Evaluation on the Flow Field Effects by the Changes of Artificial Reef Shapes

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Abstract. The artificial reef changes the flow field which will impact the surrounding fish's tropism and distribution. In this paper, FLUENT is used to simulate the flow field of three sets of artificial reefs including different size of the opening, inflow angle and cylinder shape and the change of the shape effect of flow field are discussed. Then, fuzzy evaluation method is applied to evaluate the flow field effect caused by the above three groups of artificial reef. Finally, in order to provide a theoretical basis for the optimization of the shape of artificial reefs, a special combination of three sets of optimal specimen and the three best specimens have been evaluated to verify the rationality of the evaluation system.

Introduction
Due to the human over-exploitation and utilization of fishery resources, fishery resource is facing a severe recession. Artificial reefs have been proved to be an effective way to protect and improve the marine ecological environment, to increase the amount of biological resources, to improve the ecological environment of the coastal waters and to conserve of fishery resources functions. After launching artificial reefs, the flow field near the reef will be changed, a upwelling is produced in the front of the reef and a back vortex is produced at the back of the reef[1]. The change will affect the distribution of the sediment, nutrients, etc., and there will be an impact on the surrounding fish’s tropism and distribution[2-3]. Therefore, the researches of the flow characteristics around the artificial reefs become more popular in recent years. The research of the complex flow field-effect around artificial reefs has been more mature, however, the systematic evaluation of the different shapes of the artificial reef effect of convection field has not been put forward.

In this paper a fuzzy evaluation on the effect of artificial reef shape change convection field effect has been performed to make a good evaluation on the shape of artificial reef.

Model
The calculation model used in this paper is VOF two-phase flow model, which is solved by using Fluent.

Governing Equation
(1) Continuity equation:
\[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \]  
(1)

(2) Momentum conservation equation:
\[ \frac{\partial (\rho u)}{\partial t} + \text{div}(\rho u u) = \text{div}(\mu \text{grad}u) - \frac{\partial p}{\partial x} + S_u \]  
(2)

\[ \frac{\partial (\rho v)}{\partial t} + \text{div}(\rho v v) = \text{div}(\mu \text{grad}v) - \frac{\partial p}{\partial y} + S_v \]  
(3)
\[
\frac{\partial (\rho w)}{\partial t} + \text{div} (\rho w \vec{u}) = \text{div} (\mu \text{grad} w) - \frac{\partial p}{\partial z} + S_w
\]  \hspace{1cm} (4)

Where \( u, v \) and \( w \) are the velocity in the \( x, y, \) and \( z \) direction, respectively. \( t \) is the time, \( \rho \) is the density of fluid, \( \vec{u} \) is the vector of velocity, \( \mu \) is the dynamic viscosity, \( p \) is the pressure, \( S_u, \) and \( S_v, \) and \( S_w \) are the generalized source terms of the equation to the momentum conservation.

**Turbulence Model**

\( K - \varepsilon \) turbulent model, the viscosity coefficient equation is given below\(^4\):

\[
\rho \frac{\partial k}{\partial t} + \rho u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \left( \eta + \eta_t \right) \frac{\partial k}{\partial x_j} \right] + \eta_t \frac{\partial u_i}{\partial x_j} \left( \frac{\partial u_j}{\partial x_i} + \frac{\partial u_j}{\partial x_i} \right) - \rho \varepsilon
\]  \hspace{1cm} (5)

\[
\frac{\partial \varepsilon}{\partial t} + \rho u_k \frac{\partial \varepsilon}{\partial x_k} = \frac{\partial}{\partial x_k} \left[ \left( \eta + \eta_t \right) \frac{\partial \varepsilon}{\partial x_k} \right] + \frac{c_1 \varepsilon}{k} \eta_t \frac{\partial u_i}{\partial x_j} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{c_2 \rho \varepsilon^2}{k}
\]  \hspace{1cm} (6)

\[
\eta_t = \frac{c_u \rho k^2}{\varepsilon} = \frac{c_u c_D}{c_D} \frac{1}{\varepsilon}
\]  \hspace{1cm} (7)

\[
c_u = c_u' c_D
\]  \hspace{1cm} (8)

The equation introduces coefficients \( c_1, c_2, c_u, \) and \( \sigma_k, \sigma_\varepsilon, \sigma_T, \) in this calculation, these empirical constants are 1.44, 1.92, 0.09, 1.0, 1.3, and 0.9~1.0 respectively.

