# Experimental Investigation of Hydrodynamic Characteristics of a Moored Floating WEC

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## Abstract

**This paper presents an experimental investigation on a backward bent duct buoy, a floating oscillating water column (OWC) in the wave basin. This wave energy converter is a 1:20 scaled model to the sea trial OE Buoy in Galway Bay. The physical modelling aims to model the device in a complete mooring setup. As a part of the FP7 CORES project (Grant No. 213633), the wave tank test services following main purposes:**

- **Understand the hydrodynamics of the floating device in waves.**
- **Collect test data in well-controlled condition for calibration and validation of numerical simulation.**
- **Explore the survivability of the device under extreme conditions.**

**To achieve purposes, the experimental research includes: (1) free decay/stiffness tests for the natural frequency and damping coefficients of the system; (2) free floating model tests for comparison of motions to hydrodynamic analysis; (3) conventional regular and irregular wave tests in which the test time series, first-order response amplitude operators (RAOs) and second-order responses are all given; and (4) the tests in extreme conditions for testing the survivability of the device, mooring system and umbilical cable.**

**Keywords:** wave energy converter, oscillating water column, floating structure, hydrodynamics, survivability.

## 1 Introduction

Oscillating Water Column (OWC) is one of successful wave energy converters (WECs). A good example is the successful application of bottom-fixed OWCs [1-2]. Presently, due to the availability of wave energy and for the purpose of massive wave energy production, the OWC application has been extended from onshore/nearshore regions to deeper water regions and open seas, and much effort of recent OWC research has been paid for floating types of OWCs [3-6].

Technology and practical applications of OWC have been advanced greatly since their invention. In particular, practical success of bottom-fixed OWC encourages an evolved OWC: floating-type OWC. This wave energy converter is supposed to be applicable in deep water regions and open seas, but keep the simplicity and reliability of oscillating water column wave energy converter. Apparently, the floating OWCs, like the bottom-fixed OWCs, have an advantage that there is no relative moving component in water. However, this evolution has brought some new challenges for the new system development. As a basic requirement, a floating OWC needs to be moored in a limited area in operational conditions, and must survive in extreme wave, wind and current conditions. All of these factors impose challenging criteria on the design of an economic, environmentally-friendly and easy-operable mooring system.

Nonetheless, the cost of mooring system must be included for the overall project cost in the WEC development, and the system design must consider the interference of the device and the ambient environment; the interaction of the mooring line and umbilical cable, and the arrangement of an array of such devices etc. All these problems must be addressed before any successful commercial WEC deployment. Presently, the design of such a system mostly copies the method and experience from Oil and Gas industry, because the Oil&Gas platforms have some similarities to WEC installations. There is also a lack of suitable and reliable design tools and lack of understanding of the floating wave energy device performance and operation. Therefore, a reliable design approach for floating OWCs is desirable for reducing the cost of the device whilst the device must satisfy all the requirements of a floating WEC. As a result, a good understanding of the performance of such a moored floating device in waves and a relevant validation and establishment of numerical codes/methods are a necessity.

OE Buoy is one of floating OWCs, which has been studied for some time. Small models (1:50 and 1:10) have been tested in different wave tanks, and a 1:2.5 scale model has been sea-tried in Galway Bay (it is often called a “quarter model”). Even so, the understanding of the whole system remains limited, especially the performance of the mooring system and its coupling effects with device and umbilical cable (note: umbilical cable has not been installed for the quarter model so far).

Wave tank tests of a scaled Galway Bay OE Buoy configuration, including the floating device, the mooring lines and an umbilical cable, aim to provide reliable data from well-controlled laboratory conditions for the calibration and validation of the numerical simulations. Moreover, this type of test may be helpful to understand the data collected in Galway Bay sea trials as well as to explore the scalability of floating OWCs.

## 2 Experimental Preparation

The experimental preparation includes the scaling consideration, model modification and refurbishment, the mooring system and the instrumentation.

### 2.1 Scaling factors

In the preparation of the model, the scaling is based on the Froude Similitude Law. They have following scaling factors for the physical modeling (also see [7]).

| | |
|---|---|
| Length/translational motion | $\varepsilon$ |
| Velocity | $\varepsilon^{1/2}$ |
| Time | $\varepsilon^{1/2}$ |
| Acceleration | 1 |
| Angle/angular motion | 1 |
| Frequency | $\varepsilon^{-1/2}$ |
| Force | $\varepsilon^{3}$ |
| Mass | $\varepsilon^{3}$ |
| Buoyancy | $\varepsilon^{3}$ |
| Mass/weight per unit length | $\varepsilon^{2}$ |
| Elasticity/axial stiffness | $\varepsilon^{3}$ |
| Bending stiffness | $\varepsilon^{5}$ |
| Energy/work | $\varepsilon^{4}$ |
| Power | $\varepsilon^{3.5}$ |

### 2.2 Model

The test model is an existing backward bent duct buoy (BBDB), with a dimension of 600mm long and 300mm wide. It is a scaled model to the Galway Bay OE Buoy (1:20), though the overall height of 350mm (from the device bottom to the top of the column) is not the scaled height by 1:20 as the air chamber is little higher than the scaled one. However, the immersed part of the device is still fully scaled, hence the hydrodynamics of the device in waves can be considered to satisfy the Froude Similitude Law. In this regard, we can say that the model has a scale ratio of 1:20 to the Galway Bay OE Buoy trial device (i.e., a scale ratio of 1:50 to the proposed full scale device of OE Buoy). The refurbished model is moored in the tank (see Figure 1).

