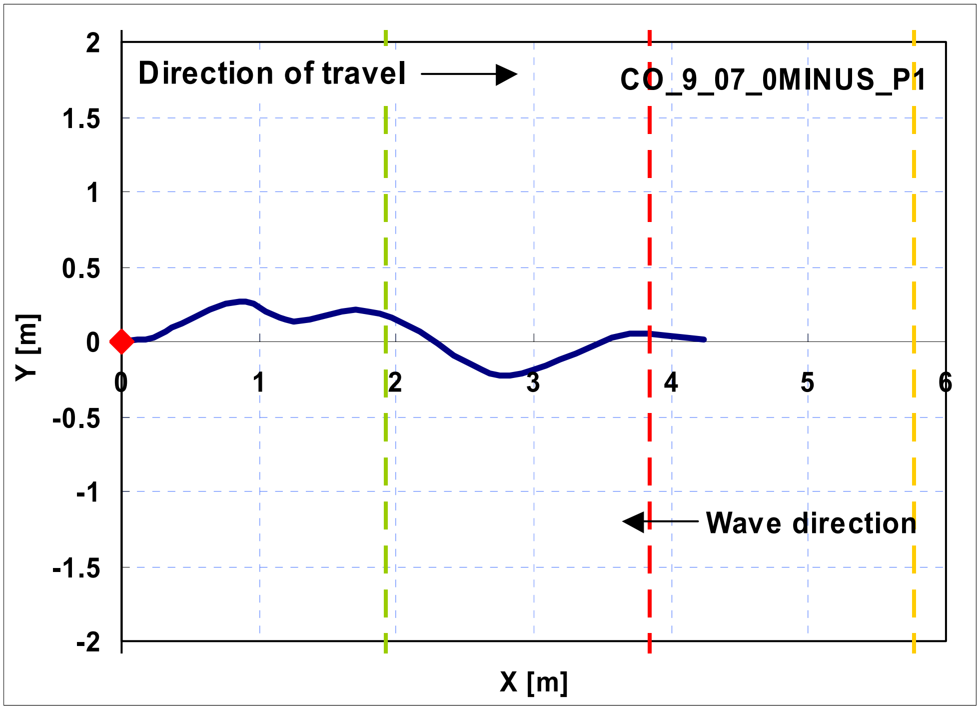
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_9_07_0MINUS_P1
Wave direction
Y [m]
X [m]
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1.5
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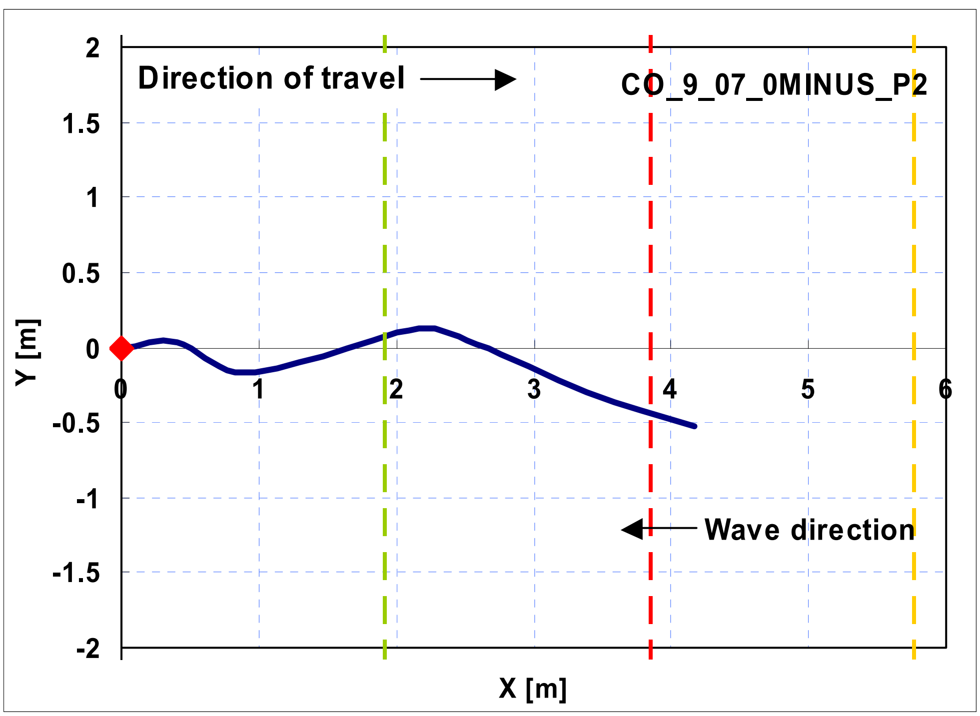
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_9_07_0MINUS_P2
Wave direction
Y [m]
X [m]
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1.5
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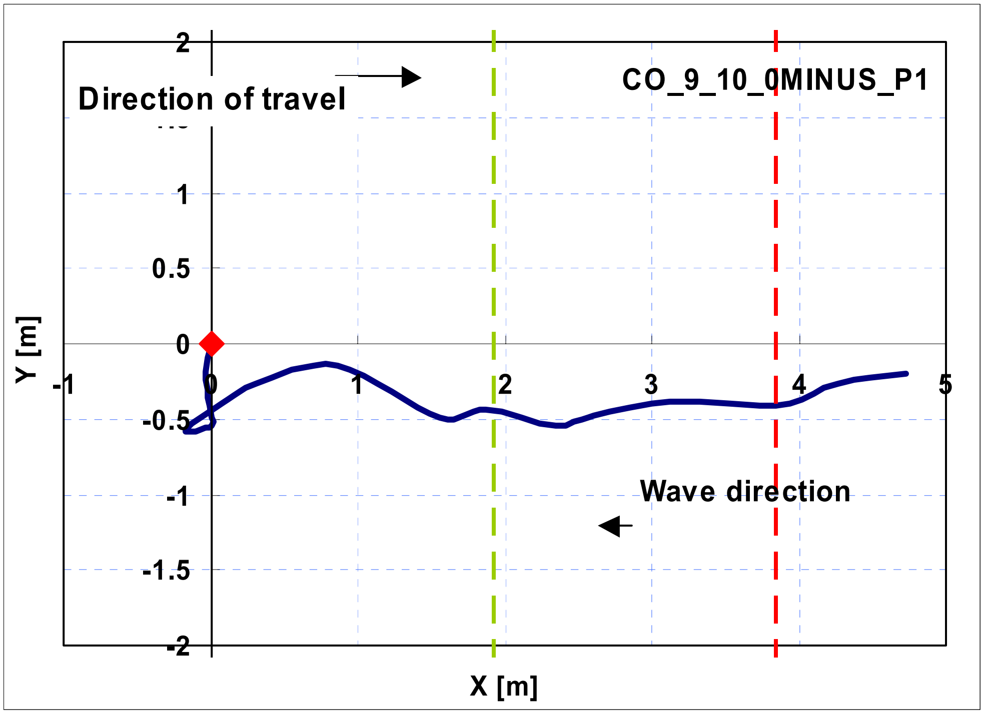
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_9_10_0MINUS_P1
Wave direction
Y [m]
X [m]
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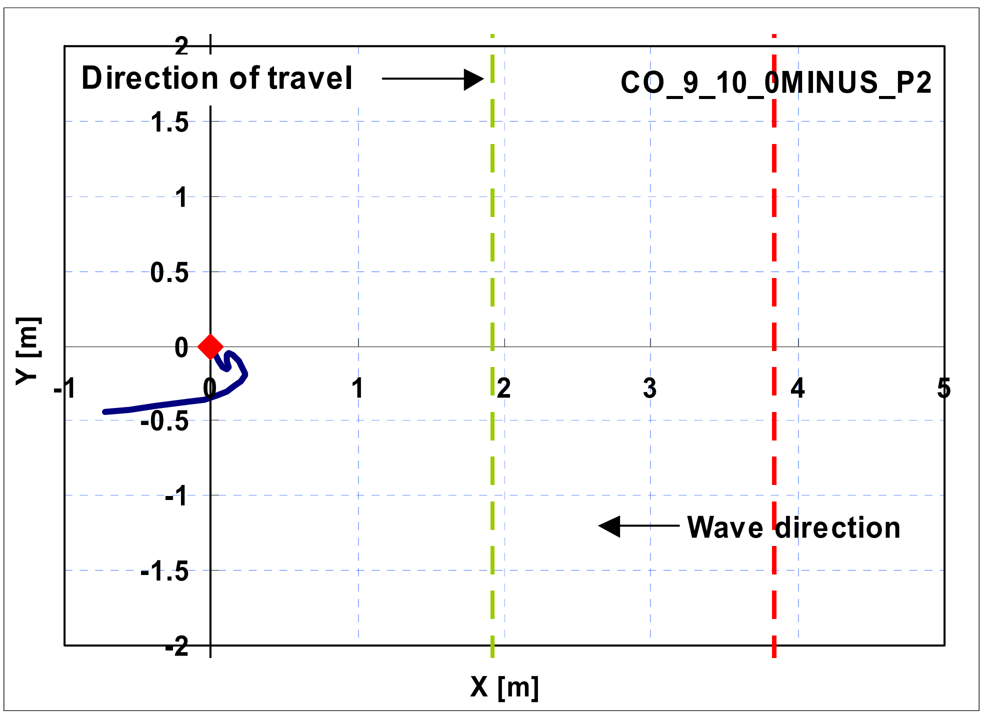
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_9_10_0MINUS_P2
Wave direction
Y [m]
X [m]
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1.5
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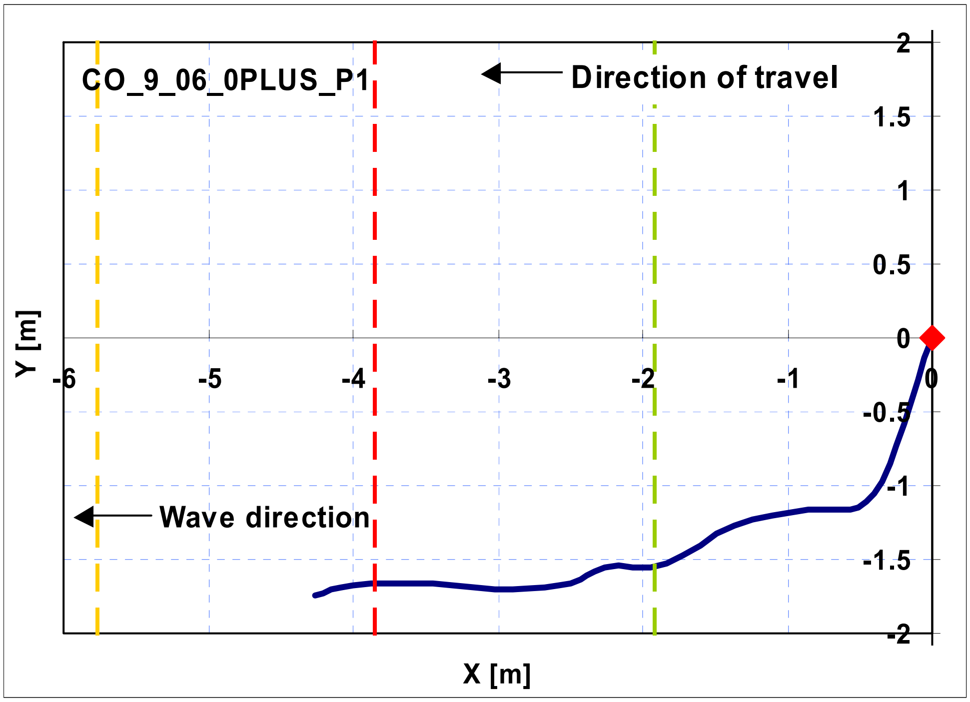
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


CO_9_06_0PLUS_P1
Direction of travel
Wave direction
Y [m]
X [m]
2
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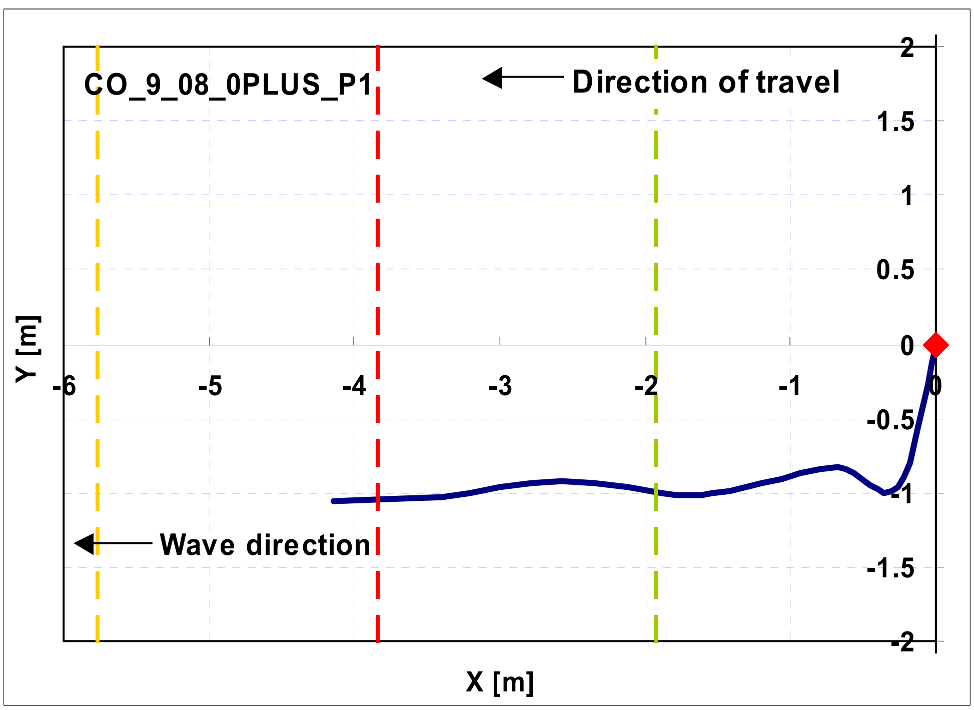
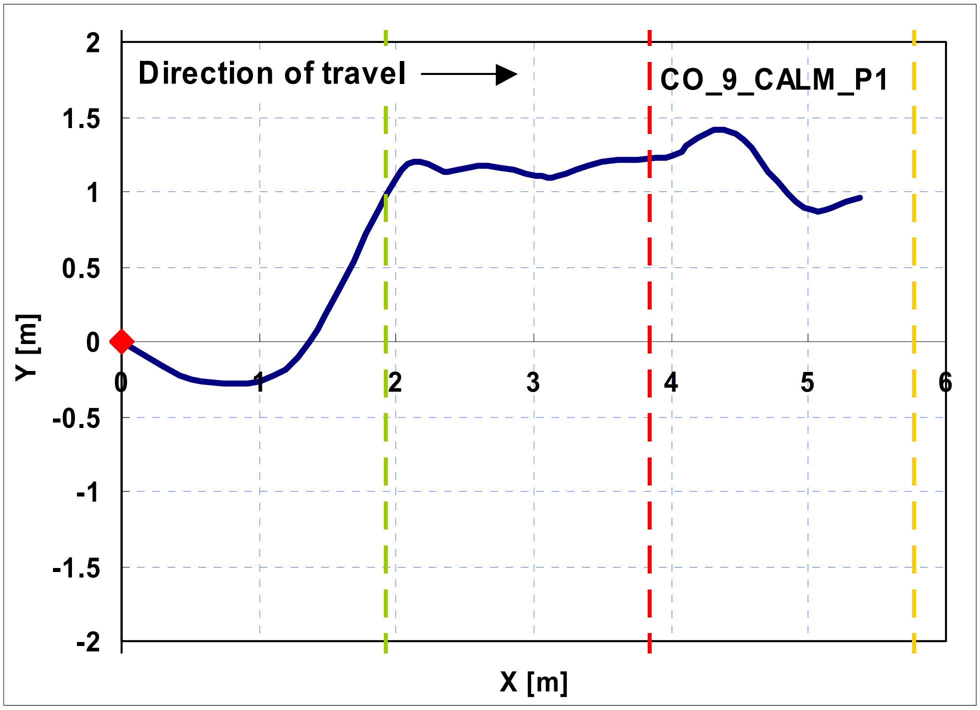
1
0.5
0
-0.5
-1
-1.5
-2
-6
-5
-4
-3
-2
-1
0


CO_9_08_0PLUS_P1
Direction of travel
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-6
-5
-4
-3
-2
-1
0


Direction of travel
CO_9_CALM_P1
Y [m]
X [m]
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1.5
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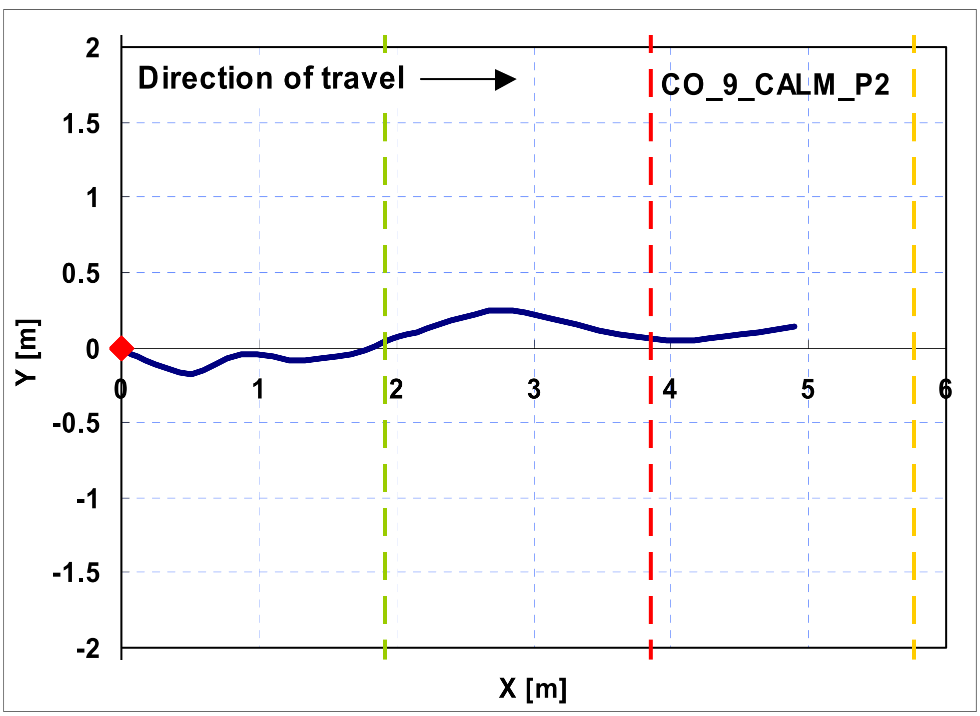
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_9_CALM_P2
Y [m]
X [m]
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1.5
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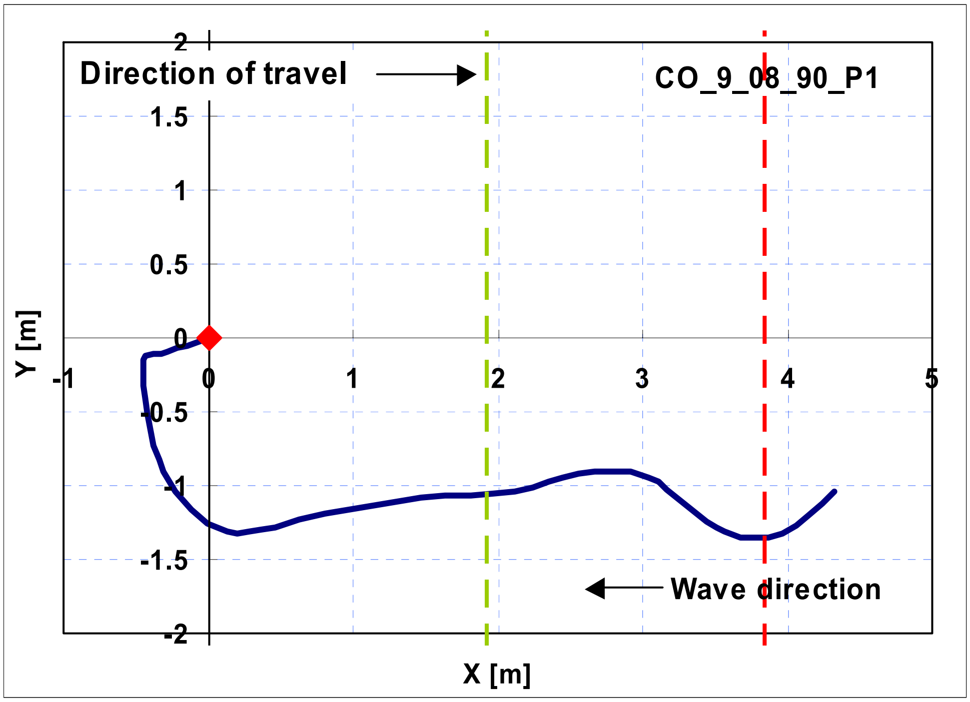
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
CO_9_08_90_P1
Wave direction
Y [m]
X [m]
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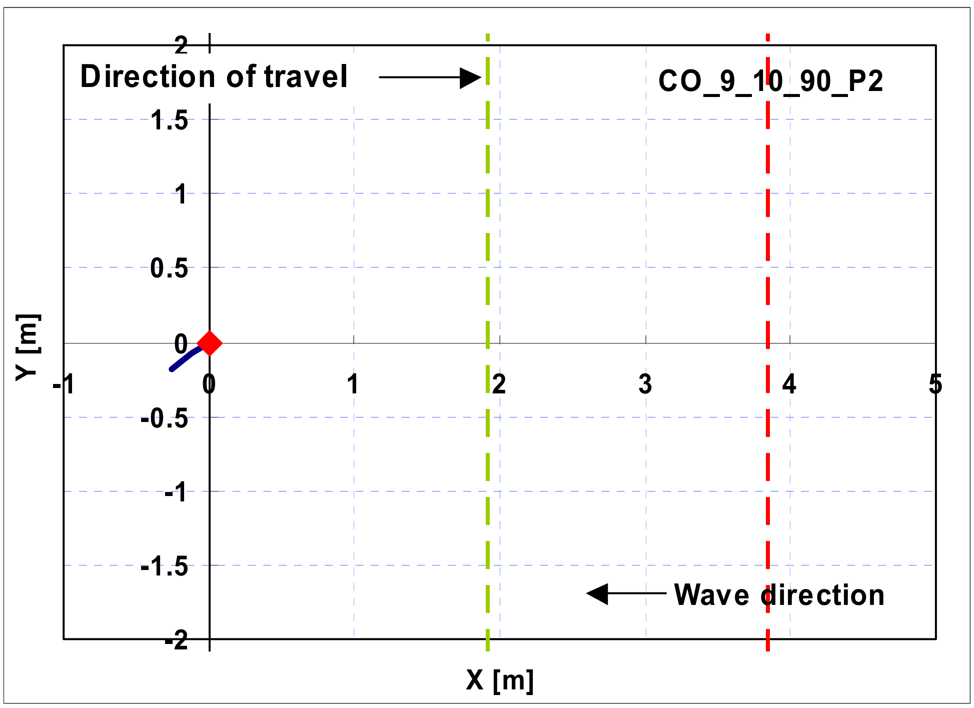
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_9_10_90_P2
Wave direction
Y [m]
X [m]
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1.5
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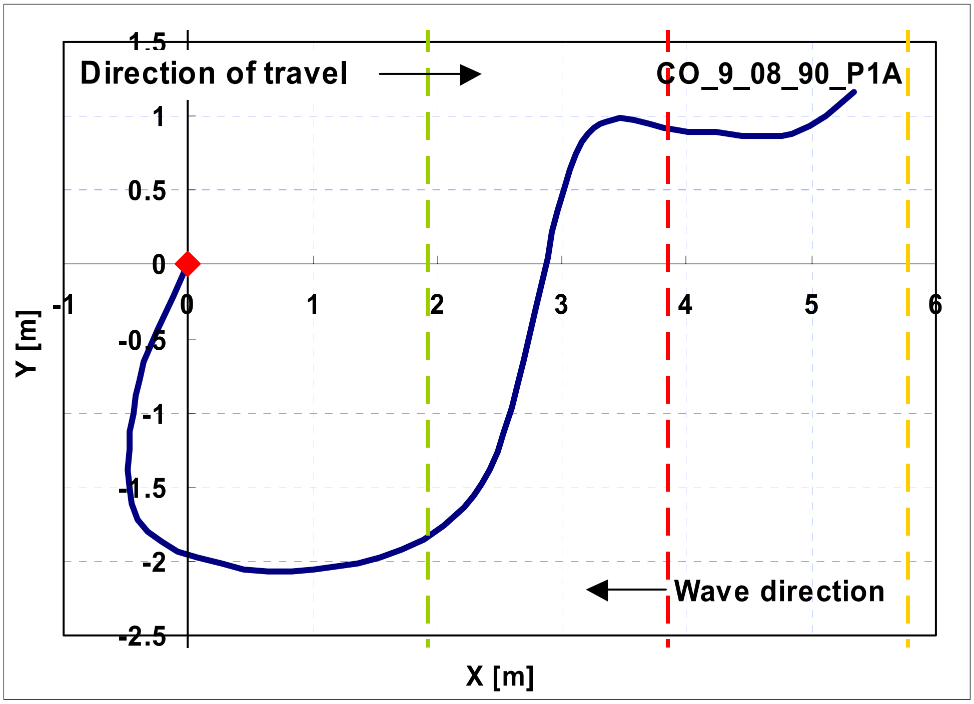
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_9_08_90_P1A
Wave direction
Y [m]
X [m]
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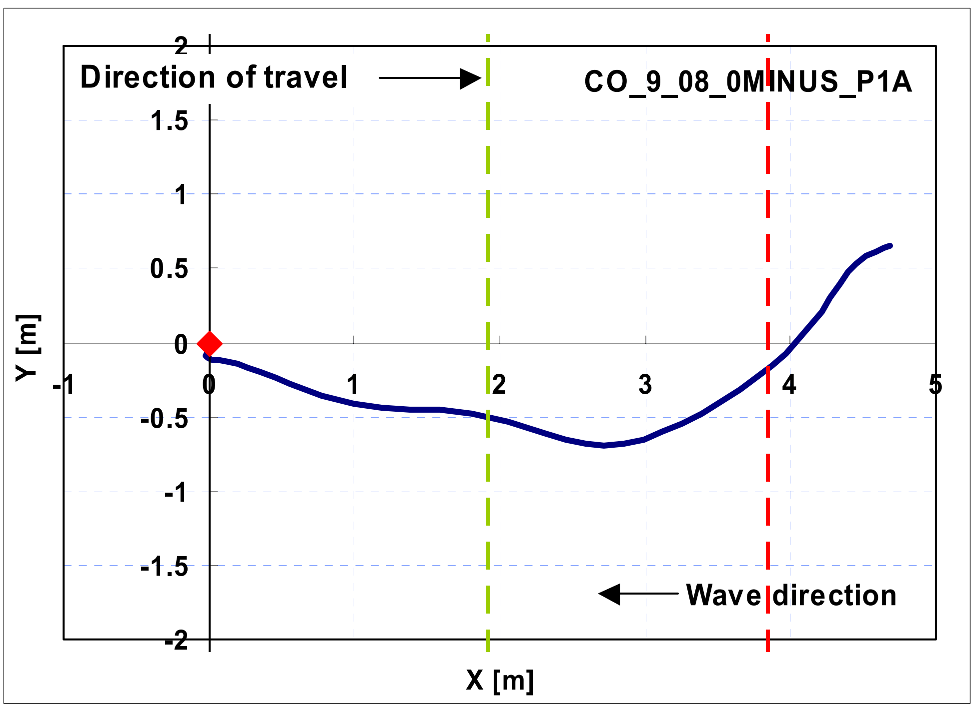
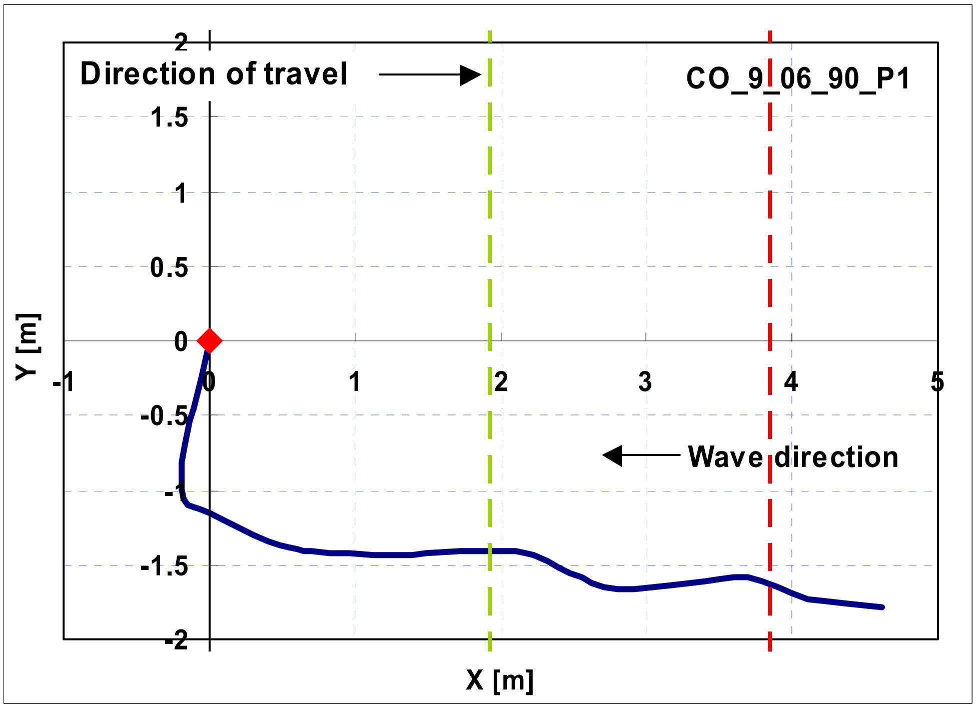
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-1
0
1
2
3
4
5
6


Direction of travel
CO_9_08_0MINUS_P1A
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
CO_9_06_90_P1
Wave direction
Y [m]
X [m]
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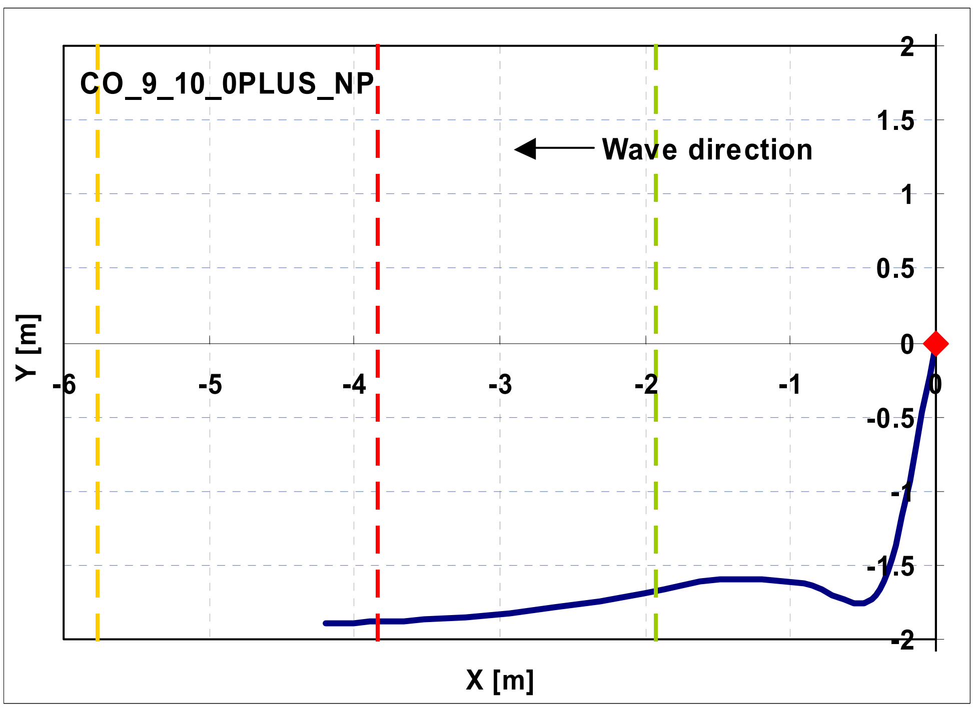
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


CO_9_10_0PLUS_NP
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-6
-5
-4
-3
-2
-1
0

APPENDIX D ANALYSED TEST RESULTS FOR FREE FALL LIFEBOAT (IOT 609)

