A forecasting method for near-field scattering characteristics of underwater complex shells

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ABSTRACT

In order to forecast near-field scattering characteristics of underwater complex shells with specific excitation quickly and efficiently, a simulation method using boundary element is proposed. Firstly, we compare the simulation results with theoretical results of rule models to verify the reliability of simulating rule models using software. Then the simulation results and tank experiment results of the complex shells are compared. It is proved that it is feasible to simulate the scattering characteristics of complex shells by using software. All the theoretical, simulation and experimental results indicate that this method could forecast the near-field scattering characteristics of underwater complex shells accurately, and it benefits further study of scattering field of complex shells.

Keywords: Scattering, BEM   I-INCE Classification of Subjects Number(s): 23.6, 75.5

1. INTRODUCTION

Research on underwater target scattering characteristics has a very important theoretical and practical value in the field of detecting and identifying of active sonar or forecasting self-noise of sonar platform. Since the fifties, there have been many scholars doing a lot of theoretical studies on scattering of elastic shells immersed in unbounded fluid (1, 2, 3). Then, some Chinese scholars researched on scattering characteristics of underwater shells, especially the sphere, ellipsoid and cylinder shells similar to underwater weapons (4, 5, 6). However, these studies were all on rule models. For complex models, it was difficult to calculate their acoustic field characteristics by theoretical methods. Researchers usually calculated them by experimental measurement which was not only a waste of manpower and material resources but also a waste of time, because measurement could be conducted until the models were completed. The measuring method has a long developing cycle and is not easy to make improvement. In (7) a method to calculate near-field scattering characteristics and pressure directivity of underwater complex targets was proposed, but theirs study needs experimental verification. Therefore, seeking a convenient and reliable method of forecasting acoustic field of complex structures is very necessary.

In order to forecast the influence of platform rear propeller noise on flank array position, we proposed a simulation method using boundary element to forecast near-field scattering characteristics of underwater complex shells with specific excitation efficiently.

2. THEORETICAL BASIS

2.1 The Basic Principle of Boundary Element Method

For single-frequency acoustic field, if the structure surface is smooth and the acoustic field velocity potential function around the structure satisfies the Helmholtz wave equation and Sommerfeld radiation condition (8), combined with the free-space Green's function

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$\psi(\vec{r}) = e^{-jkr} / r$, we can obtain Helmholtz integral equation:

$$\oiint_S \left[\phi(\vec{r}_s) \cdot \frac{\partial}{\partial n}\left(\frac{e^{-jkr_{sM}}}{r_{sM}}\right) - \frac{\partial}{\partial n}\phi(\vec{r}_s) \cdot \frac{e^{-jkr_{sM}}}{r_{sM}} \right] ds = \begin{cases} 0 & M \ in \ S \\ 2\pi\phi(\vec{r}_M) & M \ at \ S \\ 4\pi\phi(\vec{r}_M) & M \ out \ of \ S \end{cases} \tag{1}$$

Where *S* is a smooth closed surface, *M* is the point to be observed. Through element discretization of surface Helmholtz integral formula, we can obtain the boundary element solving equation:

$$\phi(\vec{r}_M) = \sum_{i=1}^{N} \left\{ A_i \phi(r_{Si}) + B_i v(r_{Si}) \right\} \tag{2}$$

Where *A*, *B* are coefficient matrixes.

When modeling, we used finite element software ANSYS to mesh a structure and imported the meshing data into SYSNOISE to calculate. After importing the meshing data, SYSNOISE can automatically generate coefficient matrixes A and B. When specific velocity boundary conditions are given, we can obtain the pressure, velocity and intensity of structure surface according to the mapping between element velocity and element pressure. Then the pressure of any point of the acoustic field can be obtained.

2.2 Theoretical Calculation of Elastic Shell Scattering

In (1) elastic shell theory was used to calculate the scattering of spherical and cylindrical shells when a plane wave radiating. According to their method, combined with Lagrange equation and wave equation, we calculated scattering characteristics of elastic spherical shells when a spherical wave radiating.

