Modelling and Calculation of Seismic Wave Field Caused by Moving Ship

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Abstract. In order to study the frequency characteristics of seafloor seismic waves generated by sailing ships. The finite element numerical simulation method is adopted and COMSOL Multiphysics software is used to establish a two-dimensional axisymmetric model to calculate the distribution of seismic wave fields and compare the correlation between horizontal and vertical components at different depths when the depth of seawater is same. The results show that the frequency characteristics of the horizontal and vertical components become larger and larger as the sound source approaches the seabed, and the influence of seawater on the vertical direction is more and more significant. According to the research results, the seismic wave characteristics of different components can be used to judge the specific information of the sailing ship more accurately.

1. Introduction
The sources in the water that can cause seismic waves mainly include currents, biological activities and moving ships. The ocean currents have a certain periodicity, and the energy of biological activity in shallow water is relatively limited. The moving ship seismic wave’s mechanism can be summarized as the ship’s own vibration, propeller radiation noise in the low-frequency components and the pressure field changes generated by the moving ship stimulate a surface wave. Its main features are

(1) The vibration is continuous, and there is no definite start time. It produces weak-strong-weak changes when the ship is moving.

(2) It has a certain amount of vibration energy, which occurs at the seabed and seawater’s interface and this kind of the surface wave can be detected, so the ship seismic wave analysis can be used as a means of target recognition.

(3) The ship seismic wave signal band is low, generally not more than 100Hz.

At present, most of the research on ship seismic waves depends on the sea test and access to data directly. Because the marine environment is very complicated, the experiment is often confined to the fixed sea area, it is difficult to obtain the seismic wave data in different environments, and it consumes a lot of manpower. Therefore, the simulation modeling method is very suitable for the study of ship seismic waves. Through simulation modeling, we can simulate the seismic wave field generated by different sound sources in different environments, and improve the research efficiency to the maximum extent, and provide the simulation data for the actual sea test.

2. Simulation and calculation

2.1. Software introduction
COMSOL Multiphysics is an integrated and efficient numerical simulation software developed by COMSOL in Sweden. It is widely used in scientific research and engineering calculation in various
fields. It is suitable for all kinds of physical processes and their coupling relationships in simulation science and engineering fields. COMSOL Multiphysics has high computational performance and outstanding multi-physics coupling analysis capabilities, which can achieve high-precision numerical simulation of any multi-physics field. In this paper, two modules of pressure acoustics and porous elastic wave are used.

2.2. Modeling
For the seismic waves caused by moving ship, the sound source can be simplified as a low-frequency point source in the water. Assuming that the sound source produces low-frequency spherical waves in the shallow sea, and the surface of the sea is a free surface of which the sound pressure is 0, and the seabed interface is the coupling interface between the acoustic field and the elastic wave field of porous media. Using the spherical wave radiation boundary in COMSOL Multiphysics can eliminate the influence of acoustic reflection for simulating the infinite domain. The air-seawater-seabed stratification model is established, and the frequency characteristics of the seabed seismic waves are analyzed.

The point source produces a spherical wave that is a special case when the pulsating sphere’s radius is very small. The acoustic wave’s front is spherical and the source radiates a uniform spherical wave. We already know that radiation sound pressure of the pulsating source is

$$p = \frac{|A|}{r} e^{i(\omega t - kr - \phi)}$$

Where $|A|$ depends on the boundary conditions, describing the specific vibration of the sphere. When the radius of the sound source is very small and the frequency of the radiated sound waves is low, the pulsating sphere satisfying such a condition can be called a point source. The single-pole source strength in COMSOL Multiphysics software can be described by reference power $P_{\text{rms}}$ in a free space as

$$S = \omega \rho_{c} c_{r} P_{\text{rms}} \sqrt{\frac{2\pi}{c}}$$

And $P_{\text{rms}} = 1 \times 10^6 \text{W}$ in this paper.

Establishing the air-seawater-seabed layered structure, the simulation model diagram as shown below. A layered structure of air-seawater-seabed is established, and its simulation model is shown in the figure below.

![Figure 1. The air-seawater-seabed simulation model](image-url)
At this time the depth of seawater is $H=200\text{m}$, the depth of the sound source $h=100\text{m}$. When we are meshing, in order to improve the accuracy of the calculation, focusing on the point source and the coupling interface. After the grid is divided, it is a complete grid of 3585 domain units and 223 boundary elements.

We focus on the seabed medium to consider the existence of the viscous fluid in the pores and the dynamic response of the coupled solid frame under the action of elastic wave. A typical sandy seabed model is selected according to the related literature. The parameters of the seabed medium are shown in Table 1.
Table 1. The parameters of the seabed medium

| Parameter Name          | Parameter Symbol | Parameter Value |
|-------------------------|------------------|-----------------|
| Density                 | $\rho_d$         | 1405kg/m³       |
| Porosity                | $\varepsilon_p$  | 0.47            |
| Permeability            | $\kappa_p$       | $1 \times 10^{-6}$ cm³ |
| Volume modulus          | $K$              | $(4.36 \cdot 10^7 + 2.08 \cdot 10^6$i Pa   |
| Shear modulus           | $G$              | $(2.61 \cdot 10^7 + 1.25 \cdot 10^6$i Pa   |
| Biot-Willis coefficient | $\alpha_B$       | 0.999           |
| Tortuous coefficient    | $\tau$           | 1.25            |

2.3. Result

In the simulation model, a point at a distance of 400 m from the sound source at the coupling interface is selected as the measurement point. Calculating the displacement level frequency characteristic curve of the point in the case of different sound source depth, where the displacement level is calculated as follows

$$DL = 10 \log \frac{d}{d_0}$$ (3)

Where $d$ is the displacement amplitude of a point at the interface, $d_0$ is the reference displacement, and $d_0 = 1 \times 10^{-5}$ m.

The depth of the sea water in the model is 200 m, so the four sound sources are selected to be 1 m, 50 m, 100 m and 150 m. Considering the depth of the draft of the ship and the influence of the sea surface boundary, it is assumed that the surface ship’s depth of the sound source is 1 m, which is the ideal case. The remaining depth is assumed to be an idealized model of different submersible depths for the submarine.

After calculating, the horizontal displacement level frequency-characteristic curves of the four kinds of sound source depth at the measurement point are

Figure 4. Horizontal DL frequency-characteristic curve (1m, 50m, 100m, 150m)
The vertical displacement level frequency-characteristic curves of the four kinds of sound source depth at the measurement point are

![Vertical DL frequency-characteristic curves](image)

Figure 5. Vertical DL frequency-characteristic curve (1m, 50m, 100m, 150m)

The correlation coefficient is used to characterize the correlation between the horizontal components and vertical components, and we have obtained the correlation of different components at different sound source depths. The results are shown as

| Depth of the source | 1m   | 50m  | 100m | 150m |
|--------------------|------|------|------|------|
| Correlation coefficient | 0.975 | 0.876 | 0.743 | 0.539 |

### 3. Conclusions

It is found that as the sound source gradually approaches the seabed, the frequency characteristics of the horizontal components and vertical components are getting bigger and bigger, and the influence of seawater in the vertical direction is more and more significant. The reason is because the interface in the vertical direction withstands a relatively large seawater pressure, which limits the propagation of the vertical energy. So the attenuation of the horizontal displacement is slower than the vertical
displacement during propagation. Using this conclusion, we can detect the location of the ship in the water more accurately.

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