OCEANTEC: Sea Trials of a Quarter Scale Prototype

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Abstract

Although the first attempts to exploit wave energy go back to similar periods of other renewable energy sources, no particular technology has yet proved to be successful. Survivability in the ocean harsh environment will be one of the key features for commercial success of Offshore Wave Energy Converters.

This paper describes the sea trials results of a new offshore Wave Energy Converter, namely the OCEANTEC WEC. The OCEANTEC WEC is an offshore floating structure, whose capture principle is based on a relative inertial movement produced by a gyroscopic system. Said movement is used to feed a conventional electric generator through several transformation stages of the primary mechanical absorbed energy.

It will also present and discuss the results of the wave tank tests performed in the CEHIPAR facilities with a fifteenth scale model. The model contained a simplified Power Take Off system with the aim of studying the performance of the WEC in regular and irregular waves.

The sea trials were carried out with a quarter scale prototype in the Northern Coast of Spain. The prototype was in commission during a short period of time in summer and autumn so that the sea environmental conditions could be scaled. The goal of these trials was to analyse the structural behaviour of the hull, the data acquisition system and the loads in the lines of the mooring system.

Keywords: Gyroscope, Wave Tank, Sea Trials.

Nomenclature

RAO = Response Amplitude Operator
QTF = Quadratic Transfer Function
σ_y = Yield strength
σ_a = Acceptable design level of strain

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1 Introduction

The OCEANTEC Wave Energy Converter (WEC) is a novel offshore floating device that can be classified as a linear absorber or attenuator. The way it extracts energy form ocean waves is based on the relative inertial motion that waves cause in a gyroscopic device. This motion is used to feed an electric generator through a series of transformation stages. The gyroscopic device is located inside a lengthened structure or hull that stays aligned with the wave front, resulting in a pitching motion.

The structure that comprises the absorber and the rest of the elements has a vessel-like design and a scalable size. This size is adapted to the predominant sea climate of the selected location. For instance, in a location with predominant wave periods between 10 and 12 s (typical of the Northern Coast of Spain), the length of the structure can range 40 to 60m.

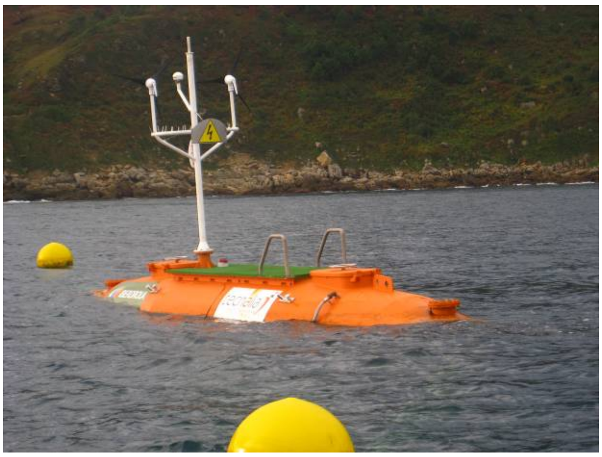

Figure 1: OCEANTEC WEC.

In order to maximise wave energy capture, the external shape of the hull is designed to maximise the pitching motion and excitation forces due to incident waves and to offer a low hydrodynamic damping. The hull has a sufficiently high draft to minimise the effects of the wind over the exposed area, and consequently to be oriented in the main wave propagation direction. Inside the fore and aft ends spaces have been reserved for solid ballast using high-density concrete as the filling material. The use of this ballast allows to modify the inertia of the hull and therefore to fit its period of resonance to the correspondent of the selected location.

One of the main characteristics of this WEC is that all the moving parts of the absorber system are completely encapsulated and protected inside the hull, which provides a high degree of security and reliability to the whole converter.

The mooring system consists of four lines that allow the WEC to face the incident wave front which maximise the directional wave energy absorption [1]. The selected configuration presents a minimum interference with the active degree of freedom for wave energy extraction, i.e. the pitch. This mooring system has been designed for depths ranging 50 to 100m.