In (1) theoretical formulas of scattering pressure of spherical and cylindrical shells when a plane wave radiating are given. So we will not repeat them in this paper.

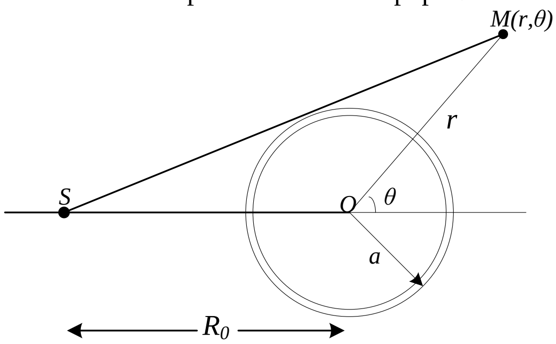


Figure 1 - A spherical wave radiating on an elastic spherical shell

In Figure 1, incident wave is spherical wave radiated by a point source, is distance between the point source and center of sphere. Using the method in (1), we can obtain the scattering expression of elastic spherical shells when spherical wave radiating:

$$p_s(r, \theta) = \sum_{n=0}^{\infty} c_n \left[j_n(kr) - jn_n(kr) \right] P_n(\cos\theta) \tag{3}$$

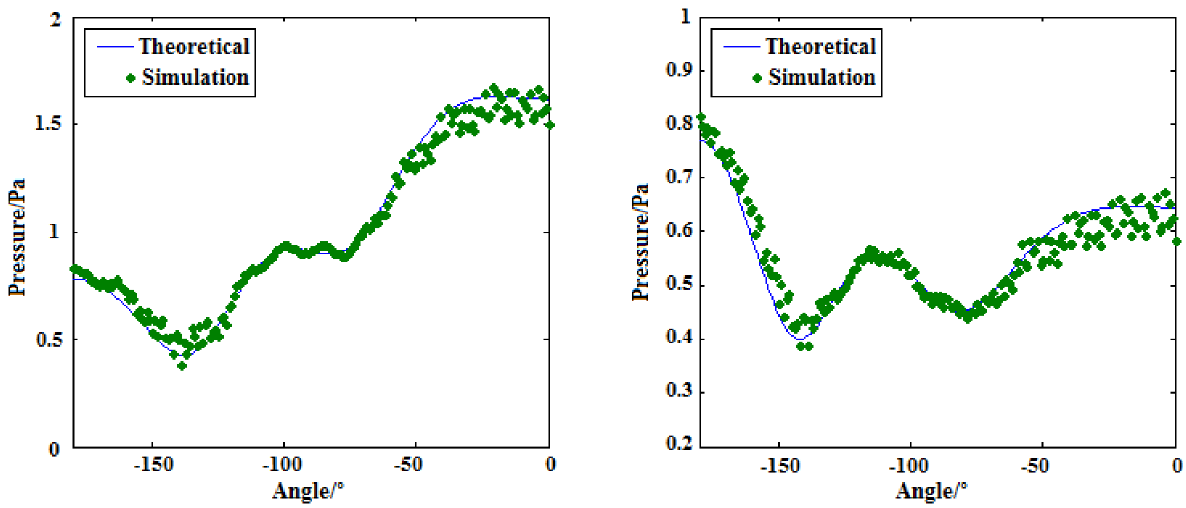
$$c_n = jkp_0(-1)^n(2n+1)h_n^{(2)}(kR_0) \times \frac{j_n(kr) + j\dfrac{Z_n}{\rho c} j_n{}'(kr)}{[j_n(kr) - jn_n(kr)] + j\dfrac{Z_n}{\rho c}[j_n{}'(kr) - jn_n{}'(kr)]} \tag{4}$$

Where $j_n(x)$ is n-order spherical Bessel function, $n_n(x)$ is n-order spherical Newman function, $P_n(x)$ is n-order Legendre polynomial, $h_n^{(2)}(x)$ is spherical Hankel function of the second kind, k is wavenumber, r is the radial distance from the observation point to center of sphere, p_0 is the acoustic pressure amplitude of incident wave, c is the acoustic velocity in the fluid, ρ and ρ_s are the densities of fluid and the shell, h is the shell thickness, a is the radius of the spherical shell, Z_n is mechanical impedance.

