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Placement Model for Artificial Reefs for Performance Improvement

Dongha Kim[1)], Jinho Woo[1)] and *Won-Bae Na[2)]

[1), 2)] *Department of Ocean Engineering, Pukyong National University, Busan 608-737, Korea*
[2)] *wna@pknu.ac.kr*

ABSTRACT

We carried out flow analysis based on the element-based finite volume method to capture the wake volume of a box-type artificial reef (AR). It is shown that the newly introduced concept – wake volume gives a better approach to quantitatively estimate wake region in comparison with the conventional way – wake length. We found that the wake region of the box-type AR can be increased when the inclination angle become 30 or 60°. At this angle, the wake volume increase from 63 to 95m^3, resulting in 3.51 times the AR volume (27m^3). Also, it is found that the flow velocities specified in the inlet do not have effect on the wake volume; hence, the performance depends solely on the installation angle if the structural stability is assured. Considering the illumination and dissolved oxygen near ARs, which are critical for fish recruitment, the establishment of larger wake region is significant to improve the performance of artificial reefs; hence, the concept and approach of wake volume is desirable.

1. INTRODUCTION

Existing artificial reefs (ARs) and their materials for blocks have weakness in the implantation and inhabitation of marine bio-resources or shortages of durability in marine environments. For example, concrete ARs have a good durability and structural stability. However, their surfaces are smooth and internal material compositions are so dense that the implantation of the spores and roots of marine plants are not easy. Besides, pH, ranging between 12 and 13, represents strong alkali and accordingly the growth of the marine plants is not easy either. On the other hand, steel ARs can be corroded, deteriorated according to the salty environment; hence, they have a strong chance to lose their performance and durability although they can be built in a large scale. Therefore, it is a major issue to develop the fabrication technique and materials development of eco-friendly ARs, which sustain both performance and durability. However, it is not easy because of the shortage of recognition, the incomplete or undeveloped equipment, and/or insufficient of data analysis. As a result, it is necessary to clear what the core techniques should be for the technical and economic arrangement of ARs for establishing a fishery space.

[1)] Graduate Students
[2)] Professor

In oceans, as water depth increases, the light intensity decreases. A certain depth that the quantity of photosynthesis (production of oxygen) equals to volume of breathing (consumption of oxygen) accordingly the net primary production becomes zero is called compensation depth. At the compensation depth, the light intensity is called compensation light intensity. In general, the compensation depth locates below the euphotic zone. The light intensity is one of the major factors helping ARs sustain their performance. Depending on weather (cloudy or sunny), the light intensity versus water depth is quite different; hence, fish collection near ARs even varies with respect to weather. The illumination and dissolved oxygen near ARs are critical for fish recruitment.

Another important factor is wake region for improving the performance of ARs. Here, wake region refers to a counter flow region behind ARs, which induced by vortex. The interaction of an AR with a prevailing water flow usually results in the formation of a wake region with eddies downstream of the reef. It is known that a wake region provides a shelter, a feeding ground, a spawning ground, a rest area, or a temporary stopover of marine bio-resources. Also, eddies and vortices just outside the wake region contain higher turbulence, which attract certain fish species. Therefore, it is better to increase the wake region for attracting marine bio-resources. The schematic flow pattern behind ARs shows how to quantitatively define the wake region, as shown in Fig. 1. In the figure, the net primary production (z) is a function of dissolved oxygen (x) and light intensity (y). It should be noted here that there is a strong debate between production and attraction for the role of wake region. In other words, some scientists point out that wake region just attracts fishes to gather in the region but the others claims that wake region also helps the production of fishes. Therefore, wake region has not been considered for the net primary production. Instead, we use the term “performance.”