The gyroscopic device or absorber consists essentially of a flywheel that rotates continuously under the action of a motor. This flywheel is installed on a gimbal that only allows it to rotate around its vertical axis (Z) and the longitudinal hull axis (X), which is orthogonal to the first one. When the flywheel rotates, the pitching motion generated by wave action on the absorber is converted in an alternating precession motion in the longitudinal axis due to the gyroscopic effect. Afterwards, this precession motion is transformed in a unidirectional rotation by means of a tailor-made coupling. This unidirectional rotation is used to feed a conventional generator.

A functional design of the absorber is shown in Figure 2.

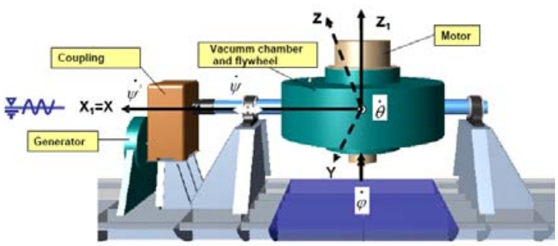

Figure 2: Functional design of the absorber system.

2 Wave tank tests

The realisation of wave tank tests prior to the commissioning of a prototype at the sea is necessary to validate all the calculations and previous studies. The main objective of wave tank tests is to obtain essential information on the dynamic behaviour of the WEC and its interaction with the marine environment (e.g. loads and motions). The WEC is subjected to different excitation states that should represent the closest real conditions during its operational life.

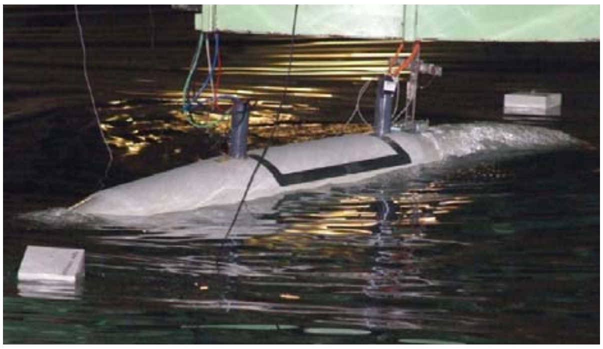

Figure 3: 1:15 scale model in wave tank test.

According to references [2-3], five different phases have been defined in the overall design and development process of the WEC. For the first two phases wave tank test have been carried out.

- Phase 1: Models for the validation of numerical simulations (verification of the concept, validation of the operation and survival under extreme wave conditions). This phase was completed at the beginning of the year 2007 testing a 1:37.5 [1].
- Phase 2: Once verified the numerical models and after a first experimentation phase, wave tank tests are refined focusing on more specific aspects of the WEC.

Numerical models have been developed in Matlab®-Simulink®, through a time domain approach making use of Cummins equation considering the degree of freedom of pitch only [4].

1:15 scale model

The wave tank tests corresponding to second phase have been carried out in CEHIPAR facilities. The basin depth is 5m., which fits to the scalable depth of the deployment location for the full-scale prototype. This phase has been developed in 2008 testing model including the PTO mechanism and a realistic configuration of the mooring system. The objective of these tests were the validation of numerical models in regular and irregular waves, the assessment of the PTO and the analysis of the influence of the parameters that define a sea state in the WEC performance.

To carry out these tests, a scale model was built, being λ=15 the selected scale factor. The choice of the scale has been determined from the two following aspects:

- The model should be small enough to allow scaling waves properly in order that energy performance could be assessed.
- The model should be big enough to house the gyroscope, the PTO and the whole instrumentation and to distribute the weights reproducing the relative position of the centre of gravity and the longitudinal

and traverse inertias as close as possible to the full-scale device.

The main dimensions of the 1:15 model tested in CEHIPAR are showed in Table 1.

Length	3.00m.
Width	0.50m.
Draught	0.35m.
Weight	347.80 kg.

Table 1: Main dimensions of 1:15 model.

Test programme development

The tests have been divided in seven series presented next.

Series 1: Drift tests

The objective of series 1 is to calculate the QTF or quadratic transfer function of the drift forces. Those are very important in order that great stresses in mooring lines can be created and the operation of the device will be limited.

