Acoustic characterization of impulsive underwater noise present in port facilities. Practical case of the Port of Cartagena †

Ivan Felis Enguix[1],*, Marta Sánchez Egea[1], Antonio Guerrero González[2] and David Arenas[1]

1   Naval Technology Center (CTN); 30320 Fuente Álamo, Murcia, Spain.
2   Technical University of Cartagena; 30202 Cartagena, Murcia, Spain.
*   Correspondence: ivanfelis@ctnaval.com; Tel.: +34-968-197-521
†   Presented at the 5th International Electronic Conference on Sensors and Applications, 15–30 November 2018; Available online: https://sciforum.net/conference/ecsa-5.

Abstract: The data recording of underwater noise is a key aspect for the prevention and improvement of management systems of maritime spaces. Thus, due to the presence of activities potentially generating impulsive noise, the ports deserve special attention. This article describes and shows the results of the spatial monitoring of both the basal noise and the impulsive noise sources present in Port Facilities. A vessel has been equipped with a smart digital hydrophone with a working frequency range between 10 and 200 kHz and an RVR of, approximately, -170 dB @ 1V / μPa. Coupling the acoustic data together with the GPS coordinates of the vessel, a GIS map with the spatiotemporal distribution of the basal sound pressure levels has been made, identifying the sources of impulsive noise of interest and its temporal characteristics. This is a preliminary step for the development of future studies on underwater noise pollution and its potential impact on biodiversity in the environment of Port Facilities with the maximum guarantees possible.

Keywords: Underwater noise monitoring, Impulsive underwater noise, Continuous underwater noise, Marine contamination, Hydrophone.

1. Introduction

One of the main sources of underwater noise is shipping traffic, with the highest levels of ambient noise concentrated in the ports due to the continuous traffic of vessels. However, ports can also be the source of impulsive noise due to the presence of potentially impulsive noise generating activities: pumping systems, refrigeration, works in ports, container loads, etc.

The objective of this work is to perform an acoustic characterization of impulsive underwater noises that may be present in Port of Cartagena. This characterization will be carried out according to the methodological criteria for the implementation of the Marine Strategies [1]. Therefore, the characterization of underwater noise proposed in the Port of Cartagena includes:

- Quantification of background levels and continuous noise.

- Location and identification of impulsive noise emission sources.

- Quantification of impulse impulsive noise levels.

- Propagation of the values obtained beyond the domain of the Port.

To do this, as shown below, a series of underwater acoustic measurements of the bay are made.

2. Materials and Methods

2.1. Materials and Methods

For the monitoring of submarine noise in the Port of Cartagena, two types of measures have been carried out:

1. Measures in different points of the perimeter of the Port, made by arranging the hydrophone by hand from the edge.
2. Measures in different points of the water area that encloses the Port, as well as int the access zone outside the infrastructure of the Port. To do this, the hydrophone has been sunk from a vessel.

The following Figure 1 shows, on the left, the location of all the measurements made whose GPS position was also recorded for the subsequent spatial processing of the noise data.
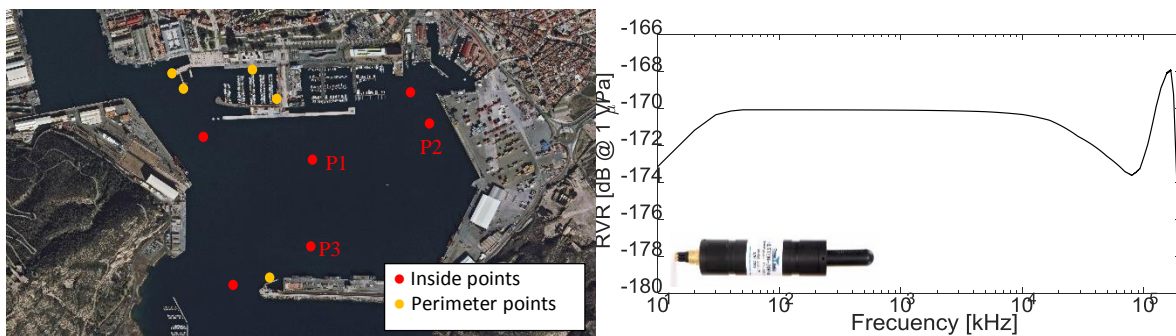

Figure 1. At left, location of all the measurements points. At right, RVR of the hydrophone used.