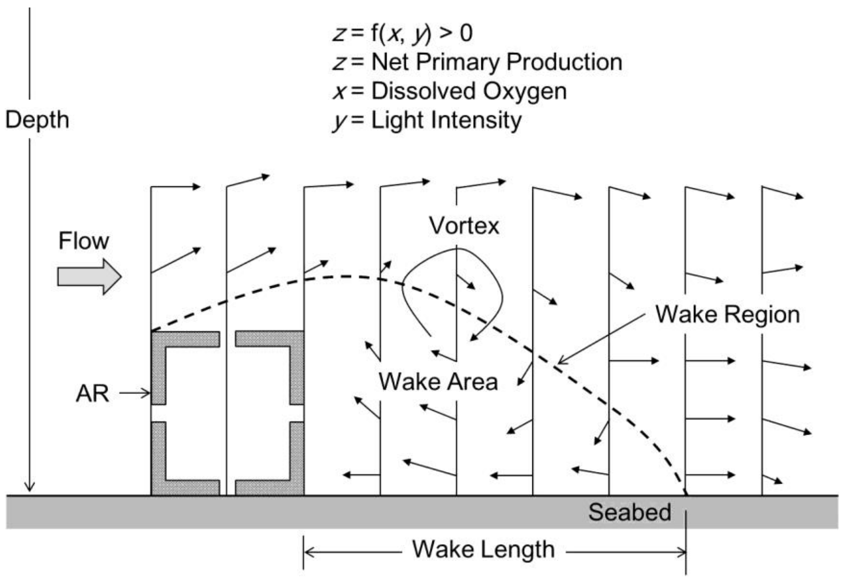


Fig. 1 Net primary production and wake region

The wake region can be represented by the wake area or the wake length as shown in Fig. 1. However, the best way to describe a wake region is the wake volume, if possible, because there are an infinite ways of defining the wake area and length. Recently, Kim et al. (2014) show how to measure wake volume using a numerical method called element-based finite volume method (FVM). Their approach is the first one to quantify the wake volume. Along with the light intensity and dissolved oxygen, wake region is a measure for how ARs work – performance.

This study suggests a placement model of a representative AR to establish the wake region, i.e. a performance improvement of AR. For the purpose, the following works are implemented. First, an assumption is made for the existence of net primary production, which means the target AR is installed at the depth not exceeding the compensation depth. Second, the remaining factor, wake region, is investigated by examining the target AR (box-type). Third, by changing critical design variables such as flow velocity and direction, the best placement model is established. For the flow analyses, ANSYS-CFX is used.

2. MATERIALS AND METHODS

Currently, the number of general ARs in South Korea is 72. The number is expected to be exceeded as time goes because the test and research ARs are in a row to be approved as the general ARs. Many individuals, companies, and research institutes have patented ARs for their own purposes so the patented ARs are ready to be the general upon the approval by the central artificial reef committee, a government power giving the permission in South Korea. Among the 72 ARs, the box-type AR, as shown in Fig. 2, is one of the simplest, widely used ARs. It is made of two materials concrete for the external box and steel for the internal box. The concrete is used for reducing the fabrication cost and the steel is used to help the structure make the internal wake region in addition to the wake region behind the AR. The size is 3×3×3m and their material properties are shown in Table 1. This AR is mainly used for fish attraction and production and its typical installation depth is 20 – 30m. According to the Korean AR practice, at the depth range, the design flow velocity is 2m/s (Woo *et al*. 2014)

To get the flow response, a computational fluid dynamics (CFD) is carried out through facilitating the ANSYS-CFX software package. CFX is popular because it adopts an element-based finite volume method (FVM), which is power to complex shapes, precision, and grid generation (Woo and Na 2014)

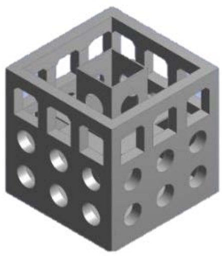
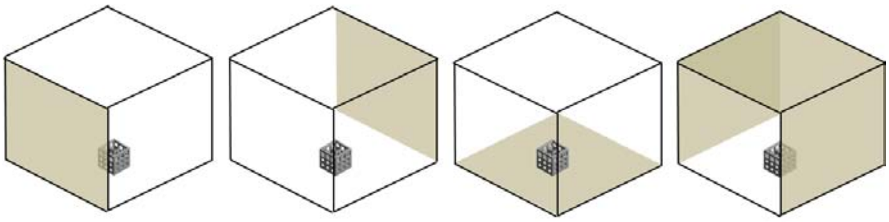


