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ENCLOSURE ACOUSTICS CONSIDERATIONS FOR THE STUDY OF THE EFFECT OF NOISE ON FISH

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RESUMEN

El estudio del comportamiento de los peces resulta extremadamente complicado en un entorno de libertad, especialmente si hablamos de su exposición a diferentes fuentes sonoras. Por este motivo, de las investigaciones en marcha son llevadas a cabo en el seno de un laboratorio, bien en peceras o bien en tanques, teniendo así un entorno controlado donde monitorizar continuamente el comportamiento de las muestras. Sin embargo, un recinto confinado difiere considerablemente de un espacio abierto. Mientras que un pez en libertad estará sometido por norma general a un campo sonoro libre, cuando hablamos de un recinto cerrado las condiciones cambian notablemente.

ABSTRACT

Studying the behaviour of fish is extremely difficult in a free environment, especially when it comes to their exposure to different sound sources. For this reason, existing research is carried out in a laboratory, either in fish tanks or in tanks, thus having a controlled environment in which the behaviour of the samples can be continuously monitored. However, a confined enclosure differs considerably from an open space. While a fish in the wild will generally be subjected to a free sound field, when we talk about an enclosed area the conditions change markedly.

Palabras Clave— Effect of noise on fish, tanks, experimental setup, numerical methods.

1. INTRODUCCIÓN Y PLANTEAMIENTO

Studying the behaviour of fish is extremely difficult in a free-ranging environment, especially when it comes to their exposure to different sound sources. This is one of the reasons why a lot of research is carried out in a laboratory, either in fish tanks or in tanks, thus having a controlled environment where the behaviour of the samples can be continuously monitored. However, a confined space differs considerably from an open space. While a fish in the wild will generally be subjected to a quasi-free sound field, in a confined enclosure the conditions change significantly. The characteristics of the enclosure will significantly influence the test results, so it seems necessary to establish an optimal configuration that approximates the generated sound field to the free conditions of the fish, especially considering the ability of the fish to determine the direction from which the sound is coming.

This paper describes the process being carried out in this regard to adjust vibroacoustic models of tanks used for feeding and fattening fish in aquaculture and in research work on the effect of noise on fish [1]. Concerning the shape and dimensions of these tanks vary (figure 1), many of them are cylindrical, others have a shape close to that of a parallelepiped. We can also find large installations [2]. Almost all of them have interior walls with low absorption.

Figure 1. https://www.acuitec.es/es/acuicultura/categoria/ 31-tanques-y-depositos. Visited 15/09/2023

2. BACKGROUND

The space and time distribution of the sound pressure it is usually referred to as “Sound Field”.

Since the sound field varies from one spatial position to another, the location and even the orientation of the microphone has a distinct influence on the result. Sometimes the sensor, the instrument, and its accessories, as well as the very presence of the operator, can alter significantly the signal to be measured.

For this reason, it is important to clarify a few concepts.

Although the complexity of any real-life sound field is very hight in almost all cases, from a metrological point of view it may frequently approximated by one of four limiting cases with well-defined properties:

- Free Field
- Diffuse Field
- Pressure Field
- Stationary Field

A free field is any sound field whose propagation direction is clearly determined.

A condition for the presence of a free field is that there are no reflecting surfaces near the sound source or the receiver. Special cases of free field are plane, cylindrical, or spherical waves, but at a considerable distance from the source any free field exhibits an approximately plane behaviour. In general, free field takes place outdoors, but it is also found inside an anechoic chamber, i.e., a room with all its surfaces covered by highly absorbent materials or structures so that the reflected sound is negligible.

A diffuse field, also known as random field, is any sound field such that all propagation directions are equally probable. In general, we have a diffuse field in large, closed rooms whose dimensions are large compared to the wavelength range of interest, particularly those with irregular shape or that contain a variety of sound reflective objects. In general, a diffuse field also has a continuous spectrum.

A pressure field is any sound field that oscillates in phase and with the same amplitude at every location of a given

spatial region. In general, this condition takes place in small enclosures where the maximum linear dimension is much smaller than the minimum wavelength of interest. In order not to surpass an amplitude variation of 1 % within the enclosure (which is equivalent to a difference of 0.1 dB, i.e., the resolution of most sound level meters), it is sufficient that its maximum dimension be about lambda/40. A typical situation is within an acoustic coupler, for instance, an acoustic calibrator where a sound source and the microphone under test share a small and closed volume. Another case is that of an artificial ear for earphone testing.
A stationary field is any sound field that oscillates in phase or opposite phase in all locations of a region. It happens only for sinusoidal tones in small enclosures, even if the conditions for a pressure field do not hold. An example is the Kundt tube or impedance tube used to measure the normal-incidence sound absorption coefficient.

As is known, there are three basic theories for the study of the sound field in an enclosure: statistical, geometrical and wave theory [4]. Any theory (or model based on a theory) must provide an answer to two phenomena that differentiate free-field propagation from that of a confined enclosure: a) the increase in perceived sound level and b) the persistence of sound once the sound source is disconnected (which we usually call reverberation and for which the parameter of reverberation time is usually used to be quantified).

