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# Estimation and Optimization of Vertical Array Shape in Steady Uniform Flow

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**Abstract.** In use of vertical array to measure underwater target sound signal, the shape of vertical array is changed by current, the offset angle can be reduced by hanging a heavy object or by add fairing around floating body or by add roughness on vertical array surface . The model to predict the line style in stream is dealt with in this paper. Different method and iteration algorithm are used in the mode, and an underwater acoustic method is given to monitor the line style in real time. Both of the predict model and the method of monitor are used in a practice test, and the result illustrates the accuracy of the predict model and its utility in the design and application of vertical array.

**Keywords:** vertical array, array shape prediction, array shape optimization, different method.

## 1. Introduction

Using vertical array to test acoustic signal, the vertical array shape is changed by the action of water flow, which deduces measurement accuracy [1,2,3]. A prediction model of overhang type vertical shape is given by WANG [4], but the model doesn't consider the influence of the resistance change with vertical array deflection angle when calculating resistance caused by water flow. A method of polynomial fitting is given by ZHANG [5], which proves that the vertical array shape is parabolic under the condition of zero buoyancy and steady flow, and fits the vertical array shape under the action of the non-uniform flow. In this paper, a prediction model of vertical shape which given by ZHANG is improved by using micro decomposition and loop iterative to forecast suspension vertical array shape underwater. The noise measurement results are revised according to the forecast results. In order to improve the measurement accuracy, the vertical array shape underwater should be remained upright as possible. Through optimization analysis, the vertical array shape underwater can be improved by increasing buoyancy and reducing resistance.

## 2. Theory of forecast

The vertical array shape underwater can be estimation by analyzing the force balance state of every vertical array segment. Force analysis of vertical array and floating body in steady stream. The weight of floating body underwater is $G_1$, the external diameter is $d_1$ and the length is $l_1$. The weight of vertical array underwater is $G_2$, the external diameter is $d_2$ and the length is $l_2$. The vertical array is pushed by current and hanged by floating body. $\Delta G$ is each vertical array segment's weight, $F_1$ is current force acting on floating body, $F_2,\ldots,F_n$ is current force acting on each vertical array segment. Vertical array keeps balance under the action of resultant force.

Force analysis starts from floating body on the top to each vertical array segment below step by step using infinitesimal analysis method. Coordinate *xoz* is established setting the center of the floating body as the origin of coordinates as shown in Fig. 1. Vertical array is divided into *n* segment, and each force equilibrium equations is given as shown in Eq. 2- Eq. 4.

There, $L_1$ is tensile force of first segment acts on floating body. $L_i (i = 2,...,n)$ is tensile force of segment *i* acts on segment *i*-1; $\Delta G$ is the weight of each vertical array segment underwater, and $\Delta G = G_2 / n$ . $F_1^{'}$ is current force acting on floating body vertical to the velocity of far field, $F_1^{'} = F_1 / \cos\theta_1$, $\Delta F$ is current force acting on each vertical array segment vertical to the velocity of far field, $\theta_1$ is drift angle of first vertical array segment and $\Delta F = F_T / n$. $F_T$ is current force acting on whole vertical array vertical to the velocity of far field; $F_1^{'}$ and $F_T$ are calculated by the semi-empirical formula[6] as shown in Eq. 5.

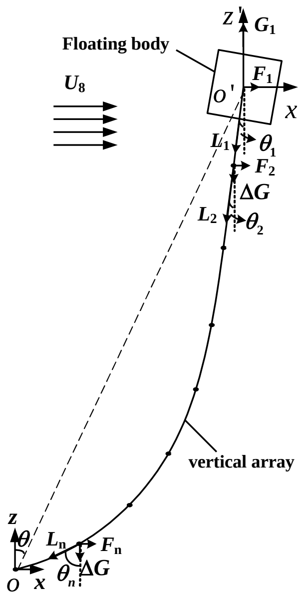



**Figure 1.** Force analysis of vertical array in steady stream.

$$\begin{cases} x_0^{'} = 0 \\ z_0^{'} = 0 \end{cases} \tag{1}$$

$$\begin{cases} \begin{cases} L_1 \cdot \cos\theta_1 = G_1 \\ L_1 \cdot \sin\theta_1 = F_1 \end{cases} \\ \sin^2\theta_1 + \dfrac{G_1}{F_1^{'}} \sin\theta_1 - 1 = 0 \\ \begin{cases} x_1^{'} = x_0^{'} - l_1 \cdot \sin\theta_1 \\ z_1^{'} = z_0^{'} - l_1 \cdot \cos\theta_1 \end{cases} \end{cases} \tag{2}$$