The main body of the device, including the backward bent (horizontal) oscillating water column and the vertical column, is manufactured of Aluminium plate of 1.5mm thick. The column has a sectional dimension of 300mm wide and 100mm high. The buoyancy of the device is mainly provided by the two floats fixed on the device: the float on the top of the horizontal column and the float at the front of the device. To simulate the external water chamber, a piece of Perspex has been made and fixed (Perspex has a density of 1.19 g/cm$^3$, close to the density of water).

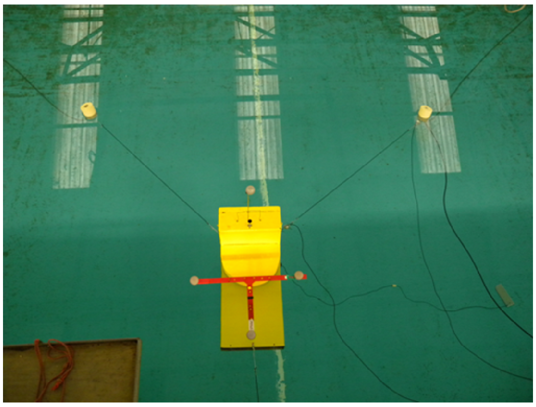


**Figure 1** OE buoy model in tank

To form a ship-model from the device, a rectangular Perspex plate of 300mm×100mm (thickness is about 6mm), weighed 0.2kg, has been made and amounted at the entrance of the horizontal column. In such a condition, the water is trapped in the column (no water comes in/out of the column). In motions, there is no oscillating water of piston mode in the column for the ship-model, but sloshing surface.

The model weighs 3.6kg itself (compared to the scaled Galway Bay OE buoy of 3.75kg). If the block plate is amounted to make ship-model, an extra weight of 0.2kg should be added for balancing the floating. Together with the block plate, the ship-model weighs 4.0kg (no water is included).

### 2.3 Mooring system

A similar mooring configuration is used for the tank test model (Figure 2), as was previous applied for the Galway Bay OE Buoy installation. A three-leg mooring line configuration was used (figure 2), two towards the mean wave direction and one in the lee. Each mooring leg assembly consists of, starting from the anchor point, i) a catenary chain from the anchor to a surface buoy and ii) a horizontal fibre rope from the surface buoy to the WEC device. Such a mooring arrangement allows to make use of both, i) good restoring features of the catenary chain, ii) elongation enhancement flexibility in the axial direction using a nylon rope and, iii) restoring features of the surface buoy as it submerges under loading. Tension measurements on the OE buoy installation confirmed that this configuration results in relative small mooring forces.

This 3D model test aimed to enhance the applied numerical model by using the tank test outcomes to identify suitable damping and stiffness characteristics, and to allow the calibration of the simulation by implementing enhanced input data. This was necessary since it was found that the modeling of a full scale system using input data based on existing methodologies, providing simulation outputs with limited applicable response and mooring load results for WEC applications.

For relevant numerical analysis conducted during the FP7 CORES project (Refs.[8-11]), two different heading angles were used: 0º and 45° (Figure 2). These two directions also studied during the 3D tank tests to allow a wide range of setups to be compared.

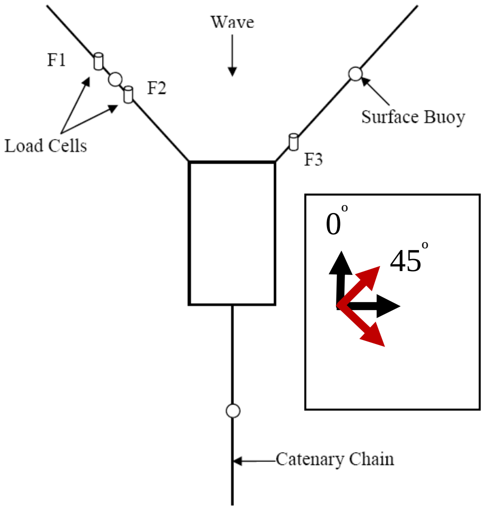



**Figure 2** Mooring system and positioning

### Chains

In laboratory condition, the most important parameter for chain modeling may be the weight per unit length in water, for it largely decides the catenary shape. The axial stiffness and the diameter are considered as second important factors here. It must be noted that the diameter of the chain may be important, if the hydrodynamic forces on the chain become important. This could be the case in the coexistence of a strong current, or if the line dynamic becomes significant.

The mooring chain used in the tank test is the one mostly used at HMRC tank test: wrapped lead-rope (diameter is about 6mm by measuring). It has a weight of 119 g/m in air, and 91.3 g/m in water. It is very close to the scaled weight per unit length as that used in Galway bay OE buoy in sea water (95.5 g/m by a scale ratio of 1:20).