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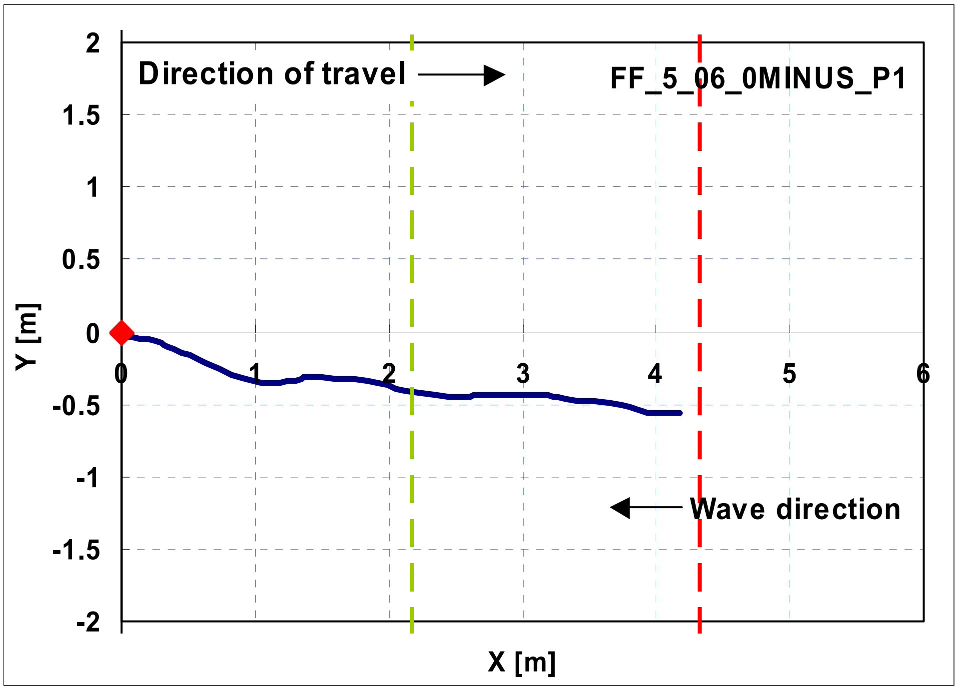
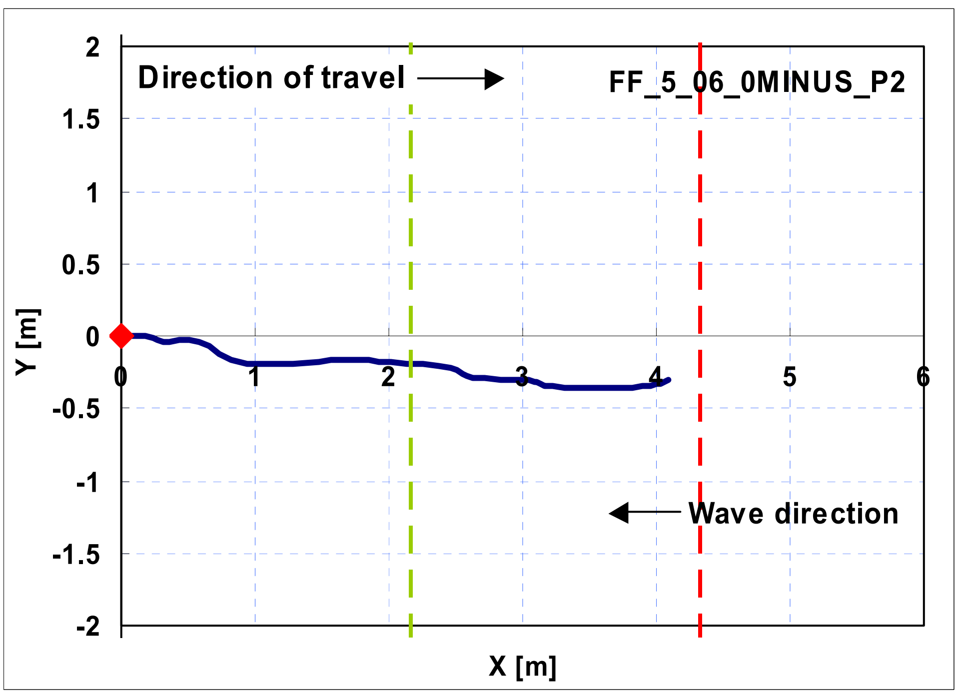
Expanded details for the complete test matrix for the IOT 609 lifeboat

Test Name	Nominal Ice Concentration (tenths)	Nominal Wave Frequency (Hz)	Launch Direction (degrees)	Power (P1/P2)	Test duration (from overhead video)	Pass [5 boat lengths]	Pass [5 boat lengths reached in ≤ 40 seconds]
FF_5_06_0MINUS_P1	5	0.6	0-	P1	17 s	Pass	Pass
FF_5_06_0MINUS_P2	5	0.6	0-	P2	15 s	Pass	Pass
FF_5_08_0MINUS_P1	5	0.8	0-	P1	19 s	Pass	Pass
FF_5_08_0MINUS_P2	5	0.8	0-	P2	22 s	Pass	Pass
FF_5_10_0MINUS_P1	5	1.0	0-	P1	48 s	Pass	Fail
FF_5_10_0MINUS_P2	5	1.0	0-	P2	27 s	Pass	Pass
FF_TESTA	5	-	0-	P1	19 s	Pass	Pass
FF_TESTB	5	-	0-	P2	13 s	Pass	Pass
FF_7_06_0MINUS_P1	7	0.6	0-	P1	19 s	Pass	Pass
FF_7_08_0MINUS_P1	7	0.8	0-	P1	24 s	Pass	Pass
FF_7_08_0MINUS_P2	7	0.8	0-	P2	11 s	Pass	Pass
FF_7_10_0MINUS_P1	7	1.0	0-	P1	30 s	Pass	Pass
FF_7_10_0MINUS_P2	7	1.0	0-	P2	17 s	Pass	Pass
FF_7_06_90_P1	7	0.6	90	P1	4 s	Pass	Pass
FF_7_06_90_P2	7	0.6	90	P2	28 s	Pass	Pass
FF_7_08_90_P1	7	0.8	90	P1	36 s	Pass	Pass
FF_7_08_90_P2	7	0.8	90	P2	50 s	Pass	Fail
FF_7_10_90_P1	7	1.0	90	P1	1 min	Pass	Fail
FF_7_10_90_P2	7	1.0	90	P2	34 s	Pass	Pass
FF_7_CALM_0MINUS1	7	-	0-	P1	28 s	Pass	Pass
FF_7_CALM_0MINUS2	7	-	0-	P2	19 s	Pass	Pass
FF_9_06_0MINUS_P1	9	0.6	0-	P1	22 s	Pass	Pass
FF_9_06_0MINUS_P2	9	0.6	0-	P2	26 s	Pass	Pass
FF_9_08_0MINUS_P1	9	0.8	0-	P1	22 s	Pass	Pass
FF_9_08_0MINUS_P2	9	0.8	0-	P2	10 s	Pass	Pass
FF_9_07_0MINUS_P1	9	0.7	0-	P1	26 s	Pass	Pass
FF_9_07_0MINUS_P2	9	0.7	0-	P2	13 s	Pass	Pass
FF_9_10_0MINUS_P1	9	1.0	0-	P1	52 s	Pass	Fail
FF_9_10_0MINUS_P2	9	1.0	0-	P2	28 s	Pass	Pass
FF_9_06_90_P1	9	0.6	90	P1	32 s	Pass	Pass
FF_9_08_90_P1	9	0.8	90	P1	1 min 26 s	Pass	Fail
FF_9_08_90_P2	9	0.8	90	P2	34 s	Pass	Pass
FF_9_10_90_P2	9	1.0	90	P2	3 s	Fail	Fail
FF_9_CALM_P2	9	-	0-	P2	1 min 24 s	Pass	Pass
FF_9_CALM_P1	9	-	0-	P1	29 s	Pass	Pass
FF_9_08_90_P1	9	0.8	90	P1	1 min	Pass	Fail
FF_9_10_0MINUS_P1	9	1.0	0-	P1	50 s	Pass	Fail
FF_9_06_0PLUS_P1	9	0.6	0+	P1	16 s	Pass	Pass
FF_9_08_0PLUS_P1	9	0.8	0+	P1	11 s	Pass	Pass
FF_9_10_0PLUS_NP	9	1.0	0+	-	20 s	Pass	Pass


Direction of travel
FF_5_06_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
FF_5_06_0MINUS_P2
Wave direction
Y [m]
X [m]
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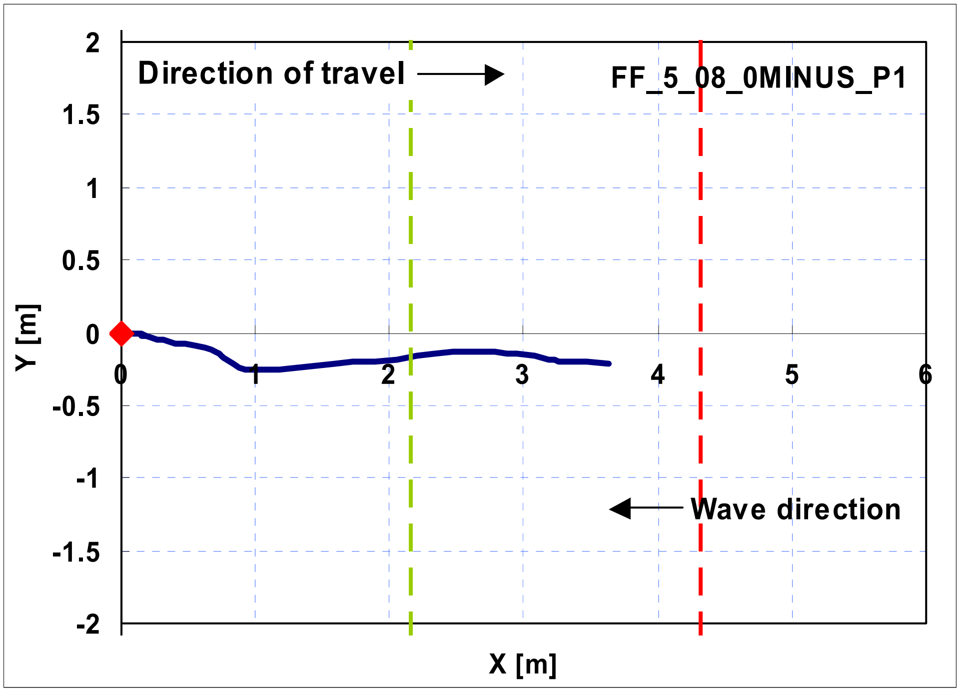
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6



Direction of travel
FF_5_08_0MINUS_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
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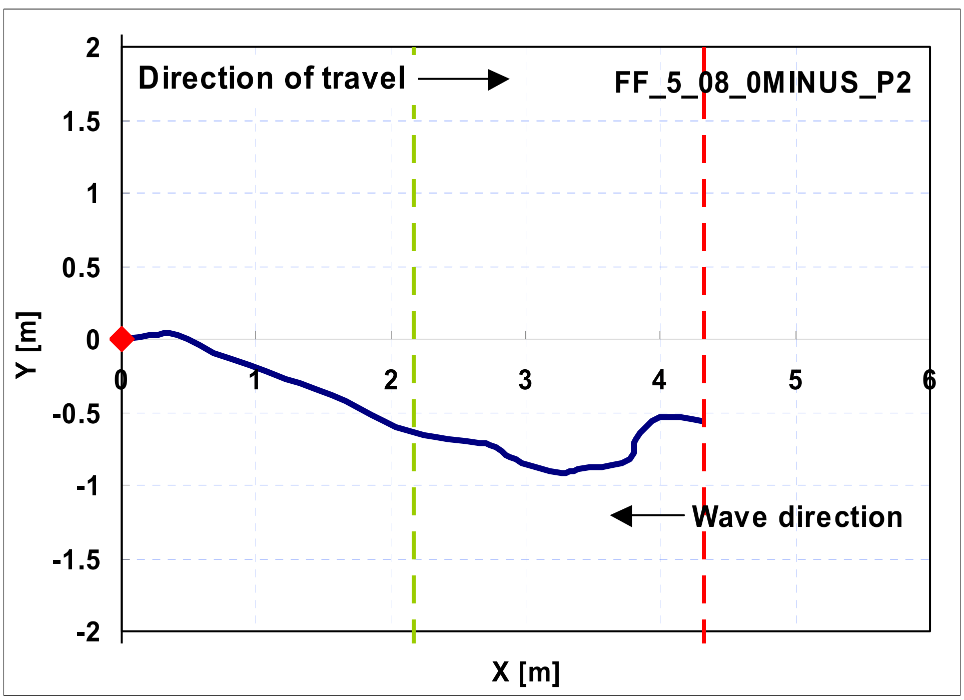
6