All measurements were made with an IcListen HF smart hydrophone with a bandwidth between 10 Hz and 200 kHz, and a sensitivity of approximately -169 dB @ 1V/μPa. Being, then, the industry's most sensitive digital broadband hydrophone. The Figure 1 left shows its bandwidth RVR sensibility.

In both configurations, the hydrophone was submerged 3 meters from the water level and series of 3-minute measurements were made, with a sampling frequency of 192 kS/s and 24 bits of resolution. During the measurements, they were scored the events due to:

▪ Continuous noise: different types of boats that crossing near the measurement points to subsequently contrast the background measurements with respect to the sound emitted by them. These measures help us characterize these sources of continuous noise whose levels are above background noise.

▪ Impulsive noise: due to boat sonars and, especially, to the process of loading marine containers to freight ships. The spectrum, duration and periodicity of these events allowed us to make a first estimate of the quantification of an impulsive noise source inherent to the activity of the Port of Cartagena. In addition, these recorded levels are the basis for the further development of the numerical propagation model.

Once the data of all the measurements have been obtained and analyzed, an acoustical propagation model has been made and run it with the experimental results. Finally, the spatial result of the model is integrated in a geo-maritime GIS hosted on the CTN website[1].

---

[1] http://www.ctninnova.com/visor-geomaritimo/

2.1. Underwater sound propagation model

It can be found several mathematical models that study the acoustic propagation in underwater media, highlighting the models of ray tracing, normal modes, parabolic equation and spectral integration. However, the configuration of these mathematical models requires several parameters whose value is not always known exactly, which can lead to unreliable results. Because of this problem, several semi-empirical models have also been developed to study the acoustic propagation in underwater media, distinguishing different types of propagation [2,3].

From these models, the ray tracing model is the most versatile and used so it will be discussed briefly. The model of ray tracing is based on the consideration that the energy of the wave can be concentrated in defined paths, so that we can think of rays instead of waves. This consideration is valid if the amplitude of the wave and the speed of the sound do not vary much in a wavelength. Thus, this condition will be fulfilled better for high frequencies, since the wavelength will be smaller. From the ray tracing model, it can be calculated the field of pressures, from which the transmission losses and the propagation time of said rays can be obtained.

In the Port of Cartagena, the depth of the bottom ($\square$ 12 m) is such that there are multiple rebounds of the signal between the sea surface and the bottom. This leads to a very important interaction of acoustic signals. This interaction is quite complex, since it is necessary to take into account the type of bottom, the sediments, how they are distributed, the possible variations that suffer in terms of depth, etc. All these difficulties make the use of mathematical models such as ray tracing risky.

However, semi-empirical models can be used, among which the Colossus model stands out [4]. This model can be used from simulations between 0.1 and 10 kHz. It takes into account the height of the waves (depending on the state of the sea), the type of bottom, the depth of the water column, the frequency and the profile of the speed of sound. This profile is considered formed by two constant segments: from the sea surface to a certain depth L, the speed of sound increases linearly with depth, while for depths greater than L, the speed decreases with depth until reaching the bottom. According to this model, the *distance of jump* or *transmission*, H, is defined as that maximum distance at which a ray makes contact with the surface or with the background of the shape given in equation:

$$H = \sqrt{\frac{L + D}{3}} \tag{1}$$

where D is the depth from the water column in meters. With this, the transmission losses are obtained according to the equations given in:

$$TL = \begin{cases} 20\log(R) + \alpha R + 60 - k_L & R < H \\ 15\log(R) + \alpha R + \alpha_T \left(\frac{R}{H} - 1\right) + 5\log(H) + 60 - k_L & H < R < 8H \\ 10\log(R) + \alpha R + \alpha_T \cdot \left(\frac{R}{H} - 1\right) + 10\log(H) + 64.5 - k_L & R > 8H \end{cases} \tag{2}$$

where R is the distance, α the absorption coefficient, k_L is a parameter called near-field anomaly, which measures the gain due to bounces between the background and the surface, in dB, and α_T is the so-called effective attenuation coefficient, which takes into account the losses due to the energy coupling between the surface and the bottom, expressed in dB/bounce. The values of these last two coefficients appear tabulated for different types of bottom and sea state, for example in [2]. As an example, for 1 kHz with calm sea and sandy bottom, k_L = 6 dB/bounce and α_T = 1.8 dB/bounce.