### Surface Buoys

Surface buoy is a buoy at which the mooring chain and the rope join together, so that it is possible to keep the catenary chain in a good shape and a horizontal rope to the floating device. The scaled buoy has a diameter of 80mm and a height of 90 mm (1:20).

### Ropes

In Galway Bay OE Buoy mooring system, the rope from the surface buoy to the device is a 44mm nylon rope. The axial stiffness is scaled down to the model for wave tank testing by a ratio of 1:25 (shown in Figure 3).

In reality, the nylon rope with the scaled diameter (or even thinner nylon rope) has much too high axial stiffness. For model test, the length of the rope is scaled down to1.2m. In the tank test, a length of 1.0m O-ring cord (2mm diameter) is used to model the axial stiffness with an extra 0.2m space for load cell connection. The combined rope has an overall axial stiffness close to the scaled-down axial stiffness, up to 15% extension (see Figure 3).

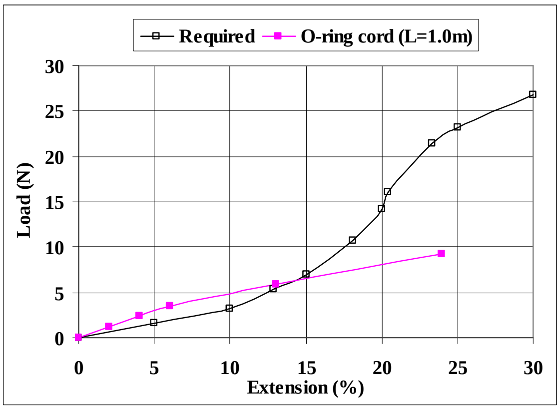



**Figure 3** Scaled axial stiffness curve and that of O-ring cord ($\varphi$ = 2mm)

## 2.4 Umbilical cable

Umbilical cable modeling is a very important part in the experimental research, though the umbilical cable is supposed not to produce significant influence to the motions of the device. The experimental investigation focused at the behaviour of the umbilical cable under the motions of the device as well as in waves. This is of importance to identify the survivability of the umbilical over its design lifetime.

A catenary and lazy-wave configurations were chosen for the umbilical cable, based on umbilical configuration designs by MCS Kenny in CORES deliverable 3.3 [8]. To achieve the hog-bend of the lazy wave configuration in the laboratory, a buoyant section was implemented in the hog bend region using small foam floats. Six floats of diameter 8mm and length 10mm were used and evenly attached over a 0.6m-long buoyant section (Figure 4).

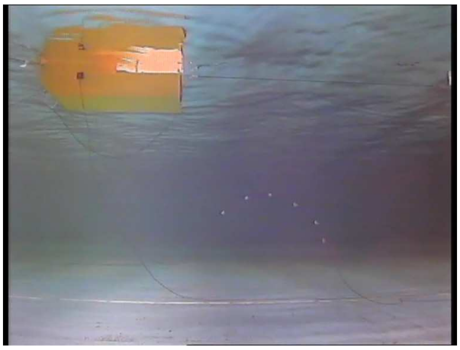


**Figure 4** Floats on umbilical cable

# 3 Facility and Instrumentation

## 3.1 Ocean Wave Tank

The wave tank test has been conducted at Hydraulics and Maritime Research Centre (HMRC), University College Cork, Ireland. The wave tank has a dimension of 25m long, 18m wide and 1m deep. There are 40 wave makers (the yellow panels in Figure 5) installed at one end of the tank. A computer control system is used to control and drive the wave makers to make different waves in the tank. Specifically, the wave makers can make regular waves with wave periods of 0.6-3s, and a maximum wave height of about 100mm; and irregular waves with peak spectral periods from 0.8s to 2.5s with a significant wave height up to 180mm. The computer controlled wave makers can also generate short-crested waves (3-D waves), waves in different heading angles, extreme waves (focused waves) etc.

**Figure 5** HMRC Ocean Wave Tank

## 3.2 Waves

For the wave tank test regular, extreme and irregular waves were used.

**Regular waves:**

The following regular waves were used:

Periods: 0.7s -2.66s (14 periods)
Targeted wave height: 60mm.

**Extreme waves:**

A extreme wave was used. The computer controlled wave panels generate waves continuously in same frequency, but in different phases for each panel. As a result, all waves generated by different panels could focus in one point in the tank. This particular point is called the "extreme wave", and at this point the model is usually placed. In such a way, the model may experience much higher waves than those conventional regular waves.

The experiments were aimed to test the survivability of the device, mooring and umbilical during the extreme events. In this test, three waves with different frequencies have been used: 204mm@1.0Hz, 286mm@0.75Hz and 275mm@0.5Hz.

**Irregular waves:**

Irregular waves have been chosen based on the Galway Bay wave records during the year of 2009. For testing purpose, the most occurring waves and the largest waves in the year have been used. For the tank test, 6 different spectra, namely B2, B4, B5, B6, B7 and B8 in the tank have been used. Table 1 lists the corresponding spectra of the waves.

