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Numerical simulation of effect of guide plate on flow field of artificial reef

Zhaoyang Jiang, Zhenlin Liang*, Lixin Zhu, Yang Liu

Marine College, Shandong University, Weihai, China

A R T I C L E I N F O

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A B S T R A C T

The main function of artificial reefs is to alter the flow field and form upwelling or complex wake region, which can promote the circulation of water column. A complex structure is considered to be necessary for an artificial reef to form the desirable flow field effect. Actually most of artificial reefs deposited in Shandong Province, China, are simple concrete structural body in recent years, which play little role in promoting the exchange of sea water. Even if the reef is design as a complex structure, it is difficult to manufacture by concrete. Therefore, a guide plate is was designed and installed on a cubic frame reef for a cost-effective purpose. We adopted the CFD method to analyze the function of the guide plate at the formation of upwelling, investigated the effect of the guide plate on flow field scope caused by different structure factors and proposed a specific cubic frame reef having the best performance on which the guide plate was installed. The results indicate that guide plate has a positive function at disturbing flow field. A smaller or larger installation angle has a significant influence on the formation of upwelling.

1. Introduction

It is known that artificial reef is designed to provide the shelters for the juvenile fish inshore and promote the circulation of sea water column between the upper and lower layer. After the placement of artificial reefs, their exposed surface can supply ample substrate for marine algae to attach and grow; the fishery resource can be protected to avoid the catch of illegal fishing gears; and the ecological environment around the artificial reef area will be improved (Brochier et al., 2015; Ponti et al., 2015; Seaman, 2000).

The artificial reef is widely deposited along the coastline of China for over thirty years. In Shandong Province, the primitive development purpose of artificial reef is to offer more adhesive area for sea algae and provide an artificial habitat for the juvenile of benthic species. And most of artificial reefs sank to the seafloor had a simple structures and smaller dimensions, such as pipe, cubic frame or even simple stones, which are usually prepared for the economic species, especially the sea cucumber or abalone. Therefore this primitive development model is considered as an extensive pattern since 2005. This pattern has partly adjusted the local fishery structure and really increased the income and benefit of partial fishermen, which was formulated based on the local fishery situation.

It is a common sense that artificial reef can form upwelling, but a simple structure of artificial reef may not evidently contribute to the formation of upwelling, such as the stone. The unit of artificial reefs piled up mostly by stones can just slow down the tidal speed of lower layer and actually reduce the circulation property of sea water to outside. Moreover, the cages farmed fish are usually suspended in the upper layer of the water column and positioned through mooring systems fixed to the seabed (Wu et al., 2014). While the fish in cage is farmed, the organic waste, such as feces and uneaten feed, sink and is deposited on the bottom sediment. Mineralization of the deposited waste consumes dissolved oxygen in the bottom sediment and releases inorganic nutrients, which can cause eutrophication and oxygen depletion and thus influence the water quality in near-field areas (Wu et al., 2014). All these things mentioned above will make the benthic animals unable to get fresh water full of adequate dissolved oxygen. Therefore, with the increase of investment in simple shape reefs, some serious problems gradually appeared. In recent years, there is a common phenomenon in the northeast coastal area of Shandong province that the sea cucumbers inhabited around the areas of artificial reef massively died, especially during the hyperthermal and rainy summer. It may be related to the thermocline and halocline caused by the slower exchange property of sea water (Liu et al., 2014). During the development period of extensive pattern, the function of artificial reef upwelling did not arouse people's attention too much, even the negative effect emerged. This problem is mainly caused by the lack of cognition in the formation mechanism of artificial reef upwelling, which is necessary to further study.

* Corresponding author. Tel.: +86 631 5688511; fax: +86 631 5688303.
E-mail addresses: jiangzy@sdu.edu.cn (Z. Jiang), liang@ouc.edu.cn (Z. Liang).

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It is usually considered if the shapes and sizes of artificial reefs are more complicated and bigger, the effect on the marine bio resources should be more positive (Woo et al., 2014). The complex structure of artificial reef could contribute to the circulation of nutritive salt between different water layers. Therefore, many specified and complex artificial reefs were designed and put into practice (Gao et al., 2008). But it is hard to prove their positive effect in a short period, especially the effect of flow filed, which usually need the laboratory test or measurement in the sea (Su et al., 2008; Jiang et al., 2010).