In this case, given the dimensions of the enclosures used and the frequencies (or wavelengths) of the test sounds, a study from the wave point of view is necessary and, given that the shapes of the contours are irregular, it is necessary to resort to numerical methods. For the study carried out, the FEM method [5,6] and the commercial software ANSYS [7] have been used. A model has also been developed using the Boundary Element Method (Matlab).

Figure 1. Image of the tank used as a reference for numerical models.

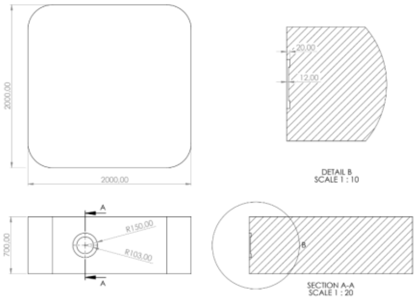

Figure 2. Dimensions of the tank shown in figure 1. It is a 2x2 m high, 0.7 m high enclosure with a sound source embedded in one of its walls.

Figure 3. Image from [3] showing the sound source deposited on the ground.

3. PROCEDURE

As discussed above, the test setup for determining the influence of noise on fish is extremely critical. As a confined space, the occurrence of a reverberant field and the effect of enclosure modes can lead to highly heterogeneous sound pressure level distributions that compromise the results of the experiments and increase their uncertainty. Therefore, it is essential to analyze the acoustic behavior of the enclosure used in the tests. The first step is to implement numerical models to predict the behavior of these enclosures. We are interested in two variables associated with the acoustic field: a) the sound pressure (or sound pressure level) and b) the particle motion (PM), in any of its expressions: displacement, velocity or acceleration [8].

In our process we have contemplated two different geometries: a) Close to the parallelepiped (figure 1) with the dimensions shown in figure 2. This tank has already been used in published works [3]; and (b) cylindrical, 12 meters in diameter and 9 meters deep. The systematics would be the same for any other enclosure.

The general characteristics of implemented models are given:

a) FEM

The model implemented in FEM, consisting of a total of 200769 elements, has a single domain corresponding to the water inside the tank. The excitation was simulated by incorporating a given vibration on the surface corresponding to the radiating plate of the loudspeaker assuming that the piston model is verified. The meshed model is shown in figure 4.

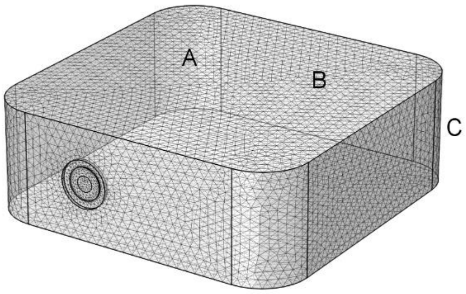

Figure 4. Finite element representation of the tank model. A, B and C are the three surfaces whose absorption is to be changed.

b) BEM

The Boundary Element Method is used to model the problem in the frequency domain, using a 3D approach. For that purpose, the circular tank is discretized using triangular elements, with constant shape functions. In the discretization process, and to ensure adequate accuracy, the element size is defined so that it is always less than 1/8th of the wavelength of interest.

Given the physical characteristics of the system, the boundary conditions to be considered consist of null particle velocity at the bottom and at the rigid walls of the tank, and null pressure on the free surface. The system is excited by a surface load, located in a small circular region at the surface, for which unit velocity is imposed. To allow for a more efficient analysis, and given the geometry of the problem, the floor of the tank is simulated using the image source method, directly accounting for the required boundary conditions. Additionally, and to reduce the discretization requirements (and consequently the computational cost), symmetry is also considered, thus modelling only half of the system.

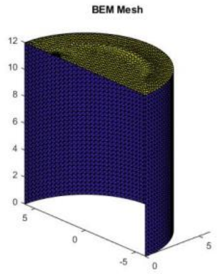

Figure 5. Mesh model implemented in BEM for the frequency of 800 Hz.

4. RESULTS

3.1. FEM Model. Results

The first step is to obtain the modal basis. Figure 5 shows four of the modal shapes of the enclosure under study. They are, of course, reminiscent of those of a perfect parallelepiped.

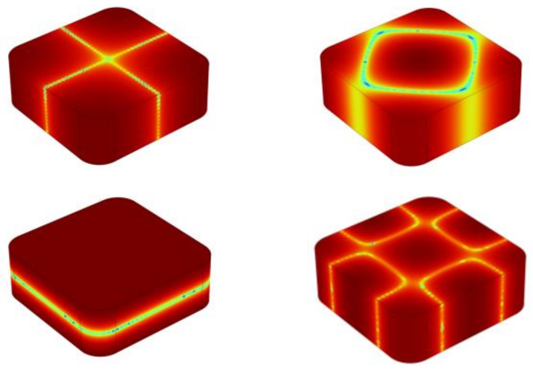

Figure 5. Four modal forms of the enclosure under study.