Fig. 2 Box-type artificial reef

Table 1 Material properties of box-type AR

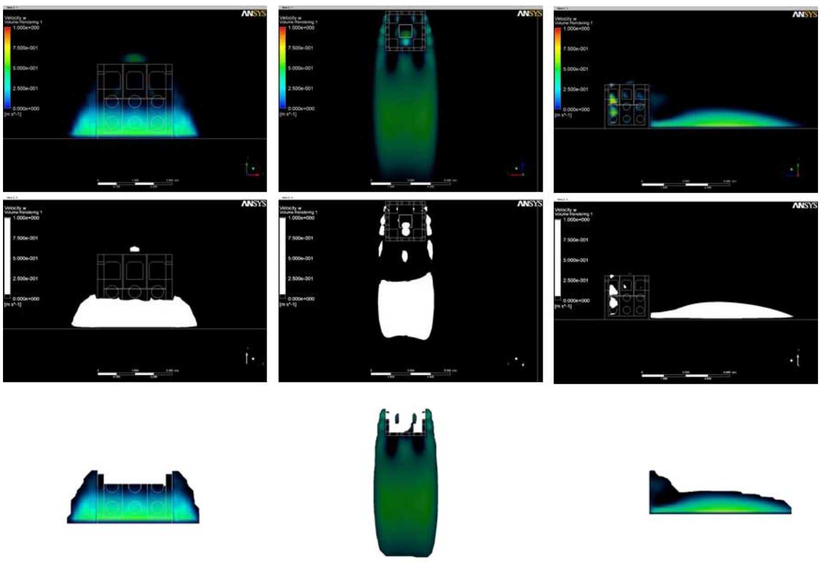
Property	Concrete	Steel
Density (kg/m^3)	2300	7850
Tensile yield strength (Pa)	1.5×10^6	2.5×10^8
Tensile ultimate strength (Pa)	5.0×10^6	4.6×10^8
Compressive yield strength (Pa)	2.1×10^7	2.5×10^8
Compressive ultimate strength (Pa)	4.1×10^7	4.6×10^8



(a) (b) (c) (d)

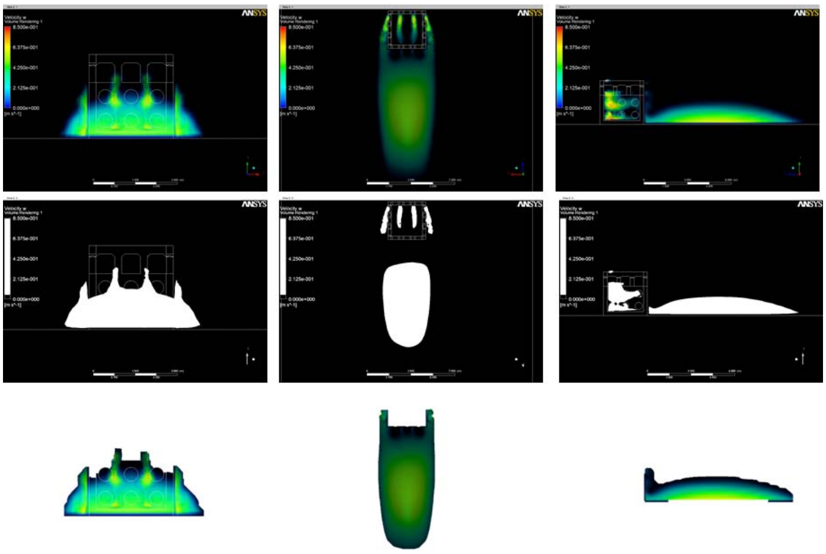
Fig. 3 Flow boundary conditions: (a) inlet, (b) outlet, (c) bottom, (d) symmetry.

As shown in Fig. 3, the flow space is built as 20×20×20m, which is 296 times the AR volume, to reduce the boundary effect on the flow around the AR. The front face is modeled as an inlet, which makes the flow come in the space. The back face is modeled as an outlet, which facilitates the flow go out from the space by assuming zero-pressure. The top, left, and right faces are modeled as symmetries, which reflect the flow space, respectively, as mirrors. The bottom face is modeled as a smooth wall because the face supports the AR.



(a) (b) (c)

Fig. 4. Wake regions of box-type AR: (a) front view, (b) top view, and (c) side view



(a) (b) (c)