3. Results and Discussion

3.1. Bavkground and continuous acoustic noise

The figure 2 shows the sound pressure levels (SPL) obtained in thirds of octave bands between 1 and 100 kHz. For each frequency band, it is performed the averaging of levels in the area delimited by the registration points. The recorded SPL have an average of 62 dB with variations of ±18 dB.
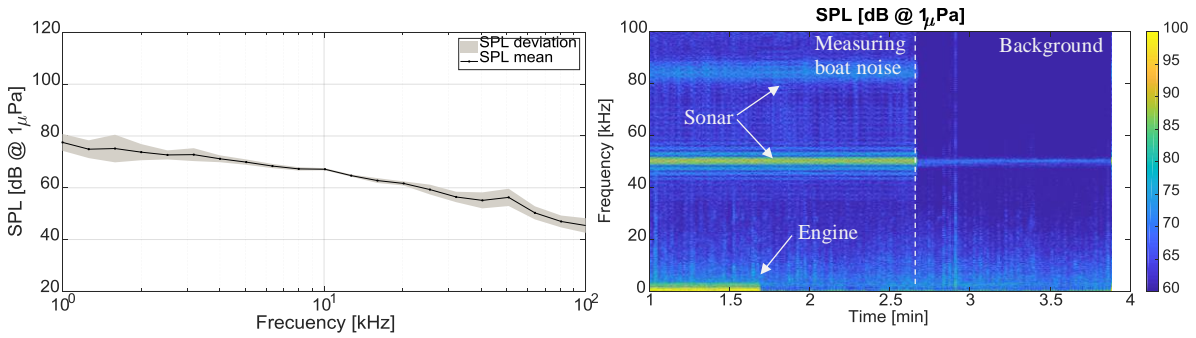

Figure 2. At left, spectrum of background noise. At right, its spectrogram at Point P1.

With these results, we have a first estimate of the basal noise in the Port of Cartagena that we can take as a basis for the study of the continuous and impulsive noise sources. However, there also were sources of continuous noise that, although they are not part of the basal noise of the port, they will be considered in this study as part of the background that is not, specifically, impulsive noise. The sources of continuous sound recorded during the measurement campaign were, basically, the passage of boats. The following Figure 3 shows the spectrum of one example of them.
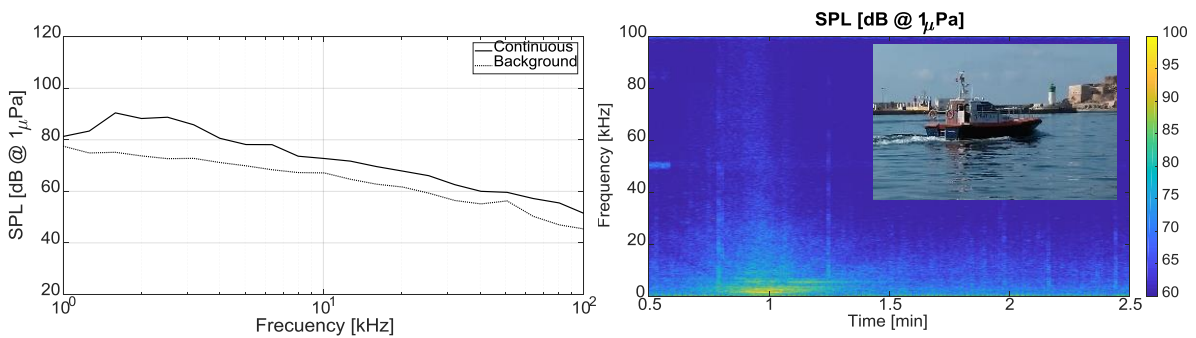

Figure 3. At left, spectrum of continuous noise source. At right, its spectrogram. (Point P3)