$$\begin{cases} \begin{cases} L_2 \cdot \cos\theta_2 = L_1 \cdot \cos\theta_1 + \Delta G \\ L_2 \cdot \sin\theta_2 = L_1 \cdot \sin\theta_1 + F_2 \end{cases} \\ \sin^2\theta_2 + \dfrac{G_1 + \Delta G}{F_1^{'} + \Delta F}\sin\theta_2 - 1 = 0 \\ \begin{cases} x_2^{'} = x_1^{'} - l_2 \cdot \sin\theta_2 / n \\ z_2^{'} = z_1^{'} - l_2 \cdot \cos\theta_2 / n \end{cases} \end{cases} \tag{3}$$

$$\begin{cases} \begin{cases} L_n \cdot \cos\theta_n = L_{n-1} \cdot \cos\theta_{n-1} + \Delta G \\ L_n \cdot \sin\theta_n = L_{n-1} \cdot \sin\theta_{n-1} + F_n \end{cases} \\ \sin^2\theta_n + \dfrac{G_1 + (n-1)\Delta G}{F_1^{'} + (n-1)\Delta F}\sin\theta_2 - 1 = 0 \\ \begin{cases} x_n^{'} = x_{n-1}^{'} - l_2 \cdot \sin\theta_n / n \\ z_n^{'} = z_{n-1}^{'} - l_2 \cdot \cos\theta_n / n \end{cases} \end{cases} \tag{4}$$

$$F_i = \frac{1}{2} C_{Di} \cdot \rho u_\infty^2 S_i \tag{5}$$

There, $C_{Di}$ is drag coefficient, $\rho$ is drag Medium density, $S_i$ is incident flow area of each segment, $u_\infty$ is flow velocity. Drift angle and coordinate position of each vertical array segment is calculated, and the vertical array shape can be obtained. The shape of vertical array is predicted by coordinate transformation as shown in Eq. 6.

$$\begin{cases} x_i = x_i^{'} - x_n^{'} \\ z_i = z_i^{'} - z_n^{'} \end{cases} \tag{6}$$

In calculations, $G_1$ is 88kg or108kg, d1 is 0.636m, $l_1$ is 1.133m; $G_2$ is -22kg, $d_2$ is 0.068m, l2 is 56.45m, $C_{Di}$ is drag coefficient, which values is determined to cross section shape; Drag coefficient of floating body is 0.66, and that of vertical array is 1.2; Seawater density ρ is 1026 kg/m3; u∞ is 1kont or 2 knots. Vertical array shape is predicted by program calculation.

According to Fig. 2, curvature of vertical array is much small when $G_1$ is 108kg and $u_\infty$ is 1 kont, $\theta$ (declination angle of vertical array as shown in Figure 1) is 34.1°, but curvature of vertical array is much small when $G_1$ is 108kg and $u_\infty$ is 2 konts, $\theta$ is 59.2°, so vertical array shape is influenced by current velocity. According to Fig. 3, vertical array shape is also influenced by floating body weight, the littler deformation of vertical array shape the heavier of floating body; $\theta$ is 39.4° when $G_1$ is 88kg and $u_\infty$ is 1kont, and $\theta$ is 29.8° when $G_1$ is 128kg and $u_\infty$ is 1kont, so vertical array shape can be improved by increasing floating body weight, but underwater mass should be increased with floating body weight increasing, which brings inconvenience in actual test.