With the development of computational fluid dynamics (CFD) method, many information measured hardly by the flume test method can be distinctly exhibited by computer, which can be adopted to optimized the design of artificial reef and shorten its application period. For example, Jiang et al. (2010, 2013, 2014) investigated the effect of reef structure on flow field and stress, and revealed the relationship between Reynolds number (R_e) and drag coefficient (C_d) of artificial reefs. Liu et al. (2012, 2013) carried out numerical analysis to study the flow field around cubic and star-shaped of artificial reefs. Liu and Su (2013) used CFD flow simulation approach to investigate the effect of layout changes on the flow field surrounding reefs. They believed that numerical results should benefit marine biologists and ocean engineers by revealing various flow patterns of different reef blocks layouts to consolidate the deployment strategy of artificial reefs. Moreover, Woo et al. (2014) and Kim et al. (2014) have analyzed the drag coefficients, wake lengths and structural responses of Korean general artificial reefs. Therefore, the flow field effect caused by the structural changes of artificial reef can be portended by CFD method before its deposition into the target sea area.

Concrete is a usual material of artificial reef for its higher density and fabricability. However, if the structure of artificial reef is more complex and its dimension is bigger, it is difficult to manufacture by concrete. Even such type of artificial reef is made, it is difficult to favorably hoisting and deposit into the target sea area for its unusual weight (Seaman, 2000; Li and Zhang, 2010; Liu et al., 2013). In view of this puzzle, Yuan et al. (2013) put forward a design idea to optimize the structure of cubic frame reef, which utilize two guide plates installed on the each profiles of frame reef to further alter the structure of flow field (Fig. 1). This type of artificial reef is considered to contribute to the formation of upwelling. It is obviously that the installation angle or the interval between two guide plates will affect the height of upwelling or scope of flow field. Therefore, it is essential to analyze the effect of guide plate on flow field scope and select some optimal cooperation forms with better effect of flow field before the artificial reef is assembled and deposited into the sea.

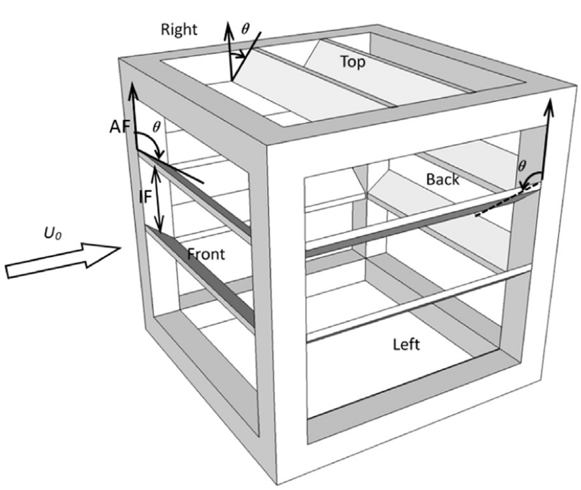

Fig. 1. A cubic frame artificial reef installed guide plates.

In this article, we adopted the CFD method to analyze the function of guide plate at the formation of upwelling, investigated the effect on flow field caused by different structure factors of guide plates and proposed some specific reef forms of cubic frame type installed guide plates. This study can provide a scientific reference for the optimization design of artificial reef.

Table 1
Orthogonal design of the first phase.

