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Wake lengths and structural responses of Korean general artificial reefs

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ABSTRACT

General artificial reefs (ARs) have been used as standard artificial reefs in Korean waters since 1971. It is believed that the structural responses of the ARs are sound enough in 2 m/s water flow and the wake regions are wide enough to attract marine bio creatures. However, no one has yet scientifically investigated the structural responses and wake regions of the general ARs due to the lack of interest and expertise. Moreover, the material types and sizes of the recently approved general ARs have been extended; hence, it is necessary to capture their behaviors and to establish a guideline for a further development and design. This study focuses on 24 representative ARs to investigate their wake regions and structural responses. For the purpose, numerical flow analyses have been carried out by modeling the 24 representatives and obtaining wake lengths, deformations, and stresses. It is shown that the wake lengths increase as AR heights increase, with a higher correlation. However, no correlations are shown between the wake lengths and flow velocities. Also, it is found that the complex type ARs have relatively larger structural responses than the other types because they are mainly made of structural steel frames and plates.

1. Introduction

It is known that the effectiveness of artificial reefs (ARs) depends on the design of a reef structure (Pickering and Whitmarsh, 1997). Here, the effective means increasing the productivity of marine species although 'attraction versus production' debate exists (Carr and Hixon, 1997). Estimating 'effectiveness' is neither easy nor simple because of unsolved sophisticated issues in biological and ecological habits of marine creatures in the region of ARs (Seaman, 2008; Kheawwongjan and Kim, 2012). It seems that engineering issues such as design and maintenance of ARs are relatively simple but they cannot be solely handled without considering the biological and ecological issues because of the main customers of ARs—marine fauna and flora (Pickering and Whitmarsh, 1997; Düzbastilar and Şentürk, 2009). Therefore, engineering issues are not easy either. However, in an engineering design point of view, structural responses and wake regions should be clear to the customers regardless of their biological and ecological behaviors. Accordingly, this study focuses on wake regions and structural response of ARs.

In South Korea, more than 62 general ARs have been approved by the Central Artificial Reef Committee, a government power giving a permission to use a specified artificial reef in Korean waters since 1971 (Woo et al., 2014). Considering the practices of ARs in South Korea, the shapes and sizes of ARs have become more complicated, bigger because of recent development in materials and increase in budget (Kim et al., 1994; Kim et al., 2008). These trends sound great for enhancement of marine bio resources but it is hard to prove its positive effect on the resources in a short period. Moreover, the structural robustness and performance of newly developed ARs are not easy to be verified by their design practice. Therefore, recently Korea Fisheries Resources Agency (FIRA) launched a research project to characterize the existing general ARs and to map their characters onto newly developed ARs. In other words, from the images of current general practice of the verified ARs, whether they are shapes, sizes, and other engineering or biological factors, the government agency aims at characterizing newly developed reefs and making verification of the candidates for future use.

Among a series of the images, along with the sizes and shapes of the general ARs, the drag coefficients were characterized in terms of normalized references such as AR height and the front velocity (Woo et al., 2014). However, it seems that more works should be done not only for drag coefficients but also for wake region and structural response of the general ARs because these are connected with the attracting performance to marine bio creatures and the stability in water flows. Accordingly, current

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(or water flow) is considered one the most important factors affecting reef stability and performance (Sheng, 2000; Miao and Xie, 2007); hence, capturing wake region and structural response of a specified AR is necessary. However, it is not easy to obtain the wake region and structural response of a complicated object, not possible to analytically calculate, time consuming and expensive to experimentally obtain, but reasonable to numerically calculate, thanks to modern development in computation mechanics.

Numerical flow analysis has been efficient in various engineering applications such as airplane, submarine, automobiles, etc. (Gylys et al., 2012; van Dam, 1999; Zakeri, 2009). Accordingly, some investigators carried out numerical flow analysis of ARs to investigate the flow field characteristics around cubic and star-shaped ARs (Li, et al., 2010; Liu et al., 2013). Recently, Liu and Su (2013) numerically investigated the influence of reef arrangements on artificial flow fields. Woo et al. (2014) characterized 24 representatives of the Korean general artificial reefs by numerically calculating drag coefficients. However, numerical analysis has not been yet applied to obtain wake regions and structural responses of the general ARs probably because of the lack of expertise and interest (Miller, 2002). Accordingly, this study focuses on calculating the wake regions and structural responses of the general ARs and then characterizing the ARs based on the characteristics.

For the purpose, first, the general ARs were initially classified into six groups in terms of their shapes—box, tunnel, arch, dome, leg, and complex types, and then 24 representatives were selected for further modeling and analyses. Second, solid models of the representative ARs were made. Third, boundary conditions for flow analyses were applied. Finally, finite volume-based flow analyses were carried out to capture their wake lengths and structural responses. From the results, the ARs were characterized by correlating the wake regions with their heights and obtaining the structural responses such as displacements and stresses.