To visualise the effect of the position of the sound source, figure 6 shows the sound pressure level in a plane parallel to the ground for three different positions of the sound source (always modelled as a piston whose points vibrate with a constant velocity). It can be seen immediately that there are large differences. The velocity of the particle at each of the positions is also shown (arrows).

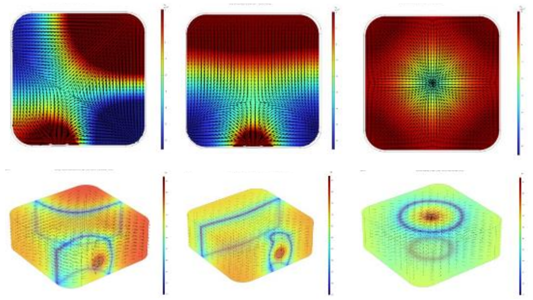

Figure 6. Sound pressure level and particle velocity distribution for 500 Hz frequency for three source positions.

The acoustic behaviour of the tank in terms of absorption of the walls is analysed by comparing the consequences of two different conditioning methods. The first one, considering all reflective surfaces (zero absorption coefficient). The other two, by modifying the absorption of the enclosures in front of the loudspeaker (A, B and C in figure 4).).

Figure 7 shows the results obtained. As is evident, the modification of the absorbent characteristics of certain walls of the enclosure has a significant effect on both the sound field and speed. All cases were analyzed for the frequencies of 120, 500 and 1000 Hz.

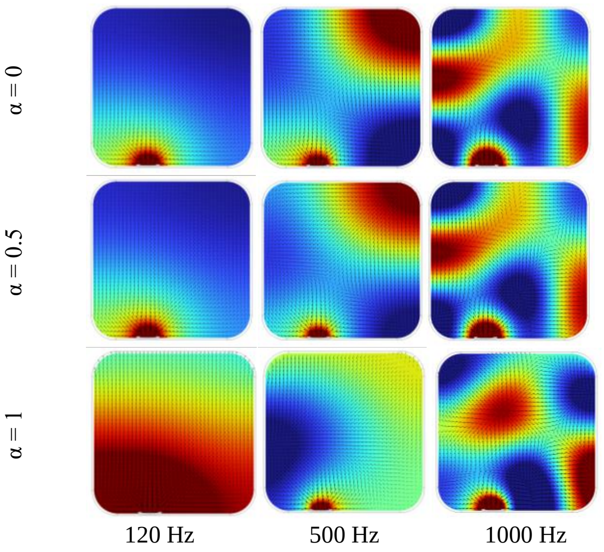

Figure 7. Sound field (sound pressure and velocities) inside the tank considering different absorption coefficients. Analysis for 100, 500 and 1000 Hz.

1.2. BEM

From data of the geometry of the enclosure and the location of the source, the model allows us to obtain the distribution of the sound pressure level, the velocity of the particle on the y-axis and on the z-axis. Figures 8, 9 10 show the results for the frequency of 800 Hz when the source is in the center of the upper surface (air-water boundary)

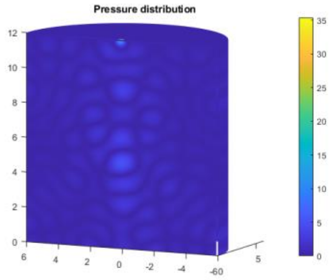

Figure 8. Distribution of sound pressure in the tank of 12 meters deep and 6 meters radius when the source is in the center of the upper surface (air-water boundary).

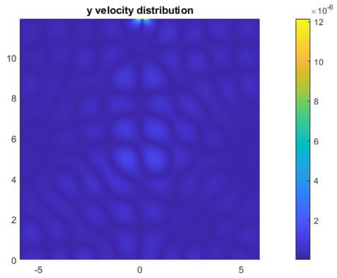

Figure 9. Particle velocity distribution on the y-axis when the source is at the centre of the upper surface (air-water boundary).

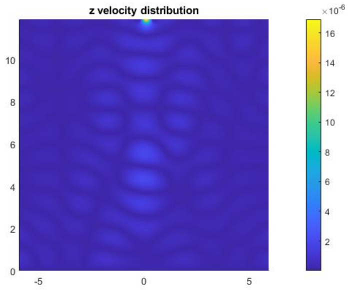

Figure 10. Particle velocity distribution on the z-axis when the source is at the centre of the upper surface (air-water boundary).

4. CONCLUSIONS

The results show that, as expected, depending on frequency, source position and wall absorption, highly heterogeneous sound pressure level and particle velocity distributions can be found.

It is concluded that it is necessary for the experimental setup to consider the control of the acoustic field inside the tank to reduce the uncertainty in the experimental results.

To complete the vibro-acoustic study, it will be necessary to characterise the material of the tank walls, determining their mechanical characteristics (including loss factor). It will also be necessary to carry out an experimental modal analysis to quantify the contribution of the vibrating walls to the internal sound field. Once these measurements have been made, it will be possible to adjust a fluid structure model to control the acoustic field inside the tank and, therefore, more precise information on the significant variables to assess the effect of noise on fish.

ACKNOWLEDGEMENTS

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