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Wave direction
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X [m]
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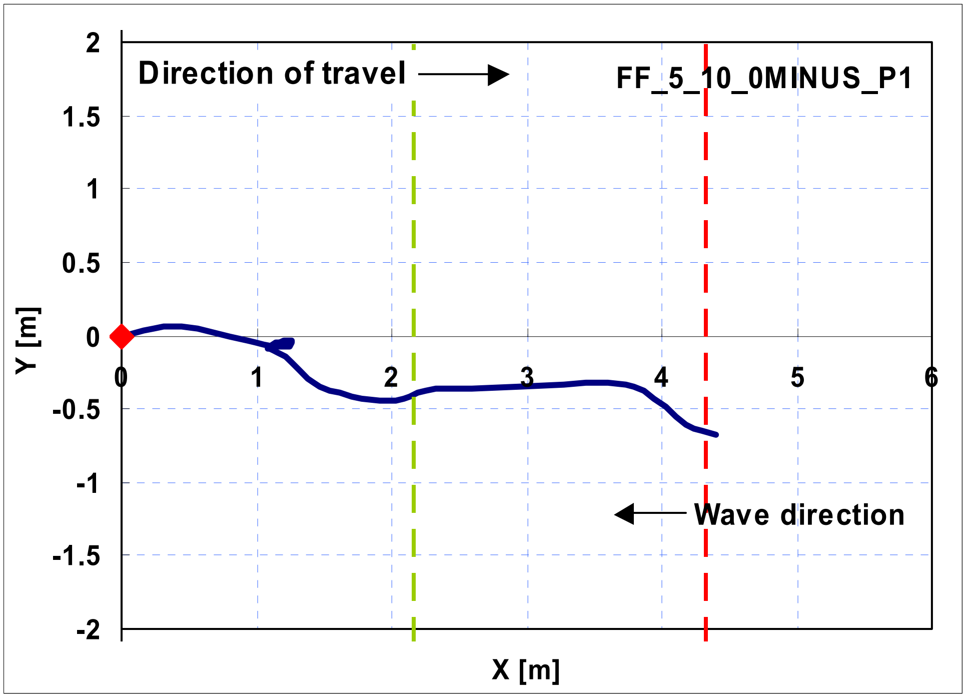
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X [m]
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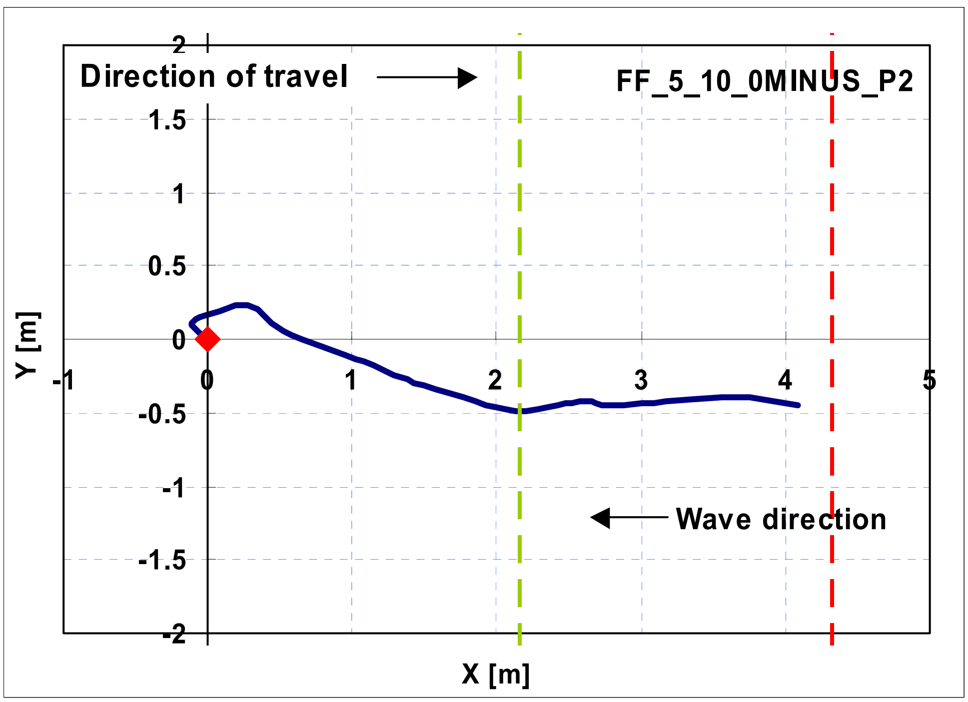
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Wave direction
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X [m]
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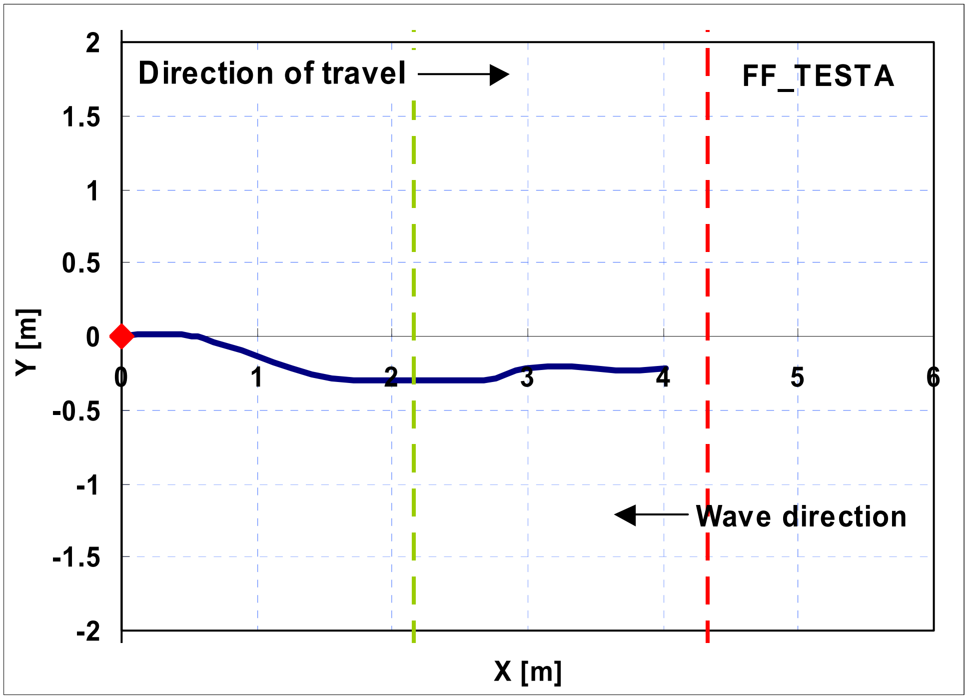
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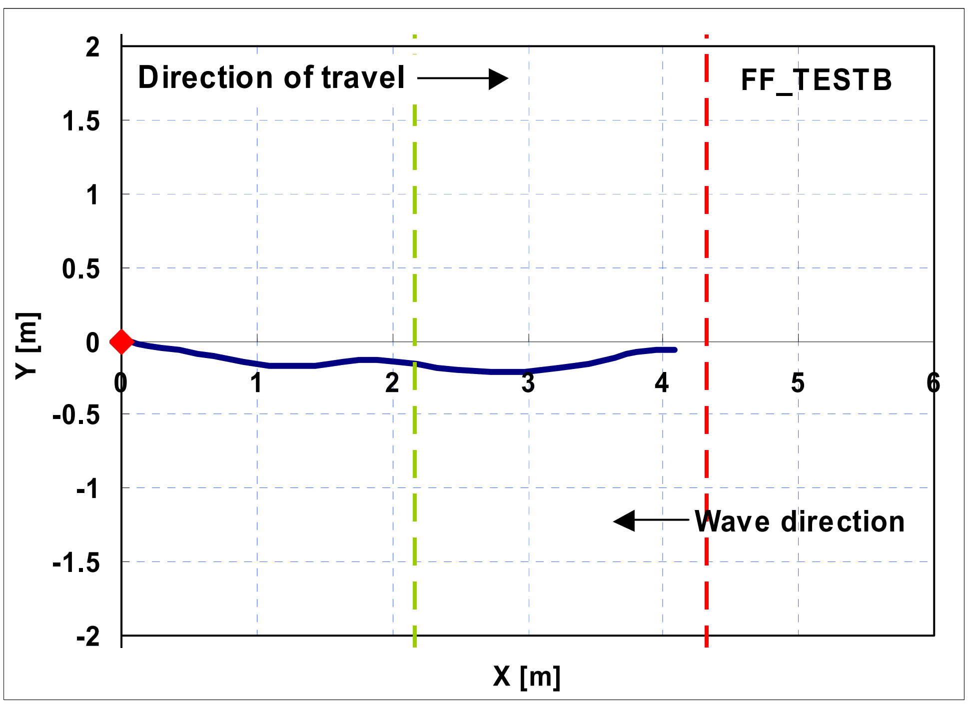
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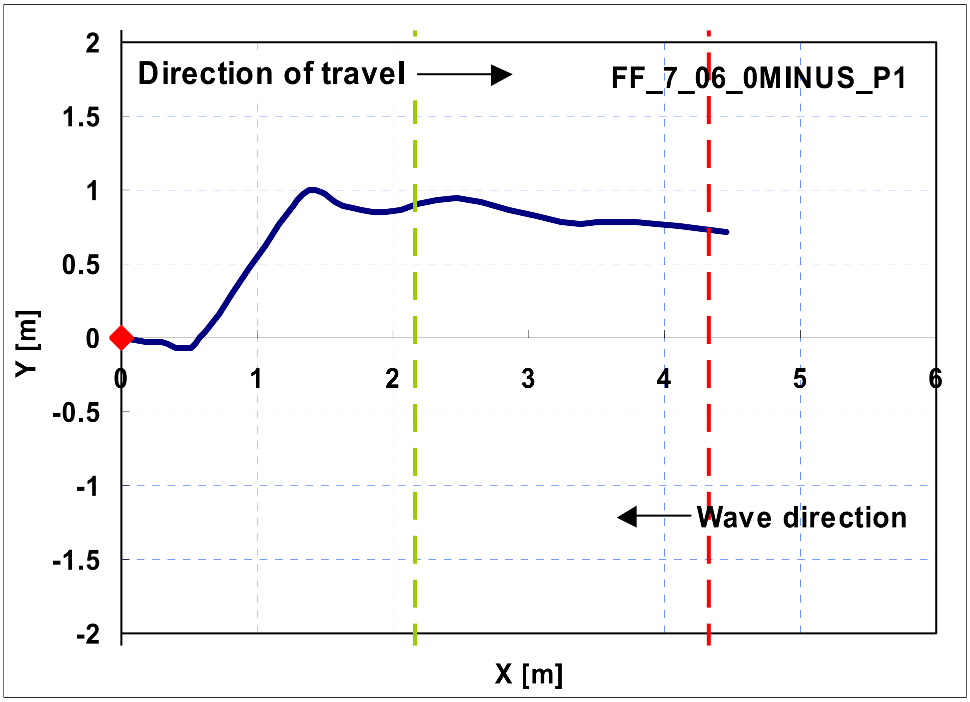
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X [m]
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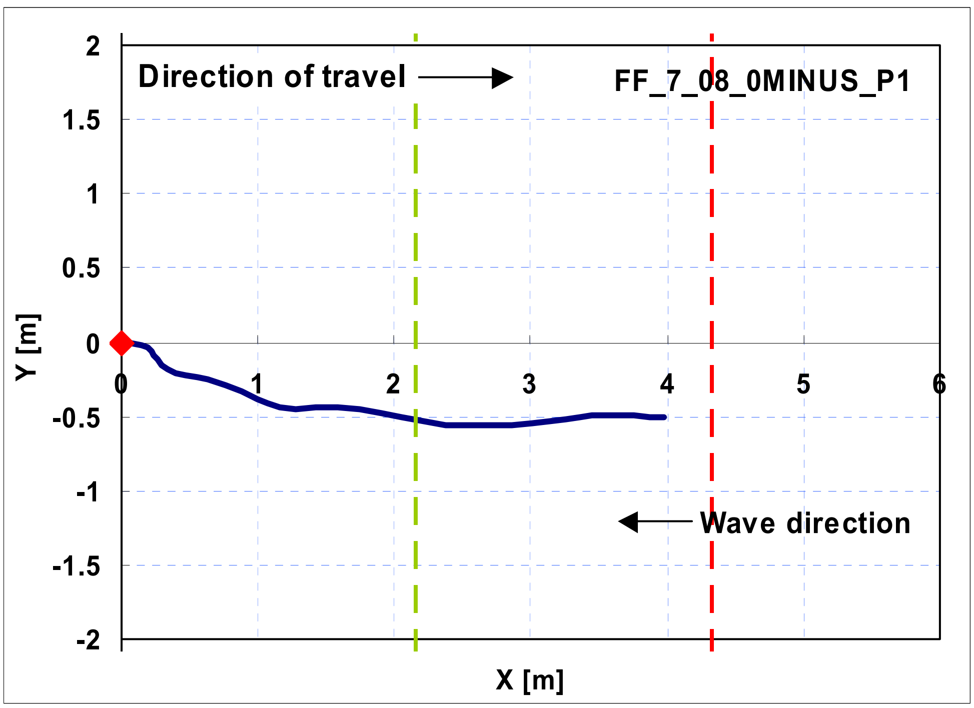
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Wave direction
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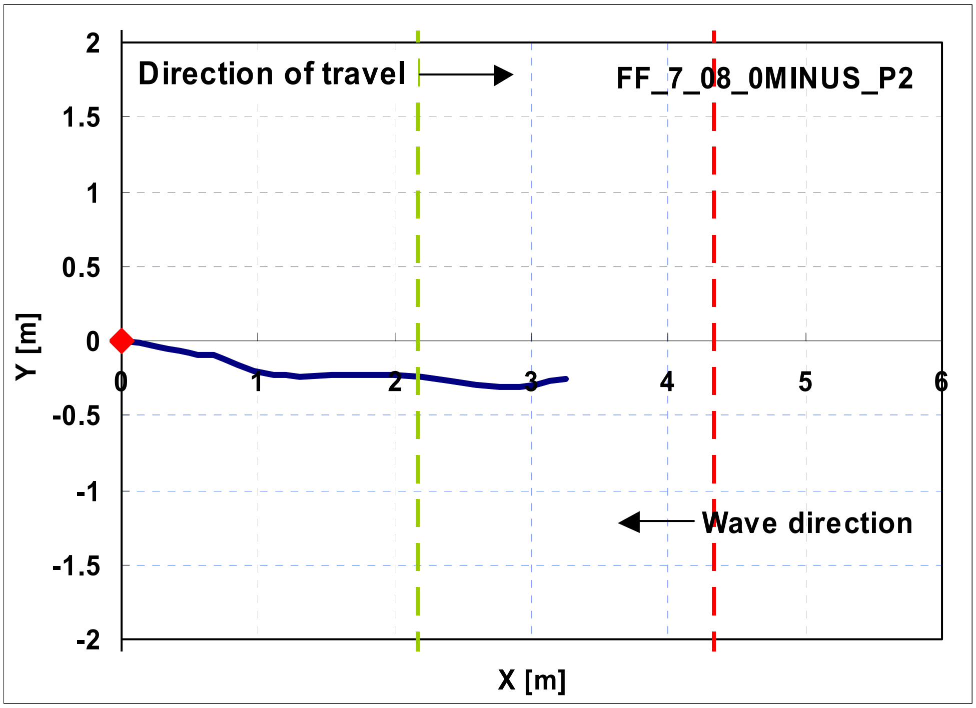
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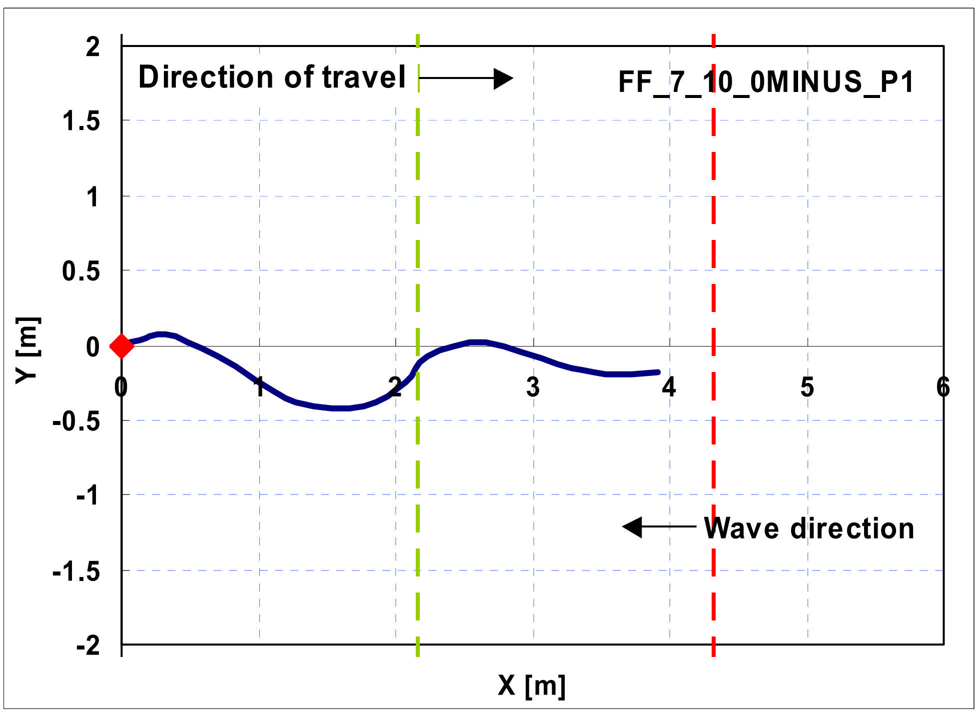
Direction of travel
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X [m]
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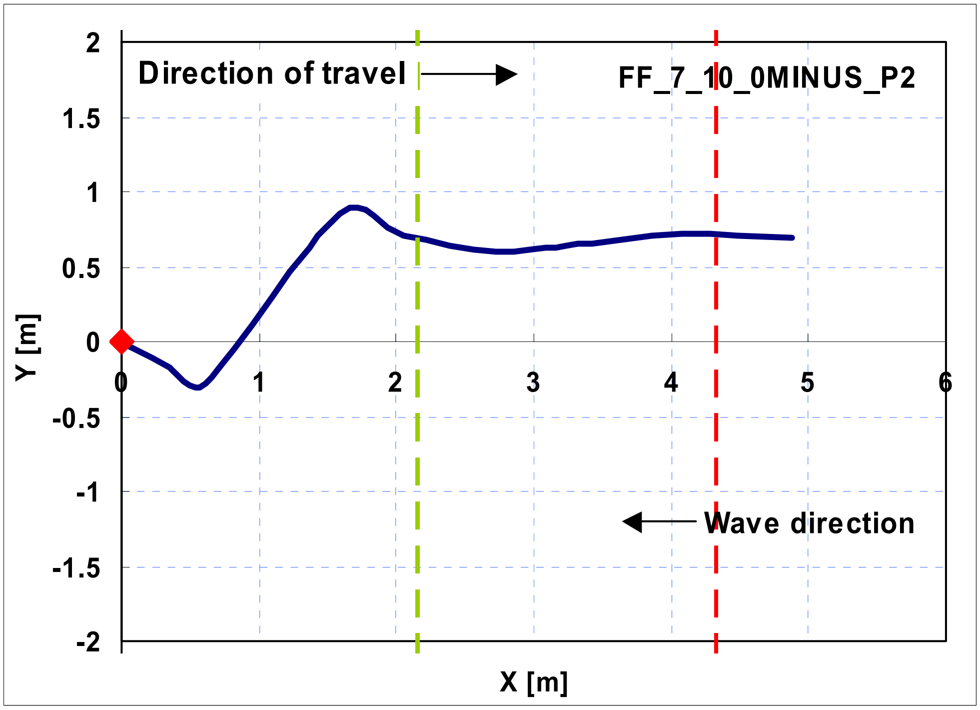
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X [m]
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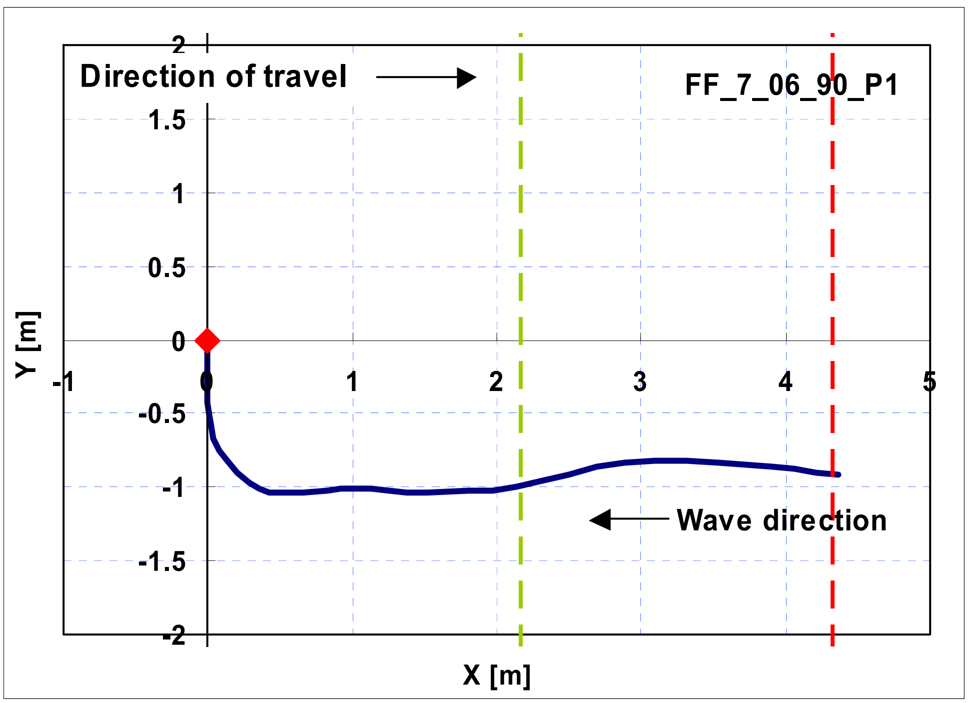
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X [m]
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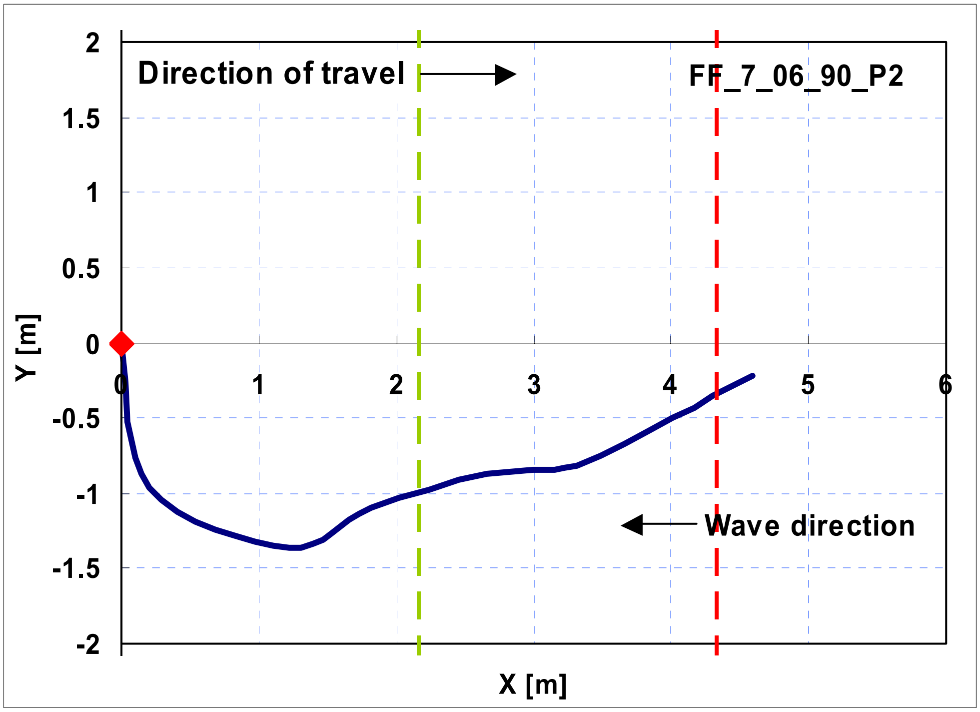
Direction of travel
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Wave direction
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X [m]
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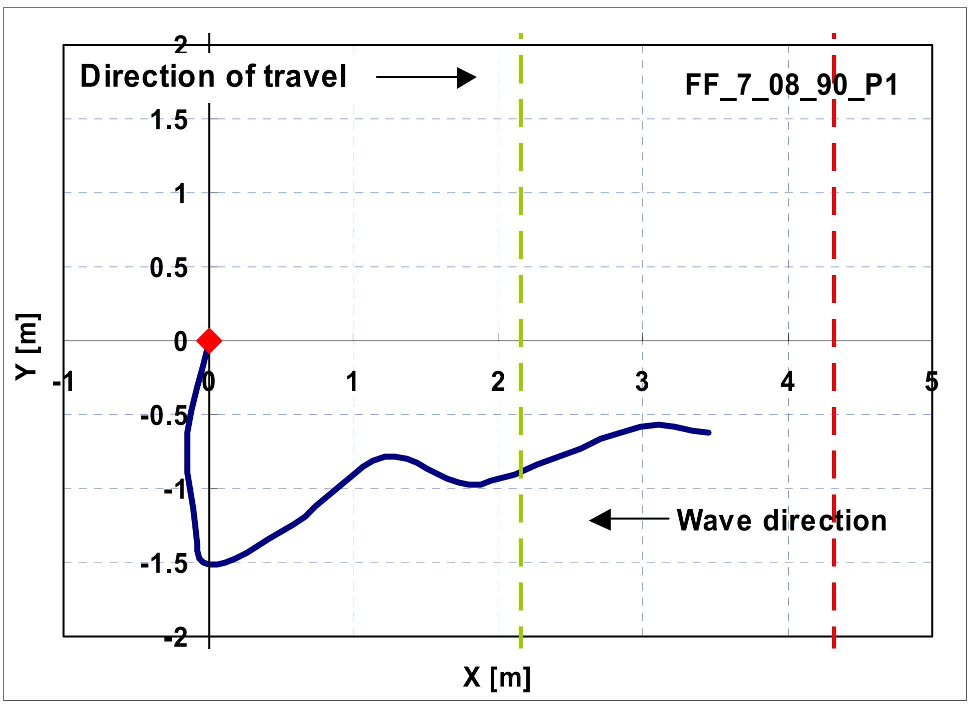
Direction of travel
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Wave direction
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X [m]
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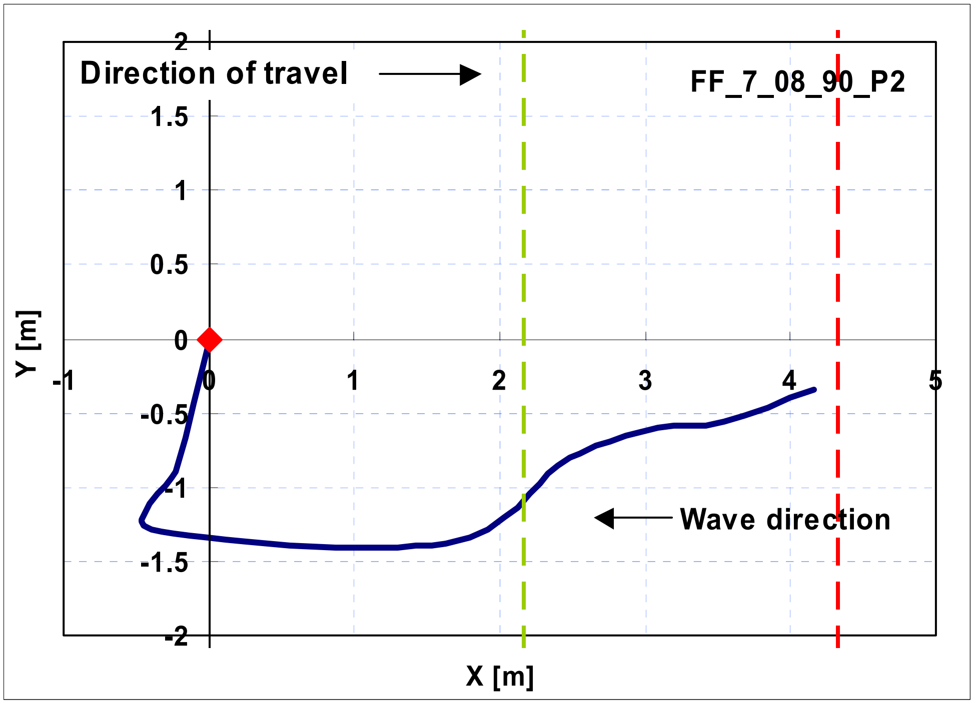
Direction of travel
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Wave direction
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X [m]
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4
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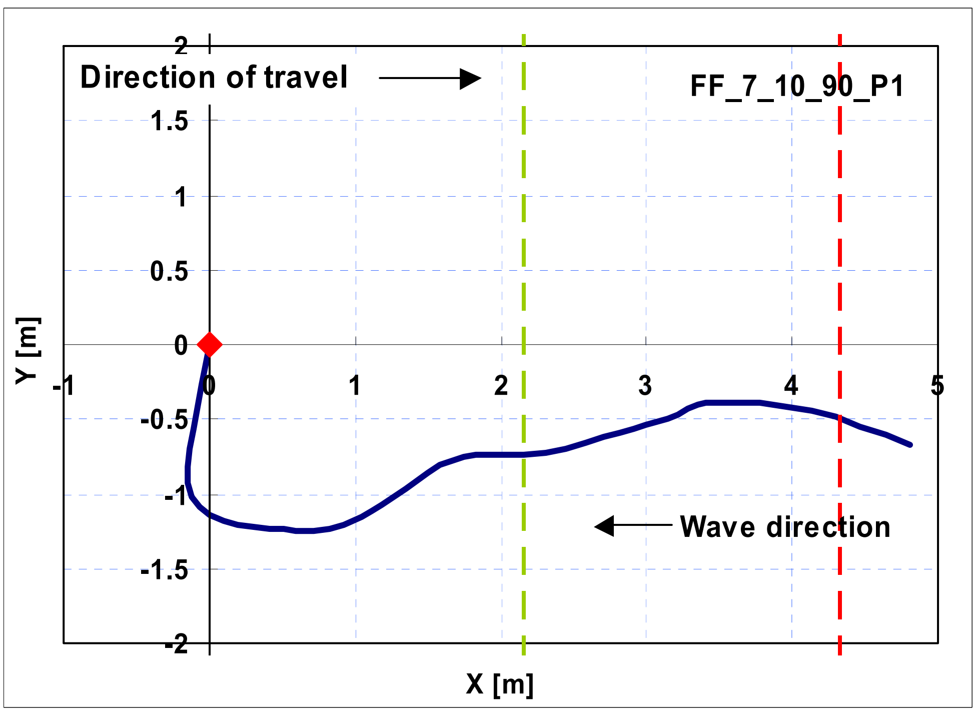
Direction of travel
FF_7_10_90_P1
Wave direction
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X [m]
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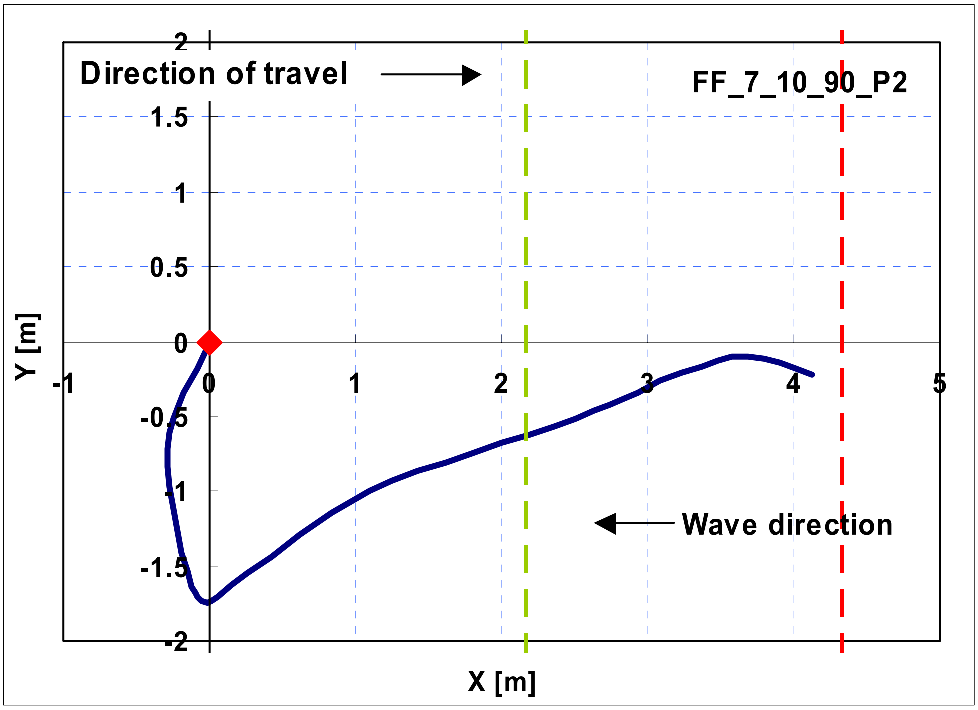
Direction of travel
FF_7_10_90_P2
Wave direction
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X [m]
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2
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4
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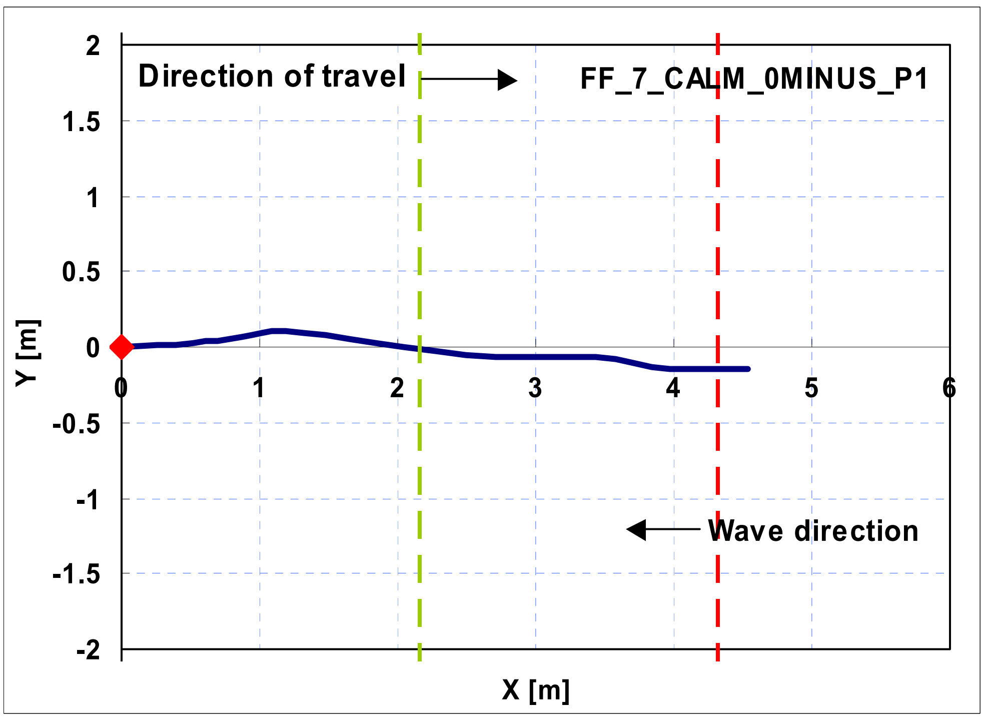
Direction of travel
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Wave direction
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X [m]
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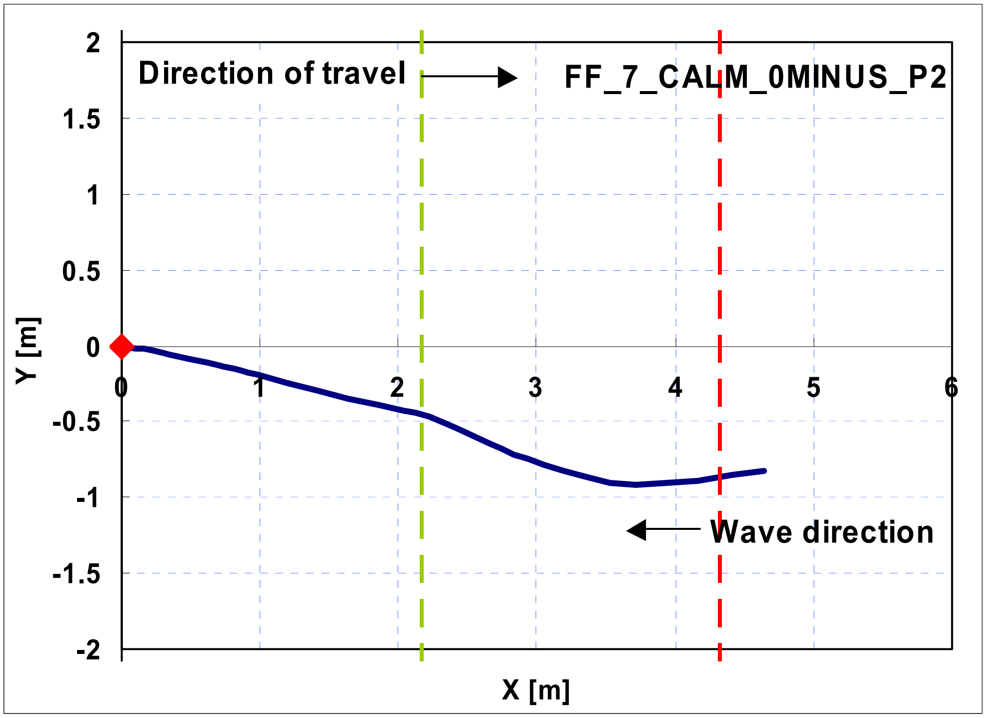
Direction of travel
FF_7_CALM_0MINUS_P2
Wave direction
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X [m]
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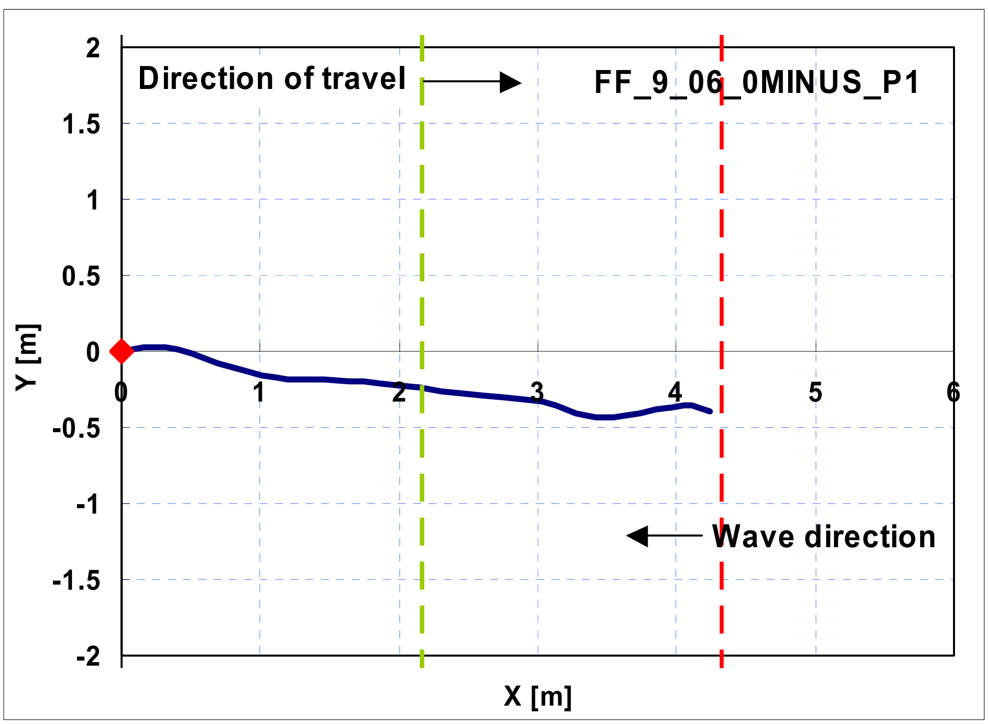
Direction of travel
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Wave direction
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X [m]
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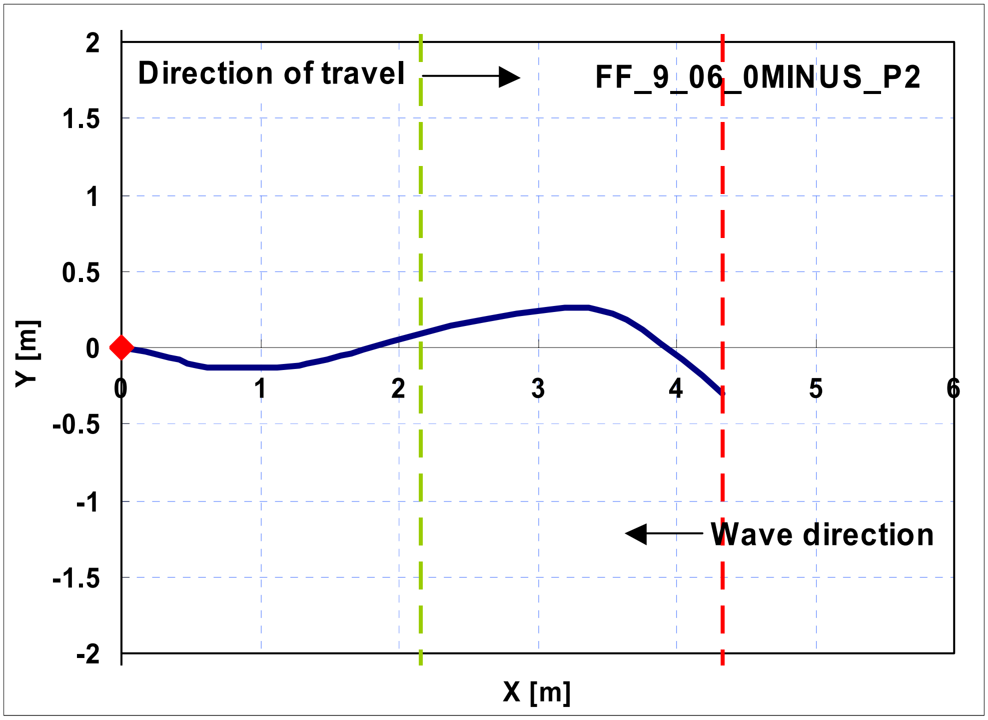
Direction of travel
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Wave direction
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X [m]
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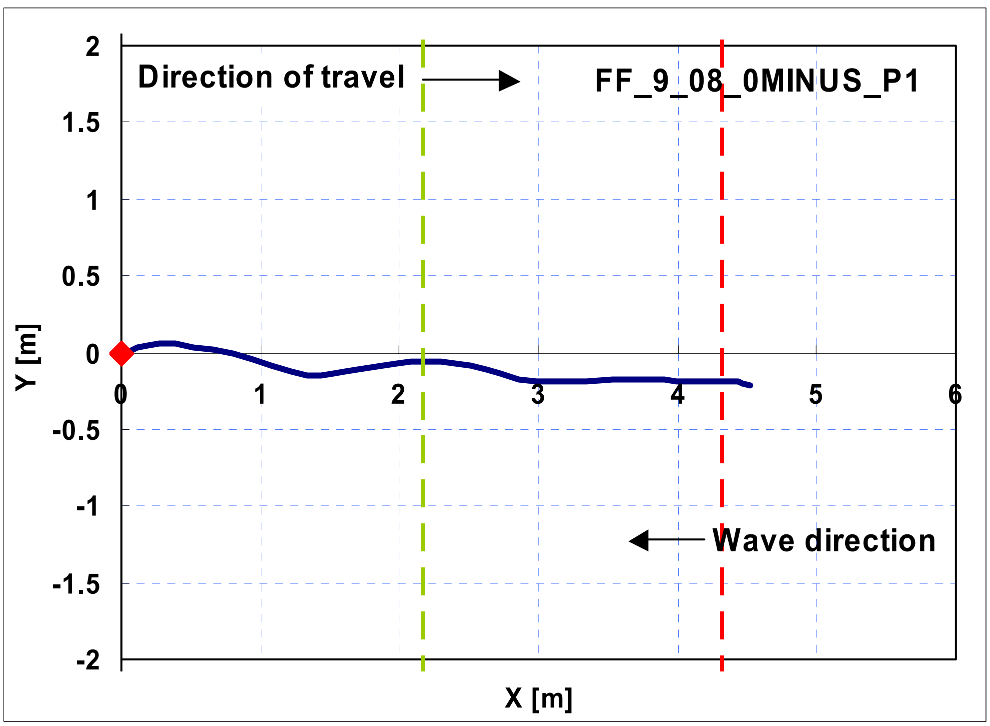
Direction of travel
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Wave direction
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X [m]
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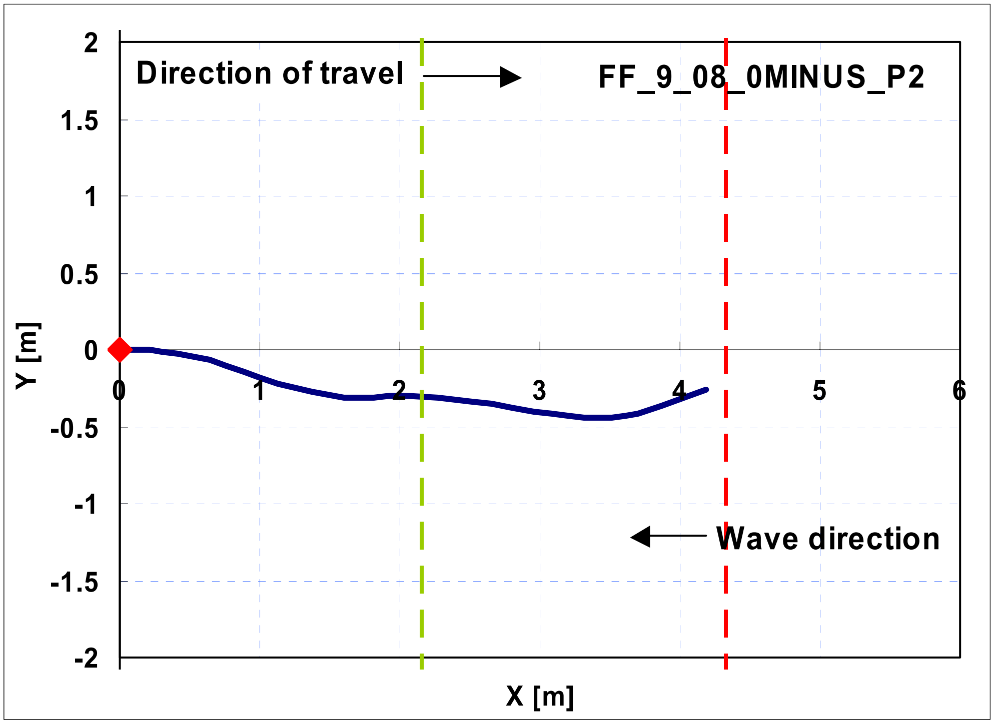
Direction of travel
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Wave direction
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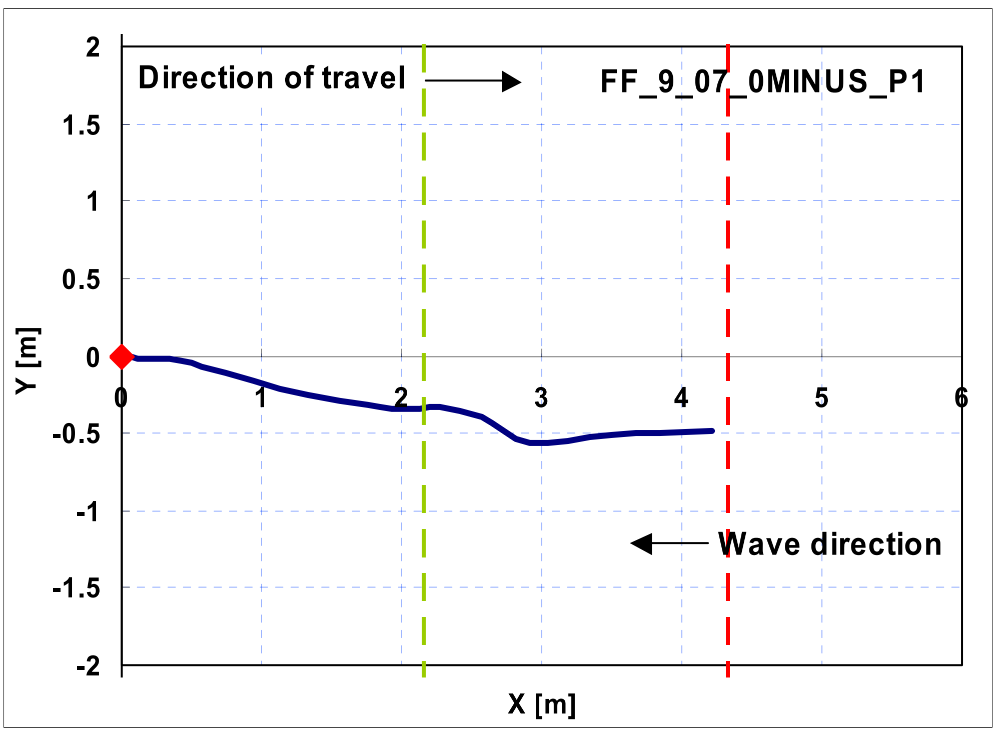
-1.5
-2
0 1 2 3 4 5 6


Direction of travel
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X [m]
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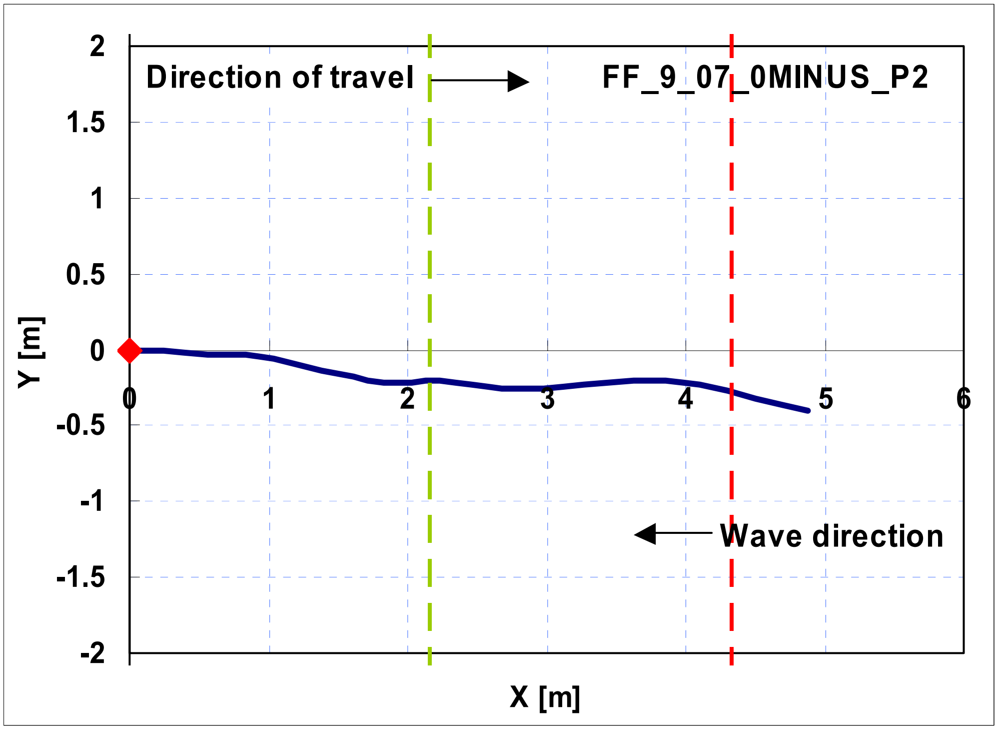
-1
-1.5
-2
0 1 2 3 4 5 6