**Table 1** Irregular waves used in the test

| Wave Name | Target | |
|---|---|---|
| | $H_s$ (mm) | $T_p$ (s) |
| B2 | 60 | 1.0 |
| B4 | 60 | 1.2 |
| B5 | 100 | 1.2 |
| B6 | 60 | 1.5 |
| B7 | 100 | 1.5 |
| B8 | 150 | 1.5 |

where $T_p$ is the spectrum peak period ($T_p = 2\pi/\omega_p$), and $\omega_p$ angular frequency at spectrum peak.

As a convention, the Bretschneider spectrum was defined by the spectral peak frequency $\omega_p$ in a form

$$S(\omega) = 5\frac{m_0}{\omega_p}\left(\frac{\omega_p}{\omega}\right)^5 \exp\left[-1.25\left(\frac{\omega_p}{\omega}\right)^4\right] \qquad (1)$$

where $m_0$ zero-order moment of spectrum and $m_0 = H_s^2/16$ ($H_s$ is the significant wave height).

The peak period or frequency may not be a well-defined parameter if the experimental/measured spectrum is used, or when the spectrum has double- or multi-peaks. In some cases, the averaged period $T_0$ may be more suitable. For Bretschneider spectrum, the peak period $T_p$ and the average period $T_0$ have a relation as

$$T_p = 1.296T_0 \qquad (2)$$

where $T_0$ is the averaged period.

## 3.3 Qualysis (3-D camera system)

Qualisys is an instrument which measures the position/movement of the floating WEC using reference markers. For measuring the motions of the device, three or more markers are needed to be fixed on the rigid body (markers shown in Figure 1). Three markers are amounted on a T-Frame which is fixed on the floating rigid-body (note that a fourth marker is used to measure the internal surface motion in the column).

To convert the 3-D data into the 6-DOF motions of a rigid-body, Qualisys itself needs at least four markers fixed on the rigid body, and these four markers must not be installed in one plane. However, in the tank test, it is found that four rigid-body markers easily cause marker merging problem (the more the markers the more marker merging problems). Practically, three markers may produce much better results due to fewer marker merging problems, but a code has to be developed for converting the 3-D data into 6-DOF motions.

# 4 Tank Tests and Data processing

## 4.1 Free decay tests

Free decay tests, performed for the device and the ship-model have been conducted. In test, the device or ship-model was initially displaced in the relevant motion mode e.g. heave, roll and pitch, and oscillated in a decay way. From the free decay tests, the natural periods of the system and the damping coefficients due to the hydrodynamic forces could be obtained.

## 4.2 Stiffness/decay tests

Since the mooring stiffness contributes importantly to the natural frequency of the moored system and the tension characteristics, stiffness tests are required. The tests were performed in still water by recording the displacement and the line tensions at the same time.

## 4.3 Free floating RAOs

Free floating test was performed to obtain response amplitude operators (RAOs) of the device and ship-model in free floating conditions. The RAOs were obtained by using sinusoidal waves and measuring the corresponding oscillating responses of the device/ship-model. By dividing the response by the respective wave height over the range of wave frequencies, a representative RAO for the device/ship-model can be found.

## 4.4 Moored conditions

Moored conditions have been carried out for both ship-model and device in conventional regular and irregular waves. The test has been conducted to understand the hydrodynamic performance of the ship-model and device in waves, and for providing reliable test data for the validation of the numerical simulation of the device in moored conditions. The ship-model, which has been blocked the water passage at the horizontal column, is supposed to isolate the water piston effect in the column (sloshing may still happen in the column).

The device was tested for three different mooring chain lengths $L_S$ = 3.8m, 4.0m and 4.2m, corresponding to Galway Bay large scale device chain lengths of 95m, 100m, and 105m respectively. By applying the definition in Ref.[9]:

$$percentage\ pretension = \frac{excursion(m)}{water\ depth(m)} \times 100\% \qquad (3)$$

a representative percentage pretension can be found between the tank tests and the Galway Bay OE buoy installation. The percentage pretension values used are given in Table 2.

**Table 2** Chain lengths and pretensions

| Mooring chain length (Ls) | | Excursion [% of Depth] |
|---|---|---|
| Galway Bay (m) | Tank (m) | |
| 95 | 3.8 | 14 |
| 100 | 4.0 | 34.4 |
| 105 | 4.2 | 60.4 |

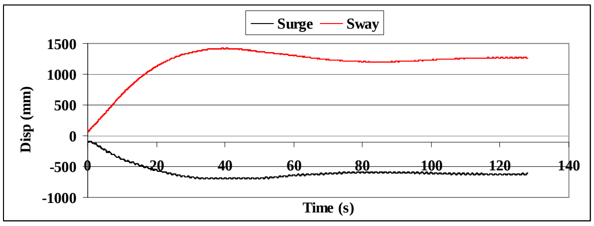
## 4.5 Umbilical test

Umbilical tests were specially applied for testing the umbilical performance for different layouts of umbilical under conventional wave conditions. The layouts below have been conducted:

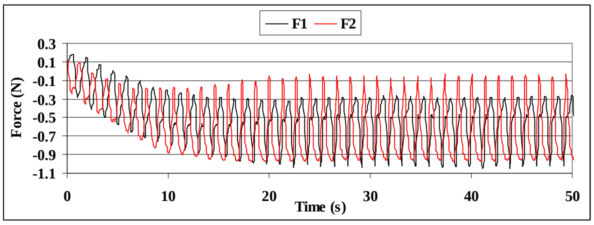
1) Lazy-wave shape of umbilical laterally to the device;
2) Catenary shape of umbilical laterally to the device;
3) Lazy-wave shape of umbilical in line with the device;
4) Catenary shape of umbilical in line with the device.