Fig. 5 Wake regions modified AR: (a) front view, (b) top view, and (c) side view

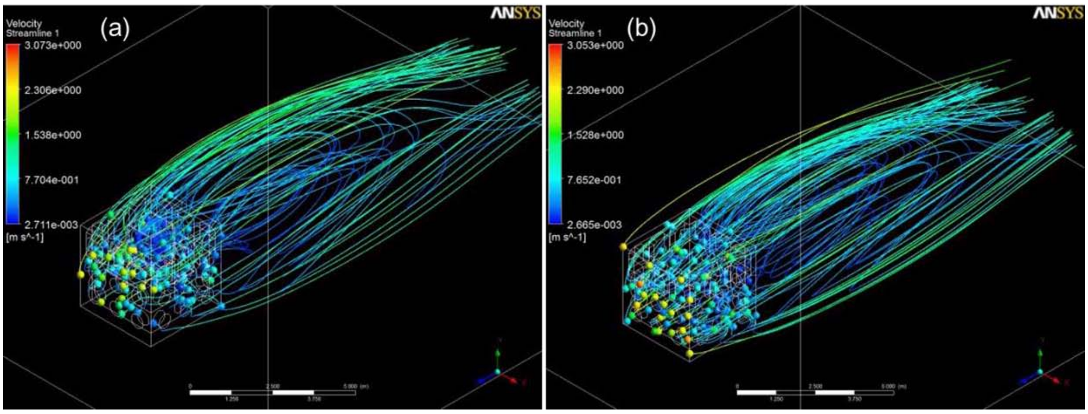


Fig. 6 Streamlines of ARs: (a) box-type AR and (b) modified AR

The internal fluid is assumed incompressible, viscous, and Newtonian water of 25°C. The turbulence model used is the k-ε model, the most common model used in computational fluid dynamics (CFD) to simulate turbulent conditions. It is a two equation model giving a general description of turbulence by means of two transport partial differential equations.

Fig. 4 shows the wake region views of the box-type AR. From the views, it is hard to quantify the wake region. This fact becomes clear when we consider the wake region views of the modified AR, as shown in Fig. 5, which is constructed by removing the internal steel box of the box-type AR. From the views, it is not easy to distinguish the difference between them. Thus, the streamlines are shown in Fig. 6 explaining that the internal circulating flows are much dominant in the box-type AR than those of the modified. Accordingly, it is demanded a method to quantitatively describe the wake region – wake volume. Fig. 7 shows the wake volume of the box-type AR, represented by summation of finite volumes, which have recirculating water flows. Each finite volume is calculated if the average velocity is the reverse to the direction of the initial water flow coming from the inlet. With this method, we investigate the effects of flow direction and flow velocity on wake region.

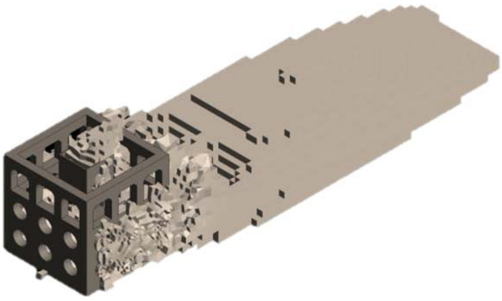


Fig. 7 Wake volume represented by summation of finite volumes, which have recirculating water flows

3. ANALYSIS RESULTS

Fig. 8 shows the linear relation between Reynolds numbers and the flow velocities (0.1, 0.5, 1.0, 2.0, 4.0, and 8.0m/s). All the cases show that the Reynolds numbers exceed 2.35×10^6, which means that turbulence is fully developed. Fig. 9 shows the wake volumes according to the flow velocities. In the case, the inclination angle is fixed to 0°. Here, the 0° Indicates the water flow is orthogonal to the front plane of the AR. It is observed that the volumes converge to about $63m^3$ regardless of the velocities. This observation can be explained by the higher Reynolds numbers in Fig. 8. Accordingly, it is found that wake volume is independent of flow velocity.

