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Characterizing Korean general artificial reefs by drag coefficients

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ABSTRACT

This study presents the processes for acquiring the drag coefficients of 24 representative Korean general artificial reefs (ARs), identifying (or excluding) some ARs having unusual ratios, grouping the ARs into three combinations, and characterizing the combinations with respect to the dimensionless characteristics, which related to the wall area, front velocity, and height. For the purpose, finite volume-based flow analysis was carried out by applying inlet, outlet, smooth wall, and symmetric boundary conditions. From the results, it is shown that the processes give a simpler way to estimate the drag coefficients – formula as functions of the characteristics. Therefore, this study gives ones how to identify, estimate, or characterize a newly developed artificial reef by simply using the characters of the existing 24 general ARs. In addition, it is found that the variation of the initial flow velocity does not change the drag coefficients but it is shown that the variation of the angle between the flow and AR directions does significantly change the drag coefficients.

1. Introduction

The roles of artificial reefs (ARs) have been expanded from the initial purposes of commercial fishing to newer and broader purposes including recreations, eco-tourism, aquaculture and marine ranching, habitat restoration, and others (Seaman, 2008; Düzbastilar and Şentürk, 2009). Because of the broad applications and histories of ARs, it may not now possible to figure out all of the current practices of ARs but it was estimated in 2008 that more than 50 countries had been involved ARs for their own purposes (Seaman, 2008). Among them, most Asian countries have focused on government-subsidized policies and programs to utilize ARs for food production (Kheawwongjan and Kim, 2012). South Korea has also similar programs to facilitate ARs such as pilot marine ranch, coastal marine ranch, and marine forest enhancement projects. Accordingly, the role of ARs becomes significant and the development and post management of ARs are of concern. Moreover, the responsibility of the authorities related to the development and management becomes important.

In South Korea, since 1971, 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. Other than those 62 general ARs, there are two more classifications, which are test and research artificial reefs. Here, test ARs mean that the ARs were developed and patented by specific developers but not fully approved as general ARs from the government power; hence, the artificial reefs are under tests and candidates for future general uses. Research ARs indicate that the ones were developed and operated under supervision of city mayors, province governors, or the Korean Fisheries Resources Agency (FIRA) to enhance marine lives in specific target sites. All of the ARs developed by government-funded research projects are initially included in this category and can be included in general ARs upon the approval.

Considering the practices of ARs started from 1971 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, 2008a, 2008b). These trends look great for enhancement of marine bioresources but it is hard to prove its positive effect on the resources in a short time period. Moreover, the structural robustness of newly developed ARs, whether they are test or research ARs, is not easy to be verified by their design practice. Therefore, recently FIRA launched a research project to characterize the existing 62 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.

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Among a series of the images, the cross-sectional areas and shapes of ARs are important as the characteristic properties because these are all connected with drag coefficient, a number or range related to drag force acting on an object in water flow. It is known that current is among the most important factors affecting reef stability and performance (Sheng, 2000; Miao and Xie, 2007). Therefore, once drag coefficient is known, drag force can be calculated, and structural response can be predictable. However, it is not easy to obtain the drag coefficient 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, and automobiles (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, star-shaped, and multi-arrayed ARs (Li et al., 2010, 2013; Liu and Su, 2013). However, numerical analysis has not been yet applied to obtain drag coefficients of ARs probably because of lack of expertise and interest (Miller, 2002). Accordingly, this study focuses on calculating the drag coefficients of the general ARs and then characterizing the ARs based on the drag coefficients.

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, finite volume 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 drag coefficients. From the results, the ARs were characterized by making new groups with respect to drag coefficients and correlating the coefficients with dimensionless characteristics.