3.2. Impulsive noises

During the measurement, only one source of impulsive noise was found. This was due to the process of loading sea containers on a freight ship moored in the eastern part of the Port (Fig. 4, left). A study of the spectrogram shows the levels and periodicity of these impulses (Fig. 4, right).
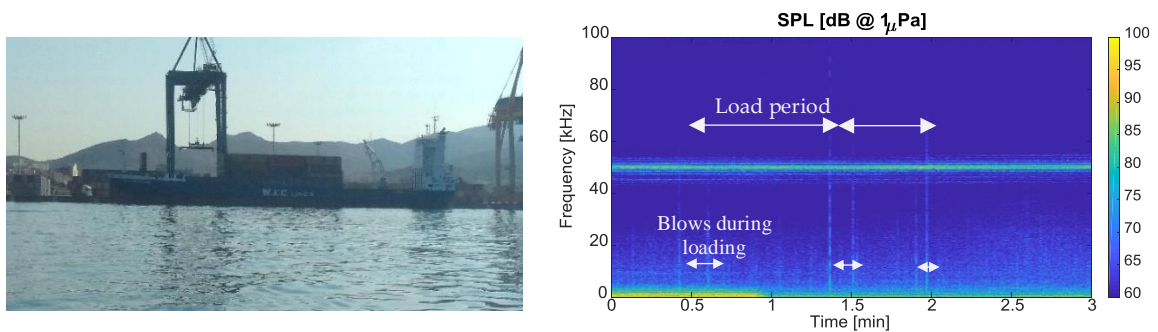

Figure 4. At left, loading of a freight ship. At right, spectrogram of the noise generated. (Point P2)

These impulse noise levels recorded at approximately 50 m from the source have a considerable bandwidth (since it is pulses) with peaks of up to 85 dB at frequencies below 20 kHz. This results in about 100 dB @ 1μPa @ 1m.

3.3. Propagation underwater noise

In these impulse noise source monitoring studies, we are interested in estimating the distance of such noise get out of the infrastructure of the Port. For this, it can be made measurements at different distances, as well as apply acoustic propagation models that take into account the characteristics of the water column and the soil.

In this case, we apply the simplified model described above to estimate the range of a source with characteristics similar to the one discussed in section 3.2. This model has been implemented on a ray tracing algorithm specifically implemented by CTN that considers the geometry of the bay in which the Port of Cartagena is located. Since this is a first approximation for a more extensive study of noise monitoring, the results of different approaches performed in said model are explained here. These studies serve as a basis for more robust subsequent studies.

Given the position of the detected impulsive noise source and the geometry of the port, figure 5 is generated. At left, it is shown two examples of the path of the rays that ray reach 5 km from the source. As can be observed, one arrives to exit while the other remains inside the Port. By performing the same procedure for different emission angles, the assembly of figure 5 right is obtained.
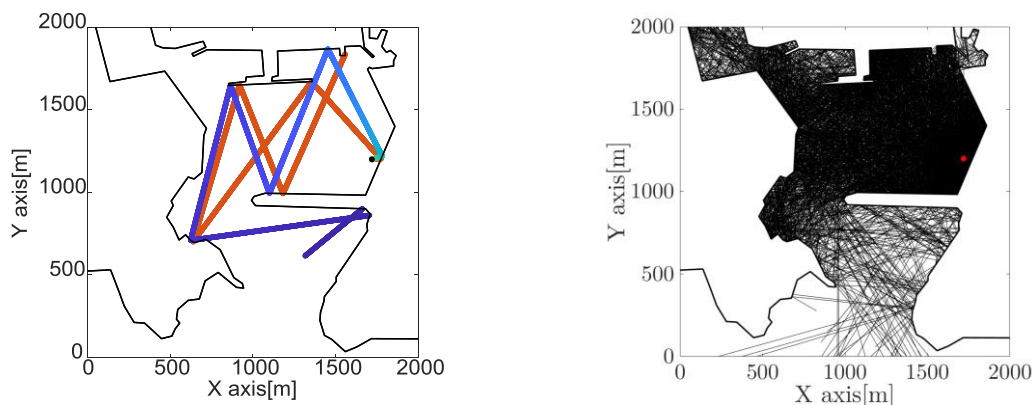

Figure 5. At left, example of the tracing of two rays. At right, tracing of all rays.