No.	Factors									
	AF(°)	IF(m)	AL(°)	IL(m)	AR(°)	IR(m)	AB(°)	IB(m)	AT(°)	IT(m)
1	30	0.3	30	0.3	30	0.3	30	0.3	30	0.3
2	30	0.6	45	0.6	45	0.6	45	0.6	45	0.6
3	30	0.9	60	0.9	60	0.9	60	0.9	60	0.9
4	30	1.2	135	1.2	135	1.2	135	1.2	135	1.2
5	30	1.5	150	1.5	150	1.5	150	1.5	150	1.5
6	45	0.3	45	0.9	135	1.5	30	0.6	60	1.2
7	45	0.6	60	1.2	150	0.3	45	0.9	135	1.5
8	45	0.9	135	1.5	30	0.6	60	1.2	150	0.3
9	45	1.2	150	0.3	45	0.9	135	1.5	30	0.6
10	45	1.5	30	0.6	60	1.2	150	0.3	45	0.9
11	60	0.3	60	1.5	45	1.2	135	0.3	60	1.5
12	60	0.6	135	0.3	60	1.5	150	0.6	135	0.3
13	60	0.9	150	0.6	135	0.3	30	0.9	150	0.6
14	60	1.2	30	0.9	150	0.6	45	1.2	30	0.9
15	60	1.5	45	1.2	30	0.9	60	1.5	45	1.2
16	135	0.3	135	0.6	150	0.9	150	0.9	30	1.2
17	135	0.6	150	0.9	30	1.2	30	1.2	45	1.5
18	135	0.9	30	1.2	45	1.5	45	1.5	60	0.3
19	135	1.2	45	1.5	60	0.3	60	0.3	135	0.6
20	135	1.5	60	0.3	135	0.6	135	0.6	150	0.9
21	150	0.3	150	1.2	60	0.6	135	0.9	45	0.3
22	150	0.6	30	1.5	135	0.9	150	1.2	60	0.6
23	150	0.9	45	0.3	150	1.2	30	1.5	135	0.9
24	150	1.2	60	0.6	30	1.5	45	0.3	150	1.2
25	150	1.5	135	0.9	45	0.3	60	0.6	30	1.5
26	30	0.3	30	1.2	150	1.2	60	0.6	150	0.6
27	30	0.6	45	1.5	30	1.5	135	0.9	30	0.9
28	30	0.9	60	0.3	45	0.3	150	1.2	45	1.2
29	30	1.2	135	0.6	60	0.6	30	1.5	60	1.5
30	30	1.5	150	0.9	135	0.9	45	0.3	135	0.3
31	45	0.3	45	0.3	60	0.9	45	1.2	150	1.5
32	45	0.6	60	0.6	135	1.2	60	1.5	30	0.3
33	45	0.9	135	0.9	150	1.5	135	0.3	45	0.6
34	45	1.2	150	1.2	30	0.3	150	0.6	60	0.9
35	45	1.5	30	1.5	45	0.6	30	0.9	135	1.2
36	60	0.3	60	0.9	30	0.6	150	1.5	135	0.6
37	60	0.6	135	1.2	45	0.9	30	0.3	150	0.9
38	60	0.9	150	1.5	60	1.2	45	0.6	30	1.2
39	60	1.2	30	0.3	135	1.5	60	0.9	45	1.5
40	60	1.5	45	0.6	150	0.3	135	1.2	60	0.3
41	135	0.3	135	1.5	135	0.3	45	1.5	45	0.9
42	135	0.6	150	0.3	150	0.6	60	0.3	60	1.2
43	135	0.9	30	0.6	30	0.9	135	0.6	135	1.5
44	135	1.2	45	0.9	45	1.2	150	0.9	150	0.3
45	135	1.5	60	1.2	60	1.5	30	1.2	30	0.6
46	150	0.3	150	0.6	45	1.5	60	1.2	135	0.9
47	150	0.6	30	0.9	60	0.3	135	1.5	150	1.2
48	150	0.9	45	1.2	135	0.6	150	0.3	30	1.5
49	150	1.2	60	1.5	150	0.9	30	0.6	45	0.3
50	150	1.5	135	0.3	30	1.2	45	0.9	60	0.6

Note: ten factors include: angle of guide plates on the front (AF), interval between two guide plates on the front (IF), angle of guide plates on the left (AL), interval between two guide plates on the left (IL), angle of guide plates on the right (AR), interval between two guide plates on the right (IR), angle of guide plates on the back (AB), interval between two guide plates on the back (IB), angle of guide plates on the top (AT), and interval between two guide plates on the top (IT); The configurations of AF and IF are shown in Fig. 1 as an example.