11th EWTEC 2015 Proceedings of the 11th European Wave and Tidal Energy Conference 6-11th Sept 2015, Nantes, France

Discussion of the effects of the underwater noise radiated by a wave energy device - Portugal

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Abstract— **Several wave energy projects are being tested at sea and little information is available regarding the real impacts in the marine environment. The lack of knowledge regarding underwater noise radiated by wave energy devices raises concerns about the impact in the marine environment, mainly, the impact on species that rely on sound to survive. This paper aims to present the results of a study carried out to characterise the noise radiated by the WaveRoller (WR) device installed in Peniche, Portugal and to assess its potential impact on marine mammals occurring in the study area.**

An acoustic campaign was carried out in September 2014. At the study site the only marine mammals occurring are cetaceans. The results indicate that the frequency ranges at which the device operates overlap those used by some low and mid-frequency cetaceans. Only behavioural responses would be expected if the organisms swim near the WaveRoller. Cetaceans were not detected around the WaveRoller device probably because of the low depth where the device was installed.

To conclude, facing the lack of knowledge regarding the underwater noise radiated by wave energy devices this study brings a new contribution to the state of the art presenting the characterization of the underwater sound radiated by the WaveRoller, a totally submerged wave energy device.

***Keywords*— Wave energy device; WaveRoller; underwater noise; cetaceans.**

I. INTRODUCTION

The underwater acoustic environment is the result of both natural and man-made sources of noise [1]. Many marine species take advantage of sound propagation conditions in the ocean to interact with the environment using sound for reproduction, feeding, orientation and communication [2]. Any acoustic disturbance resulting from a man-made activity should be carefully assessed in order to understand its impact on marine species and implement mitigation measures if needed.

During the last years an increase of underwater noise levels have been registered as result of human activities in the marine environment and are now being considered under different legal frameworks (for example the OSPAR Convention and the Marine Strategy Framework Directive). Some potential impacts of underwater noise of man-made activities on acoustic sensitive species are hearing impairment, behavioural disturbance, auditory masking and in a severe situation death [2].

Due to concerns and the lack of information about the noise produced by wave energy devices this is one of the stressors usually considered in environmental impact studies of wave energy projects [3].

Compared with other types of renewable energy, wave energy technologies are still in their infancy. As different devices are being designed to operate at different conditions most of the projects are at demonstration or pre-commercial phase [4]. As well, information about the noise radiated by different technologies and its potential impacts on the marine ecosystem is scarce [5].

This paper presents the results of a monitoring campaign to assess the noise of an oscillating wave surge converter, the WaveRoller, and discuss its potential impacts on cetacean species occurring at the site.

II. THE WAVEROLLER

The WaveRoller is an oscillating wave surge converter which, depending on tidal conditions, is mostly or fully submerged and anchored to the seabed.

One prototype of this device was installed and tested in Peniche (Portugal) near shore at 10 m depth. It has three flaps but at the moment of the experiment only the middle one was installed (Fig. 1). As the WaveRoller panel moves and absorbs the energy from ocean waves, the hydraulic piston pumps attached to the panel pump the hydraulic fluids inside a closed hydraulic circuit. All the elements of the hydraulic circuit are enclosed inside a hermetic structure inside the device and are not exposed to the marine environment. The high-pressure fluids are fed into a hydraulic motor that drives an electricity generator. The electrical output from this renewable wave energy power plant is then connected to the electric grid via a subsea cable [6].

Fig. 1 The WaveRoller prototype tested in Peniche, Portugal.

III. Study Site Characterization

The seabed is sandy in the study area and depth ranges between 10 to 25 m depth. There is light shipping traffic passing mainly of small fishing and recreational boats. The device was deployed at 800 m from the coast line and grid connected where the sound radiated by the breaking waves largely contributes to the natural acoustic environment in this zone.