3. SIMULATION OF ELASTIC SHELL SCATTERING FIELD

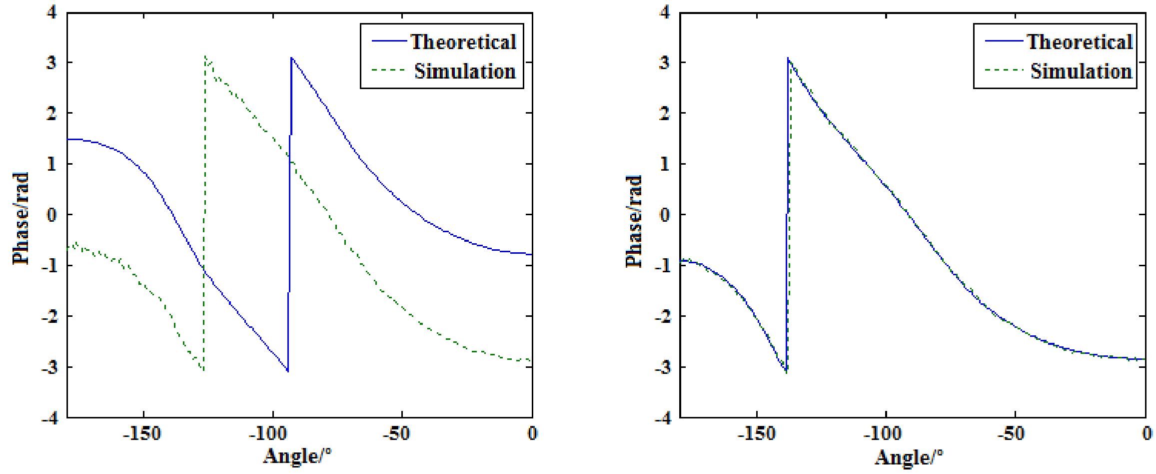
In order to verify the feasibility of calculating elastic shell scattering problem by using boundary element software, we compared the theoretical results with the simulation results. Firstly, we used the finite element software ANSYS modeling and meshing, and then imported the meshing data into SYSNOISE to simulate. The analysis model is coupled direct boundary element in frequency domain (9).

We simulated scattering characteristics of elastic spherical shells when plane and spherical waves radiating and elastic cylindrical shells when plane wave radiating separately. The fluid medium is water, acoustic velocity is 1500 m/s, density is 1000 kg/m^3, material of shell is iron, radius of spherical shell is 1 m, thickness of shell is 8mm, the incident acoustic pressure amplitude is 1 Pa, the distance from point source to center of sphere is 2 m, simulation frequency is 1 kHz, field points to be calculated are arcs with the radius of 1.01 m and 1.1 m and angles of $\theta \in [-\pi,0]$, step is 1°, the incident direction of acoustic source is from $\theta = -\pi$. Because simulation software cannot generate infinite model, we used finite cylinder that height is much larger than radius instead. Radius of cylindrical shell is 0.1 m, height is 10 m, shell thickness is 8mm, the incident acoustic pressure is 100 Pa, the incident plane wave direction is from $\theta = -\pi$, field points are arc with radius of 0.15 m and angles of $\theta \in [-\pi,0]$, located at the middle of the axis, step is 1°. Through theoretical calculation and SYSNOISE simulation, the scattering pressure amplitude and phase of elastic spherical shell when plane wave radiating are shown in Figure 2 and Figure 3. The scattering pressure amplitude and phase of elastic spherical shell when spherical wave radiating are shown in Figure 4 and Figure 5. The scattering pressure amplitude and phase of elastic cylindrical shell when plane wave radiating are shown in Figure 6.