**Computational Area and Mesh Generation**

A sink with 1.6m long, 0.45m wide and 0.6m high was adopted in this calculation, as shown in Fig.1. The water depth is 0.4 m and the artificial reef is put in the center of the sink. A hybrid grid is used to combine the characteristics of the structural grid computing efficiency and the complex boundary of the unstructured grid, and the grid is discrete to the computing domain using Gambit.

**Boundary Conditions and Parameter Settings**

Fluent is based on finite volume method, the algorithm of steady-state solver is selected as PISO algorithm. Air is the first phase, and the water is the second phase. The pressure reference point which is located at sink on the surface does not change via time, air density is set to be 1.225 g/cm\(^3\), water inlet velocity boundary is 0.18 m/s, the reef body model, the bottom and sides of the sink are set to be wall, friction coefficient is 0.5, choose 5000 iteration steps, which can achieve convergence.

**Simulation of Flow Field**

This paper mainly analyzes two aspects of the shapes of fish reefs: opening ratio and the shape of a cylinder optimal artificial reef for sorting. The distribution of flow fields around the fish reefs with the opening ratio of 0, 0.1, 0.2, 0.3, 0.4 and 0.5 is shown in Fig. 2. The numerical simulation of three prismatic columns, four prisms, five prisms, six prisms and cylindrical flow fields respectively is shown in Fig. 3.
Evaluation Method

In this paper the method of fuzzy evaluation is adapted to evaluate the results of the numerical simulation. An artificial reef evaluation method considering various factors is proposed, and a good artificial reef scheme of flow field effect is proposed.

Fuzzy Evaluation Method

Fuzzy theory was proposed by American automation expert professor L.A. Zadeh in 1965. A system or object that evaluates to a fuzzy concept. The method used is very logical. Demanding mathematical methods are often called fuzzy mathematics, and the fuzzy assessment process is as follows:
(1) List the characteristic value of matrix: (each evaluation object has m indicators, and evaluates the advantages and disadvantages of n schemes.)

\[
X = \begin{bmatrix}
x_{11} & x_{12} & \cdots & x_{1n} \\
x_{21} & x_{22} & \cdots & x_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix}
\]

\[
i=1, 2, \ldots, m, j=1, 2, \ldots, n, \text{ which } X_{ij} \text{ is the } i \text{ characteristic value of scheme } j \text{ index.}
\]

(2) Defining characteristic value type:

The larger the value, the better. The corresponding index of the maximum characteristic value of the scheme concentration indicator i is 1, and the characteristic value of the target is 0. The smallest index has a relative membership of 0, which makes up the pros and cons.

Its relative membership matrix is:

\[
R = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1n} \\
r_{21} & r_{22} & \cdots & r_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

\[
r_{ij} \text{ is referred to as the relative superiority of the programme index.}
\]

\[
r_{ij}^r = \frac{x_{ij} - x_{imin}}{x_{imax} - x_{imin}}
\]

Selection of Evaluation Indexes

After launching the reef on the bottom of the nearshore, it can change the direction of flow, wave, tide and so on and can produce upwelling and backflow around the reef. The upwelling can promote the exchange of upper and lower sea water, increase the oxygen content of water body, and promote the exchange of nutritive salt. The formation of backflow vortex can slow the flow rate, which is conducive to the accumulation of feeding organisms and the breeding of the attached organisms, along with the sediment of the base and nutrient salts. Therefore, the scale of upwelling and eddy current scale can be used as the evaluation index for the effect of fish reef flow field. In addition, the surface area provided by artificial reefs can provide habitats for fish. Based on the above, this paper first discusses the following aspects in the selection of indicators: upwelling, back eddy and reef surface area.

Establishment of Evaluating System

(1) Evaluation index system model

To determine evaluation index, this paper uses analytic hierarchy process, to build a coherent for flow field of artificial reefs effect evaluation index system and the selection of indicators are stratified. It is divided into two levels: the first layer is the target layer, which is the flow field effect of artificial reefs. The second layer is the criterion layer, which includes three indicators: upwelling, backflow and reef surface area, which are again sub-standard layer for uplift and backflow. Scheme layer: it is a further subdivision of the three indicators in the criterion layer for more accurate evaluation of its comprehensive evaluation. The indicators of the above layers are represented as tree-like hierarchical structure diagrams, as shown in Fig.4, thus a reasonable evaluation system is established.
(2) Determination of weights:

Based on the artificial reef to affirm the target weights of the evaluation of the effect of flow field, to minimize the subjective factors of the evaluation process, the expert consulting method (Delphi) and analytic hierarchy process (AHP) with the combination of methods. First of all, through the analytic hierarchy process to establish a comprehensive evaluation index system of the flow field effect of artificial reefs and by establish the blank form and attach selected indicators on the basis of background information, such as printing, by the artificial reef and fluid mechanics experts, to establish judgment matrix. After the expert scores were recovered, the criteria of the selected indicators were reassessed, and the judgment matrix is tested in consistency. In this process, some unnecessary indexes are removed and a more reasonable index system is established. Secondly, it will be determined that a good evaluation system will be sent to the relevant experts in the form of a letter, to evaluate the importance of different indicators, establish comparison matrix, and carry out weight calculation.