2. Theoretical background

The interaction of a reef with a prevailing current usually results in the formation of a wake region with eddies downstream of the reef (Wolanski and Hamner, 1988). It is known that the wake region attracts certain marine species by providing a shelter, a feeding ground, a spawning ground, a rest area, or a temporary stopover (Sheng, 2000). Also, eddies and vortices just outside the wake region contain higher turbulence, which may attract certain fish species (Wolanski and Hamner, 1988).

The wake region is usually defined as the space outlined by the dot line in Fig. 1 (Oh et al., 2004), which is also used in automobile industry (Guilmineau, 2008). As shown, the region is defined as the space of recirculating flow immediately behind a moving or stationary solid body caused by the flow of surrounding fluid. The wake region provides the deposition of sediments and nutrients (McManus and Woodson, 2012; Prairie, et al., 2012) so that it is an obvious benefit to increase the wake region for attracting more marine species.

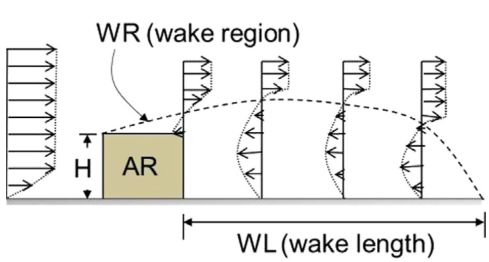

Fig. 1. Definition of wake region (WR) and wake length (*WL*).

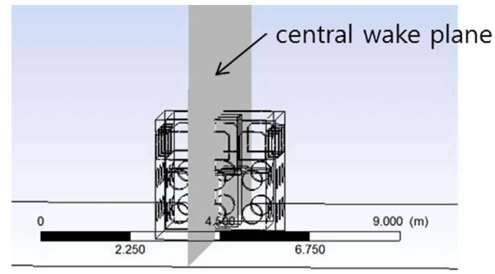

Fig. 2. Definition of the central wake plane.

It is ideal to capture the 3 dimensional distribution of the wake region. However, it is not easy to investigate its volume; instead, the wake region is typically represented by a representative wake length as shown in Fig. 1. Unfortunately, there is no concrete discussion how to determine the reference plane, which includes the representative wake length. In fact there are infinite ways to select the reference plane; nonetheless, in practice, the central plane is regarded practical, typical as defined in Fig. 2. Accordingly, this study firstly implements the central plane and then other planes to determine the representative wake length.

It is known there is a relation between wake length and AR height (Korean Fisheries Society, 1997). However, there is no literature showing any ranges of the proportional coefficients and even wake lengths because of the difficulty in hydraulic experiments and the sophistication of current ARs. Moreover, the correlation of wake length with flow velocity is not established. Therefore, this study focuses on the wake region lengths of the 24 general ARs and their relations with AR height and flow velocity.

Along with the wake region, the structural responses of ARs become important because of the various types of shapes and materials of ARs. According to Baine (2001), total 17 material types have been used in ARs, which include concrete, rock, offshore platforms, steels, etc. This fact shows that the structural responses such as deformation and stress are quite different, mainly due to the material types. Besides, because current shapes of ARs become complicated especially in Asian countries (e.g., Japan and Korea); it is expected that some ARs behave in totally different scales. Therefore, this study also focuses on the structural responses of ARs.

3. Materials and methods

Fig. 3 shows the conceptual shapes of the general ARs. As mentioned earlier, based on these shapes, the general ARs were grouped such as box, tunnel, arch, dome, leg, and complex types. Table 1 shows the names (identification symbols) and features of the 24 representatives. Here, the ARs from AR01 to AR05 are classified into the box type, the ARs from AR06 to AR08 the tunnel type, from AR09 to AR11 the arch type, from AR12 to AR14 the dome type, from AR15 to AR17 the leg type, and AR 18 to AR24 the complex type. These 24 ARs have been used to produce and/or attract fish, shellfish, and seaweed (e.g., AR01 for fish, AR04 for fish and seaweed). The models shown in Table 1 were constructed in the real scales. Fig. 4 shows the descriptions of length (*L*), width (*B*), height (*H*), and flow direction. The dimensions and material properties are listed in Tables 2 and 3 for the 24 representatives. It should be noted here that the dimensions in Table 2 are constructed by mapping each AR to a cuboid.

In the numerical analyses, ANSYS Workbench and CFX were used for modeling and flow analysis of the ARs. It is shown from many investigators that ANSYS CFX software is fully integrated into the ANSYS Workbench environment and the reliability has