IV. The Ambient Noise at the WaveRoller Site

In September 2013 an experiment was carried out to assess the ambient noise at the study area. During this experiment several acoustic recorders were deployed at pre-defined positions and over transects with a receiver tethered from a boat at a number of monitoring stations. From this experiment the soundscape in the vicinity of the device is mainly subject to natural ambient noise and chains of the moored buoys. Away from the device deployment site the background noise is lower. Broadband sound pressure levels varied between 86 and 119 dB (re 1μPa) [7].

V. Methodology

The experiment was carried out on the 3rd and 4th of September 2014 and was split into two parts with different objectives: 1) to characterise the noise produced by the WaveRoller; 2) to characterise the noise propagation. For underwater recordings two autonomous hydrophones digitalHyd SR-1 were used using a sampling frequency of 101652 samples (≈ 50 kHz). The system was deployed by using the configuration presented in the Fig.2 with the hydrophone at mid-water depth. For all the measurements the hydrophone was fixed to the seabed using the following scheme:

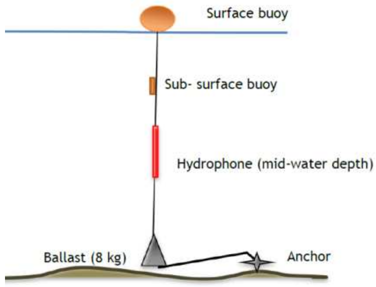

Fig. 2- Deployment scheme.

Complementary information about wave height and period as well as information about power production were provided by the promoter AW-Energy. A CTD (Valeport Limited© miniCTD) was used to measure water temperature, salinity and depth. A GPS (Garmin GPS map 60 GPCSx) was used to mark the position where measurements were carried out.

A. Sound characterization experiment

Sound measurements to characterise the radiated noise were obtained at 220 m from the WaveRoller. A second hydrophone was deployed at 350 m distance from the device where (site 15 m depth). The hydrophones were programmed to record 10 minutes each half-hour during a period of 24 h.

B. Sound propagation experiment

In order to assess the propagation of the noise radiated by the WaveRoller one hydrophone was deployed near the WaveRoller, at 165 m distance, using the configuration presented in Fig.2. The hydrophone was programmed for continuous recordings. A second hydrophone was used for measurements at 300 m, 600 m, 900 m and 1200 m distance from the WaveRoller along two transects as presented in the Fig. 3. At each sampling point 5 minutes recording were carried out. The same deployment scheme was used without the anchor. The boat engine was turned off during the records. Along Transect 1 depth ranges between 17 to 27 m and along Transect 2 ranges between 15 to 17 m.

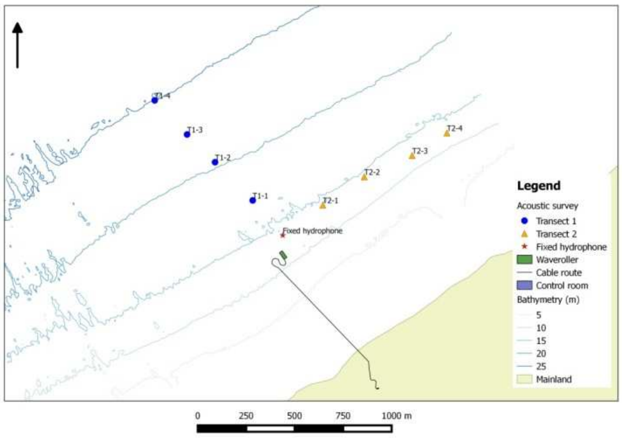

Fig. 3- Underwater noise sampling points for the sound propagation experiment.

C. Sound analysis

All the records were analysed by using Matlab routines to calculate the broadband sound pressure levels with the averaging time of 5 minutes. Also the power density spectrum, one-third octave band spectrum and the spectrogram were calculated. The records were analysed in the frequency range between 50 Hz and 20 kHz, using an NFFT window of 101652 samples or 1 s.

D. Data analysis

A statistical Spearman test was used to understand how the variation of sound pressure levels is correlated with the WaveRoller power production, wave height and wave period.