Direction of travel
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Wave direction
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X [m]
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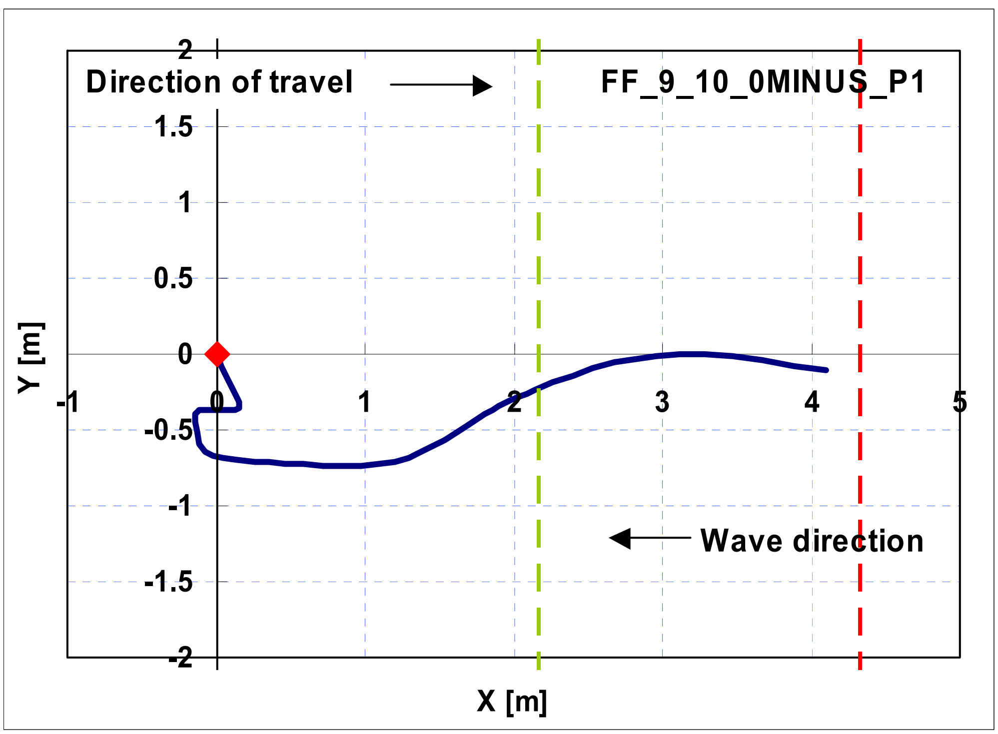
Direction of travel
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X [m]
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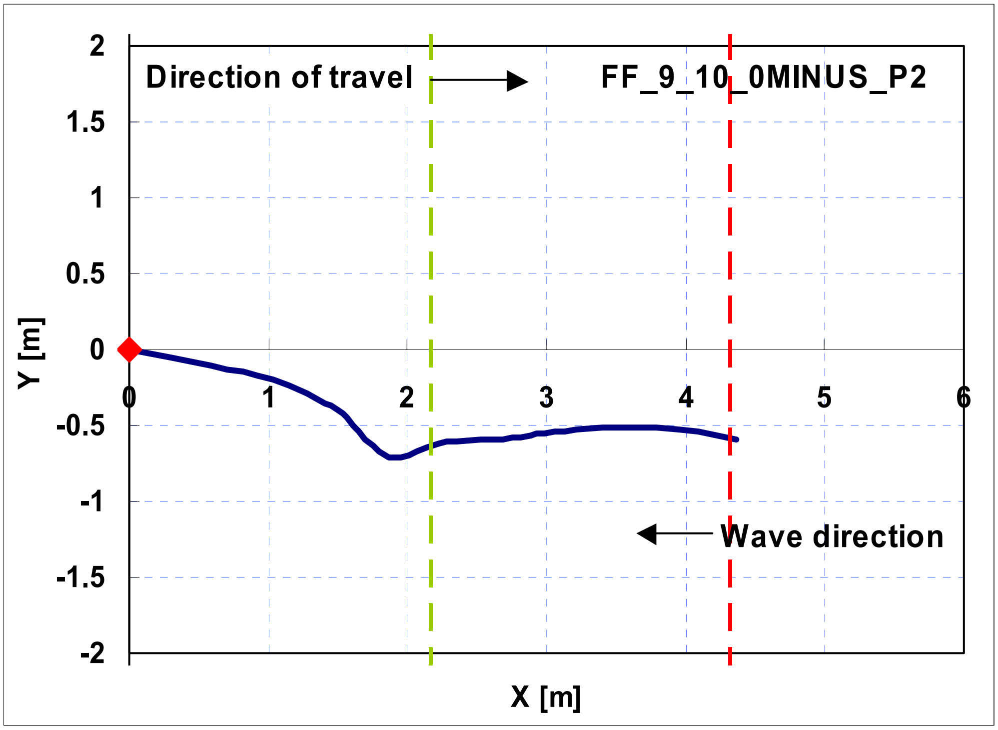
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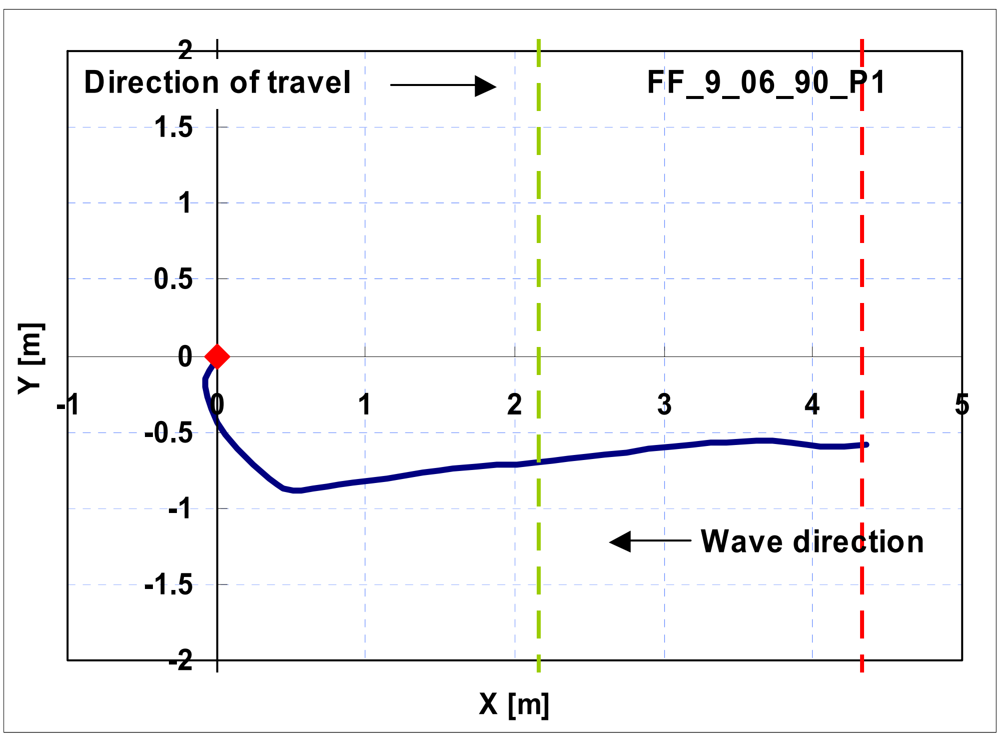
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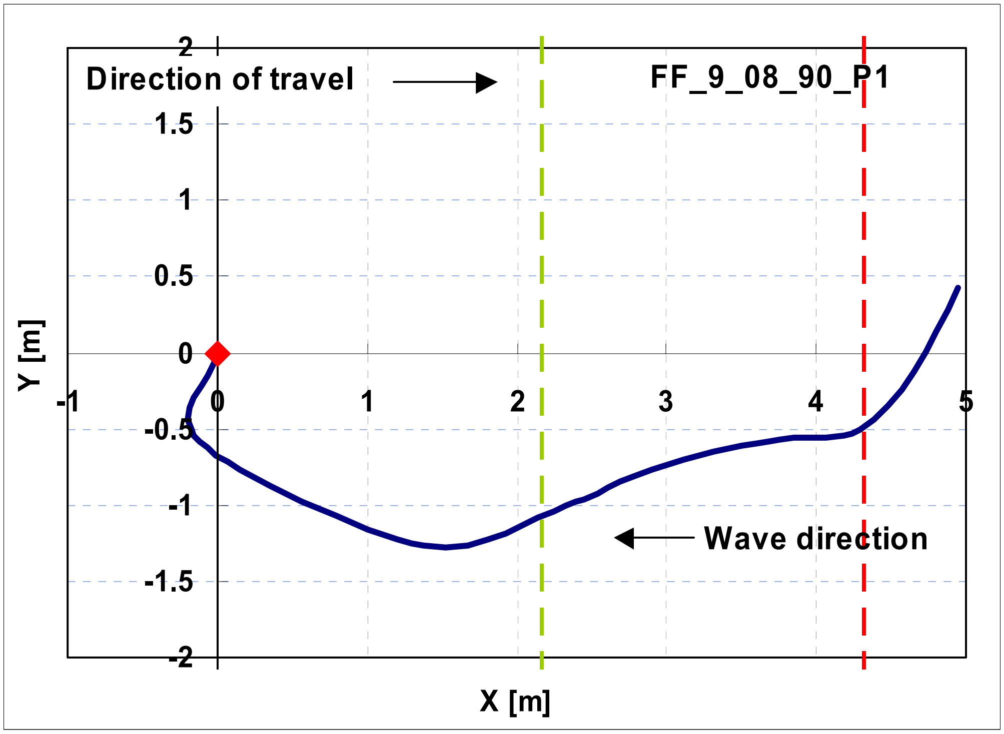
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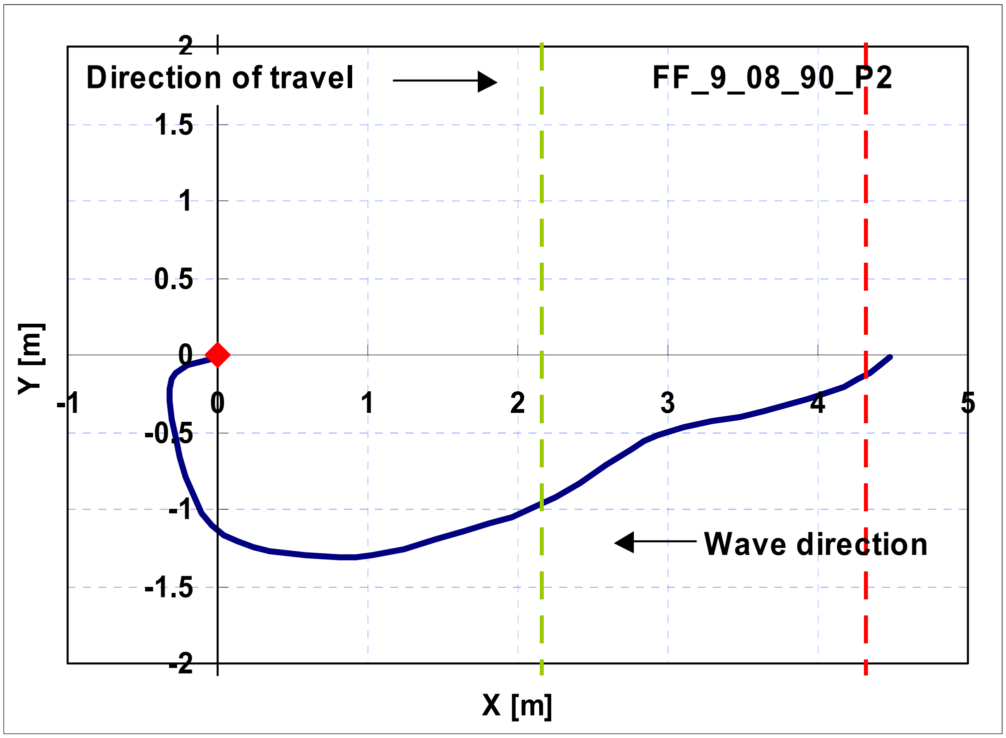
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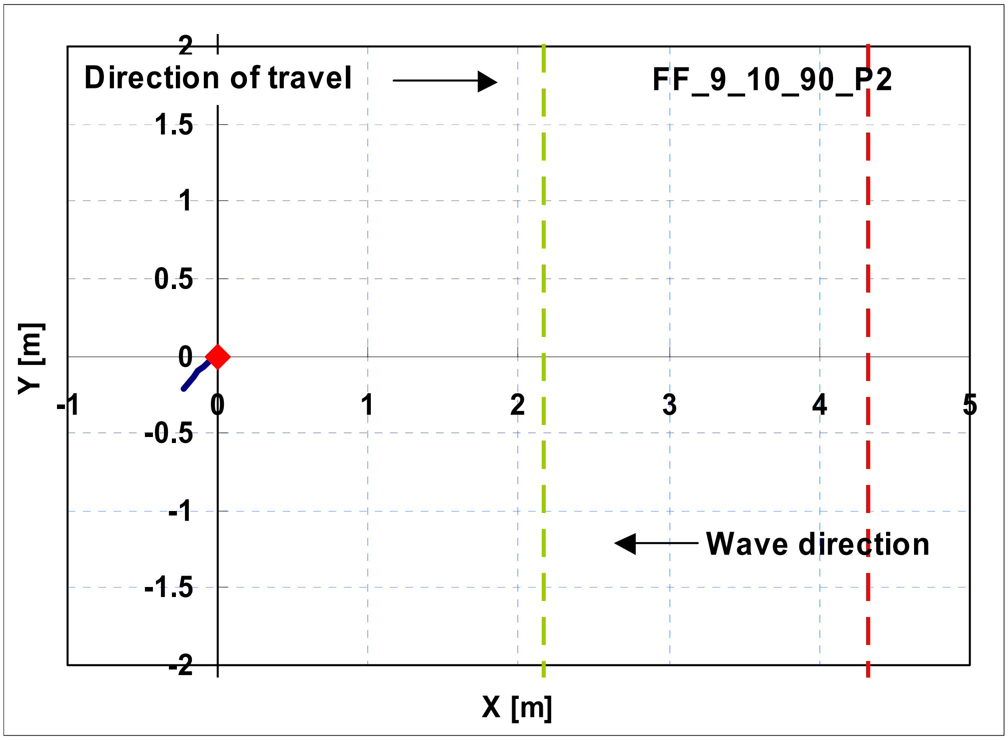
Direction of travel
FF_9_10_90_P2
Wave direction
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X [m]
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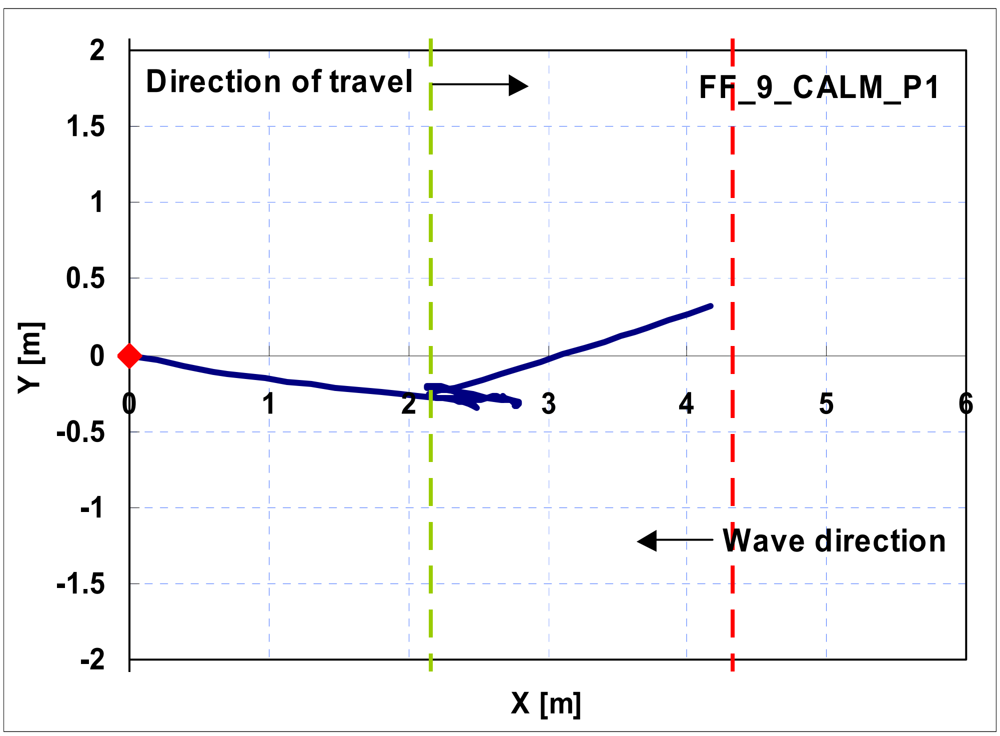
Direction of travel
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Wave direction
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X [m]
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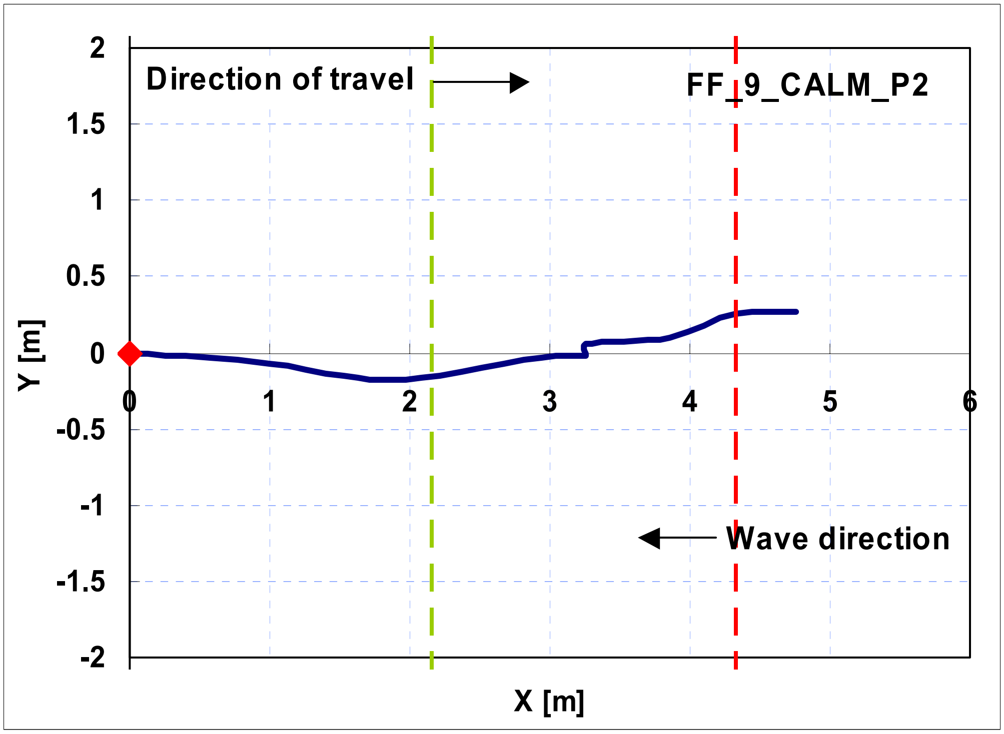
Direction of travel
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Wave direction
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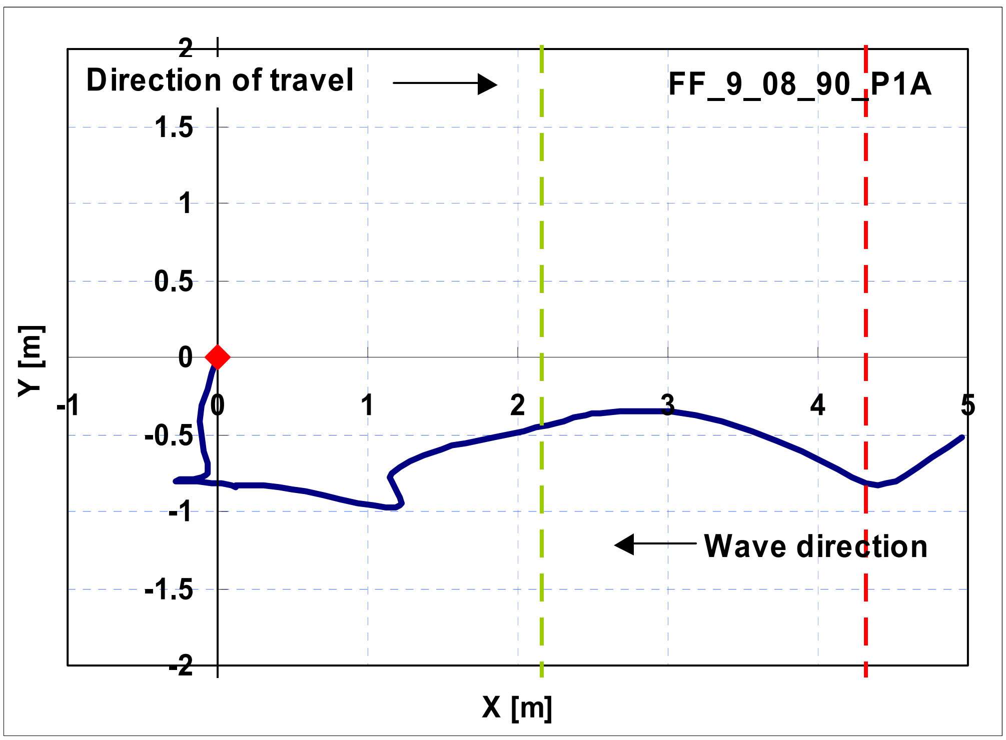
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X [m]
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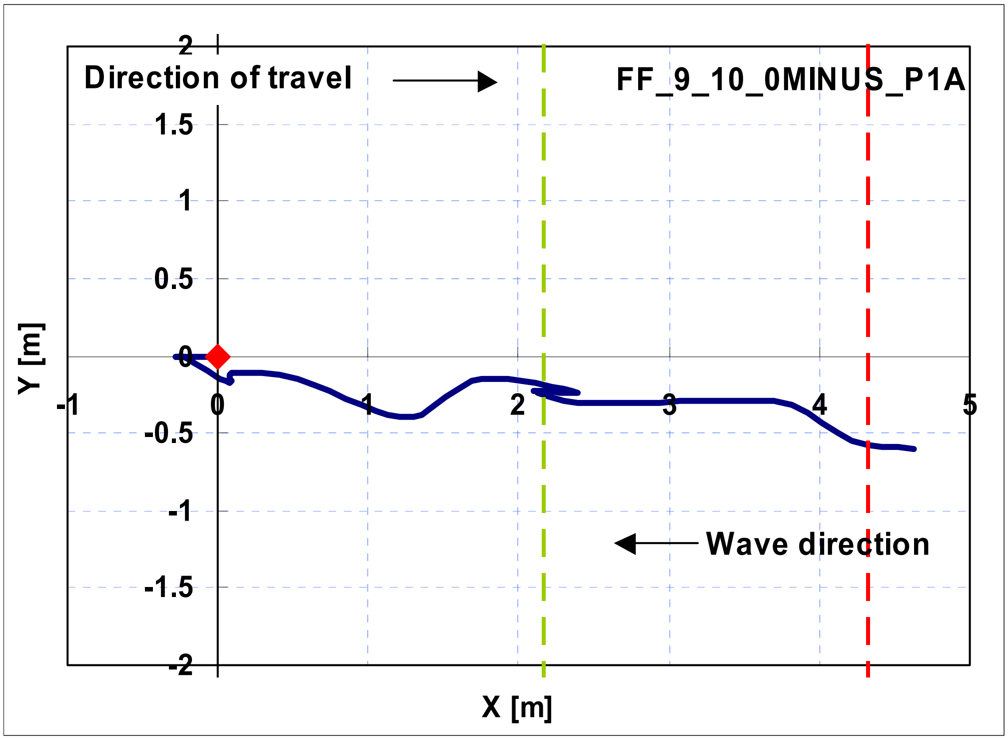
Direction of travel
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Wave direction
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X [m]
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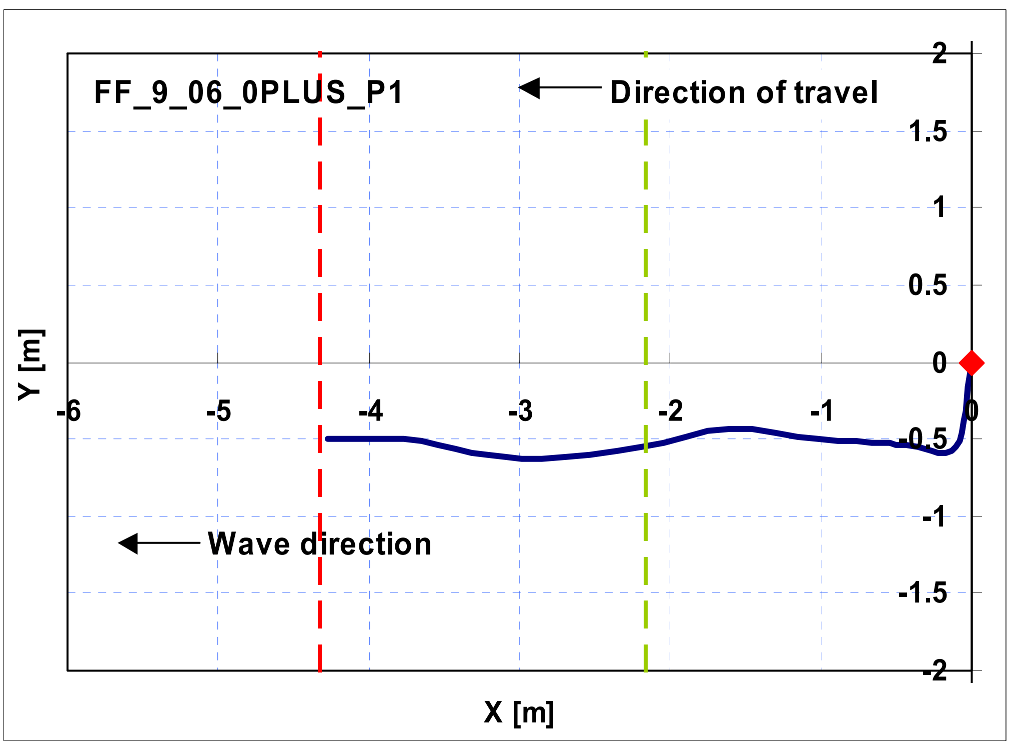
FF_9_06_0PLUS_P1
Direction of travel
Wave direction
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X [m]
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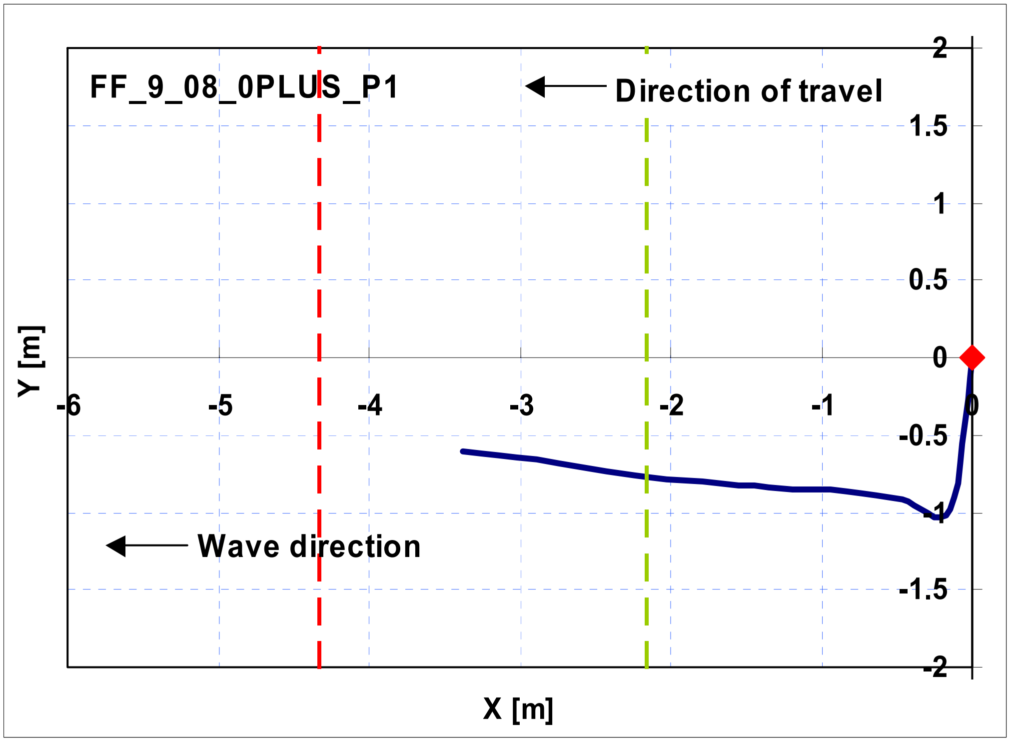
FF_9_08_0PLUS_P1
Direction of travel
Wave direction
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X [m]
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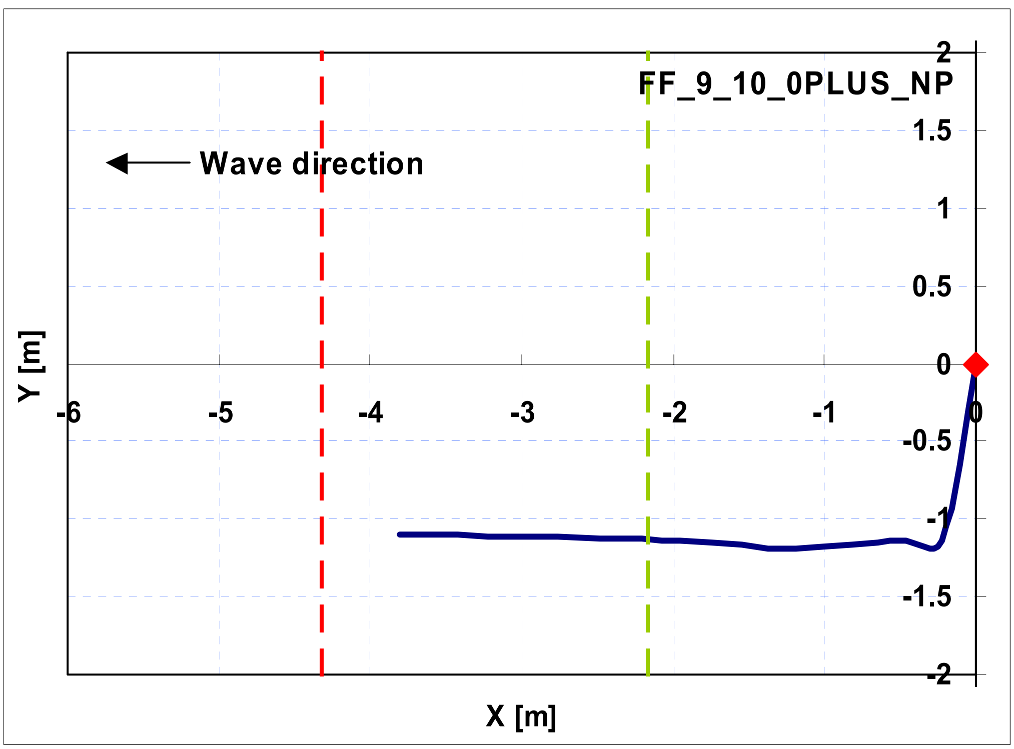
FF_9_10_0PLUS_NP
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-1.5
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-5
-4
-3
-2
-1
0

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APPENDIX E ANALYSED TEST RESULTS FOR MAD ROCK LIFEBOAT (IOT 681)

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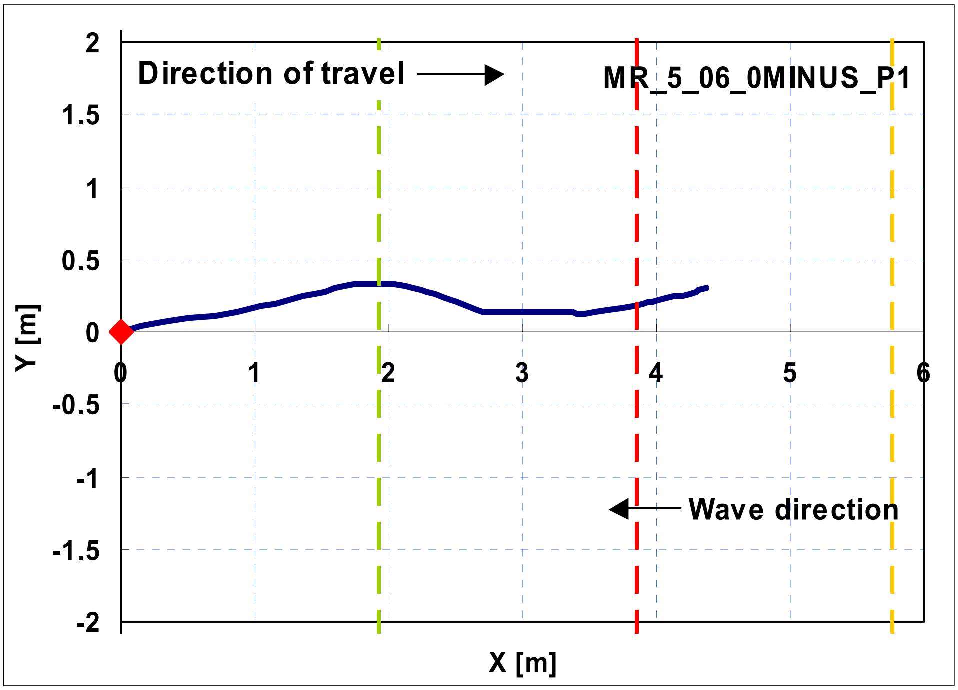
Expanded details for the complete test matrix for the IOT 681 lifeboat