All the series tests, except the first, were carried out with a mooring system dynamically equivalent to real one and with similar configuration to this. In series 1, instead of this, a mooring system based on lines and springs were used, so that the drift forces could be calculated, for regular waves.

Series 2: Decay tests

The objective of series 2 is to obtain the transfer function of each degree of freedom. The information obtained is necessary to adjust the numerical models. In Figure 4 appears the experimental pitch decay test compared with the obtained in numerical models.

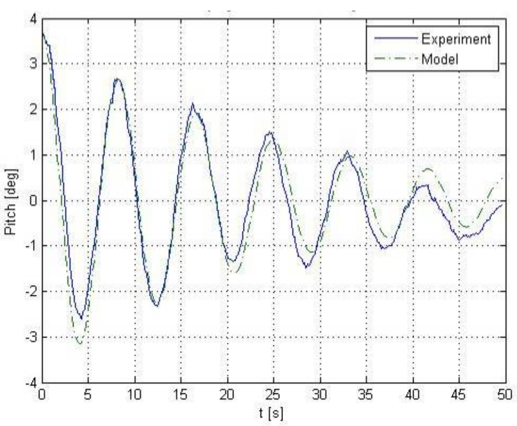

Figure 4: Pitch decaying test.

Series 3: Regular waves tests

In this series regular waves are used to obtain the RAO (Response Amplitude Operators) for every degree, and for all the registered signals. The 1:15 model was tested with the regular waves showed in Table 2 with two propagation directions , 180º - 160º, and also with the gyroscope working and not.

H (m)	T (s)
1.00	5.5
1.25	6.5
1.50	7.0
1.75	7.5
2.00	8.0
2.25	9.0
2.50	11.5

Table 2: Regular waves tested.

The definition of the remaining test series, which consists on irregular waves tests, has been based on reference [4]

Series 4 and 5: Long-crested waves.

The fourth series contains seven sea states as indicated in Table 3. In order to evaluate the spectral shape on the energy production each sea state is repeated using a Pierson-Moskovitz and Jonswap formulation of spectral shape. This comparison has been carried out with two propagation directions, 180º - 160º.

Hs (m)	Tp (s)
1.0	6.5
1.5	7.5
1.5	8.0
2.0	8.3
2.5	9.0
3.0	10.5
3.5	12.0

Table 3: Long-crested waves tested.

For the series in which sea state are tested, following the recommendations of [5], the duration of each sea state corresponds to 60 minutes in full scale, i.e. at test in scale 1:15 will last fort 15 minutes.

Series 6: Short crested wave tests

This test series will show how sensitive the system is to a short-crested sea compared to long-crested sea. The sensitivity to the directional spreading can be evaluated by changing the parameter. The sea states that appear in Table 4 tested have a Jonswap 3D spectral shape. Each sea state has been repeated with two different spreading parameters.

H_s (m)	T_p (s)	Spreading parameter
1.5	8.0	1
2.0	8.3	1
2.5	9.0	1
1.5	8.0	3
2.0	8.3	3
2.5	9.0	3

Table 4: Short-crested waves tested (3D Spectrum).

Series 7: Variation of wave period

The last series show the energy production changes if the peak period is changed for cons constant value of the significant wave height.

This seventh series consists in three waves tested in series 4 to which two different peak period values has been added.

3 1:4 Sea trials

Sea trials were carried out with a quarter scale prototype in the Northern Coast of Spain. The prototype was in commission during a short period of time in September and October so that the sea environmental conditions could be scaled. The goal of these trials was to analyse the structural behaviour of the hull, the data acquisition system and the loads in the lines of the mooring system.

After carrying out wave tank tests, results were analysed to adjust the shape, force and displacement coefficients used in the simulations for the design of the quarter scale prototype.

Quarter scale prototype

The prototype consists on a steel hull with concrete ballast that reproduces the relative position of the centre of gravity and the longitudinal and traverse inertias as close as possible to the full-scale device. As this prototype does not contain the absorber, the ballast has a design that can modify its weight and inertia in order that it makes easier to include the absorber within the hull in future trials. The main dimensions of the quarter scale prototype are indicated in Table 5.