VI. RESULTS

During sampling, the mean wind speed was less than 5 m/s. The mean significant wave height varied between 0.9 and 1.8 m and the period between 9 and 12 s. The values of these 3 parameters decreased along the sampling period. CTD profile presented a typical summer profile for the Portuguese west coast with water temperature at the surface being 20 ºC and near bottom 15 ºC. Sound speed ranges between 1525 m/s at the surface and 1510 m/s near bottom.

A. Sound characterization experiment

Average broadband SPL measured with Hydrophone 2 varied between 115 and 126 dB re 1 µPa rms and with Hydrophone 1 between 115 and 121 dB re 1 µPa rms with. SPL values decreased over time.

In order to characterise the sound produced by the WaveRoller an acoustic segment was extracted from the acoustic data recorded at 220 m from with hydrophone 2. The fundamental frequency of the WaveRoller sound ranges between 100 and 130 Hz and its maximum instant component is about 120 dB at 120 Hz. Frequency span can be observed until 2.5 kHz (Fig. 4).

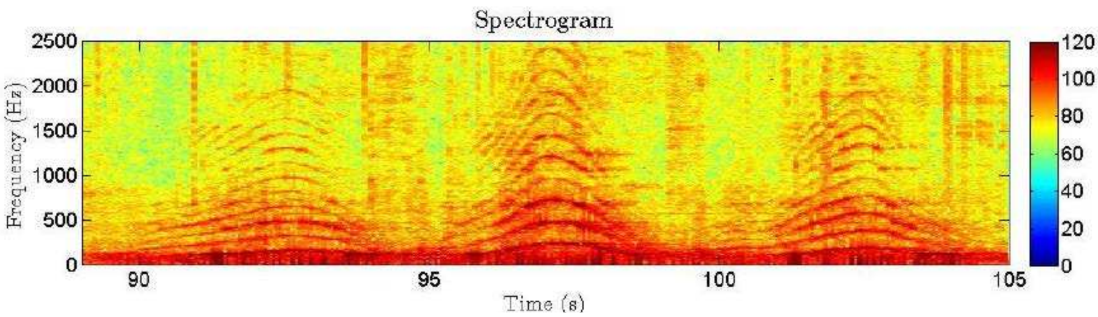

Fig. 4- Time-frequency analysis of the sound radiated by the WaveRoller.

Analysing the 1/3 octave bands spectrum most part of the energy occurs at the frequency band of 125 Hz.

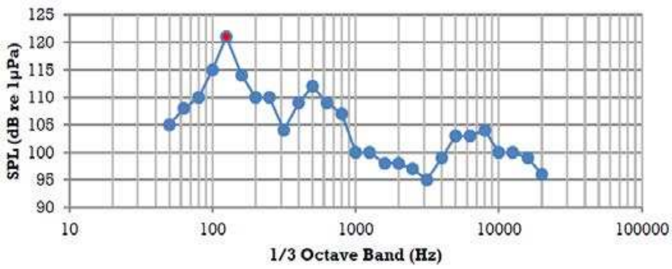

Fig. 5- 1/3 octave band spectrum of the noise radiated by the WaveRoller.

Comparing the spectrum of records at different power production levels a decrease in SPL with power production is identified for the frequency bands until 1 kHz. A strong correlation between SPL at 220 m and the power production was found (ρ= 0,782; n= 47).

B. Sound propagation experiment

In Fig. 6 the broadband sound pressure levels measured at different distances from WaveRoller along Transect 1 and 2 and near the WaveRoller (WR in the figure) are presented. Highest SPL values were measured at 300 m (120 dB – Transect 1, 122 dB Transect 2) with a small difference to the SPL levels measured in the fixed position near the WaveRoller in both transects (123 dB Transect 1, 122 dB transect 2). The results are consistent in both transects indicating the device noise decays within the first 300 m around the device.

When the spectrum of the records near the WaveRoller are analysed the dominant frequency band is 125 Hz. For the measurements along the Transects other frequency bands are dominant. However, along the Transect 1 higher SPL levels were found at 300 m in the 125 Hz band. For the other measurements the SPL was similar. Along the Transect 2 it a slightly decrease of the SPL in the 125 Hz with distance was observed.