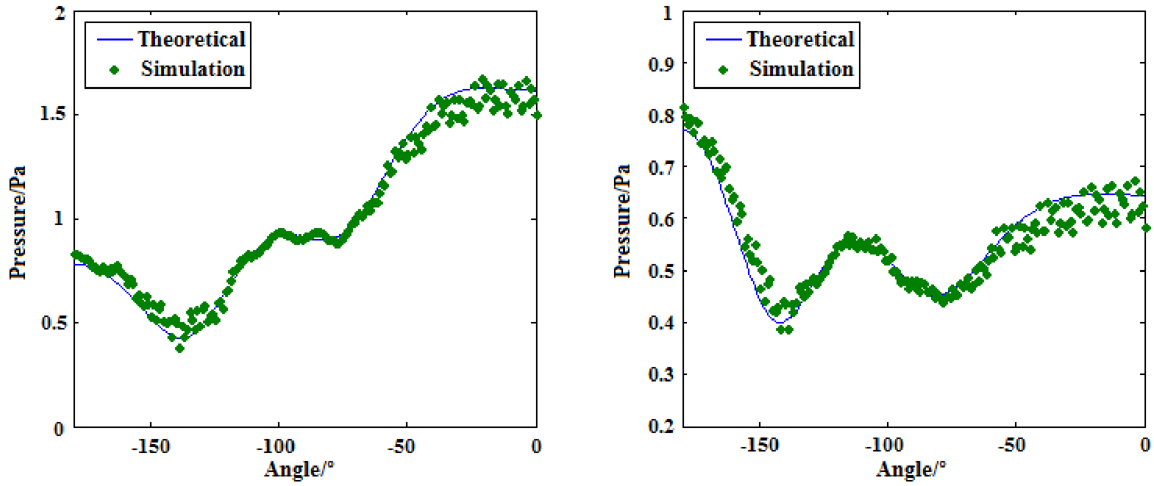
(a) Radius of field points is 1.01m (b) Radius of field points is 1.1m

Figure 2 - Scattering pressure amplitude of elastic spherical shell when plane wave



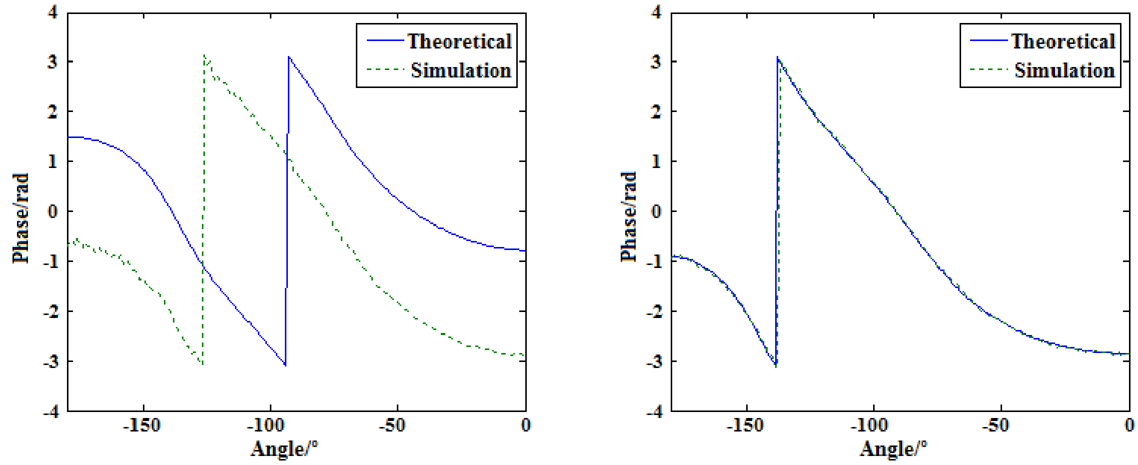
(a) Radius of field points is 1.01m (b) Radius of field points is 1.1m

Figure 3 - Scattering pressure phase of elastic spherical shell when plane wave radiating