Length	11.25 m
Width	1.875 m
Draught	1.313 m
Weight	18.48 t

Table 5: Main dimensions of 1:4 prototype.

The mooring system consists of four lines that allow the WEC to face the incident wave front which maximise the directional wave energy absorption. The four lines are placed at 45º, 135º, 225º and 315º as shown in Figure 5, oriented according to the four cardinal points since the original orientation of the WEC will be NW so that it will be most of the time facing the predominant wave propagation direction in the location area. The mooring system has been designed so that the tidal range does not affect the WEC performance.

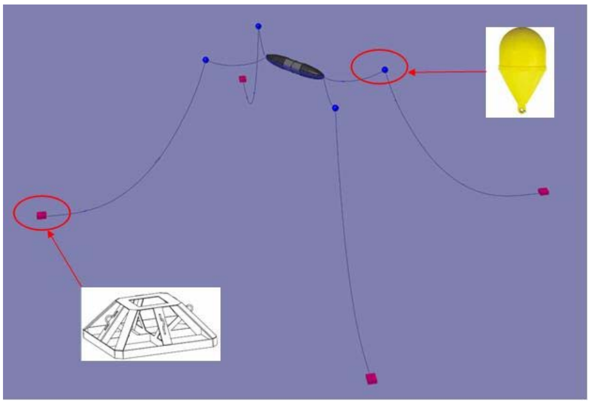

Figure 5: 3D View of the mooring system.

Each line of the mooring system configuration consists of two main sections separated by a buoy with enough floatability to ensure that the line does not submerge itself when subjected to the environmental conditions more favourable to the energy extraction. Thus, the influence on the pitching mode of the vertical load associated to the mooring line is minimal as the buoy supports the weight of practically the whole line.

The second section of each mooring line hangs until the seabed where is connected to one of the four deadweights that constitute the anchoring system. Said deadweights are made of reinforced concrete and are place in a form that define a test site area of 100x100m.

During sea trials some variables are monitored, therefore, the prototype is equipped with different sensors to have information about mainly its structural and dynamical behaviour. A list of the recorded signals and sensor is showed in Table 6.

Signal description	Sensor
Mooring lines stress	Load cells
Slamming pressures in the hull	Piezoelectric accelerometers
Hull deformations	Strain gauges
Alarms (temperature, humidity, batteries level…)	Multiple sensors
Prototype movements (6 DOF)	Gyroscopic systems
Prototype positioning and horizontal movements	GPS
Following-up ARGOS	Radiobeacon

Table 6: Signals and sensor put on board.

The data acquisition system hardware platform selected has been the National Instruments Compact Field Point. The communication system consists on two parts, a communication module placed within the prototype and a monitoring module situated in land. Both modules are communicated by means of wireless modem. A monitoring application has been developed using LabView™ software.

As the prototype is not grid connected, power supply is a critical issue to maintain all the electrical and control equipments on board working during all the sea trials. To this aim, the prototype is equipped with some batteries and two small wind turbines that feed the power system.

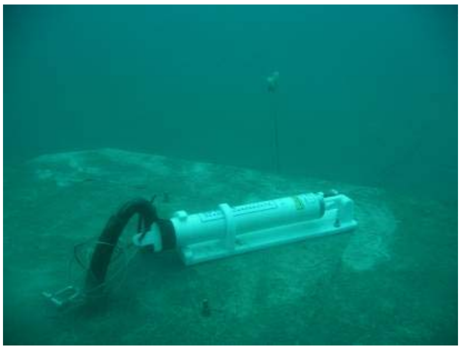

Figure 6: Current profiler installed.

Concerning sea conditions, with the purpose of knowing the hydrodynamic conditions during the sea trials period, three current profilers have been placed on seabed centred on the test site area. With these current profilers wave, tidal, and current parameters are measured and also water temperature.

Site selection and authorization

The sea trials have been carried out in Cala Murgita, situated between Pasaia and San Sebastian, in the Northern Coast of Spain, as indicated in Figure 7.