Results

Flow effects by different shapes of artificial reefs are evaluated:

Based on the values of the selected indexes, the eigenvalue matrix X is established. The larger the eigenvalue, the better. The relative membership degree of the maximum eigenvalue is 1, and the relative membership of the minimum eigenvalue is 0 and the relative superiority is calculated according to the formula (11). Finally, the relative superiority of each reef flow field effect is calculated and the order is shown in Tab.1 and Tab.2. Compared with the optimal order, the flow field effect is the best when the opening ratio is 0.2, followed by 0.1 and 0.4. For cylinder shape change, the cylindrical flow field has the best effect, followed by four prism and six prism.

<table>
<thead>
<tr>
<th>Open-ratio r</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative superiority</td>
<td>0.5000</td>
<td>0.5222</td>
<td>0.5875</td>
<td>0.4343</td>
<td>0.5168</td>
<td>0.5000</td>
</tr>
<tr>
<td>Relative superiority ranking</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cylinder</th>
<th>Triangular prism</th>
<th>Quadrangular prism</th>
<th>Pentagonal prism</th>
<th>Hexagonal prisms</th>
<th>Cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative superiority</td>
<td>0.3000</td>
<td>0.5554</td>
<td>0.4805</td>
<td>0.5242</td>
<td>0.7000</td>
</tr>
<tr>
<td>Relative superiority ranking</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Discussion

Optimization Design Model

The above numerical simulation is analyzed and compared to obtain the artificial reef with good flow field effect. The fish likes to trap the open fish reef, and when the reef opens, it will promote the circulation of nutrients in the bottom of the body to a certain extent. In the study of the opening ratio, the opening ratio of the opening ratio is 0.2 and the distribution of the eddy current distribution is relatively good. When the surface area of the flow surface is positive three prism, the
upwelling distribution area is larger. The circular flow trend of the cylinder is obvious, and the scale of the back vortex formation is the largest. In this paper, the angle of inflow is 90 degrees, and the final design of the fish reef is a cylinder with a diameter of 10 cm. The middle opening is a cylinder of 2 cm and the reef height is 10 cm. The design is mainly based on the advantage of the upwelling of the triangular prism and the eddy current of the column. The fish reef opening can increase the inhabiting area of the fish, which is beneficial to lure the fish, as shown in Fig. 5. Upwelling model of optimizing design of reefs and back eddy current distribution as shown in Fig. 6, on the basis of the cylindrical fish reef model after optimization design upwelling and back-eddy flow is improved, combines the advantages of three prismatic and cylindrical flow field, in order to increase the fish habitat area, so the opening in the center of the reefs, choose a relatively good opening ratio of 0.2, the reefs upwelling height is 15.31 cm, upwelling width is 9.47 cm. Back-eddy flow height 10.02 cm, back vortex height 11.18 cm, maximum flow velocity of 12.94 cm/s.

Comparison of Artificial Reef Models

Flow field effect of the comprehensive evaluation index for the optimization design model, and his mouth than rectangular and cylindrical 0.2 evaluate the merits of the flow field effect, the optimal size and to the various index, optimal weighted eventually come to the comprehensive As shown in Tab. 3, the optimization design of flow field effect is best, followed by the column.

![Model of artificial reef in optimal design.](image)

![Flow field of around model of artificial reef in optimal design (unit:m/s).](image)

<table>
<thead>
<tr>
<th>Models</th>
<th>Optimization design model</th>
<th>quadrangular prism opening</th>
<th>Cylinder -ratio 0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative superiority</td>
<td>0.8688</td>
<td>0.0147</td>
<td>0.7900</td>
</tr>
<tr>
<td>Relative superiority ranking</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Conclusion

(1) This paper presents a method of fuzzy evaluation and evaluates the numerical simulation results and verifies the feasibility of the evaluation method.

(2) On the basis of the results of the study, the paper raises the fish reef model of optimization design. The main body of artificial reef is the cylinder, and the flow surface adopts 90 degrees of incident flow angle and the opening ratio of the opening ratio is 0.2.
Acknowledgement

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References