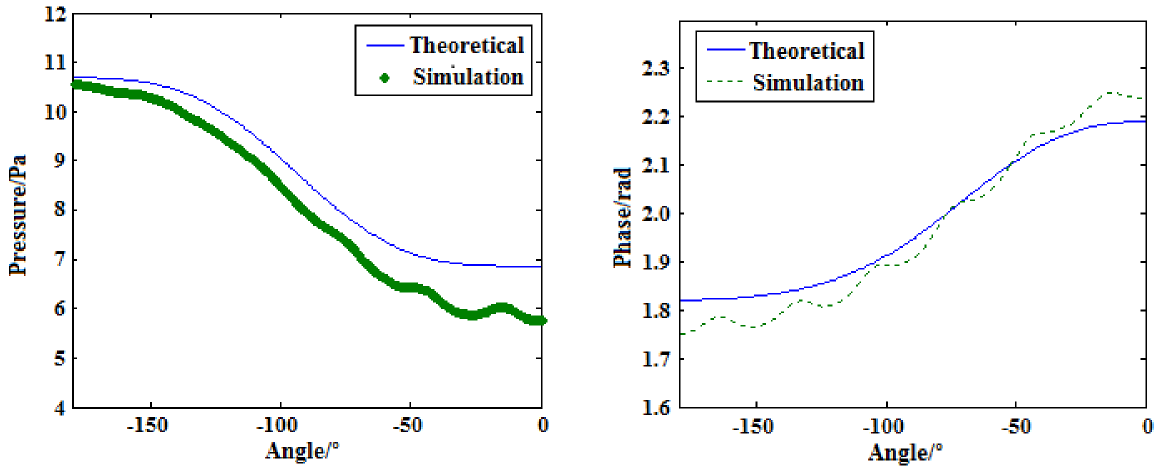
(a) Radius of field points is 1.01m (b) Radius of field points is 1.1m

Figure 4 - Scattering pressure amplitude of elastic spherical shell when spherical wave



(a) Radius of field points is 1.01m (b) Radius of field points is 1.1m

Figure 5 - Scattering pressure phase of elastic spherical shell when spherical wave radiating



(a) Amplitude (b) Phase

Figure 6 - Scattering pressure of elastic cylindrical shell when plane wave radiating

Figure 2-6 indicates that the results calculated by SYSNOISE are consistent with the theoretical results both in amplitude and phase. Where cylindrical shell has the biggest error between simulation and theoretical results. The reason is that theoretical model is an infinite long cylinder while simulation model is a finite long cylinder instead. In summary, validity and reliability of our forecasting method can be verified preliminary. Wherein, when plane waves radiating, the initial phases of theoretical calculation and simulation are different, leading to a result that the overall phases shift. But it does not affect the conclusion drawn.

4. EXPERIMENTAL MEASUREMENT AND SIMULATION ANALYSIS OF COMPLEX SHELL MODEL

4.1 Experiment Measurement

Tests are accomplished in an anechoic pool with the size of 50×10×15 m^3, length of the model is 4.1 m and diameter is 0.9 m. The first section of the model is an ellipsoidal head, the middle section is a cylindrical shell with two cylindrical covers at flank, and the tail section is a conical shell. Thickness of the shell is 8 mm, material is iron. The model is full of air inside, hanging in the water with the nearest distance of 5 m to the boundaries. The acoustic source is a point source with a distance of 0.2 m to the tail section, transmitting continuous wave pulse signals of 6 ms length and 500 ms interval. There are 6 hydrophones fixed at the flank of the model. The relative position of the model, the acoustic source and hydrophones is shown in Figure 7.