## 4.6 ALS test

Accidental Limit State (ALS) tests have been conducted for 14 regular waves and 4 irregular waves (B2, B4, B5 and B6 in Table 1). In the ALS test, the model was positioned in a complete moored state before data recording. When one of the front mooring line was taken off, the data acquisition systems started to record data. The data record lasted two minutes for regular wave test (normally the recording time for regular wave test is one minute), and four minutes for irregular wave test (same as that in conventional irregular wave test), so that the transient motions (drifting) and the steady motions (oscillation) can be both recorded.




(a) Device surging and swaying in a regular wave



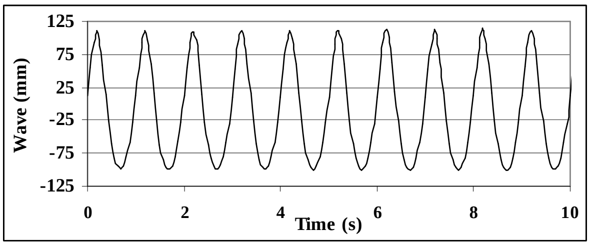

(b)Forces on chain and on rope under ALS

**Figure 6** Time series of ALS test

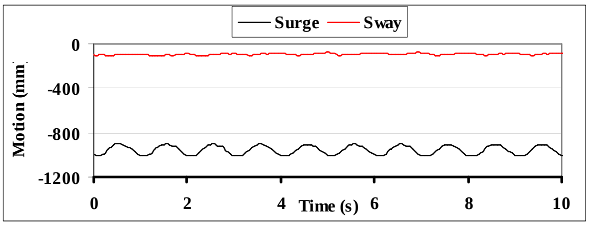
Unlike the conventional wave tests, ALS test has been conducted for the transient drifting from the original moored position and the oscillation around a new equilibrium position. For the data analysis, the data must be separated into two different parts: transient and steady parts. For the transient part, the main purpose is to examine the drift distance in surge and sway (the first 20-30 seconds in Figure 6). The second part is for the steady response (oscillation) in a new position. Under the accidental limit state, the forces on the chain and rope may be very interesting.

### 4.7 Extreme tests

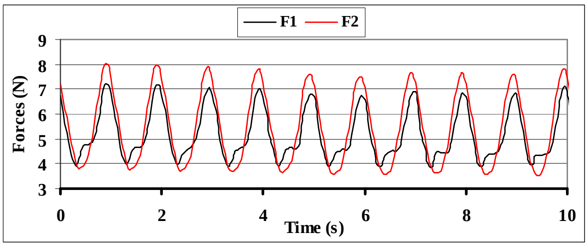
The main purpose of the extreme wave test was to test the survivability of the device in such an condition. The loads to the device and the device drift were the main concerns for the test. The loads are more related to the safety of the mooring system, while the device drift is more important to the umbilical survivability. Figures 7a-c show the time series of the wave, surge and sway and the forces on chain and on rope. It can be seen that the "huge" wave is no longer linear, and has shape crests and flat troughs.




(a) Extreme wave at 1.0Hz




(b)Device surging and swaying in a extreme wave




(c)Forces on chain and on rope

**Figure 7** Time series in Extreme test

## 5 Results and Analysis

### 5.1 Free Decay Test

A typical free decay record is shown in following figure. However, for a small model like this model, the free decay experiments in heave and pitch are not easy, due to the possible interaction between different motion modes, and the irregular shape of the device at the waterline, and the possible influence of free surface in the column (see figure 9). Nonetheless, the natural periods for heaving, rolling and pitching are listed in Table 3.

It is interesting to notice that the natural periods of heaving and rolling have not changed too much, probably due to the fact that in these two motions there is less water coming in/out of the column, thus the blockage at the water entrance has a significant effect on their natural periods. From Figure 9, it can be seen that the short period motion is superimposed in a long period motion. It is very likely that the short period is actually the water-piston period. But, when the device is pitching, the water could easily come in and out of the column, thus the water in column has very little influence on the pitching natural periods for the device, in which the pitching natural period is the pitch period itself.

**Table 3** Natural periods of free-floating

| Mode | Natural period (s) | |
|---|---|---|
| | Ship-model | Device |
| Heave | 1.15 | 1.10 |
| Roll | 2.25 | 2.0 |
| Pitch | 1.05 | 5.0 |