## 3. Optimization analysis of drag reduction

### *3.1. Add fairing around floating body*

Through calculation and analysis, the floating body produces great resistance under the action of the current, the drag coefficient $C_D$ is 1.2, but the fairing produces small resistance under the action of the current, the drag coefficient $C_D$ is 0.07. Setting fairing weight as 0 kg underwater, vertical array shape is predicted as shown in figure 4. The dotted line is vertical array shape adding fairing around floating body. $\theta$ is 32.3 ° when $G_1$ is 108kg and $u_\infty$ is 1 kont, and $\theta$ is 57.9 ° when $G_1$ is 108kg and $u_\infty$ is 2 konts, so vertical array shape can be optimized with adding streamlined shell around floating body.

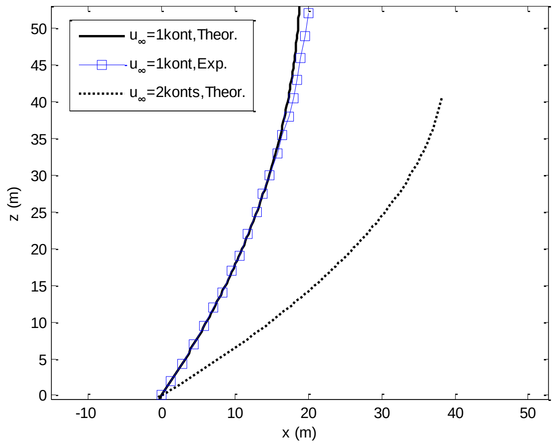



**Figure 2.** Vertical array shape in different velocity stream.

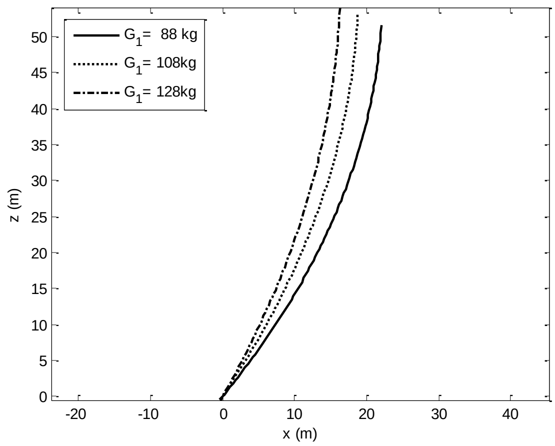
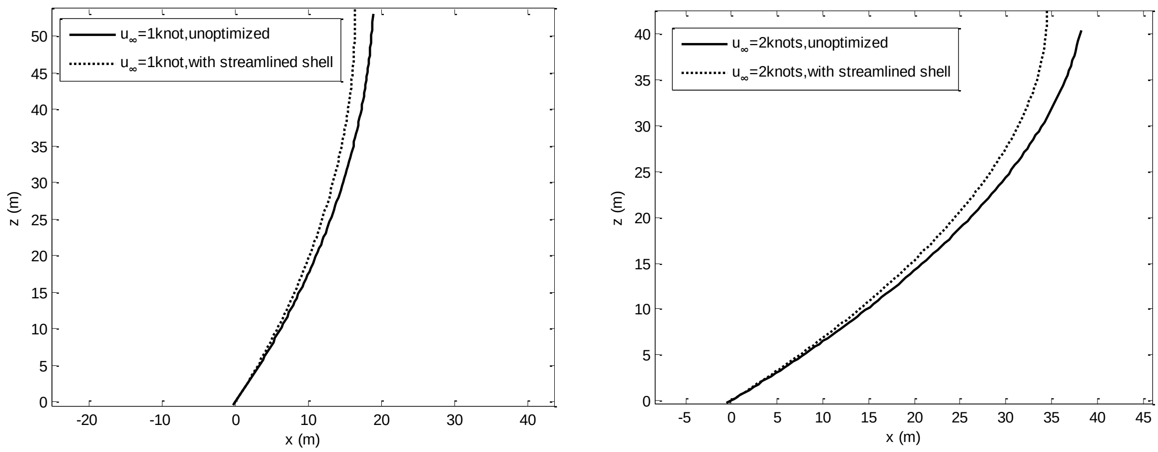