Test Name	Nominal Ice Concentration (tenths)	Nominal Wave Frequency (Hz)	Launch Direction (degrees)	Power (P1/P2)	Test duration (from overhead video)	**Pass [5 boat lengths]**	**Pass [5 boat lengths reached in ≤ 40 seconds]**
MR_5_06_0MINUS_P1	5	0.6	0-	P1	16 s	Pass	Pass
MR_5_06_0MINUS_P2	5	0.6	0-	P2	8 s	Pass	Pass
MR_5_08_0MINUS_P1	5	0.8	0-	P1	25 s	Pass	Pass
MR_5_08_0MINUS_P2	5	0.8	0-	P2	15 s	Pass	Pass
MR_5_10_0MINUS_P1	5	1.0	0-	P1	42 s	Pass	Fail
MR_5_10_0MINUS_P2	5	1.0	0-	P2	18 s	Pass	Pass
MR_TESTA	5	-	0-	P1	17 s	Pass	Pass
MR_TESTB	5	-	0-	P2	37 s	Pass	Pass
MR_7_06_0MINUS_P1	7	0.6	0-	P1	11 s	Pass	Pass
MR_7_08_0MINUS_P1	7	0.8	0-	P1	16 s	Pass	Pass
MR_7_08_0MINUS_P2	7	0.8	0-	P2	9 s	Pass	Pass
MR_7_10_0MINUS_P1	7	1.0	0-	P1	48 s	Pass	Fail*
MR_7_10_0MINUS_P1A	7	1.0	0-	P1	19 s	Pass	Pass
MR_7_10_0MINUS_P2	7	1.0	0-	P2	23 s	Pass	Pass
MR_7_06_90_P1	7	0.6	90	P1	21 s	Pass	Pass
MR_7_06_90_P2	7	0.6	90	P2	12 s	Pass	Pass
MR_7_08_90_P1	7	0.8	90	P1	16 s	Pass	Pass
MR_7_08_90_P2	7	0.8	90	P2	28 s	Pass	Pass
MR_7_10_90_P1	7	1.0	90	P1	N/A		
MR_7_10_90_P1A	7	1.0	90	P1	1 min 24 s	Pass	Fail
MR_7_10_90_P2	7	1.0	90	P2	30 s	Pass	Pass
MR_7_CALM_0MINUS_P1	7	-	0-	P1	34 s	Pass	Pass
MR_7_CALM_0MINUS_P2	7	-	0-	P2	9 s	Pass	Pass
MR_9_06_0PLUS_P1	9	0.6	0+	P1	N/A		
MR_9_08_0PLUS_P1	9	0.8	0+	P1	12 s	Pass	Pass
MR_9_10_0PLUS_NP	9	1.0	0+	-	36 s	Pass	Pass
MR_9_06_0MINUS_P1	9	0.6	0-	P1	36 s	Pass	Pass
MR_9_06_0MINUS_P2	9	0.6	0-	P2	13 s	Pass	Pass
MR_9_08_0MINUS_P1	9	0.8	0-	P1	24 s	Pass	Pass
MR_9_08_0MINUS_P2	9	0.8	0-	P2	15 s	Pass	Pass
MR_9_07_0MINUS_P1	9	0.7	0-	P1	18 s	Pass	Pass
MR_9_07_0MINUS_P2	9	0.7	0-	P2	11 s	Pass	Pass
MR_9_10_0MINUS_P1	9	1.0	0-	P1	40 s	Pass	Pass
MR_9_10_0MINUS_P2	9	1.0	0-	P2	22 s	Pass	Pass
MR_9_06_90_P1	9	0.6	90	P1	32 s	Pass	Pass
MR_9_08_90_P1	9	0.8	90	P1	34 s	Pass	Pass
MR_9_10_90_P2	9	1.0	90	P2	3 s	Fail*	Fail*
MR_9_CALM_P2	9	-	0-	P2	22 s	Pass	Pass
MR_9_CALM_P1	9	-	0-	P1	20 s	Pass	Pass
MR_9_10_0MINUS_P2A	9	1.0	0-	P2	14 s	Fail	Fail
MR_9_06_90_P1A	9	0.6	90	P1	32 s	Pass	Pass

Expanded details for the complete test matrix for the IOT 681 lifeboat (cont'd)

Test Name	Nominal Ice Concentration (tenths)	Nominal Wave Frequency (Hz)	Launch Direction (degrees)	Power (P1/P2)	Test duration (from overhead video)	**Pass [5 boat lengths]**	**Pass [5 boat lengths reached in ≤ 40 seconds]**
MR_9_08_90_P1A	9	0.8	90	P1	4 s	Fail	Fail
MR_9_10_90_P2	9	1.0	90	P2	19 s	Pass	Pass
MR_9_10_90_P2A	9	1.0	90	P2	4 s	Fail*	Fail*
MR_9_06_0PLUS_P1A	9	0.6	0+	P1	36 s	Pass	Pass

* lifeboat may have failed test due to mechanical problems


Direction of travel
MR_5_06_0MINUS_P1
Wave direction
Y [m]
X [m]
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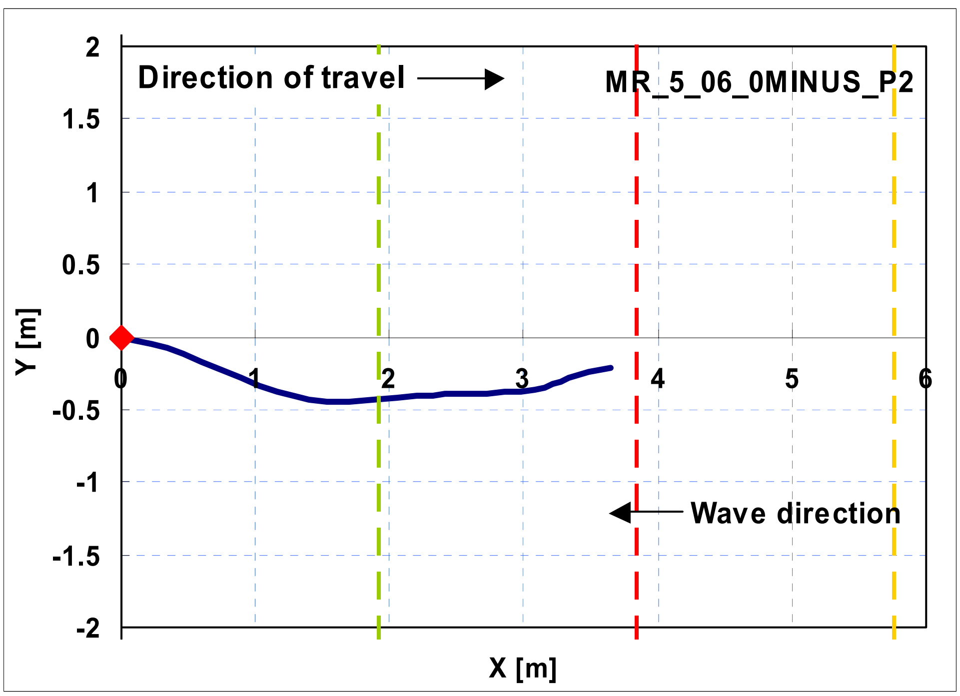
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_5_06_0MINUS_P2
Wave direction
Y [m]
X [m]
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0.5
0
-0.5
-1
-1.5
-2
0
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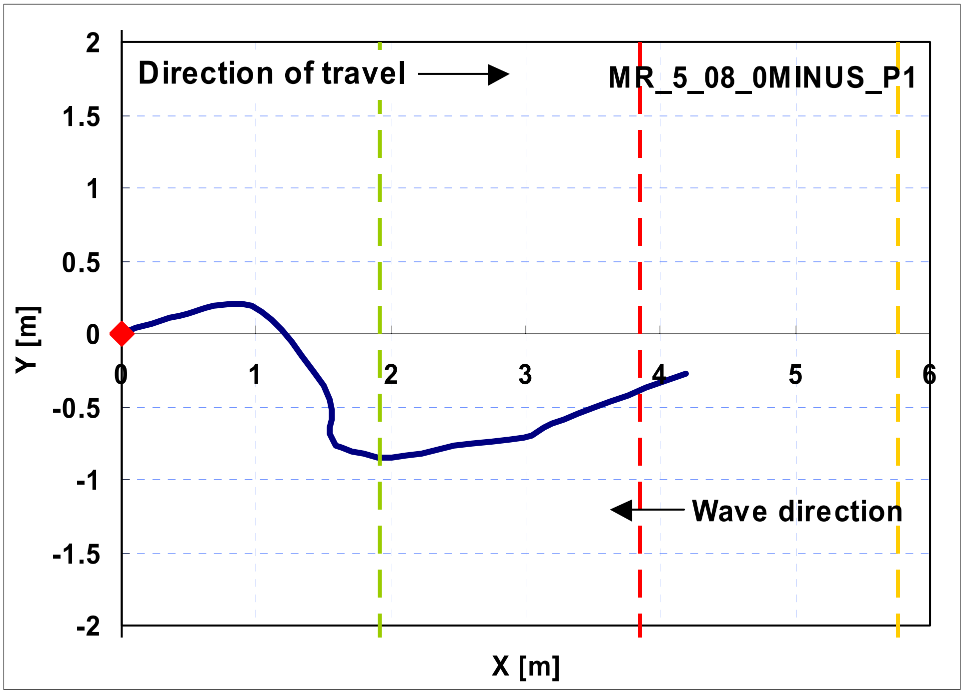
2
3
4
5
6


Direction of travel
MR_5_08_0MINUS_P1
Wave direction
Y [m]
X [m]
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-1
-1.5
-2
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1
2
3
4
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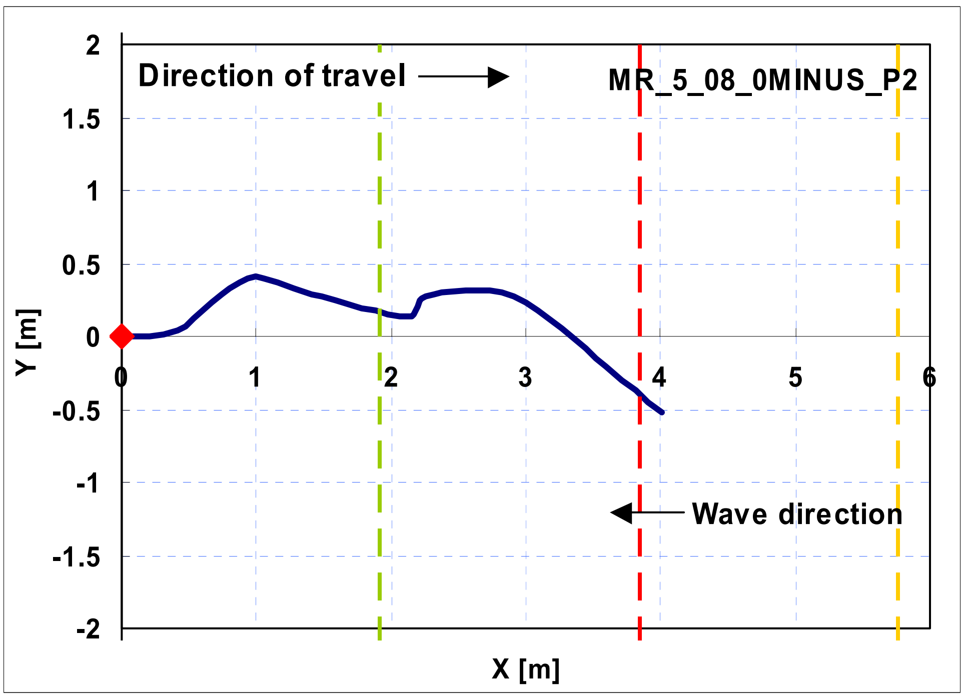
6


Direction of travel
MR_5_08_0MINUS_P2
Wave direction
Y [m]
X [m]
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1.5
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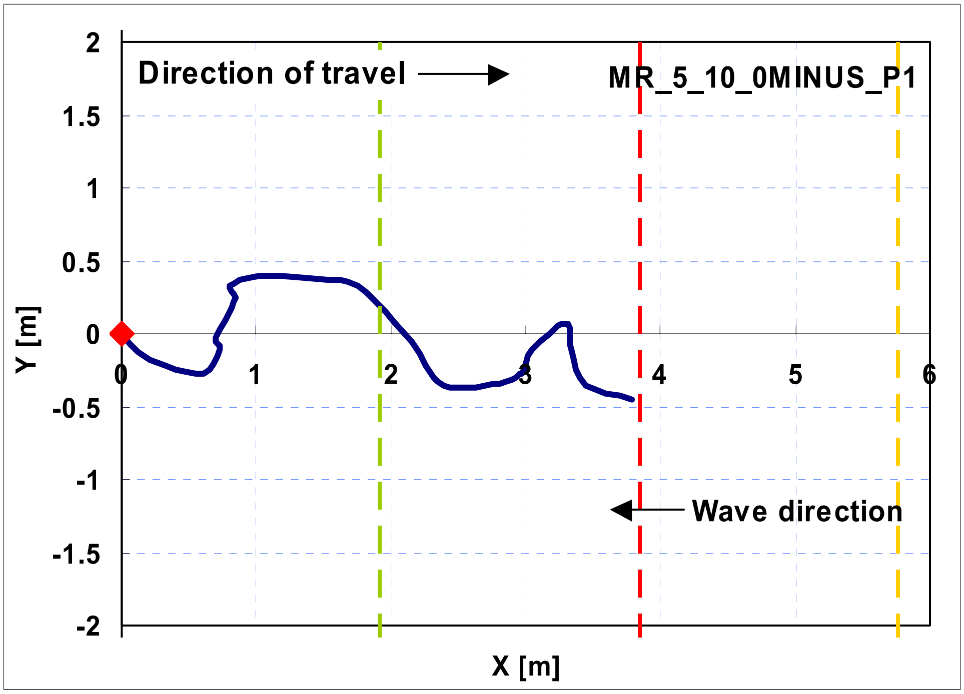
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_5_10_0MINUS_P1
Wave direction
Y [m]
X [m]
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1.5
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0.5
0
-0.5
-1
-1.5
-2
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1
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3
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5
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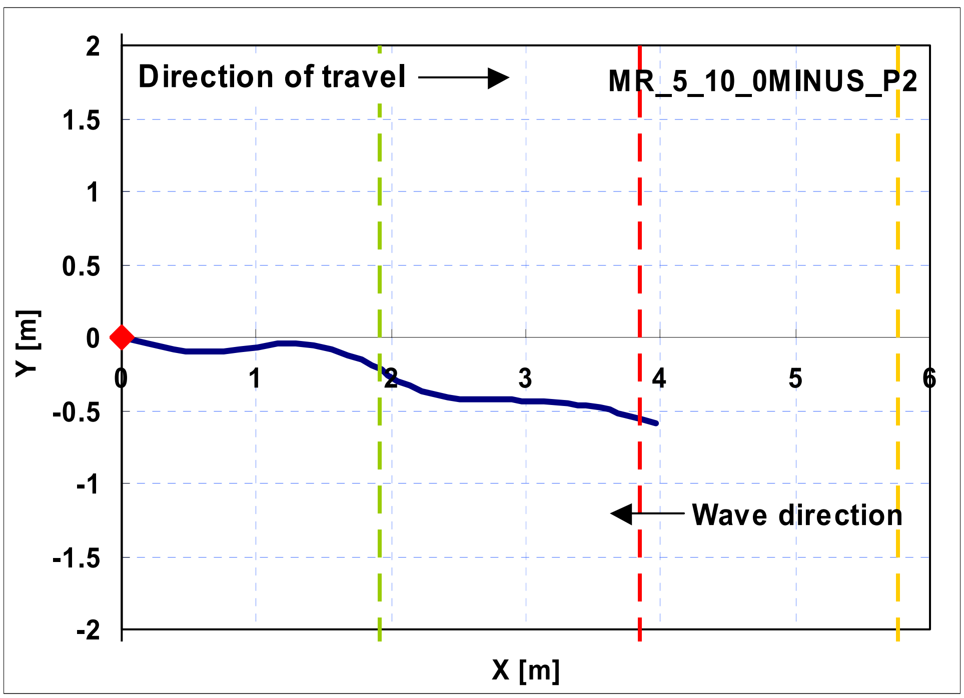
Direction of travel
MR_5_10_0MINUS_P2
Wave direction
Y [m]
X [m]
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0.5
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-1.5
-2
0
1
2
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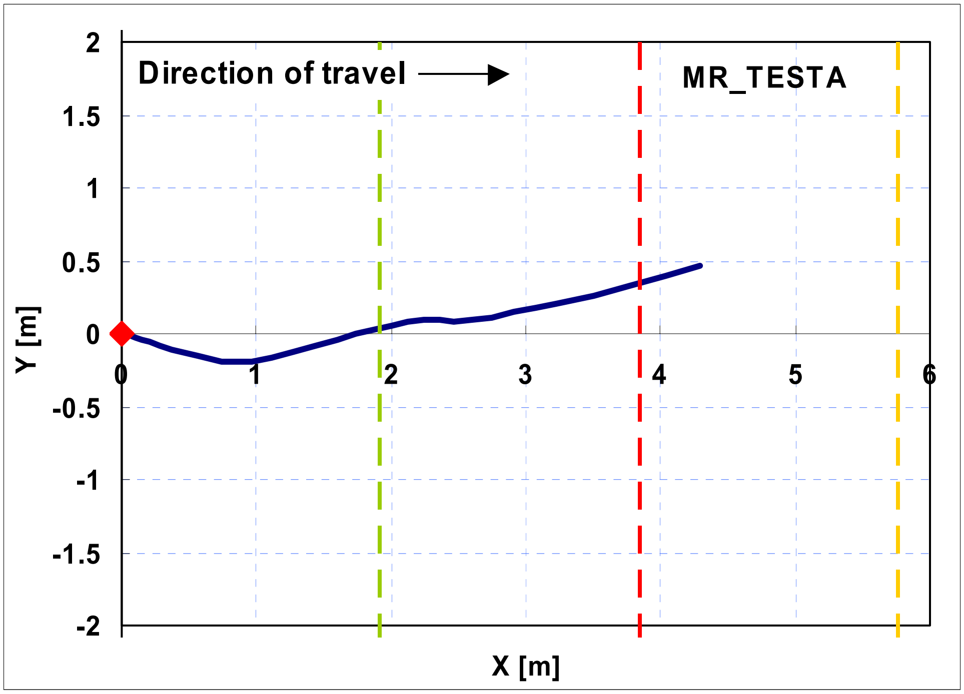
4
5
6



Direction of travel
MR_TESTA
Y [m]
X [m]
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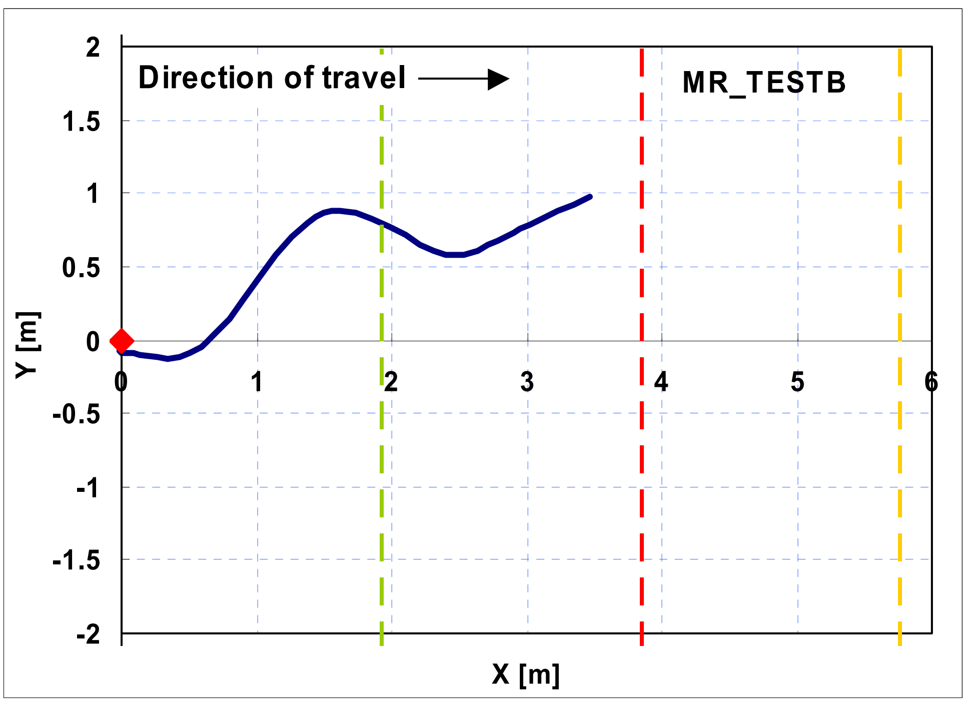
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6