2. Theoretical backgrounds

In fluid mechanics, drag refers to forces which act on a solid in the direction of the relative fluid flow velocity. Drag forces can be classified into the following categories: (1) parasitic drag consisting of pressure drag (or form drag), friction drag (or skin friction), and interference drag; (2) lift-induced drag; and (3) wave drag (aerodynamics) or wave resistance (water wave dynamics). Among these, pressure drag and friction drag follow the drag equation and these two are fully involved in the total drag force acting on ARs in the direction of the motion (Hasanloo et al., 2012); hence, pressure drag and friction drag are discussed as below.

Pressure drag arises because of the form of the solid. This drag is a force resulted from pressure differences across an obstacle in a flow field. For example, in the ocean, pressure drag occurs when currents flow over and around an object. The general size and shape of a solid are the most important factors in pressure drag; hence, solids with a larger apparent cross-section have a higher drag than thinner solids. Since pressure drag follows the drag equation, the drag rises with the square of speed, and thus becomes more important for a high speed object.

Friction drag arises from the friction of the fluid against the 'skin' of the object that is moving through the fluid. This drag is due to the tangential forces resulted when a fluid flows over a surface; hence, a rough surface gives more frictional drag. It is directly related to the wetted surface – the contacted surface area with the fluid. Friction drag also follows the drag equation and rises with the square of the velocity.

Considering a smooth body moving through a viscous, incompressible fluid with speed (v), the drag coefficient (C_d) is defined as Eq. (1).

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2} \tag{1}$$

Here, F_d is the drag force and ρ is the fluid density. It should be noted here that the total drag force is the sum of friction drag and pressure drag and the drag coefficient is a function of Reynolds number (Re). Considering an example of the friction drag (flow over a flat plate parallel to the flow), the total drag is equal to the friction drag and accordingly the drag coefficient is as shown in Eq. (2).

$$C_d = \frac{\int_{surface} \tau_w dA}{\frac{1}{2}\rho v^2} \tag{2}$$

Here, τ_w is the shear stress caused by flow and A is the total surface area in contact with the fluid (i.e., wetted area); hence the drag coefficient depends on the shear stress.

Considering an example of the pressure drag (flow over a flat plate normal to the flow), the total drag is equal to the pressure drag because the wall shear stress is perpendicular to the flow direction and therefore does not contribute to the drag force. In the case, the drag coefficient is as shown in Eq. (3).

$$C_d = \frac{\int_{surface} p dA}{\frac{1}{2}\rho v^2} \tag{3}$$

Here, p is the pressure caused by flow and A is the frontal area (or projected area) of the object. For this geometry, the flow separates from the edges of the plate and there is back-flow in the low energy wake of the plate. It should be noted here that the drag coefficient for all objects with sharp edge is essentially independent of Reynolds number (for $\mathrm{Re} \geq 1000$) because the separation points and therefore the size of the wake is fixed by the geometry of the object (Fox et al., 2004). Therefore, we assumed that the drag coefficients of all of the 24 representatives are independent of Reynolds number according to the sharp edges of the 24 representative ARs. In other words, regardless of the Reynolds number, the drag coefficients are assumed to be constants. In addition, because most of the 24 representative ARs are installing normal to the flow direction, we assumed that pressure drag is the major one contributing the drag force. Thus, Eq. (3) is used in the study. In general the pressure magnitude cannot be analytically determined; hence, experimental or numerical work should be resorted to determine the drag coefficient.

3. Materials and methods

Prior to carrying out a flow analysis of the ARs, seven basic shapes, described in Table 1, were modeled to verify the effectiveness of the numerical simulation. These shapes were a cuboid, disk, ring, hemisphere with the open end facing, hemisphere with the open end facing down, C-section with the open end facing the flow, and C-section with the open end facing downstream. Because of the relatively simple shapes, we were able to compare the simulated the drag coefficients with the pressure drag reported by Fox et al. (2004), which is listed in Table 1 along with those obtained as part of this work. Because of the objects had sharp edges, the Reynolds numbers were greater than 1000 and, accordingly, the drag coefficients were independent of Re. As listed in Table 1, the data were in agreement to within 10%.

Fig. 1 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 2 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 tunnel type from AR06 to AR08,