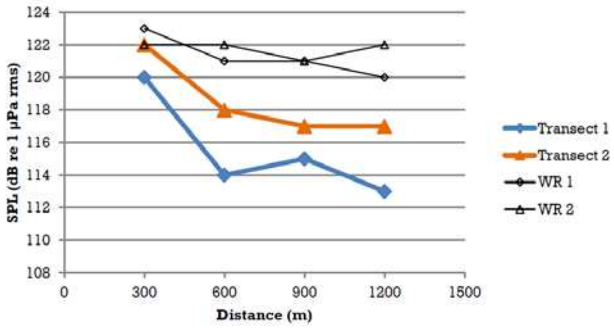

Fig. 6- Broadband sound pressure levels at different distances from the WaveRoller.

VII. WAVEROLLER VS. OTHER SOURCES OF NOISE

In Fig. 7 underwater noise levels of different marine activities are presented and compared with the WaveRoller. In the figure it is evident that the noise emitted by the WaveRoller is below the noise emitted by other marine activities, including pile driving which is one of the noisiest activities that may be carried out during marine renewable energy construction, especially in offshore wind projects.

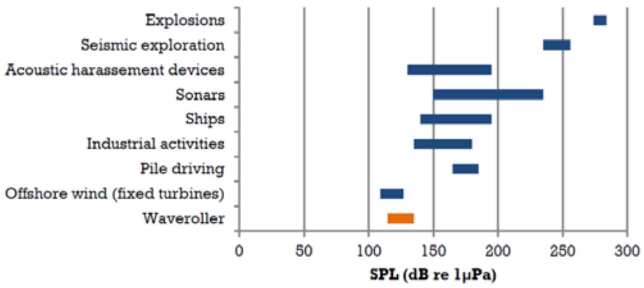

Fig. 7- Underwater SPL of different marine activities (Sources [2, 8])

VIII. POTENTIAL IMPACT ON MARINE MAMMALS

Concerns regarding acoustic impact of anthropogenic activities in the marine environment are being introduced in legislation at global level (e.g. Marine Strategy Framework Directive) and guidelines. Information about the acoustic impacts of marine renewable devices is scarce. Mostly information is based on theoretical assumptions based on other technologies or assessed through models [9].

The work carried out was designed to characterise the source and propagation of the noise emitted by the WaveRoller but the obtained results can also give some information for the discussion on the potential effects on the marine environment.

Nowadays, some invertebrates, fish and marine mammals are indentified as the main receptors in the marine environment but acoustic impact assessment is strongly focused on marine mammals since they rely on sound to survive.

The marine mammals group is split into 4 main groups: pinnipeds (seals, sea lions and walruses), cetaceans (dolphins, whales and porpoises), sirenians (manatees and dugongs), and fissipeds (polar bear).

The cetaceans group is subdivided into two sub-groups, mysticetes and odontocetes. These have different ways of using and interpreting the sound and therefore they may be affected at different levels by the same sound. In general mysticetes are more sensitive to low frequencies while odontocetes are more sensitive to high frequencies. Note that mysticetes are considered low-frequency cetaceans and odontocetes are subdivided in mid and high-frequency cetaceans.

In the study site only cetacean species are expected to occur and these include baleen whales, common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncatus*), sperm whale (*Physeter macrocephalus*), harbour porpoises (*Phocoena phocoena*) [10]. The occurrence of bottlenose and common dolphins were confirmed in the marine mammal monitoring activities which have been carried out during the summer of 2014.

Among other factors, the acoustic impact depends on spatial relationships between the sound source and the receptor, its sensitivity, received exposure level, duration and duty cycle of the sound. The main impacts that have been observed in cetacean species are behavioural modifications, auditory masking, hearing injury (temporary or permanent threshold shift) and in a severe situation also death. There is no threshold ranking establishing the levels a source will cause any particular reaction. However, there are accepted noise exposure criteria that can be used, as [11], where criteria for behavioural reactions and injury are suggested. According to these authors, animals are categorised based on functional hearing characteristics and threshold levels are defined to predict behavioural modifications and injury (Fig. 9).