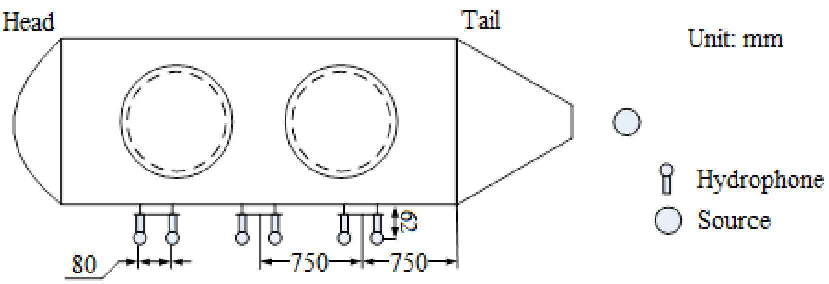


Figure 7 - Relative position of model, source and hydrophones from vertical view

4.2 Simulation

3D mesh model is established by ANSYS shown in Figure 8 and is imported into SYSNOISE. The size, material, thickness etc. of the model are consistent of experimental model. The element type is shell. Setting the model in an infinite fluid field, acoustic source is a point source at 0.2 m far from the tail section, material of fluid is water, acoustic velocity is 1500 m/s, and density is 1000 kg/m^3. The scattering field is calculated by coupled direct boundary element method in frequency domain.

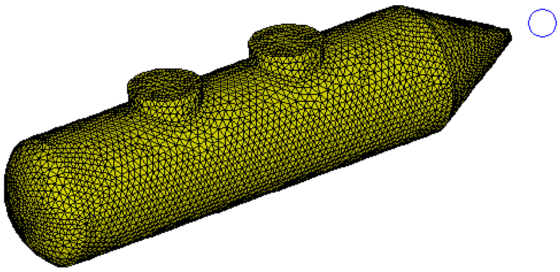
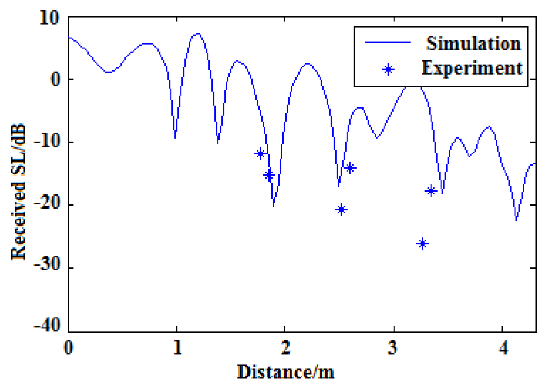


Figure 8 - Arrangement of source and simulation mesh of the shell model

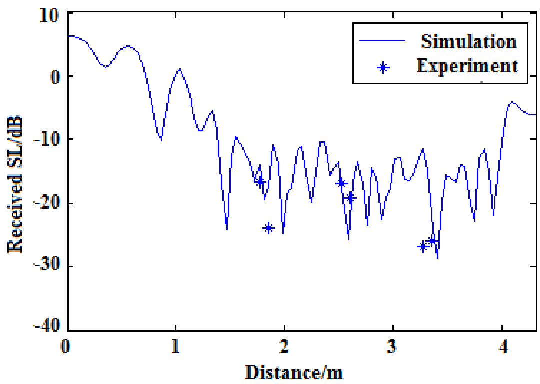
4.3 Experimental and Simulation Results

Figure 9 shows the experimental and simulation results of the hydrophones. Y-coordinate is the relative source level between received and transmitting source level, and X-coordinate is transverse distance from field points to the source. The 6 points in each plot indicate 6 hydrophones' data separately.

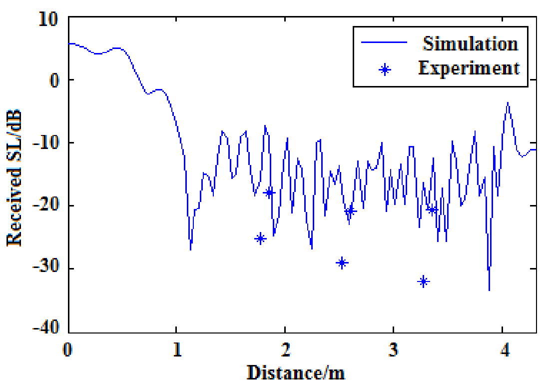
As can be seen from the figure, the experimental measured data is broadly in line with the simulation data. Due to the large near-field fluctuation, measurements are difficult to be conducted in near-field. The more accurate results need further testing.