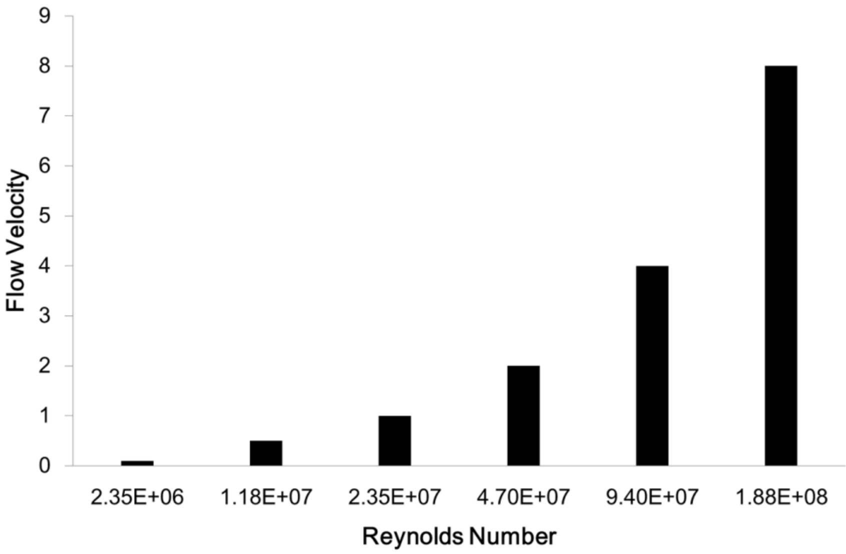


Fig. 8 Relation between Reynolds number and flow velocity

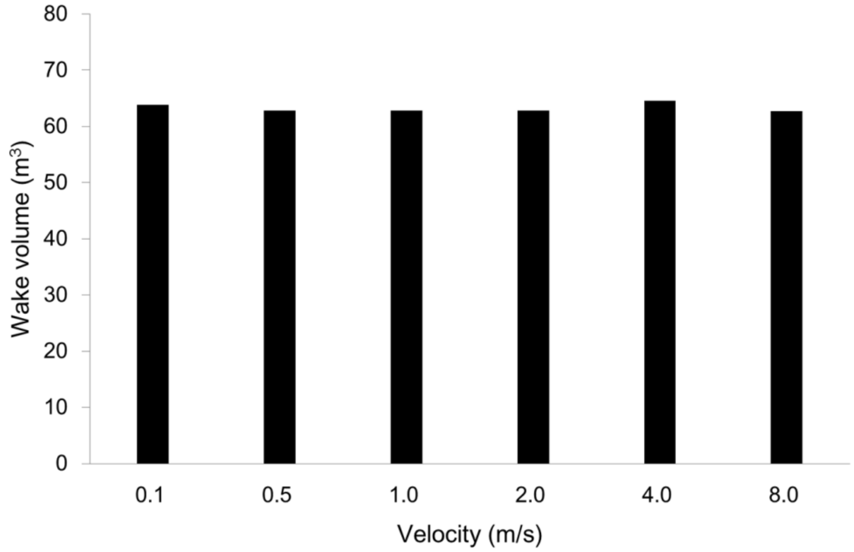


Fig. 9 Wake volumes according to inlet velocities (0.1 to 8.0 m/s)

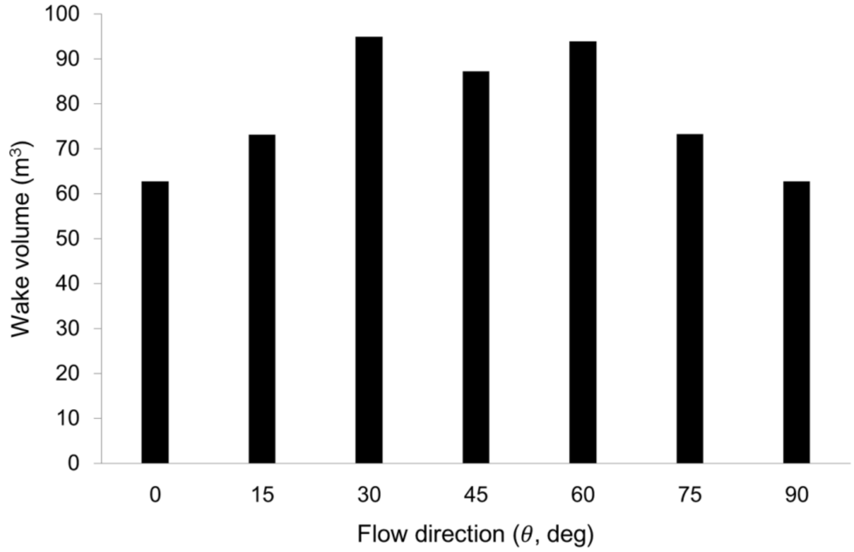


Fig. 10 Wake volumes according to flow directions (0 to 90°)

Fig. 10 shows the wake volumes according to flow directions. In the case the flow velocity is fixed to 2.0m/s (design velocity). As shown, the wake volumes are symmetric regarding the 45° because it is also symmetric as shown in Fig. 2. The maximum wake volume is obtained at the inclination of 30 or 60° and the minimum wake volume at 0 or 90°. The range of the wave volume ranges from 63 to 95m^3, resulting in 2.33 to 3.51 times the AR volume (27m^3), respectively. Therefore, in point of performance, the AR is better to be located with the inclination of 30 or 60° with respect to the flow direction. However, it is required to check the structural stability according to the inclination. Kim et al. (2004) showed that the maximum von-Mises stress and displacement are

1.41MPa and 3.493×10^{-5}, respectively, which are not significant at all. Therefore, at the inclined angle the stability is secured and performance is obtained.

4. CONCLUSIONS

We found that the wake region of the box-type AR can be increased when the inclination angle become 30 or 60°. At this angle the wake volume increase from 63 to 95m^3, resulting in 3.51 times the AR volume (27m^3), respectively. Also, it is found that the flow velocities specified in the inlet do not have effect on the wake volume; hence the performance depends solely on the installation angle if the structural stability is assured. Considering the illumination and dissolved oxygen near ARs, which are critical for fish recruitment, the establishment of larger wake region is significant to improve the performance of artificial reefs.

5. ACKNOWLEDGEMENT

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