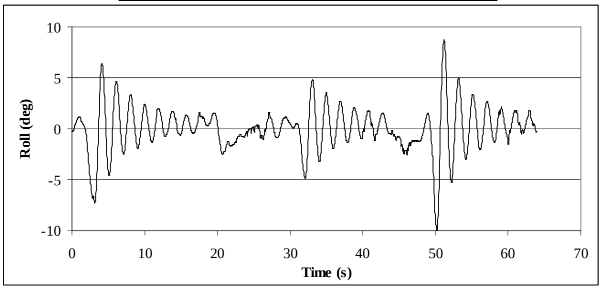



**Figure 8** Device free-decay test in roll

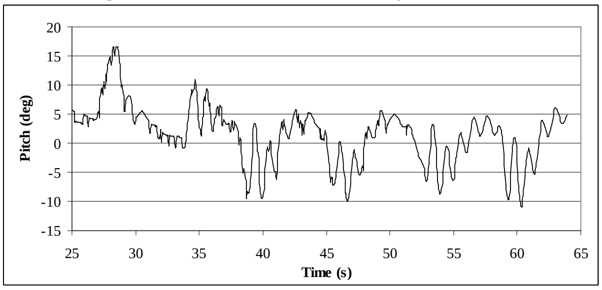
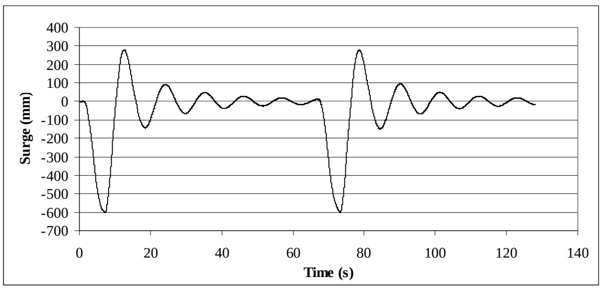


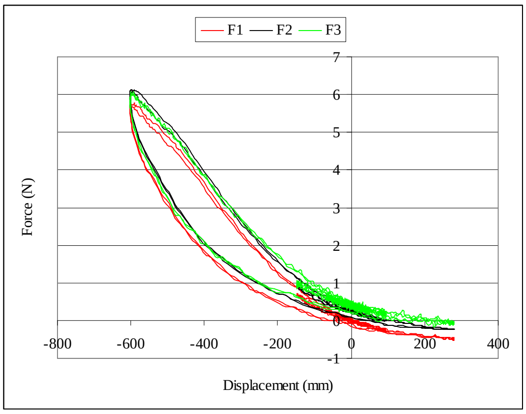

**Figure 9** Ship-model free-decay test in pitching

### 5.2 Moored Decay Test

Similar to the pitch & roll free decay tests natural periods and damping characteristics could be identified for all motions in surge, sway, heave and pitch, roll, yaw. For illustration, the time series of the decay test in surge is plotted as in Figure 10(a). The measured forces against surge are given in Figure 10(b). Their natural periods are listed in the Table 4.




(a)Ship-model stiffness/free-decay test in surge




(b)Forces and surge

**Figure 10** Ship-model stiffness decay test in surge

**Table 4** Natural periods in moored conditions

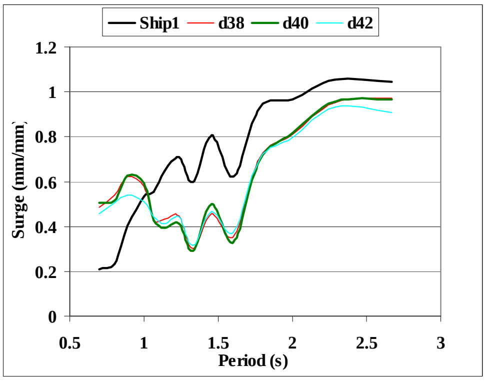
| Mode | Natural period (s) | | | |
|---|---|---|---|---|
| | Ship-Model | Device | | |
| | | 3.8m | 4.0m | 4.2m |
| Surge | 11.1 | 5.37 | 12.1 | 16.9 |
| Sway | 17.7 | 11.5 | 18.8 | 27.1 |
| Heave | - | 1.01 | 1.2 | 1.03 |
| Roll | 2.0 | 1.78 | - | 1.93 |
| Pitch | 5.35 | 4.53 | - | 5.35 |
| Yaw | 6.45 | 4.55 | - | 8.50 |

## 5.3 Free Floating RAOs

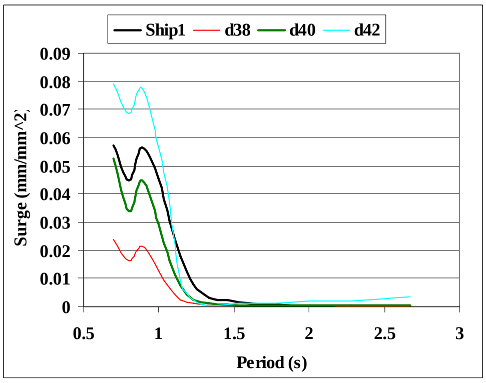
Under wave excitation, the floating model may experience the second-order forces, which may drive the model away from the original position. This is especially evident when the wave period is short. Hence, in some short wave tests, the model drifts very fast away from the original position. In these cases, only short record is available for data analysis. For example, in some cases, only 10 second data out of 60 seconds are useful before the model changed the orientation too much or drifted too far away from the original position.

## 5.4 Test for Conventional Moored Conditions

For conventional moored tests, in monochromatic waves, the first order RAOs (proportional to wave height) and the second-order responses (drift, proportional to wave height squared) can be obtained. For panchromatic waves, the device may experience the first-order responses (in same frequency with waves) and the second-order low frequency and drifting responses. Figure 11 shows the 1st and 2nd responses of surging.