Direction of travel
MR_TESTB
Y [m]
X [m]
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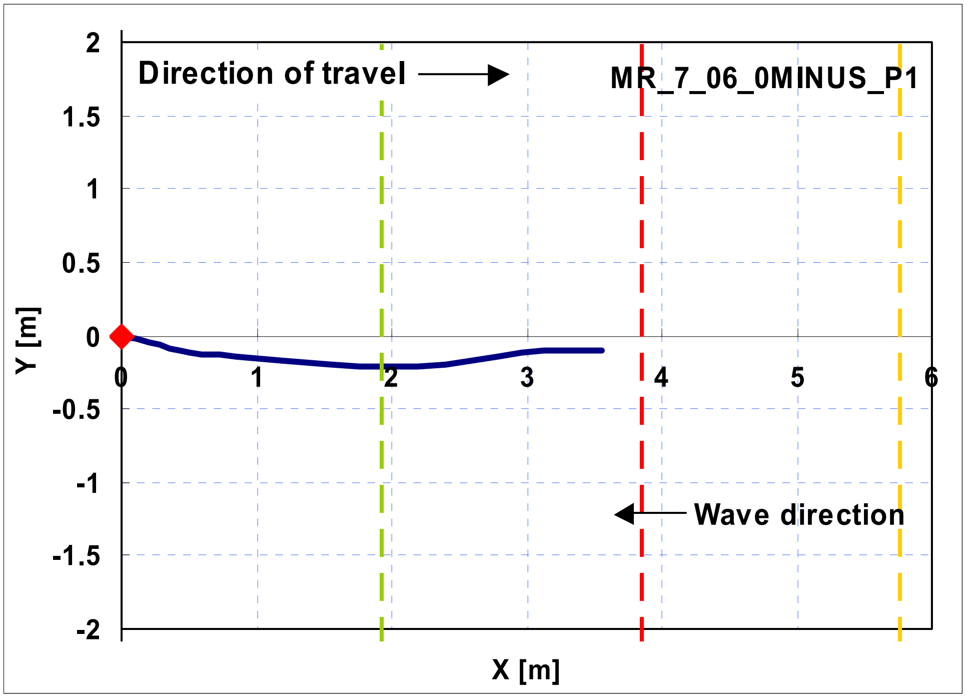
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_7_06_0MINUS_P1
Wave direction
Y [m]
X [m]
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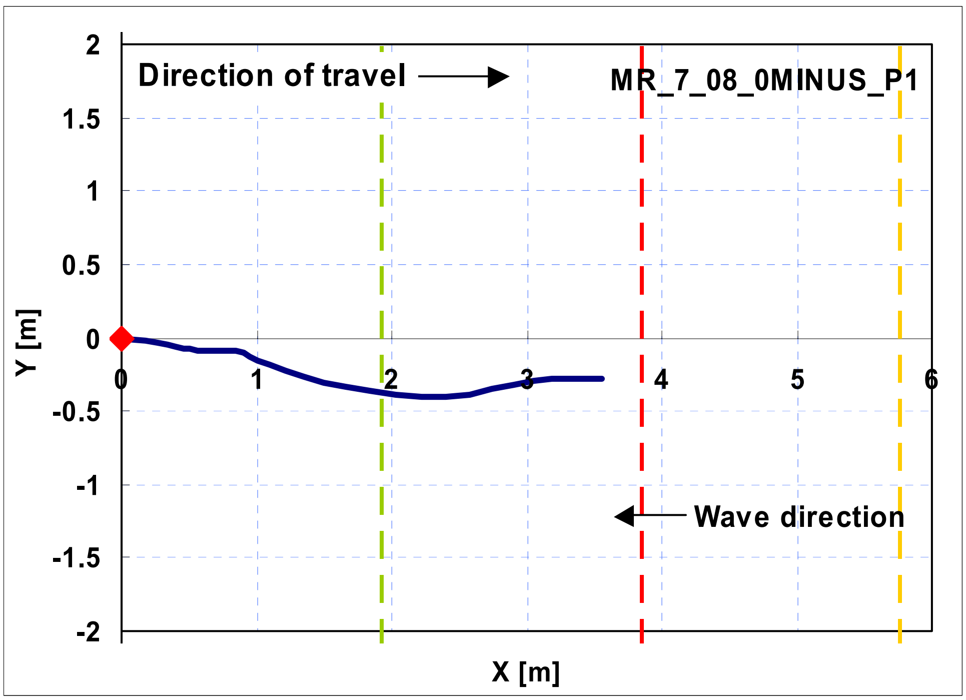
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_7_08_0MINUS_P1
Wave direction
Y [m]
X [m]
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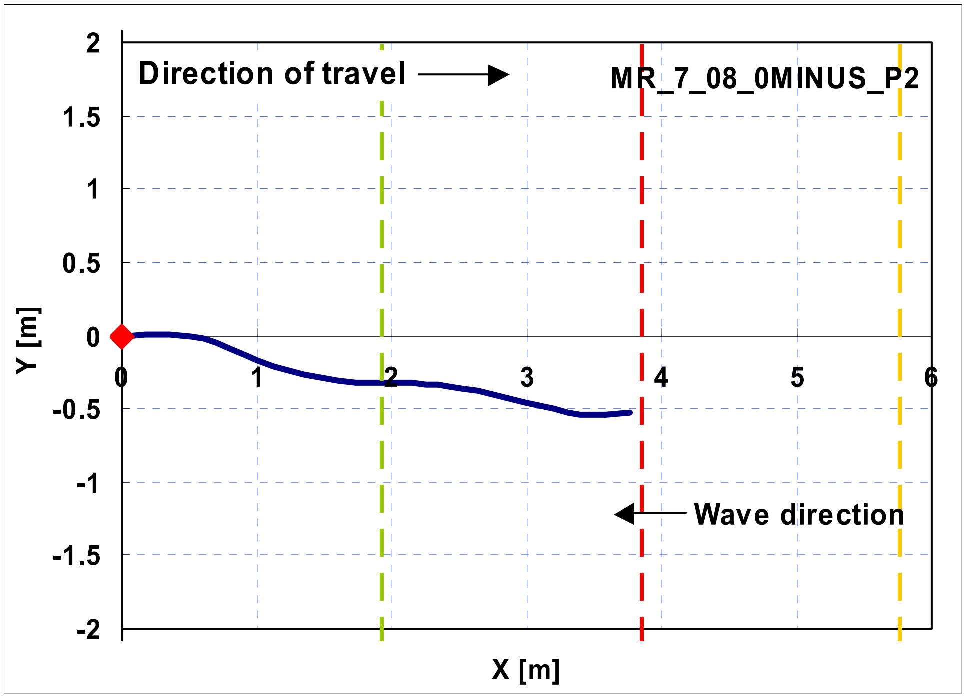
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_7_08_0MINUS_P2
Wave direction
Y [m]
X [m]
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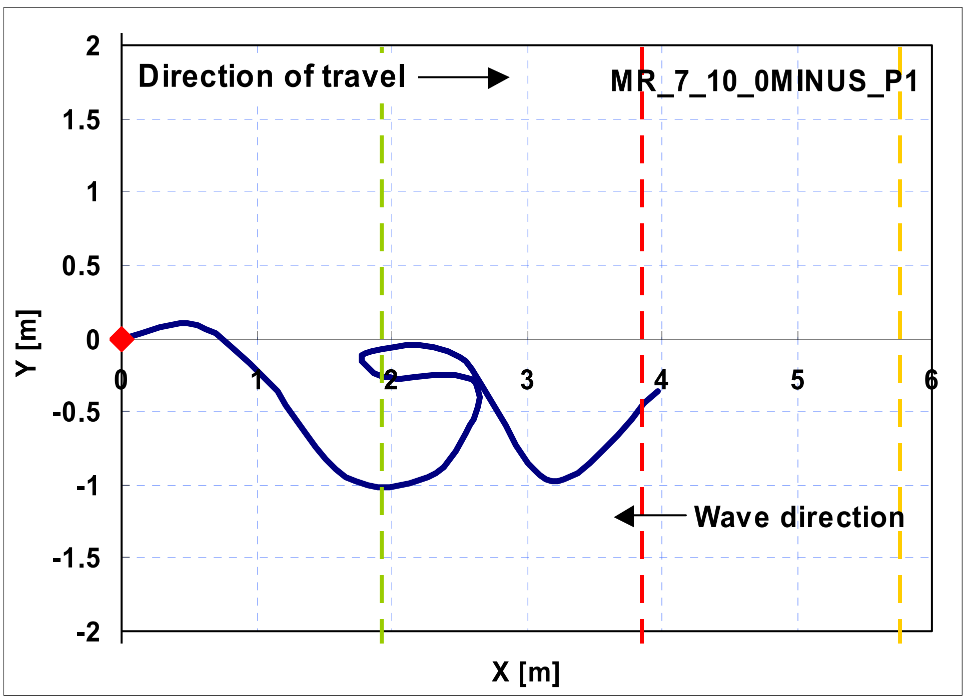
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_7_10_0MINUS_P1
Wave direction
Y [m]
X [m]
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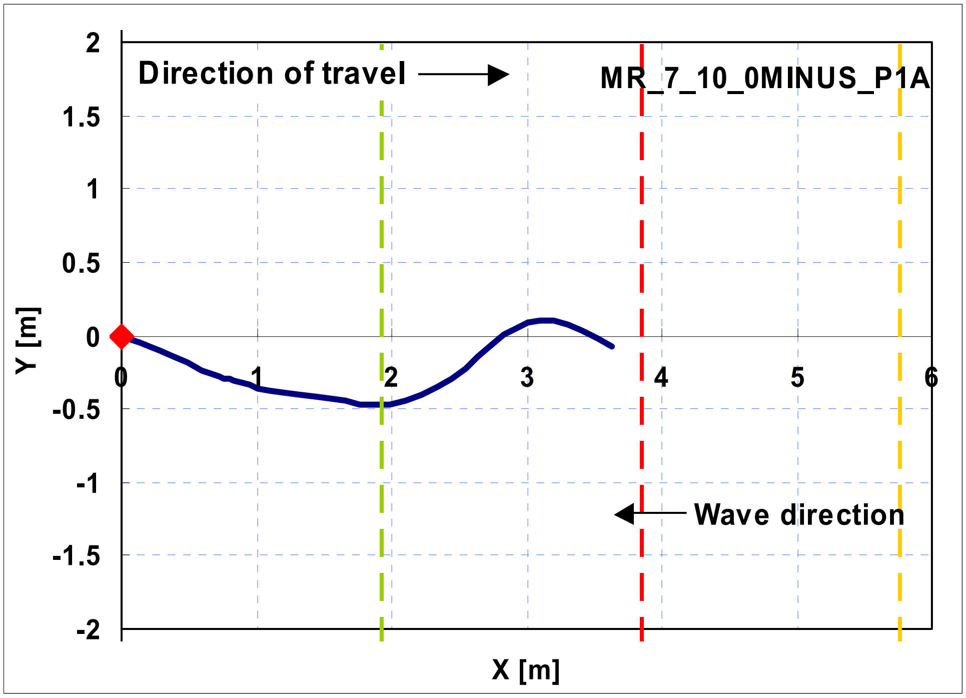
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_7_10_0MINUS_P1A
Wave direction
Y [m]
X [m]
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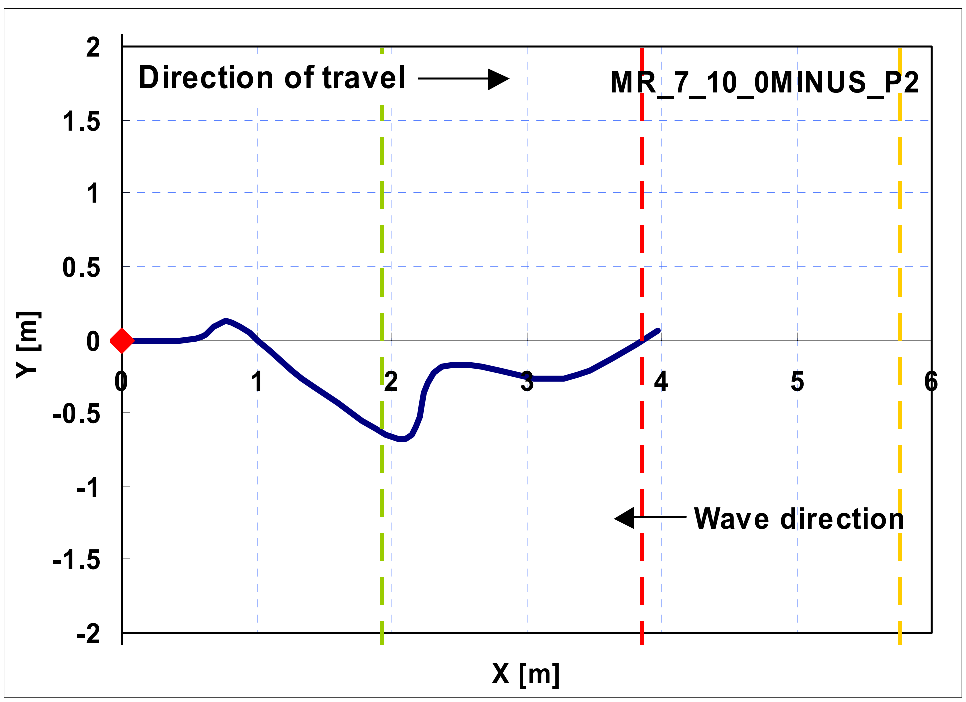
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_7_10_0MINUS_P2
Wave direction
Y [m]
X [m]
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1.5
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0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
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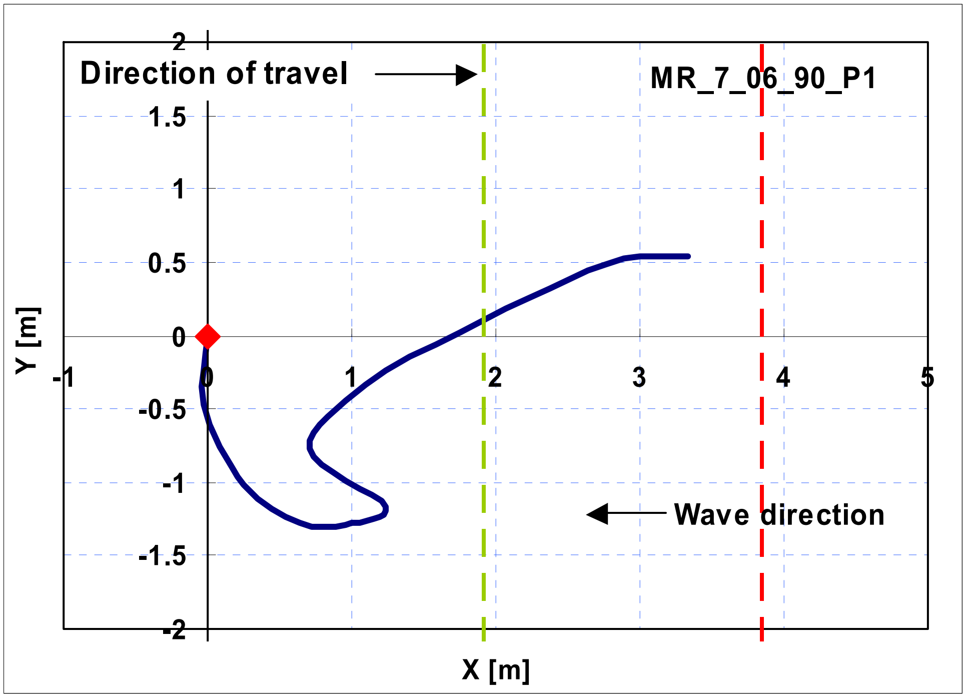
Direction of travel
MR_7_06_90_P1
Wave direction
Y [m]
X [m]
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2
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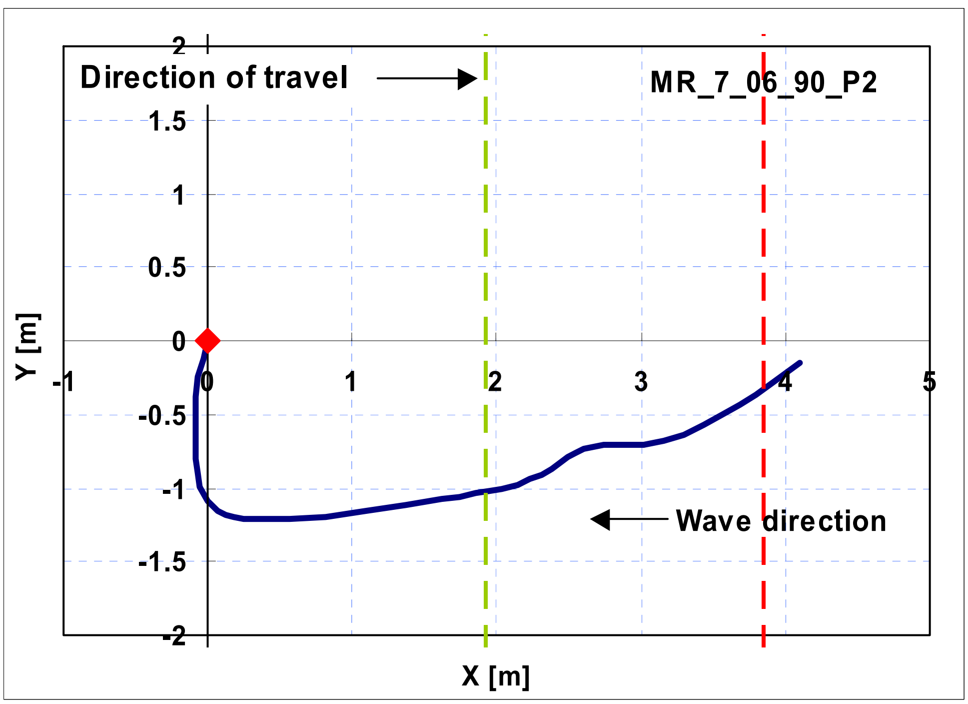
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Wave direction
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X [m]
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-1.5
-2
-1
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2
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4
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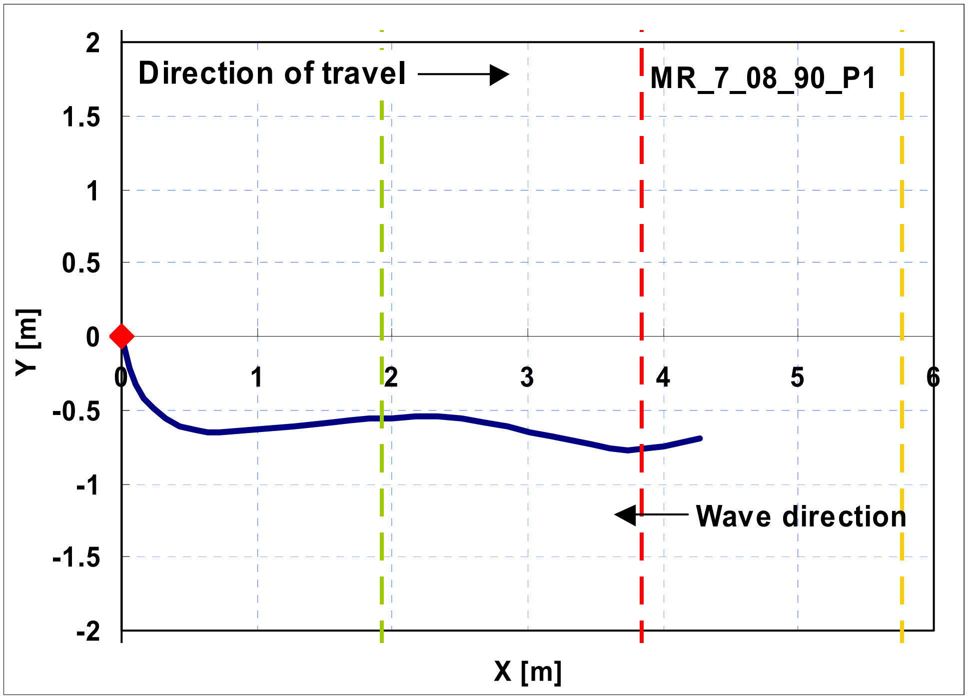
Direction of travel
MR_7_08_90_P1
Wave direction
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X [m]
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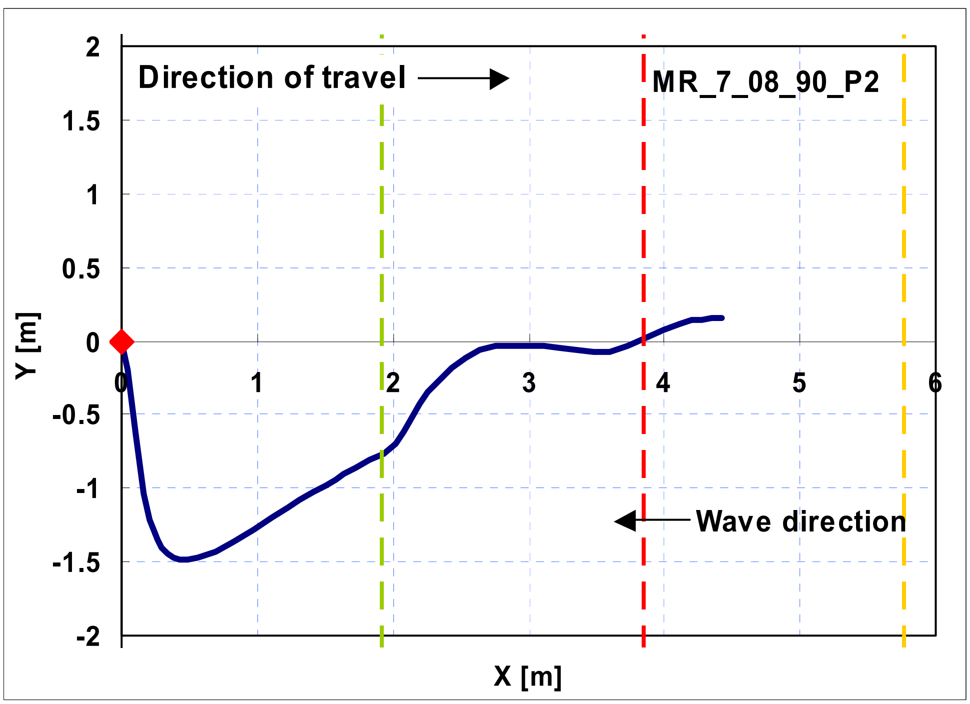
Direction of travel
MR_7_08_90_P2
Wave direction
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X [m]
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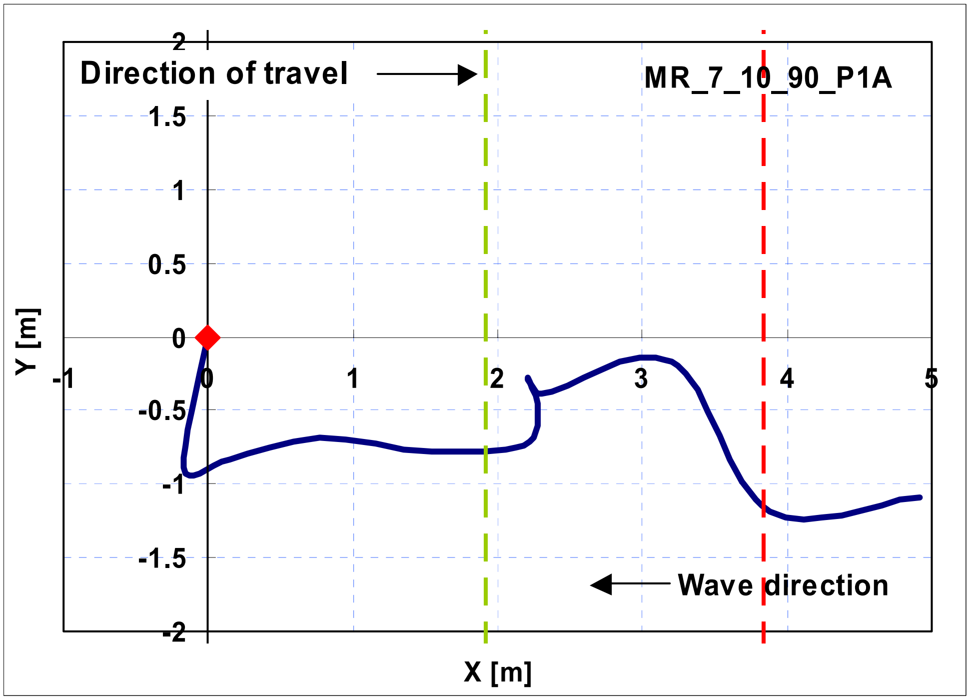
Direction of travel
MR_7_10_90_P1A
Wave direction
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X [m]
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4
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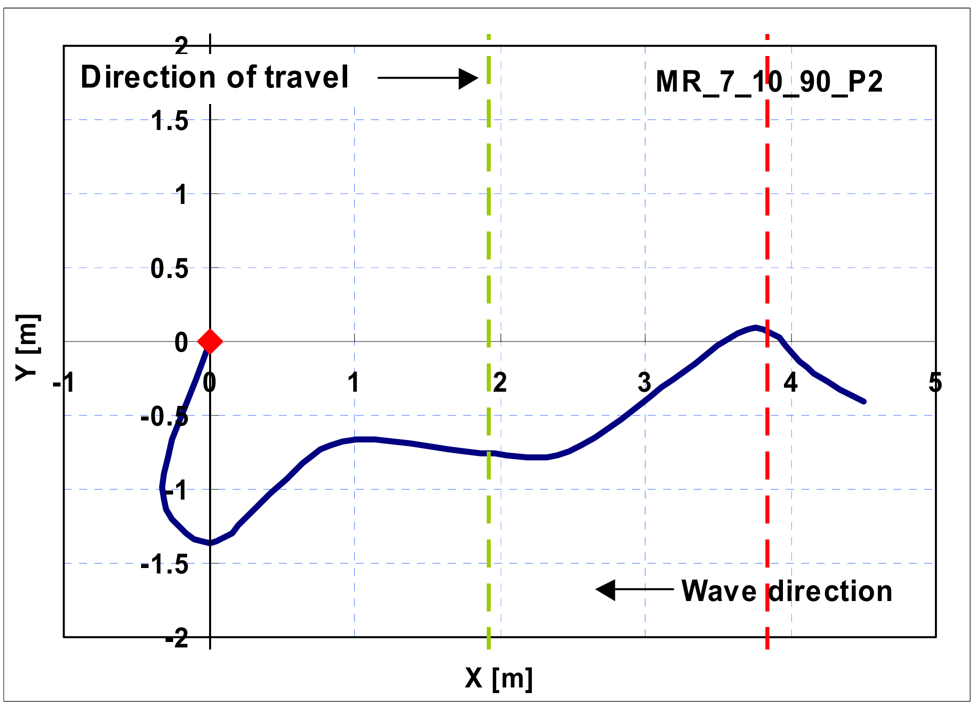
Direction of travel
MR_7_10_90_P2
Wave direction
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X [m]
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-1
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-2
-1
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2
3
4
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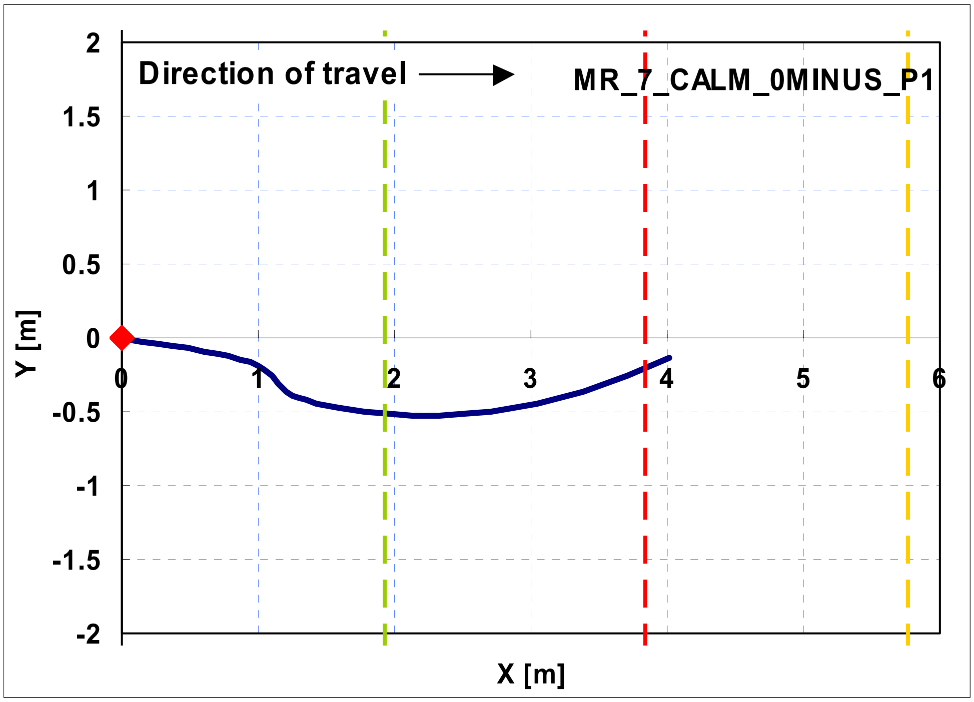
Direction of travel
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X [m]
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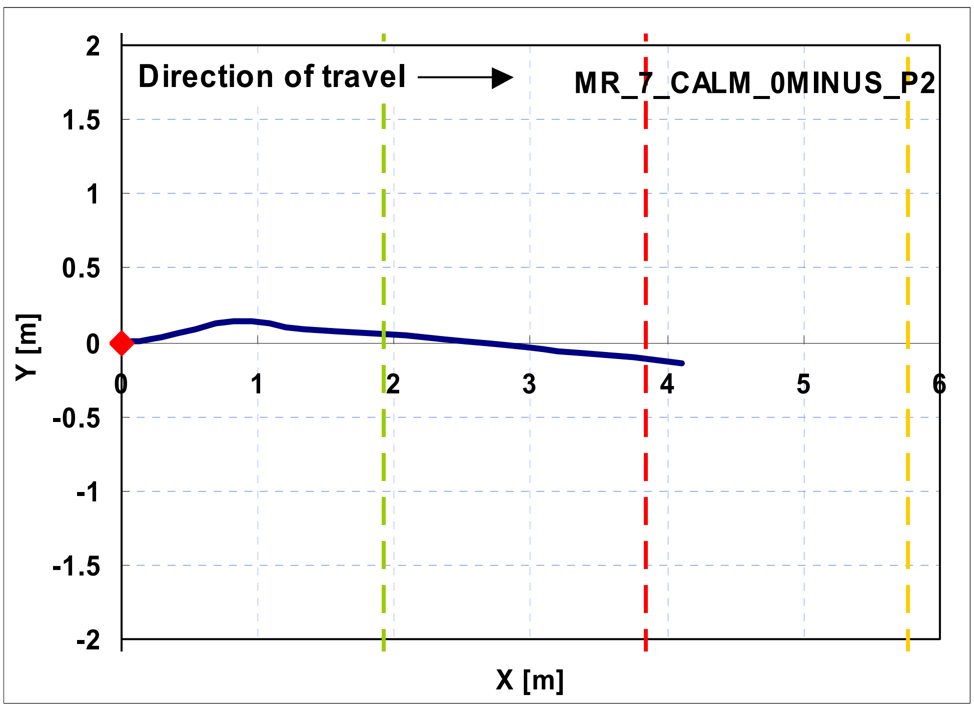
Direction of travel
MR_7_CALM_0MINUS_P2
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X [m]
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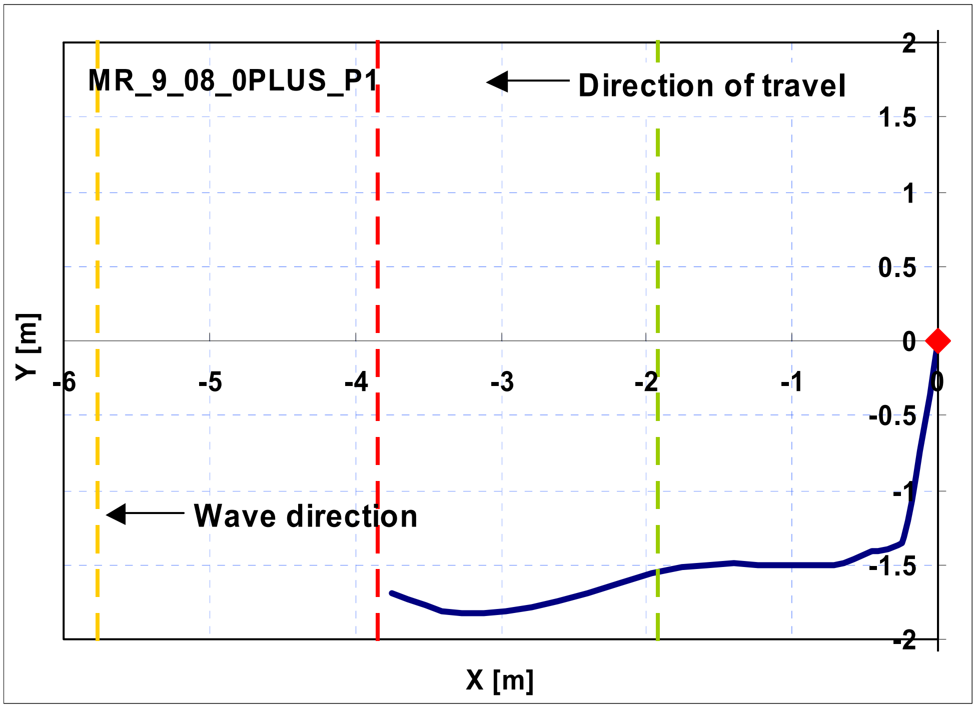
MR_9_08_0PLUS_P1
Direction of travel
Wave direction
Y [m]
X [m]
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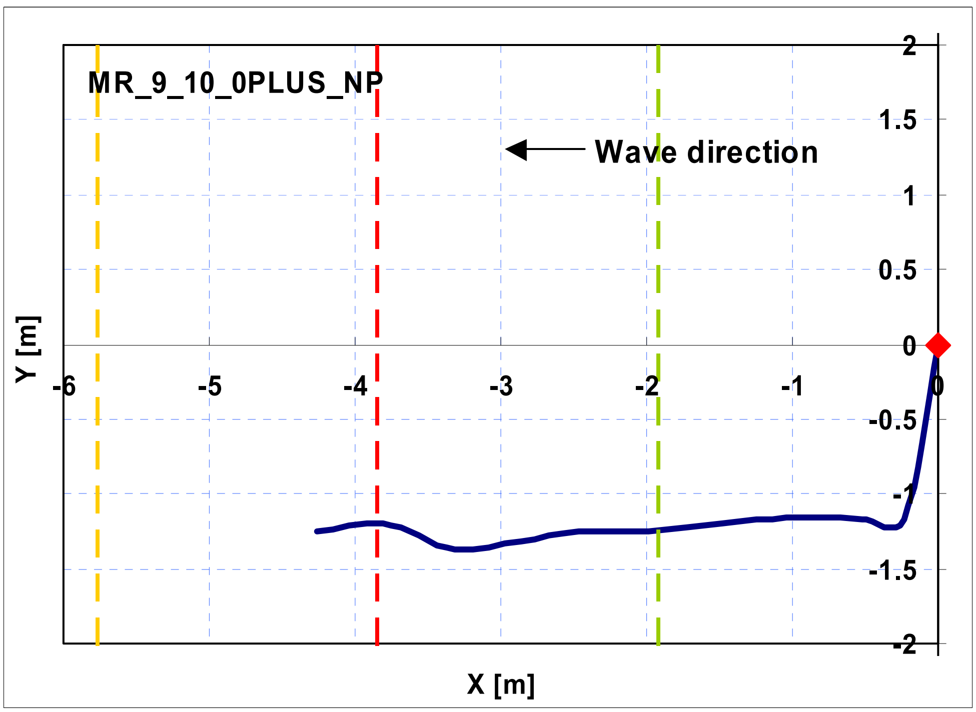
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Wave direction
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X [m]
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-2
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-5
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-1
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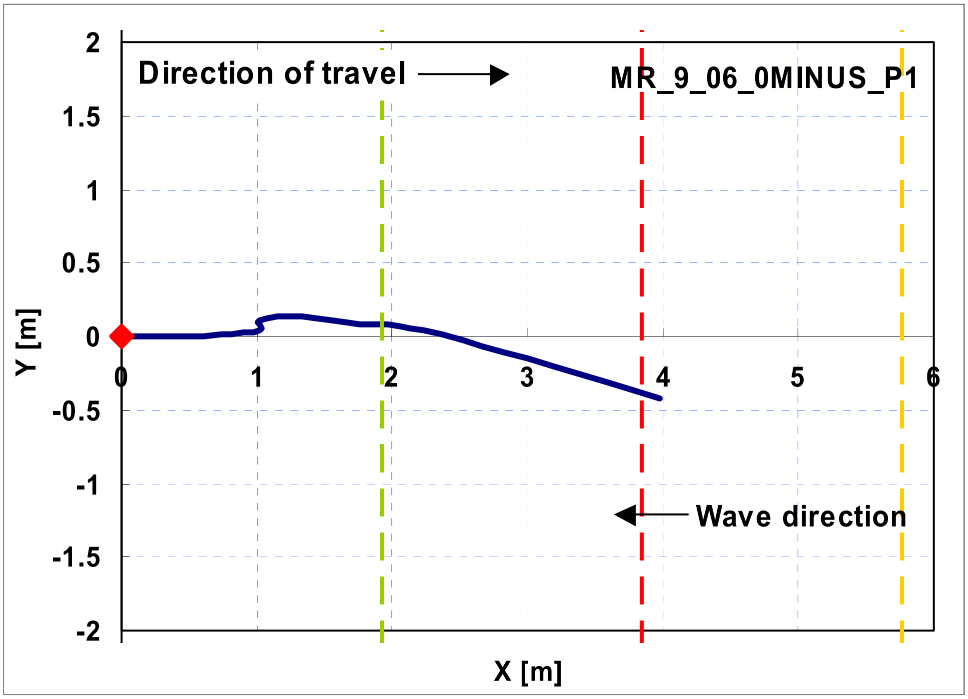
Direction of travel
MR_9_06_0MINUS_P1
Wave direction
Y [m]
X [m]
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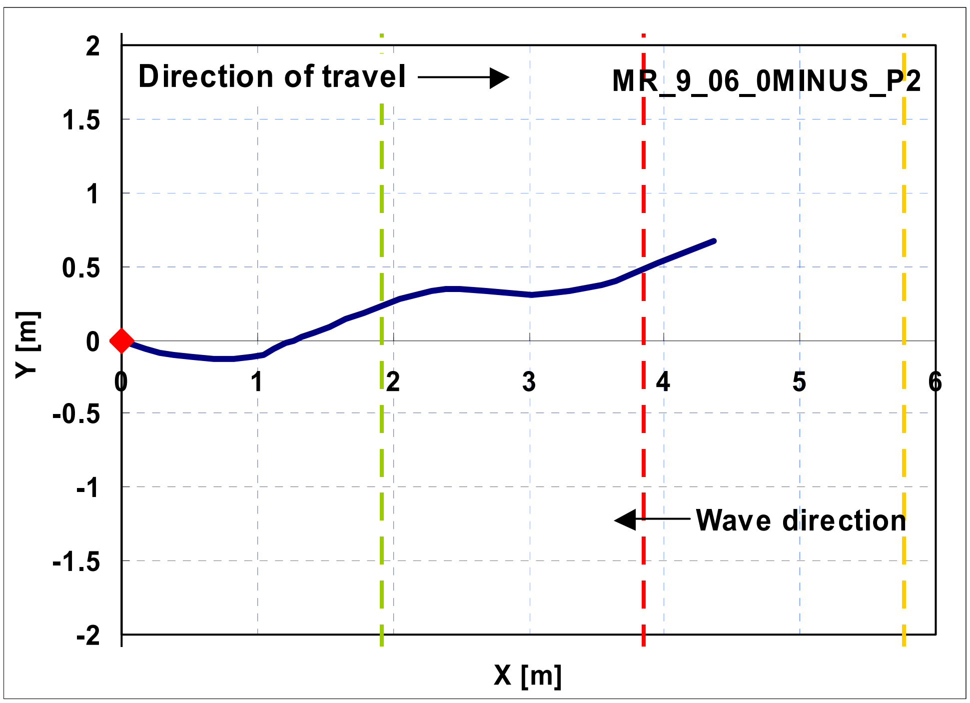
Direction of travel
MR_9_06_0MINUS_P2
Wave direction
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X [m]
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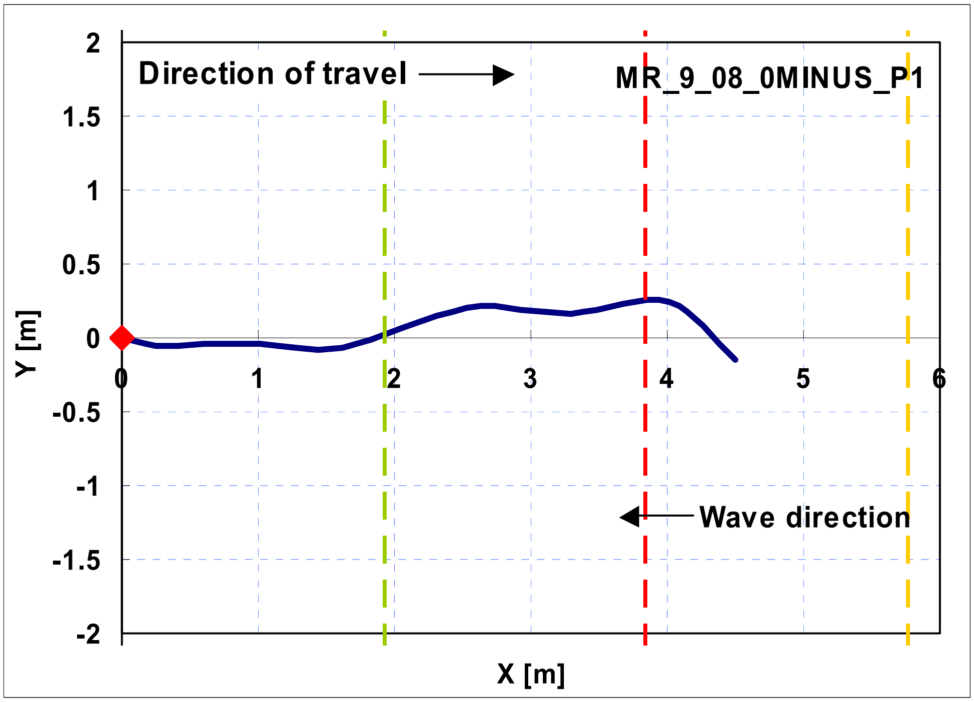
Direction of travel
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Wave direction
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X [m]
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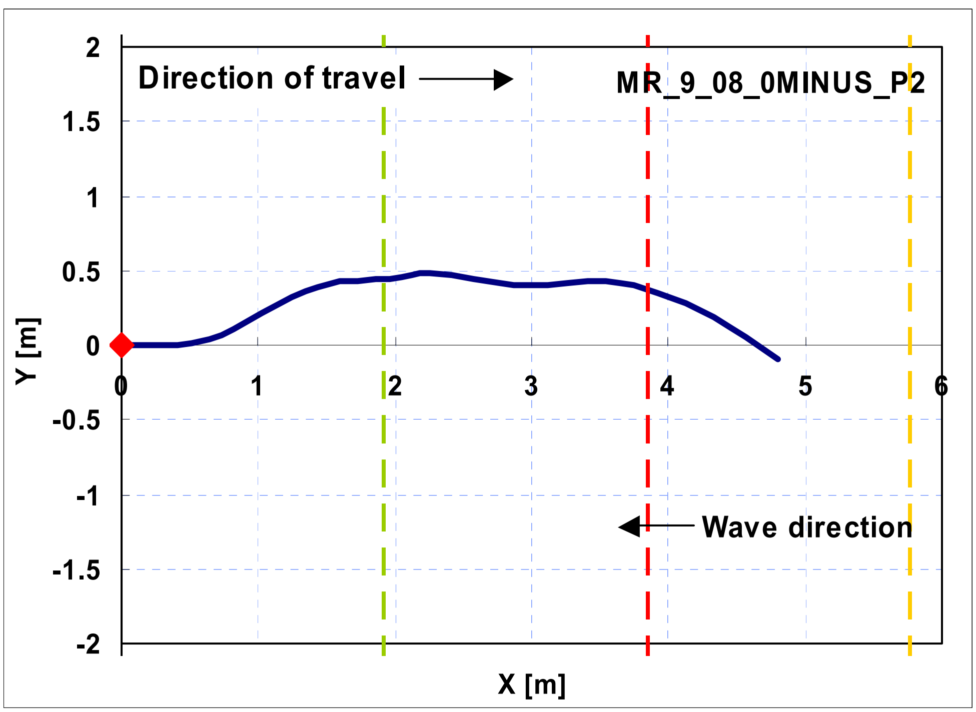
Direction of travel
MR_9_08_0MINUS_P2
Wave direction
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X [m]
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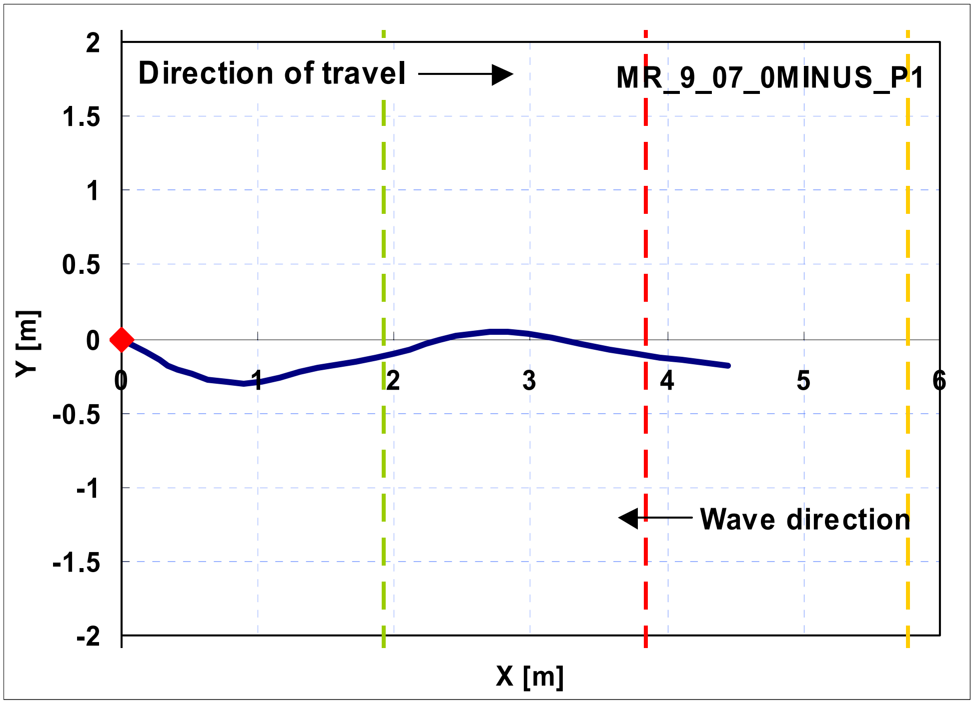
Direction of travel
MR_9_07_0MINUS_P1
Wave direction
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X [m]
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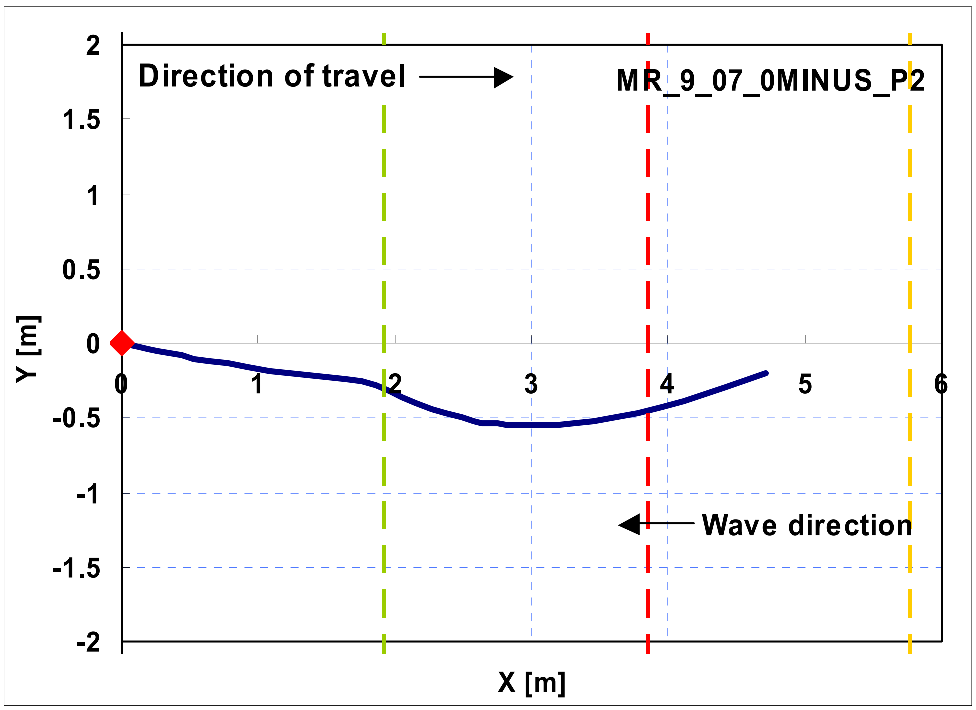
Direction of travel
MR_9_07_0MINUS_P2
Wave direction
Y [m]
X [m]
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-1
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3
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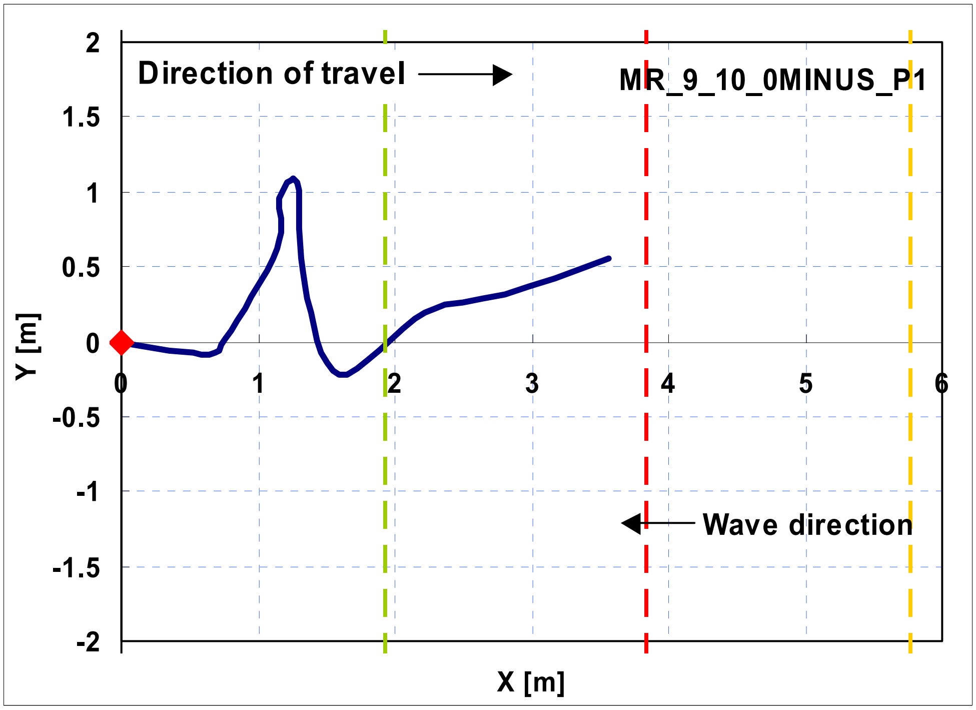
Direction of travel
MR_9_10_0MINUS_P1
Wave direction
Y [m]
X [m]
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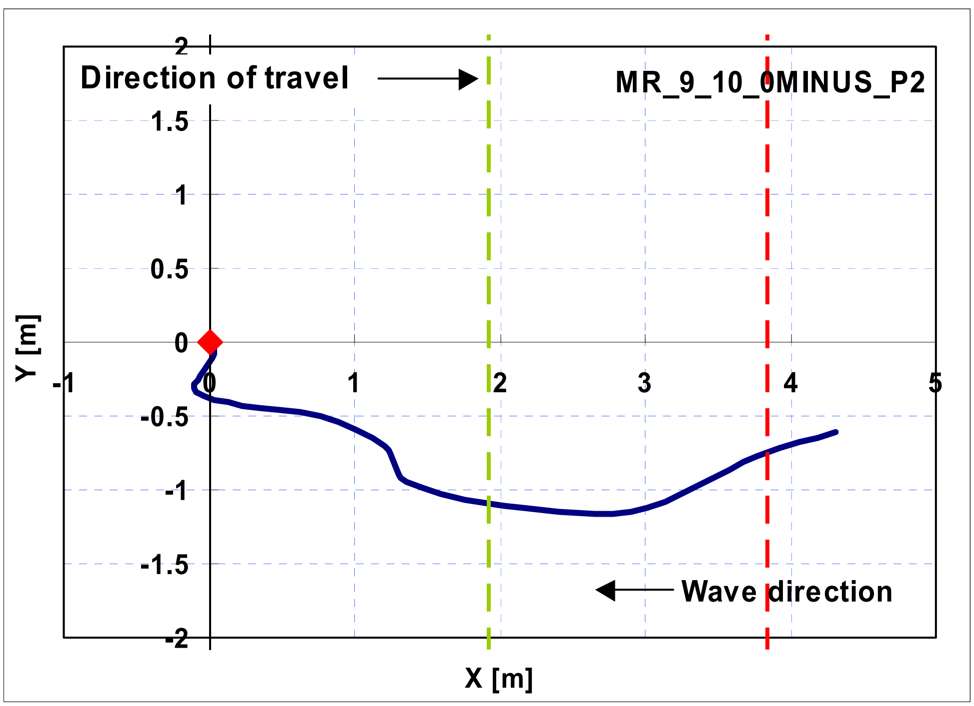
Direction of travel
MR_9_10_0MINUS_P2
Wave direction
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X [m]
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2
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4
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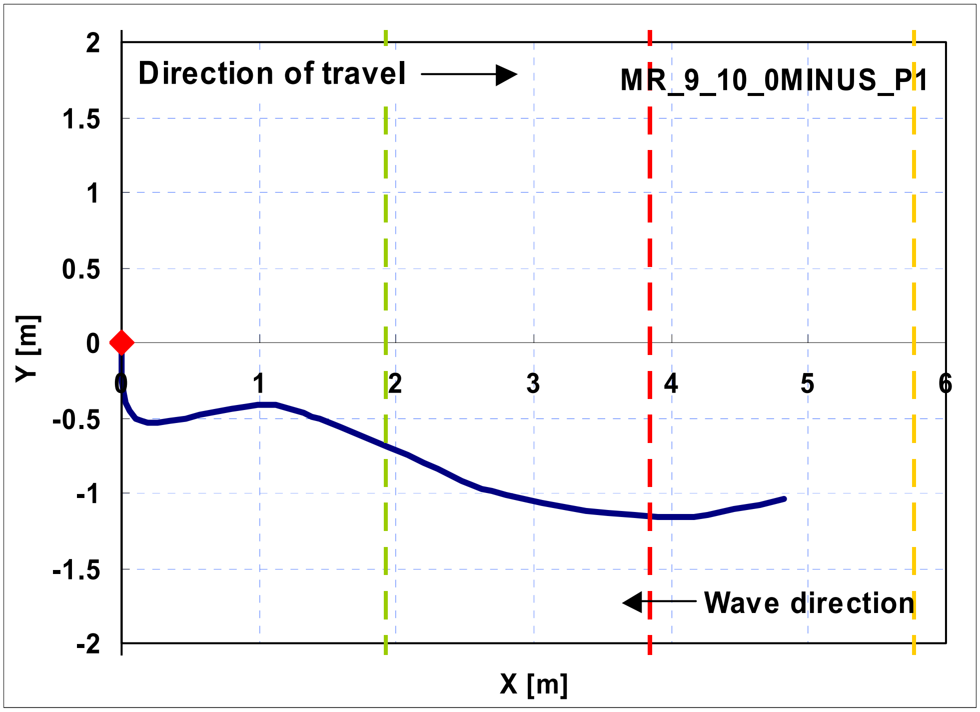
Direction of travel
MR_9_10_0MINUS_P1
Wave direction
Y [m]
X [m]
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-1
-1.5
-2
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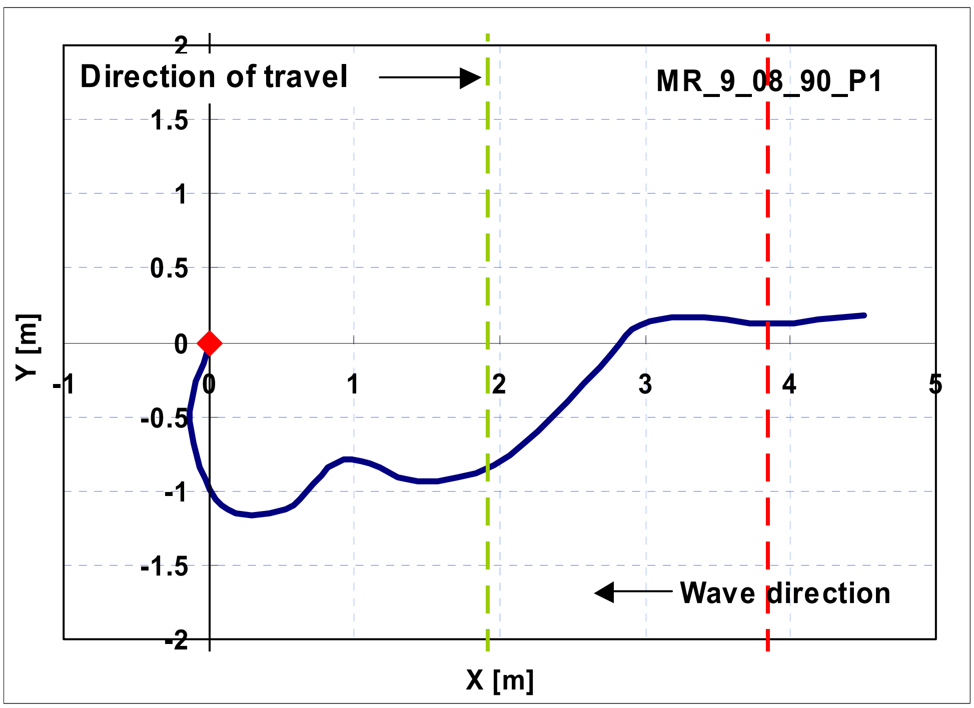
1
2
3
4
5
6