Quantifying the percentage of rays that come out of the Port with respect to the emitted, we obtain Figure 6 left. It is observed that only 10% of the rays leave with 5 km of travel length and up to 20% with 7.5 km. As will be seen below, these distances are enough for decrease the generated impulsive noise level.

To observe the effect of the acoustic propagation along these rays, we initially compare the transmission losses due only to cylindrical geometrical divergence and absorption with the transmission losses of the semi-empirical model given by the equations (2). Figure 6 right shows that both models have the same losses within a few meters of the emission. At closer distances, the semi-empirical model presents fewer losses since, in this region, it takes into account the spherical divergence of the wave. For larger distances, the large number of reflections leads to a sharp increase in losses that limits propagation. Specifically, for 1 kHz, there are reductions of 35 dB in 100 m and 55 dB in 1000 m, much greater than those foreseen by divergence and absorption only.
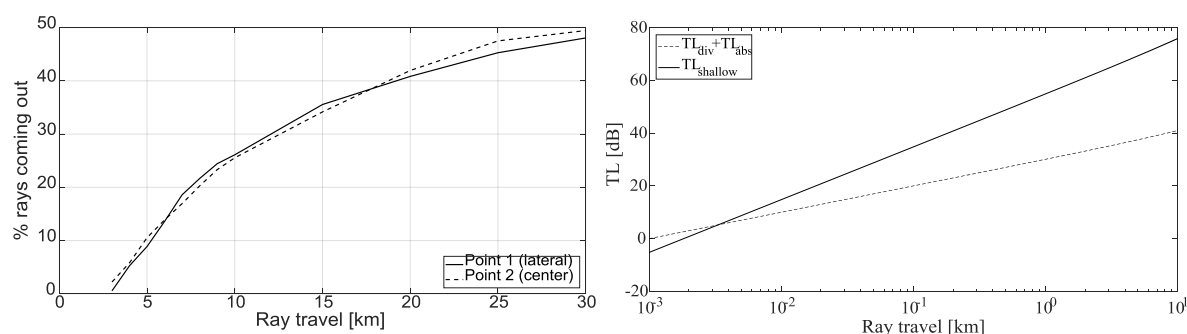
Figure 6. At left, percentage of rays that leave the port. At right, comparison of transmission losses with different propagation models.

From the above results we can estimate that a source of impulsive noise with a SPL of, for example, 100 dB @ 1 μPa, located both inside the Port of Cartagena, will present strong losses. Thus, this noise will reach the mouth of the Port with a level below the own background noise.

5. Conclusions.

After analyzing the background and continuous noise levels in the Port of Cartagena, it has been observed that impulsive noise must have a level above 80 dB @ 1 μPa to be detected. Only one source of impulsive noise has been detected that corresponds to the process of loading sea containers, which is carried out in the eastern part of the Port. Although this source is not usually indicated in the search for impulsive sources, it should be included. However, taking into account the geometry of the port as well as the transmission losses due to the propagation in shallow water, it is estimated that this noise does not reach the outside of the bay with a high level.

Nevertheless, these studies are the basis for the realization of other developments that will allow to advance both experimentally and theoretically in these studies. It is proposed to further refine the propagation model considering the deviations in depth in the interior and exterior of the Port.

However, this methodology is extensible to analyze noise generated in other bays with port activities with a greater impact on marine fauna.

References

1. P.Ruiz, et al. *Sound impacto of Mutriku oscillating water column plant: Unerstanding MSFD Descriptor 11*. XIV Jornadas españolas de ingeniería de costas y puertos. Alicante, 24 y 25 de Mayo de 2017.
2. Robert J. Urick, *Principles of Underwater Sound*, Ed. Península Publishing, 3ª Edición, 1983.
3. T.G. Leighton, capítulo *Fundamentals of Underwater Acoustics*, pp. 373-443, en Fundamentals of Noise and Vibrations, Frank Fahy y John Walker, Ed. Taylor and Francis, 1ª Edición, 1998.
4. M. Schulkin y J.A. Mercer, *Colossus Revisited: A Review and Extension of the Marsh-Schulkin Shallow Water Transmission Loss Model*, Applied Physics Laboratory, University of Washington, APL-UW 8508, 1985.