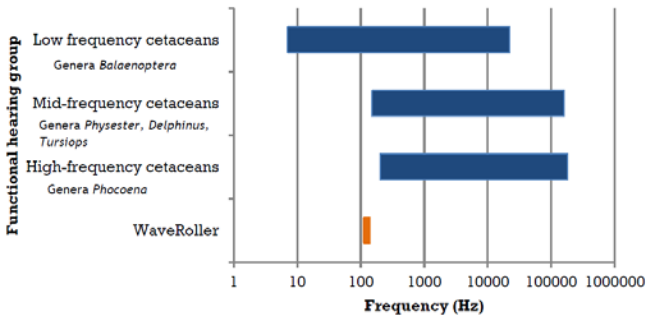

Fig. 8- Functional marine mammal hearing groups, auditory bandwidth (estimated lower to upper frequency hearing cut-off, genera represented in each group (adapted from Southall et al., 2007) and WaveRoller its 1/3 octave band frequency.

Injury is considered an elevation of the hearing threshold to a specific frequency (can be temporary – reversible, or permanent – irreversible) and sound exposure level (SEL) is currently accepted as the best metric to measure it. Injury can be assumed if SEL is higher than 215 dB re 1μPa2-s, for non-pulse sounds. Using an Aquatic Acoustic Metrics Interface

(AAMI, version 1.2.2; [12]) the calculated SEL of the Waveroller sound is 150 dB re 1µPa2-s and therefore no injury is expected.

There are several factors influencing a potential behavioural disturbance, some examples are the animal condition (species, age, sex, current activity, prior experiences) and the characteristics of the acoustic source. Behavioural responses are a graduated phenomenon and some noise-induced changes in behaviour are more significant than others and therefore it is difficult to set SPL or SEL levels for behavioural disturbance [11].

For low-frequency cetaceans it is assumed that the avoidance behaviour or other types of response might occur when received levels are 120-160 dB re µPa. For mid-frequency cetaceans behavioural responses were already registered for different noise sources (ship and pingers for example) when received levels are around 90-120 dB re 1µPa in some cases and around 120-150 dB re 1µPa in another. In captive animals behavioural changes were only detected when received levels were above 170 dB re 1µPa. For high-frequency cetaceans behavioural responses have already been identified when received levels are around 140 dB re 1µPa in high frequency ranges. Most of the information for high-frequency cetaceans are based on studies carried out with harbour porpoises. Since sound levels of the WaveRoller may differ between 115 and 130 dB re 1 µPa, behavioural responses might be expected for low and mid-frequency cetaceans if they swim close to the device. However, and possibly because of the low depth the device was installed (10 m), the presence ofcetaceans around has not been detected in the sound records neither on visual observations conducted along transects in the area at the time the noise survey was carried out.

Also in the Fig. 9 it is possible to see that cetaceans considered in the mid and high frequency functional hearing groups might not detect the sound produced by the WaveRoller since SPL in 125 Hz frequency bandwidth is below the threshold level for this group. On the other hand cetaceans from the low-frequency functional hearing group can detect the sound radiated by the Waveroller. However, and as already mentioned it is not expected that individuals from this sub-group come close to the WaveRoller site since they occur in higher depths than those where the devices are to be installed.

IX. Conlusions

The noise levels radiated by the WaveRoller are low comparing with other marine activities and at the study site the attenuation of the sound is greater until 300 m far from the device. At 1 km from the device the device noise can still be identified however, it is not dominant in the soundscape and a longer transect would be necessary to assess the extension of the acoustic footprint ot the device.

The overlap of the WaveRoller noise frequencies with those used by low and mid frequency cetaceans would possibly induce some behavioural reactions. However, the sound frequency and levels are not expected to affect marine mamals occuring in the area because the device is installed at lower depths than those which are usually used by these species.[11].

Acknowledgment

This research was supported by AW-Energy.

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