**Figure 3.** Vertical array shape in different buoyancy.




(*a*) $u_\infty$=1knot (*b*) $u_\infty$=2knots

**Figure 4.** Vertical array shape of unoptimized and with adding streamlined shell around float bowl.

### *3.2. Add roughness on vertical array surface*

When water flows around cylinder, if the flow in the boundary layer is laminar flow, the velocity of water near the surface of the cylinder is very small, causing separation of the boundary layer prematurely, resulting in a larger pressure difference resistance, and the drag coefficient of the slender cylinder is usually taken as 1.2; If the flow in the boundary layer is turbulent flow, the velocity of water near the surface of the cylinder is much more lager, causing separation of the boundary layer lately, resulting in a smaller pressure difference resistance, and the drag coefficient of the slender cylinder is usually taken as 0.8[7]. Actually, the flow in the boundary layer is laminar flow when the velocity of current is 2 knots. The flow in the boundary layer can be changed into turbulent flow by adding roughness on vertical array surface which named as artificial torrent.

According to Fig. 5, three vertical array shape are shown under different condition when $G_1$ is 108kg and $u_\infty$ is 1 knot. The third curve is very close to line by adding roughness and fairing around floating body, and $\theta$ is 24.5°. According to Fig. 6, three vertical array shape are shown under different condition when $G_1$ is 108kg and $u_\infty$ is 2 knots. $\theta$ is 51.4° with adding roughness on vertical array surface. $\theta$ is 47.6° with adding roughness on vertical array surface and streamlined shell around floating body.

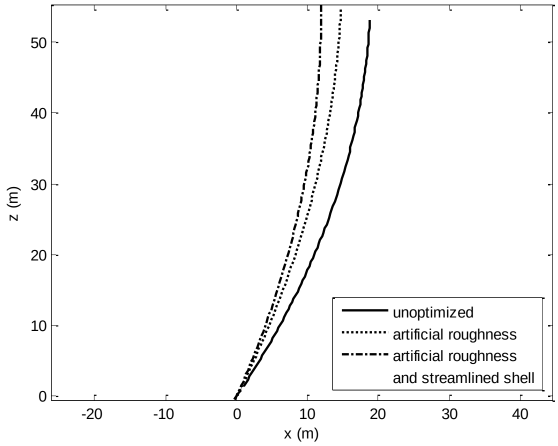



**Figure 5.** Vertical array shape in 1knots stream with adding roughness.

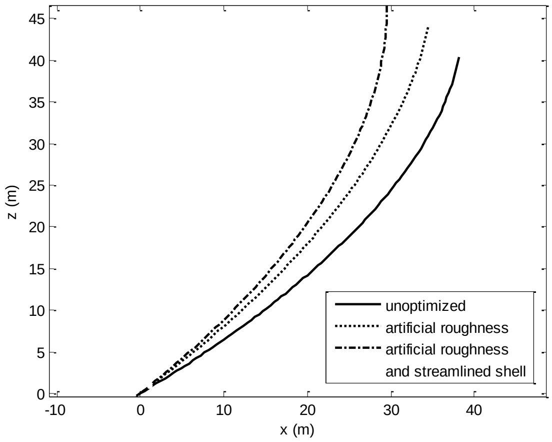



**Figure 6.** Vertical array shape in 2 knots stream with adding roughness and streamlined shell.

## 4. Summary

A prediction model of vertical array shape is improved, and accuracy of formation prediction is also improved, which providing theoretical support for the sea test and data processing. Through drag reduction optimization analysis, either adding fairing around floating body or adding roughness on vertical array surface can improve the vertical array shape underwater. Both adding fairing around floating body and adding roughness on vertical array surface can improve the vertical array shape underwater much better; The curve is very close to line when $u_\infty$ is 1 knots, which has very little effect on the measurement results; the curvature of the vertical array shape is changed a little, which can adapt to the complicated sea conditions when $u_\infty$ is 2 knots.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