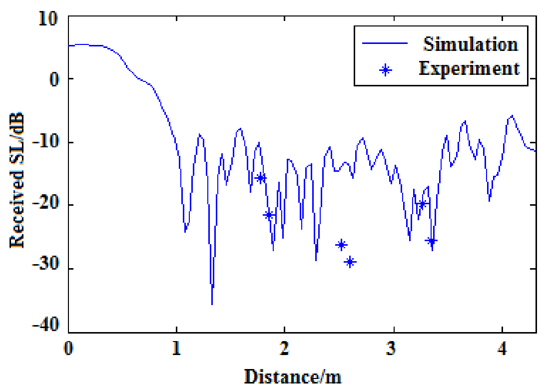
(a) 1kHz



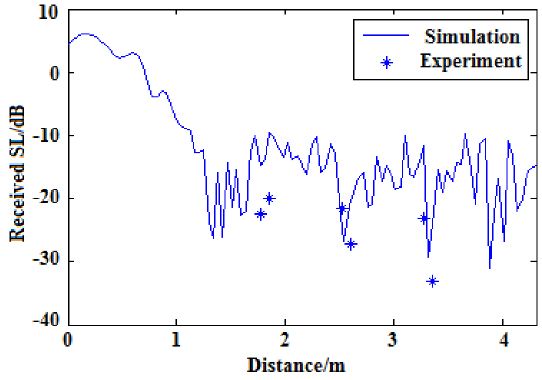
(b) 2kHz



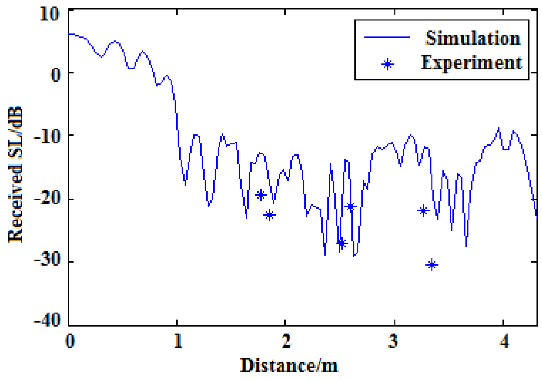
(c) 2.5kHz



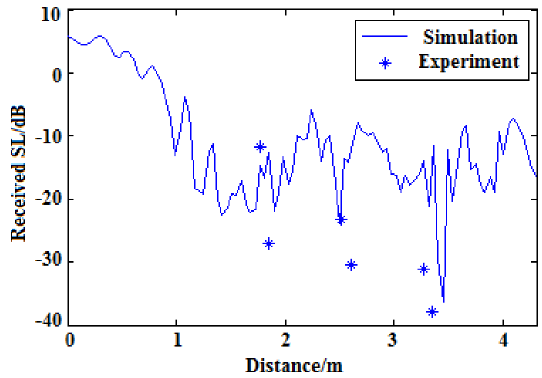
(d) 3kHz



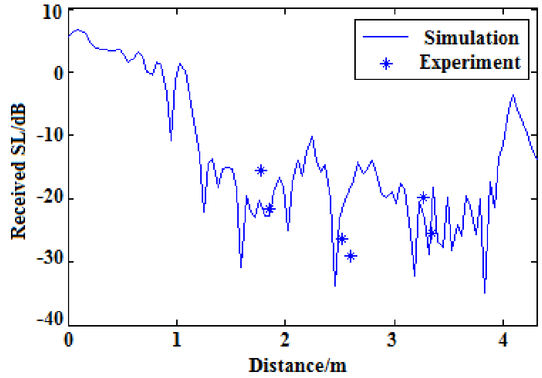
(e) 3.5kHz



(f) 4kHz



(g) 4.5kHz



(h) 5kHz

Figure 9 - Comparison of experimental and simulation results

5. CONCLUSIONS

A simulation method of near-field scattering characteristics of underwater complex shells by using boundary element software is proposed. Firstly, we use theoretical results of rule models to verify the accuracy of the method both in amplitude and phase. Then experimental measured results and simulation results of irregular model are compared to validate the effectiveness and reliability of this method more forcefully. Above all, the simulation method can be used to forecast near-field scattering characteristics of underwater complex shells with specific excitation, such as self-noise problems caused by wake flow or propellers, to reduce the design cycle of structure model.

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