Direction of travel
MR_9_08_90_P1
Wave direction
Y [m]
X [m]
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1.5
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-1
-1.5
-2
-1
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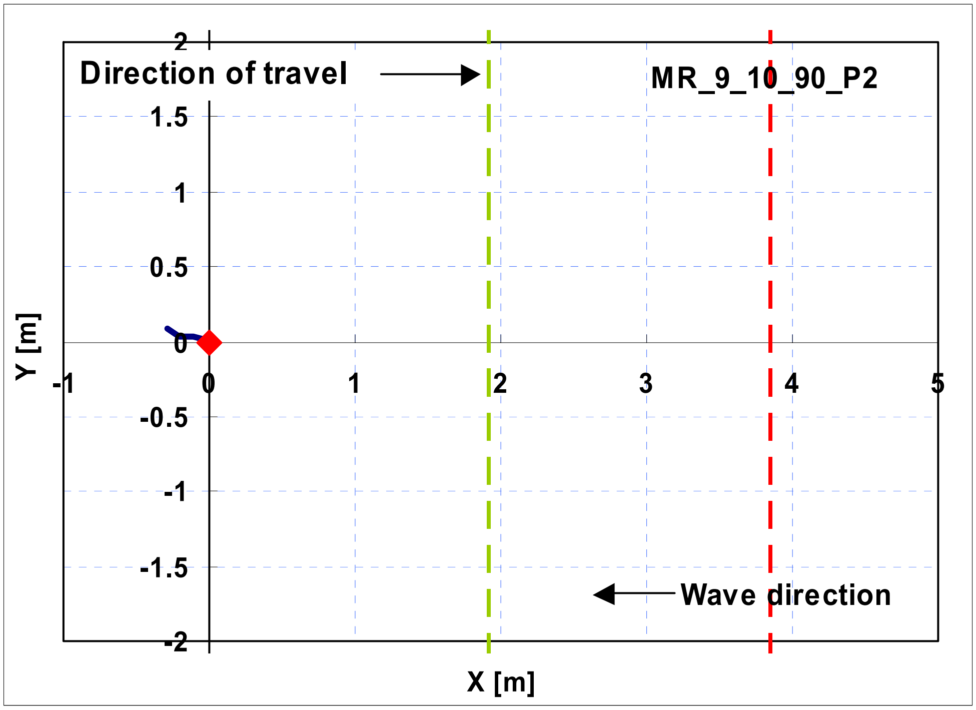
Direction of travel
MR_9_10_90_P2
Wave direction
Y [m]
X [m]
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-1
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-2
-1
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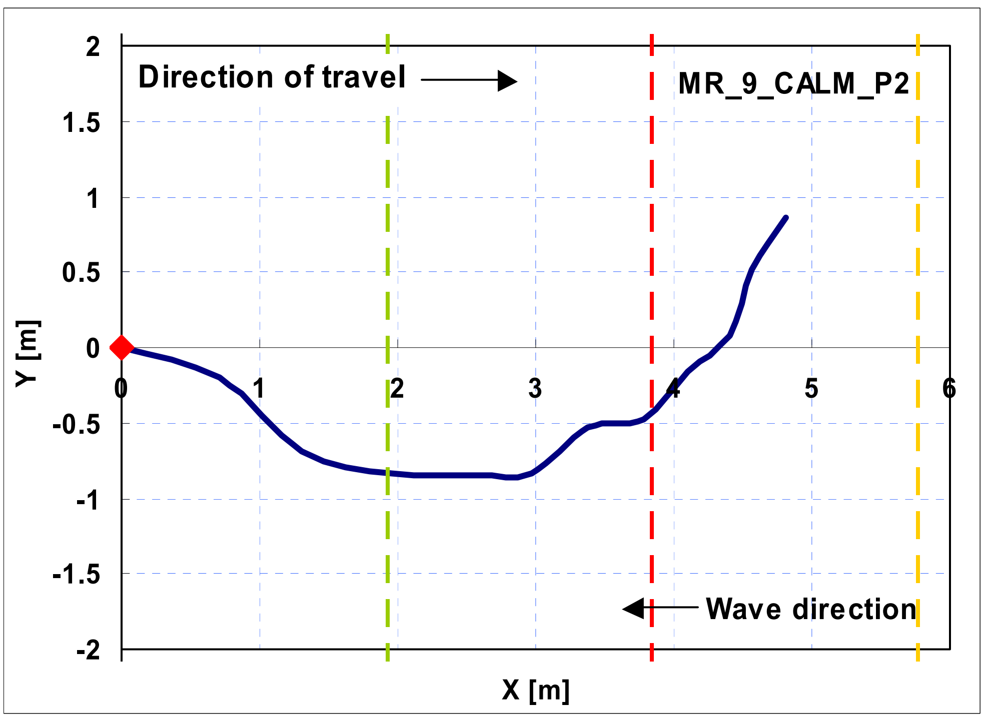
Direction of travel
MR_9_CALM_P2
Wave direction
Y [m]
X [m]
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1.5
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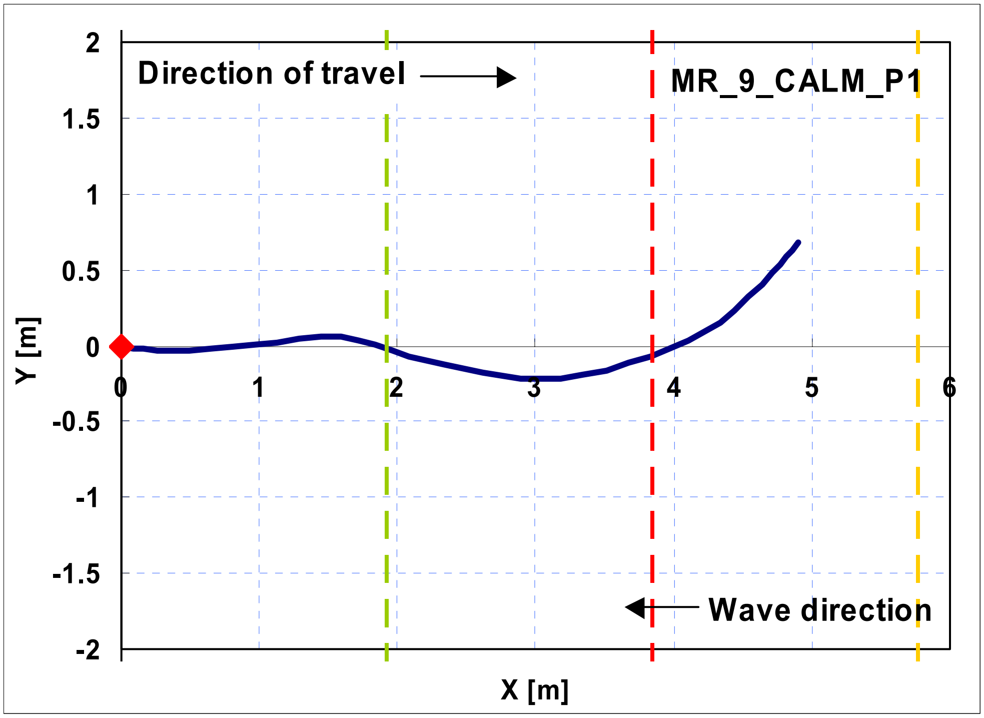
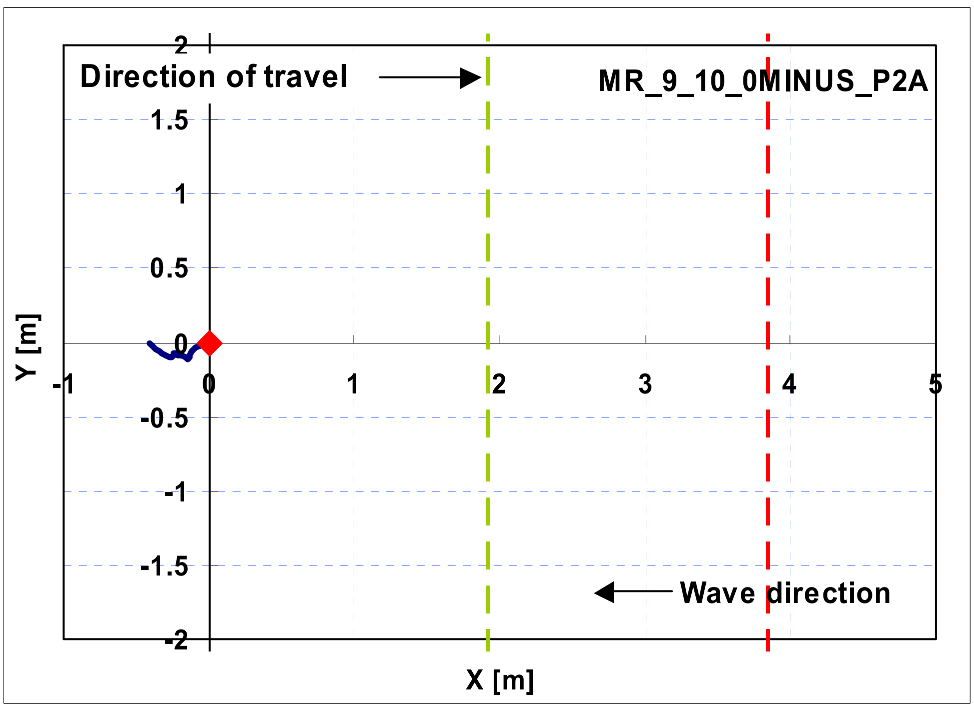
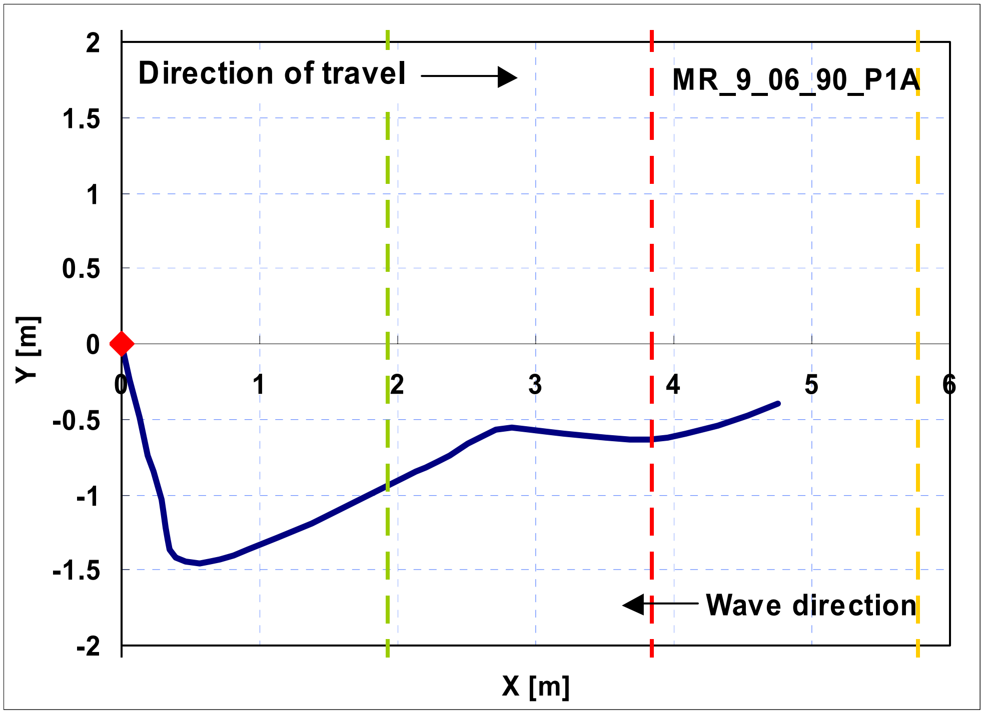
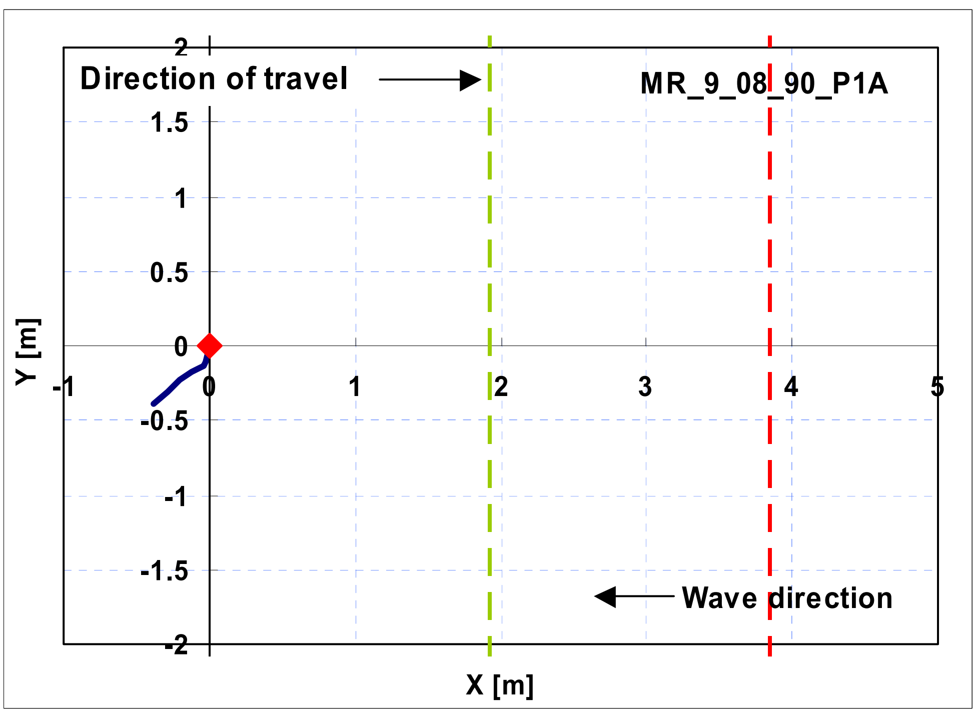
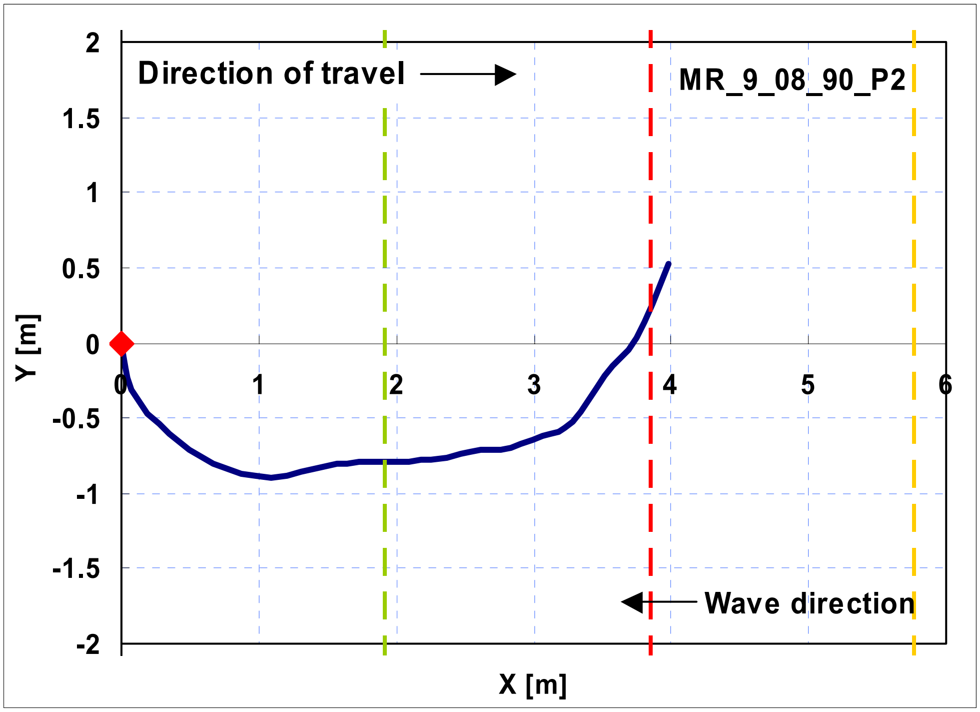
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6

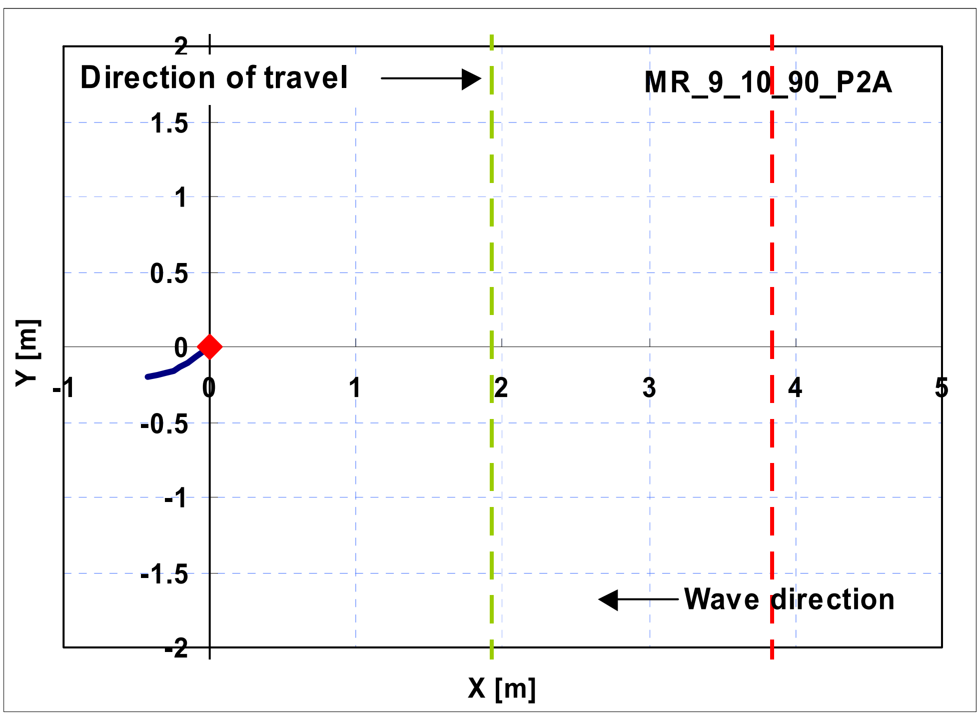

Direction of travel
MR_9_CALM_P1
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6

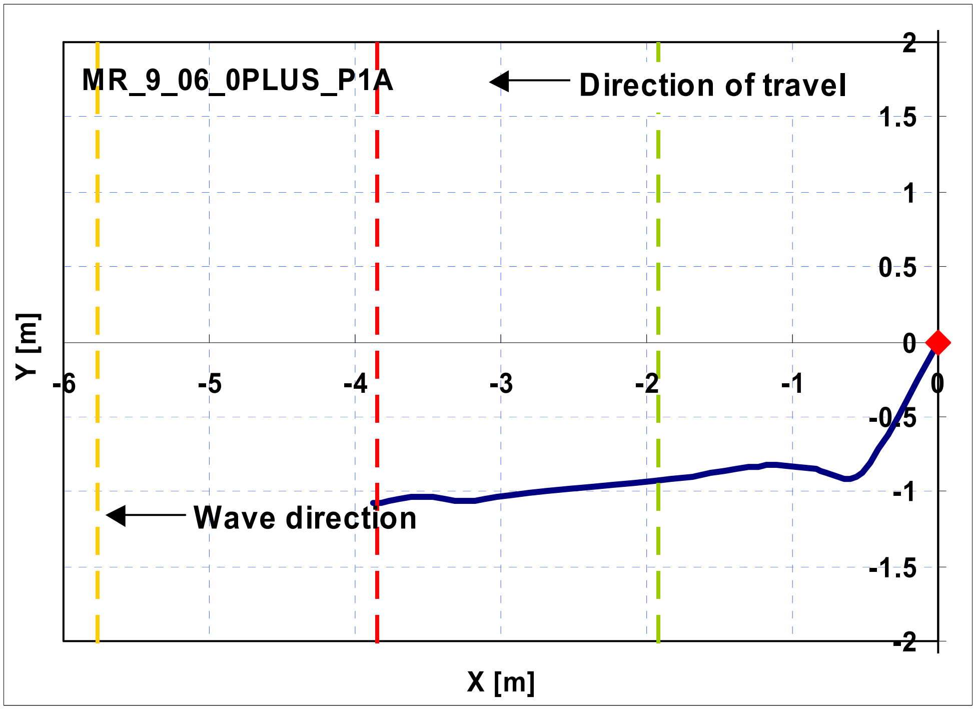

Direction of travel
MR_9_10_0MINUS_P2A
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
MR_9_06_90_P1A
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_9_08_90_P1A
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


Direction of travel
MR_9_08_90_P2
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6


Direction of travel
MR_9_10_90_P2A
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
0
1
2
3
4
5


MR_9_06_0PLUS_P1A
Direction of travel
Wave direction
Y [m]
X [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-6
-5
-4
-3
-2
-1
0

APPENDIX F VIDEO LOG

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IOT 544 LIFEBOAT

Test CO_0: CO_TEST1
Still water test. Began at power level P1, and moved up to P2 about one minute into test. Vessel not visible in parts of video.