(a)RAOs




(b) 2nd Responses

**Figure 11** First and second responses of surging of the ship-model and device in waves (d38, d40 and d42 are referring to the mooring chain lengths of 3.8m, 4.0m and 4.2m, respectively)

## 5.5 Survivability Test

In this section, the test results in extreme conditions are discussed. These tests include accidental limit state (ALS) tests in regular and irregular waves, and the tests in extreme waves.

### ALS test (accidental limit state)

The accidental limit state is a condition when a mooring line has failed. In this case, the ALS test is looking at the survivability of the mooring device under an abnormal mooring condition: only two mooring lines are in action (a front mooring line was disconnected to simulate failure). To simulate the process of the survival condition, the whole process after the line failure has been recorded during the ALS test, i.e., both the transient drifting from the original position and the oscillating in a new position in waves have been both recorded.

To analyse the motions and forces under such a condition, two phases of the whole process will be considered. During the first phase, the main consideration is the drifting of the device which will give an indication whether the device is still in a limited area (a survival condition), see Figure 12. In the second phase, the oscillating around a new position will be considered.

The maximum forces on the left front mooring line are also examined (Figures 13a & 13b). It can be seen that in the ALS condition, the maximum forces are smaller than those under the complete conditions. It is quite unexpected because it seems more reasonable that the forces should be much larger when one front mooring line is failed.

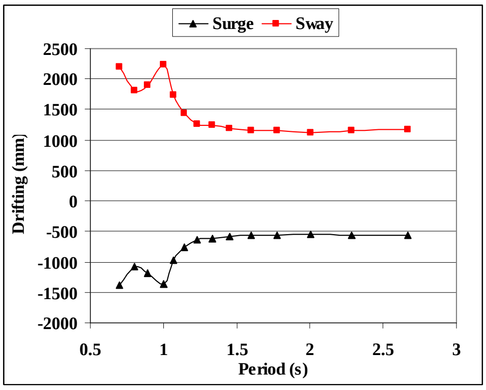
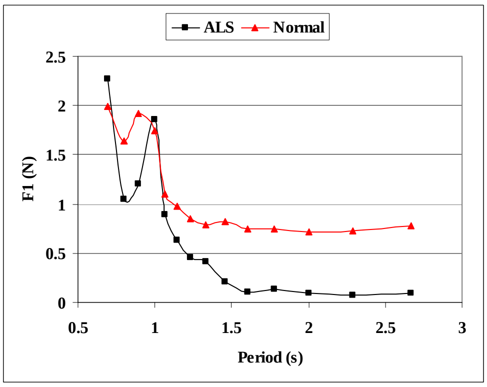
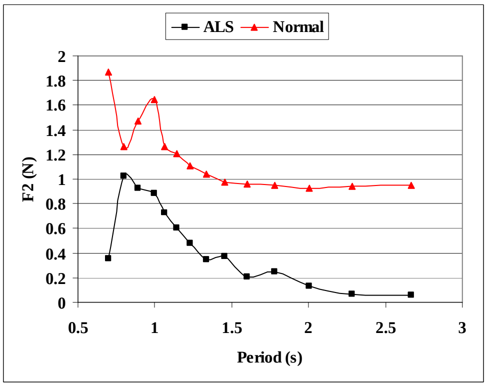



**Figure 12** Drifting in surge and in sway in ALS




(a) Force on chain (F1)




(b) Force on rope (F2)

**Figure 13** Maximum forces on chain and on rope

### Extreme test

In Extreme test, the largest motion happens in surging, especially for the period of 1.0s, where the motion responses are very large. Table 5 shows that 1st order and 2nd order motions. To be comparable, the drift distances have been plotted against the mooring chain length (see Figure 14). It can be seen that the mooring chain length has significant effect on the drifting distance. In a first order approximation, the drifting distance is increasing linearly with the chain length.

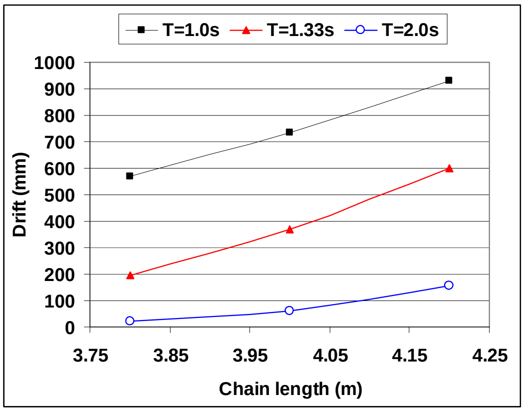



**Figure 14** Drift distance against mooring chain length

One interesting result in the extreme test is the forces. By adding the pretension, the drifting force and half of the oscillating force together, we can work out the maximum force on the rope. A plot for maximum F2 against chain length is shown in the Figure 15. It can be seen that the maximum force on the rope may not happen in the highest pretension configuration in the test conditions, while the highest pretension configuration has a smallest drift in surge under the extreme wave conditions.