Figure 7: Test site localization.

The test site selection was based on the evaluation of some aspects such as accessibility, proximity to a port, wave climate, authorisation requirements and environmental impact. The centre of the test area selected is placed in coordinates: XUTM = 585.52 m; YUTM = 4.799.033m. This area has a depth of 29-30m and is characterized by a sandy seabed.

The main factor to define the calendar to carry out the sea trials is the scalability of the sea states. In order that the trials were hydrodynamically equivalent the relation between the model dimensions with regard to wave length and wave height have to be maintained. Because of these the desired sea states should have small wave heights and short wave periods. These conditions fulfil during the summer and the beginning of autumn.

Once decided the test site and the period for trials the third issue is to have authorization for the installation. This was granted for a period of four months from July to October 2008 regarding prototype commissioning. For the deadweights the authorization period granted was one year.

About the marking system the recommendations of reference [6] have been followed. The suited marking system consisted of two marking buoys in the head part of the test area.

Trials development

The quarter scale prototype was commissioned the second week of September and was deployed till mid through October.

The mean significant height during this period was 1.4m. A comparison between the wave height recorded by the three current profilers is shown in Figure 8.

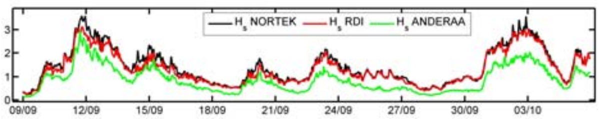

Figure 8: Significant height recorded during sea trials.

The highest significant height recorded during the sea trials has a value near to 3.5m; with maximum wave height up to 5 – 5.5m. This means that the prototype has been exposed to equivalent waves of up to 20-22m height. This wave height is higher than the value corresponding to extremal conditions in the Northern Coast of Spain, for where the prototype has been design. This proves its survival.

With regard to tides, the highest amplitude in the test area was 4m. This not presented any problem for the mooring system as the performance of the hull is not affected by tides.

A large amount of information has been obtained about the structural behaviour of the hull from strain gages. In Figure 9 is drawn the strain recorded by one of the most loaded strain gauges (i.e. inside the fore and space) during a sea state with significant height of 3m. It can be seen that the values are below the design level. ($\sigma_a = 0.8 \cdot \sigma_y = 220$ MPa).

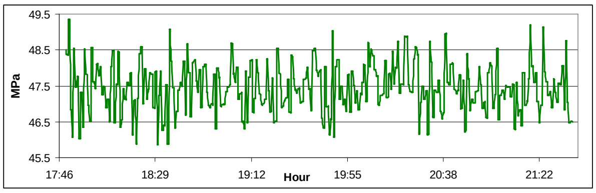

Figure 9: Record of strain gauge 5 (03/10/2008)

After sea trials, the prototype has been thoroughly checked making inspections of the hull and other structural elements. Also, once the mooring lines have been withdrawn the effect of the sandy seabed has been analysed.

Next the key milestones for the whole trials process are cited:

- Prototype manufacturing: May – August 2008
- Authorization granted: Cala Murgita, July 2008 (+12 months)
- Installation of marking buoys - July 2008
- Installation of deadweights, mooring lines and wave & tide recorder - August 2008
- Commissioning of 1:4 prototype: Sept-Oct 2008

Figure 10: 1:4 scale prototype commissioned in September 2008.

Future work

A second program of 1:4 will be carried out in the same test site with the absorber device and a complete PTO system. The main goal of these trials will be to evaluate the power performance of the WEC.

4 Conclusions

The conclusions that can be obtained form analyses tests and sea trials are:

- Numerical models have been adjusted with results from waves tank tests.
- It has been shown from tank testing that the presence of the mooring system does not significantly affect the motion of the OCEANTEC WEC during normal operation.
- In sea trials, the prototype has been exposed to high wave sea states with no problem for the survival, which shows the structural and mooring system reliability
- From data analysis it has been obtained a good correlation with design values, and the robustness has been proved.
- The information obtained is a valuable input to improve WEC design, the installation process and to identify new resources for following sea trials.

5 References

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