Test 1: CO_5_06_0MINUS_P1
Carriage blocking view of boat launching. From observations, vessel passed 5.0 boat lengths.

Test 2: CO_5_06_0MINUS_P2
Vessel passed 5.0 boat lengths.

Test 3: CO_5_07_0MINUS_P1
Vessel passed 5.0 boat lengths.

Test 4: CO_5_07_0MINUS_P2
Vessel passed 5.0 boat lengths.

Test 5: CO_5_08_0MINUS_P1
Motor was not enabled at start of test. Vessel passed 5.0 boat lengths.

Test 6: CO_5_08_0MINUS_P2
Vessel passed 5.0 boat lengths.

Test CO_A: CO_TESTA
Still water test. Vessel had difficulty making way through ice and did not reach 2.5 boat lengths.

Test CO_B: CO_TESTB
Still water test. Vessel reached 5.0 boat lengths after being jammed in ice for part of the test.

Test 7: CO_5_10_0MINUS_P1
Fail; vessel could not make headway into waves.

Test 8: CO_5_10_0MINUS_P2
Vessel had difficulty getting through the waves and ice, but passed 5.0 boat lengths.

Test 21: CO_7_06_0MINUS_P1
Vessel passed 5.0 boat lengths.

Test 22: CO_7_08_0MINUS_P1
Vessel passed 5.0 boat lengths.

Test 23: CO_7_08_0MINUS_P2
Vessel did not quite make 5 boat lengths in overhead video analysis, due to limited field of view. Test considered a pass since vessel travelled through the waves and ice with relative ease.

Test 24: CO_7_10_0MINUS_P1
Fail; vessel could not make headway into waves.

Test 25: CO_7_10_0MINUS_P2
Vessel passed 5.0 boat lengths. For part of test, an attempt was made to drive using coxswain view only.

Test 26: CO_7_06_90_P1
Vessel passed 5.0 boat lengths.

Test 27: CO_7_06_90_P2
Vessel passed 5.0 boat lengths.

Test 28: CO_7_08_90_P1
Vessel had difficulty turning to face into waves, but passed 5.0 boat lengths.

Test 29: CO_7_08_90_P2
Vessel passed 5.0 boat lengths.

Test 30: CO_7_08_90_P2A
Vessel passed 5.0 boat lengths.

Test 31: CO_7_10_90_P2
Vessel passed 5.0 boat lengths. Battery may have been low for this test – vessel was not quite at full power P2.

Test 32: CO_7_10_90_P1
Vessel had difficulty getting through the waves and ice, but passed 5.0 boat lengths.

Test 57: CO_9_06_0MINUS_P1
Vessel made slow progress, but passed 5.0 boat lengths.

Test 58: CO_9_06_0MINUS_P2
Overhead video now available for analysis. From observations, vessel passed 5.0 boat lengths.

Test 59: CO_9_08_0MINUS_P1
Vessel made very slow progress and was pushed back by waves, but managed to reach 5.0 boat lengths.

Test 60: CO_9_08_0MINUS_P2
Vessel passed 5.0 boat lengths.

Test 61: CO_9_07_0MINUS_P1
Vessel passed 5.0 boat lengths. It was noted that the ice floe size had decreased since the start of testing that day.

Test 62: CO_9_07_0MINUS_P2
Vessel passed 5.0 boat lengths.

Test 63: CO_9_10_0MINUS_P1
Vessel made very slow progress, but passed 5.0 boat lengths.

Test 64: CO_9_10_0MINUS_P2

Fail; vessel could not make headway into waves.

Test 65: CO_9_06_0PLUS_P1
Vessel was helped along by the waves, and reached 5.0 boat lengths.

Test 66: CO_9_08_0PLUS_P1
Vessel was helped along by the waves, and reached 5.0 boat lengths.

Test CO_C: CO_9_CALM_P1
Still water test. Vessel reached 5.0 boat lengths.

Test CO_D: CO_9_CALM_P2
Still water test. Vessel reached 5.0 boat lengths.

Test 67: CO_9_08_90_P1
Vessel passed 5.0 boat lengths.

Test 68: CO_9_10_90_P2
Fail; vessel could not make headway and was pushed back by waves.

Test 69: CO_9_08_90_P1A
Vessel passed 5.0 boat lengths with some difficulty maintaining a straight path.

Test 70: CO_9_08_0MINUS_P1A
Vessel passed 5.0 boat lengths.

Test 71: CO_9_06_90_P1
Vessel made very slow progress but passed 5.0 boat lengths.

Test 72: CO_9_10_0PLUS_NP
Test performed with no power. Vessel was pushed or helped along by the waves and passed 5.0 boat lengths.

IOT 609 LIFEBOAT

Test 9: FF_5_06_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 10: FF_5_06_0MINUS_P2
Vessel reached 5.0 boat lengths*.

Test 11: FF_5_08_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 12: FF_5_08_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 13: FF_5_10_0MINUS_P1
Vessel had difficulty making way through waves and ice, but reached 5.0 boat lengths.

Test 14: FF_5_10_0MINUS_P2
Vessel reached 5.0 boat lengths*.

Test FF_A: FF_TESTA
Still water test. Vessel reached 5.0 boat lengths*.

Test FF_B: FF_TESTB
Still water test. Vessel reached 5.0 boat lengths*.

Test 33: FF_7_06_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 34: FF_7_08_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 35: FF_7_08_0MINUS_P2
Vessel reached 5.0 boat lengths*.

Test 36: FF_7_10_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 37: FF_7_10_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 38: FF_7_06_90_P1
Vessel reached 5.0 boat lengths.

Test 39: FF_7_06_90_P2
Vessel reached 5.0 boat lengths.

Test 40: FF_7_08_90_P1
Vessel reached 5.0 boat lengths.

Test 41: FF_7_08_90_P2
Vessel had difficulty getting through the waves and ice, but reached 5.0 boat lengths*.

Test 42: FF_7_10_90_P1
Vessel reached 5.0 boat lengths.

Test 43: FF_7_10_90_P2
Vessel reached 5.0 boat lengths*.

Test FF_C: FF_7_CALM_0MINUS_P1
Still water test. Vessel reached 5.0 boat lengths.

Test FF_D: FF_7_CALM_0MINUS_P2
Still water test. Vessel reached 5.0 boat lengths.

Test 73: FF_9_06_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 74: FF_9_06_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 75: FF_9_08_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 76: FF_9_08_0MINUS_P2
Vessel reached 5.0 boat lengths*.

Test 77: FF_9_07_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 78: FF_9_07_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 79: FF_9_10_0MINUS_P1
Vessel made slow progress and was pushed back by waves, but reached 5.0 boat lengths*.

Test 80: FF_9_10_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 81: FF_9_06_90_P1
Vessel reached 5.0 boat lengths.

Test 82: FF_9_08_90_P1
Vessel reached 5.0 boat lengths.

Test 83: FF_9_08_90_P2
Vessel reached 5.0 boat lengths.

Test 84: FF_9_10_90_P2
Fail; vessel could not make headway into waves.

Test FF_E: FF_9_CALM_P2
Still water test. Vessel became stuck in ice for part of test, but finally reached 5.0 boat lengths.

Test FF_F: FF_9_CALM_P1
Still water test. Vessel reached 5.0 boat lengths.

Test 85: FF_9_08_90_P1A
Repeat of Test 82. Vessel had difficulty turning to face waves and was pushed back, but managed to pass 5.0 boat lengths.

Test 86: FF_9_10_0MINUS_P1A
Vessel had difficulty getting through the waves, but reached 5.0 boat lengths.

Test 87: FF_9_06_0PLUS_P1
Vessel was helped along by the waves, and reached 5.0 boat lengths.

Test 88: FF_9_08_0PLUS_P1
Vessel was helped along by the waves, and reached 5.0 boat lengths*.

Test 89: FF_9_10_0PLUS_NP
Test performed with no power. Vessel was helped along by the waves, and reached 5.0 boat lengths*.

* entire vessel path is not shown in plots from overhead video analysis

IOT 681 LIFEBOAT

Test 15: MR_5_06_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 16: MR_5_06_0MINUS_P2
Vessel reached 5.0 boat lengths*.

Test 17: MR_5_08_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 18: MR_5_08_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 19: MR_5_10_0MINUS_P1
Vessel had difficulty making way through the waves, but reached 5.0 boat lengths.

Test 20: MR_5_10_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test MR_A: MR_TESTA**
Still water test. Vessel reached 5.0 boat lengths.

Test MR_B: MR_TESTB**
Still water test. Vessel reached 5.0 boat lengths*.

Test 44: MR_7_06_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 45: MR_7_08_0MINUS_P1
Vessel reached 5.0 boat lengths*.

Test 46: MR_7_08_0MINUS_P2
Vessel reached 5.0 boat lengths*.

Test 47: MR_7_10_0MINUS_P1
Vessel had difficulty making headway, and was pushed back by the waves. Eventually reached 5.0 boat lengths. It was noted that there may have been a mechanical problem with the model.

Test 48: MR_7_10_0MINUS_P1A
Vessel reached 5.0 boat lengths*.

Test 49: MR_7_10_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 50: MR_7_06_90_P1
Vessel reached 5.0 boat lengths*.

Test 51: MR_7_06_90_P2
Vessel reached 5.0 boat lengths.

Test 52: MR_7_08_90_P1
Vessel reached 5.0 boat lengths.

Test 53: MR_7_08_90_P2
Vessel reached 5.0 boat lengths.

Test 54: MR_7_10_90_P1
No overhead video available.

Test 55: MR_7_10_90_P1A
Vessel made slow progress and was pushed back by waves, but eventually passed 5.0 boat lengths.

Test 56: MR_7_10_90_P2
Vessel reached 5.0 boat lengths.

Test MR_C: MR_7_CALM_0MINUS_P1
Still water test. Vessel reached 5.0 boat lengths.

Test MR_D: MR_7_CALM_0MINUS_P2
Still water test. Vessel reached 5.0 boat lengths.

Test 90: MR_9_06_0PLUS_P1
No overhead video available.

Test 91: MR_9_08_0PLUS_P1
Vessel was helped along by the waves, and reached 5.0 boat lengths*.

Test 92: MR_9_10_0PLUS_NP
Test performed without power to the vessel. Vessel was helped along by the waves, and reached 5.0 boat lengths.

Test 93: MR_9_06_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 94: MR_9_06_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 95: MR_9_08_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 96: MR_9_08_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 97: MR_9_07_0MINUS_P1
Vessel reached 5.0 boat lengths.

Test 98: MR_9_07_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 99: MR_9_10_0MINUS_P1
Vessel had difficulty making headway through waves, but eventually reached 5.0 boat lengths*.

Test 100: MR_9_10_0MINUS_P2
Vessel reached 5.0 boat lengths.

Test 101: MR_9_06_90_P1
Vessel reached 5.0 boat lengths.

Test 102: MR_9_08_90_P1
Vessel reached 5.0 boat lengths.

Test 103: MR_9_10_90_P2
Fail; vessel could not turn to make headway into waves. It was noted that a problem with the rudder might have prevented the vessel from performing properly.

Test MR_E: MR_9_CALM_P2
Still water test. Vessel reached 5.0 boat lengths.

Test MR_F: MR_9_CALM_P1
Still water test. Vessel reached 5.0 boat lengths.

Test 104: MR_9_10_0MINUS_P2A
Fail; vessel could not make headway.

Test 105: MR_9_06_90_P1A
Vessel reached 5.0 boat lengths.

Test 106: MR_9_08_90_P1A
Fail; vessel could not make headway.

Test 107: MR_9_10_90_P2
Vessel reached 5.0 boat lengths.

Test 108: MR_9_10_90_P2A
Can't determine if test is a pass or fail – noticed that the rudder is again having problems.

Test 109: MR_9_06_0PLUS_P1A
Vessel reached 5.0 boat lengths.

* entire vessel path is not shown in plots from overhead video analysis

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APPENDIX G PRESSURE SENSOR WAVE ANALYSIS PLOTS

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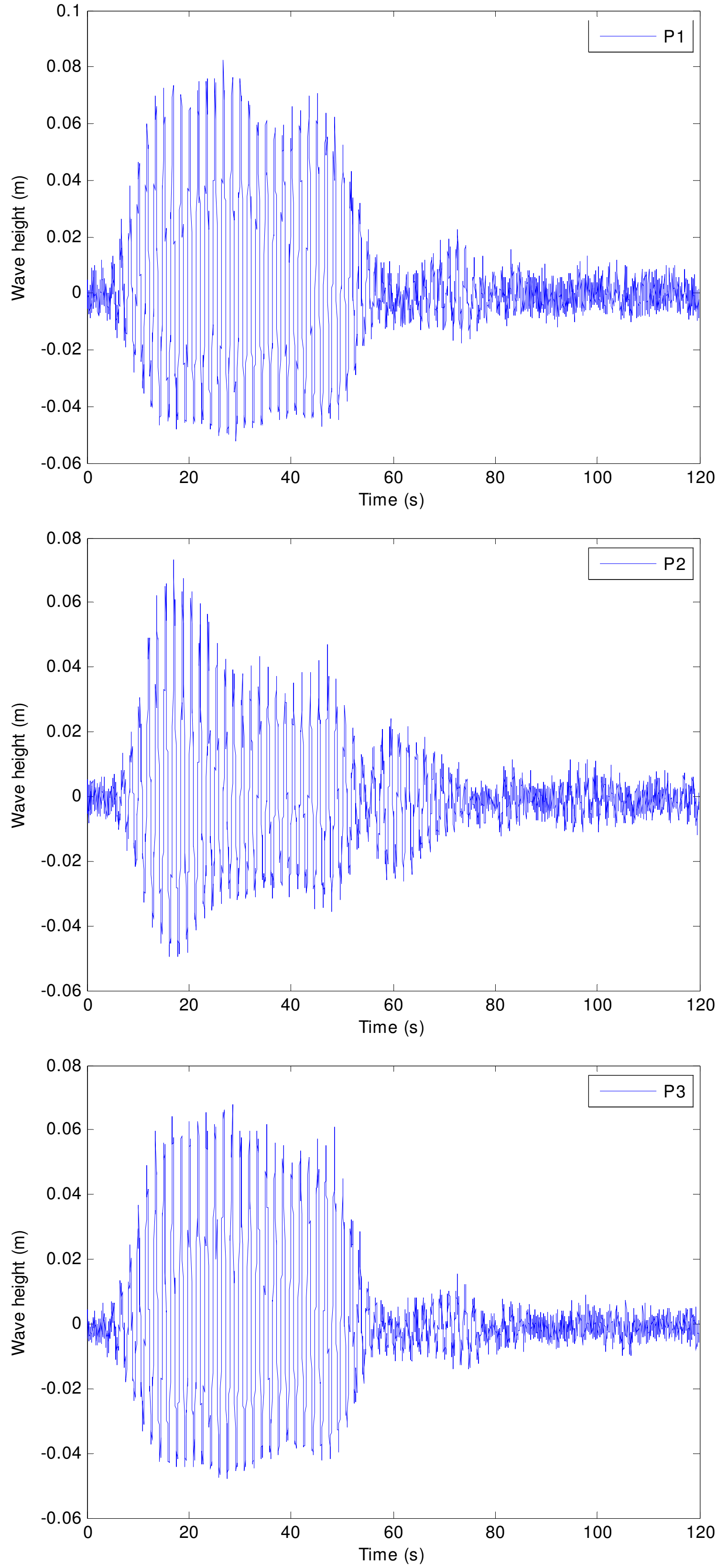
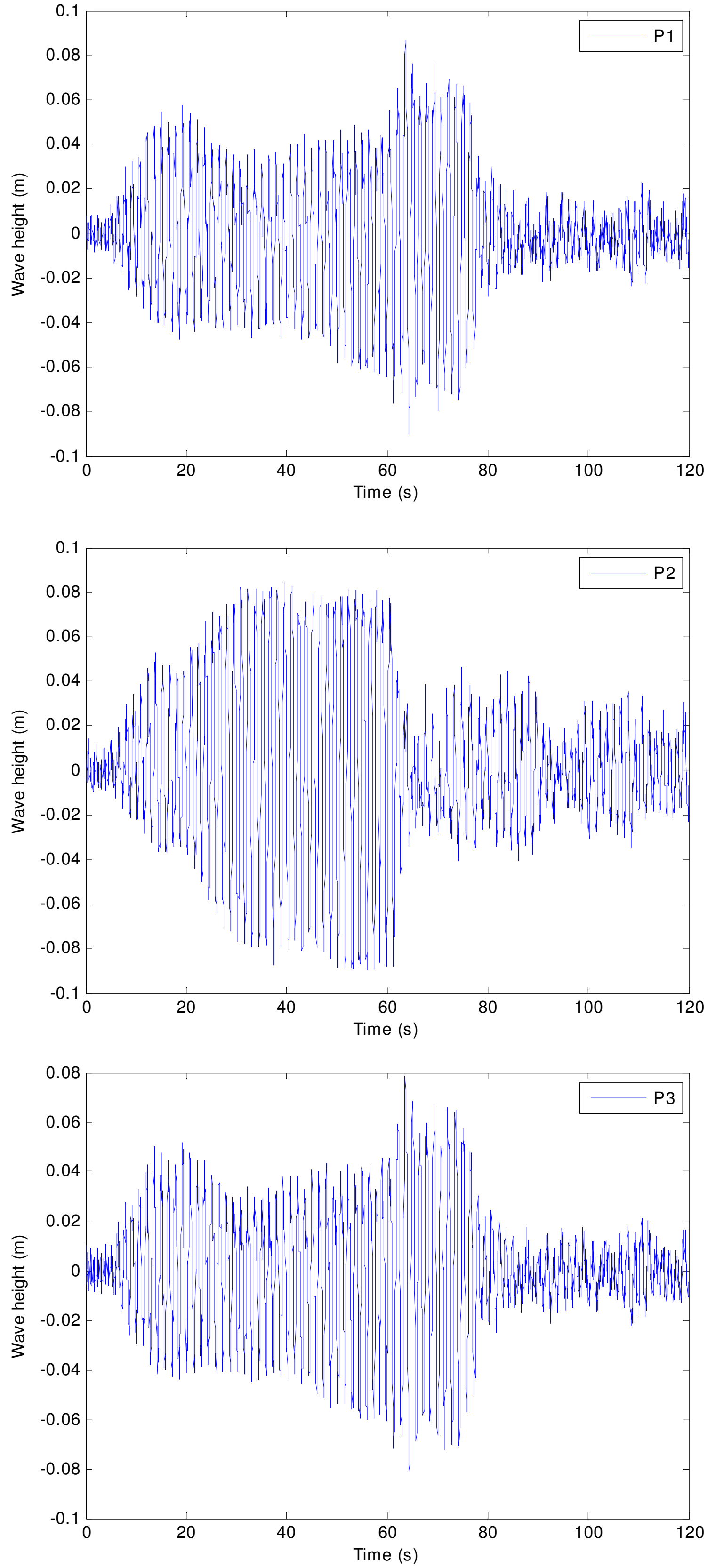
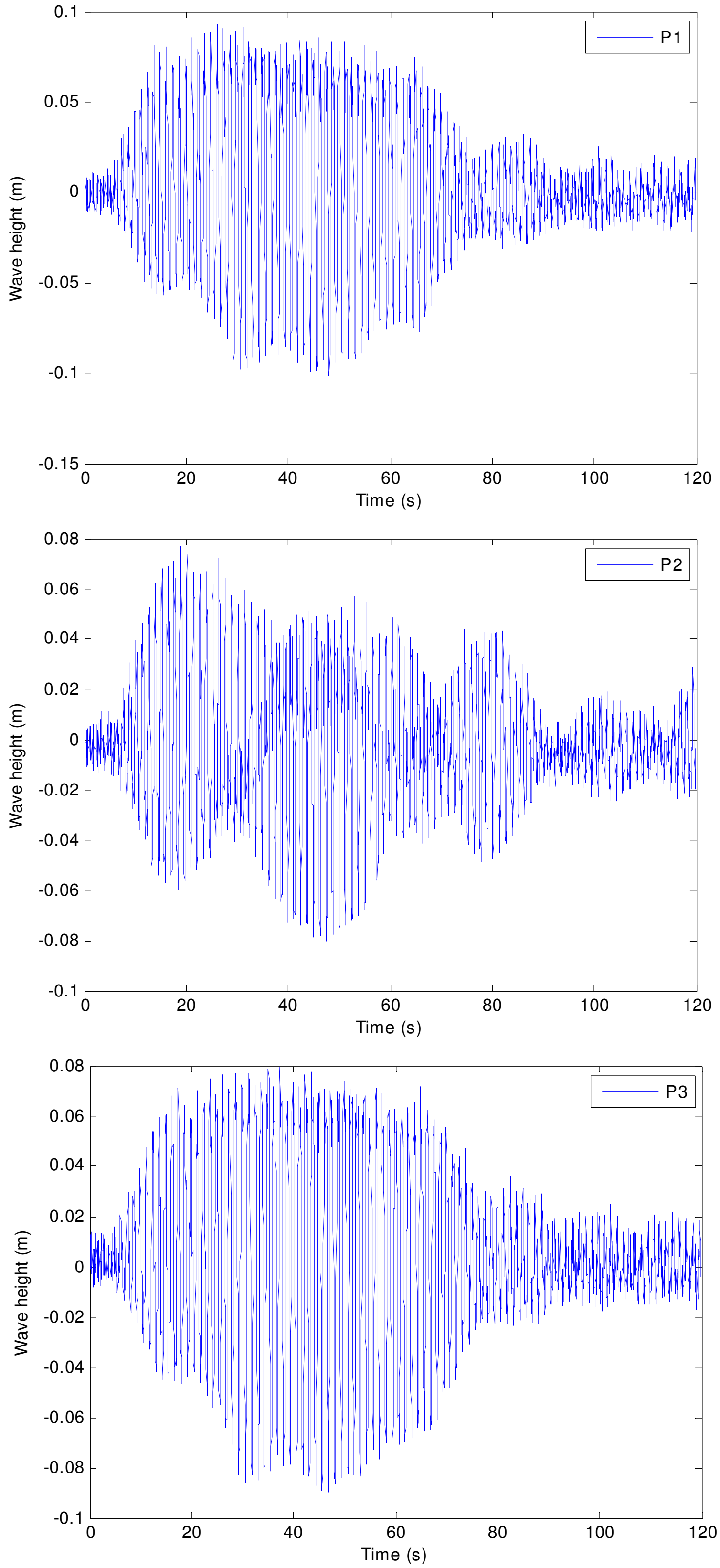


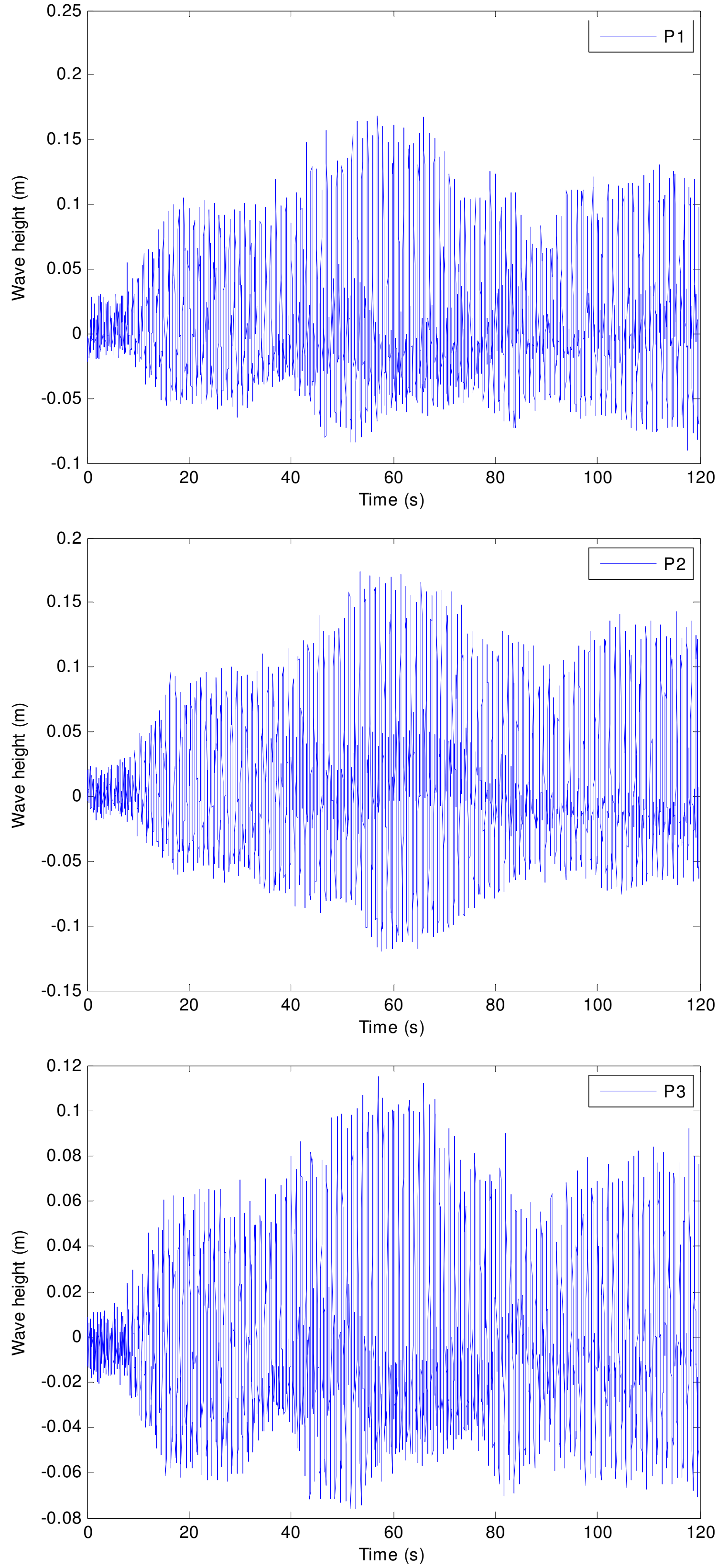
Test no. 90 (MR_9_06_0PLUS_P1): Wave frequency = 0.6 Hz, ice concentration = 9/10^{ths}



Test no. 4 (CO_5_07_0MINUS_P2): Wave frequency = 0.7 Hz, ice concentration = 5/10ths



Test no. 12 (FF_5_08_OMINUS_P2): Wave frequency = 0.8 Hz, ice concentration = 5/10ths



Test no. 55 (MR_7_10_90_P1A): Wave frequency = 1.0 Hz, ice concentration = 7/10ths

APPENDIX H SELECTED PHOTOGRAPHS OF TESTING

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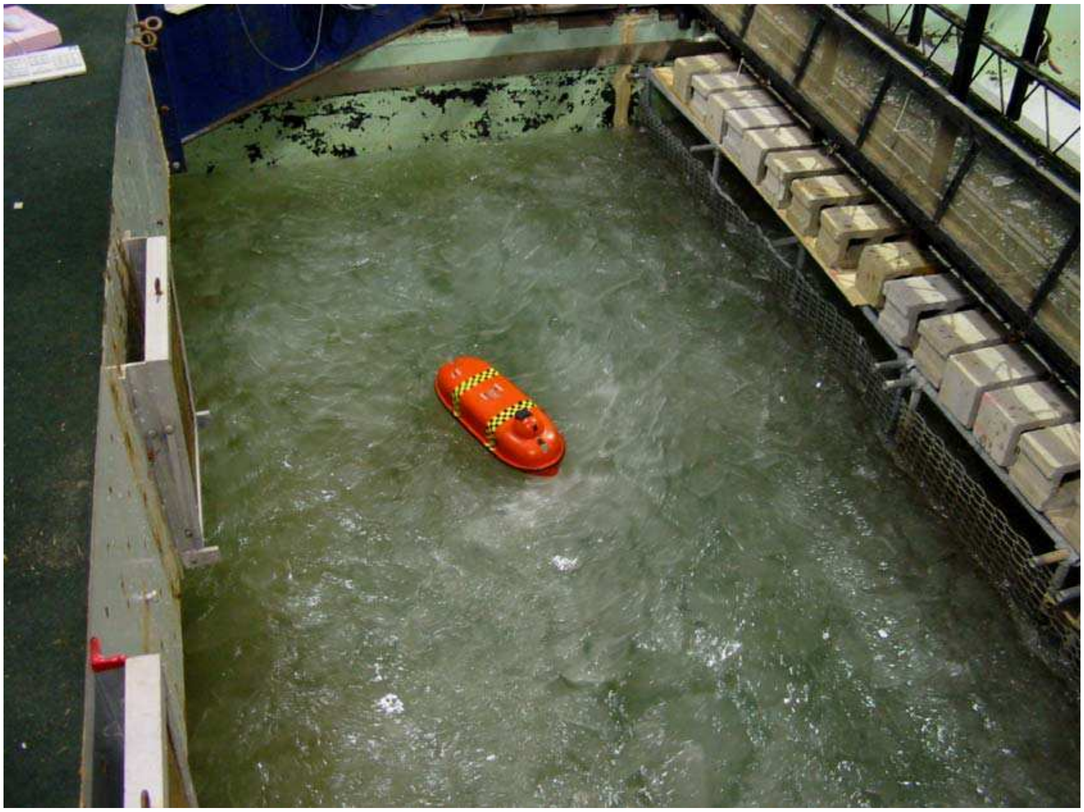
Ice tank with wave machines



IOT 544 boat jammed in ice at end of failed test

Recovering IOT 681TEMPSC model at end of test

Photograph during a test, showing the rafting and dense concentration of ice at the end of the tank

Piece size distribution after several hours of testing – note slushy ice


90° launch deployment position