**Table 5** Drifting and oscillation in surge in Extreme Test

| Chain=3.8m | | Chain=4.0m | | Chain=4.2m | |
|---|---|---|---|---|---|
| Drift (mm) | Osc (mm) | Drift (mm) | Osc (mm) | Drift (mm) | Osc (mm) |
| 569 | 105 | 734 | 111 | 931 | 103 |
| 195 | 151 | 371 | 150 | 601 | 157 |
| 23 | 169 | 61 | 161 | 155 | 160 |

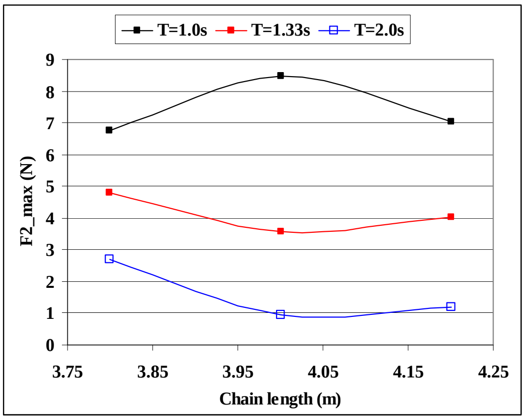



**Figure 15** Maximum Force on the rope (F2)

## 6 Concluding remarks

The experimental investigation on a 3-D model of OE Buoy including mooring system has been conducted at HMRC Ocean Wave Tank. From the wave tank test and its relevant analysis, following conclusions can be drawn:

i. The model test has targeted the modeling of the OE Buoy model at Galway Bay test site. Due to the water depth variation, and due to some technical difficulties, the model scaling is not finished in a single scale ratio. For example, the existing model has a scale ratio of 1:20, while the mooring system has a combination of scale ratio 1:20 and 1:25. The main purposes of the wave tank test are to provide data for the calibration and validation of the numerical model and for a basic understanding of the hydrodynamic performance of the device in waves.

ii. The model test covers a range of “pretensions”, so different arrangements of sea trials can be tested. For example, the variation of the water depth, which causes significant changes in the mooring system, should be covered.

iii. 3-D Tank tests were performed based on the several wave measurements recorded at Galway Bay to identify an umbilical response, and showed no large motion of the umbilical and it was concluded that the umbilical arrangement is safe.

iv. For the accidental limit state (ALS) test, due to a failure of a front mooring line, the model drifts away from the original mooring position, and in a final stage it oscillates around a new equilibrium position. From the force measurement, the maximum forces on mooring chain and on the rope may be smaller than those in complete mooring condition. However, the large drifting distance away from the original mooring position may produce a problem for the umbilical cable due to possible large bending/buckling.

v. In the extreme test, it is found that a large drift in surge may happen, especially for the soft mooring configuration (with the longest mooring chain in the test). It is also found that for a stiff mooring system (in the test case of chain length=3.8m), the maximum forces may not be the largest. That means the stiff mooring configuration may be preferable for both the limitation of the drift and of the force on the chain/rope in the severe wave conditions.

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## References

[1] C. Josset, A. H. Clement. (2007): A Time-Domain Numerical Simulator for Oscillating Water Column Wave Power Plants. *Renewable Energy*, Vol.32, pp.1379-1402.

[2] F. O. Falcao. (2010): Wave Energy Utilization: A Review of the Technologies. *Renewable and Sustainable Energy Reviews,* Vol.14, pp.899-918.

[3] D. C. Hong, S. Y. Hong, S. W. Hong. (2004): Numerical Study of the Motions and Drift Force of a Floating OWC Device. *Ocean Engineering*, Vol. 31, pp.139-164.

[4] R. K. Sykes, A. W. Lewis, G. P. Thomas. (2007): A Physical and Numerical Study of a Fixed Cylindrical OWC of Finite Wall Thickness. Proceedings of the 7th European Wave and Tidal Energy Conference, 11-13th Sep. 2007, Porto, Portugal.

[5] R. K. Sykes, A. W. Lewis, G. P. Thomas. (2009): A Hydrodynamic Study of a Floating Circular OWC. Proceedings of the 8th European Wave and Tidal Energy Conference, 7-10th Sep. 2009, Uppsala, Sweden.

[6] K. Toyota, S. Nagata, Y. Imai, T. Setoguchi. (2009): Research for evaluating performance of OWC-type Wave Energy Converter Backward Bent Duct Buoy. Proceedings of the 8th European Wave and Tidal Energy Conference, 7-10th Sep. 2009, Uppsala, Sweden.

[7] S. A. Mavrakos, V. J. Papazoglou, M. S., Triantafyllou, J. Hatjigeorgiou. (1996): Deep Water Mooring Dynamics. *Marine Structures*, Vol. 9, pp.181-209.

[8] MCS, (2009): Analysis of Mooring and Umbilical Components: Design Report. CORES Deliverable D 3.3, MCS Reference No. 1-4-5-032/DR02.

[9] MCS. (2010): Mooring Data for Tank Tests. MCS Memorandum, No. 1-4-5-032-MEMO-04.

[10] MCS, (2009): Umbilical Data for Tank Tests. MCS Memorandum, No. 1-4-5-032-MEMO-03.

[11] MCS, (2008): Design Options for Mooring Configurations: Design report. CORES Deliverable D3.2, MCS Reference No. 1-4-5-032/DR01.