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Journal of Hydro-environment Research xx (2015) 1–13

Journal of Hydro-environment Research

www.elsevier.com/locate/jher

Research paper

Fully three-dimensional Reynolds-averaged Navier–Stokes modeling for solving free surface flows around coastal drainage gates

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Received 23 September 2014; revised 3 March 2015; accepted 3 March 2015

Available online ■ ■ ■

Abstract

In this study we carry out numerical simulations of free surface flow through the drainage gates of the Saemangeum tidal barrier that is located in the west coast of South Korea and is also known as the world largest man-made tidal barrier. Instead of using depth-averaged numerical models, which have been widely used in hydraulic and coastal engineering, we employ the fully three-dimensional free surface flow model of Kang and Sotiropoulos (2012b) to simulate the flow around the gates. The numerical model is based on the two-phase level set method solving the air and water simultaneously and the curvilinear immersed boundary method that is able to handle arbitrarily complex geometries. In the simulations turbulent flows are also resolved by the shear stress transport $k - \omega$ model. The numerical model is applied to simulate fifteen different flow conditions with various gate opening scenarios, and for selected test cases laboratory experiments are also carried out. The computed flowfields at various flow conditions are compared with the laboratory measurements and the field observations and the comparisons showed satisfactory agreements both quantitatively and qualitatively. Using numerical simulation results, we elucidate the structures of turbulent flows associated with a high-speed jet-flow like structure and a hydraulic jump at the far downstream of the gates. The results presented in this paper demonstrate the predictive capabilities of the numerical model and its potential as a powerful engineering tool for estimating the discharge-water level relationship and the three-dimensional flowfield of real-life drainage gates.

Keywords: Tidal barrier; Reynolds-average Navier–Stokes equations; Drainage gates; Free surface flow; Level set method

1. Introduction

Tidal barriers are the coastal structures which are often used to secure sea areas for irrigation or industrial purposes. These structures act to protect the estuarine or coastal regions from waves, currents or saltwater intrusion, or are sometimes used for the production of renewable energy. Saemangeum tidal barrier (or dike), which is located along the southern part of the west coast of the Korean Peninsula, is one of such structures (see Fig. 2). The Saemangeum tidal barrier was constructed during 1991–2010 as part of the Saemangeum reclamation project. Its total length and the area inside the barrier amount approximately to 34 km and 400 km^2, respectively, which makes the project one of the biggest land reclamation works in history. The construction of the barrier is completed now, and in the future, part of the lake regions inside the barrier will be converted into either agricultural or industrial land, while the rest will remain as a freshwater lake after desalination. To discharge the freshwater inside the lake periodically, two drainage gates – Sinsi and Garyok Gates – were installed at the tidal barrier.

One of the critical issues nowadays in relation with Saemangeum reclamation project is to determine the elevation of

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http://dx.doi.org/10.1016/j.jher.2015.03.004

Please cite this article in press as: Kim, S.J., et al., Fully three-dimensional Reynolds-averaged Navier–Stokes modeling for solving free surface flows around coastal drainage gates, Journal of Hydro-environment Research (2015), http://dx.doi.org/10.1016/j.jher.2015.03.004

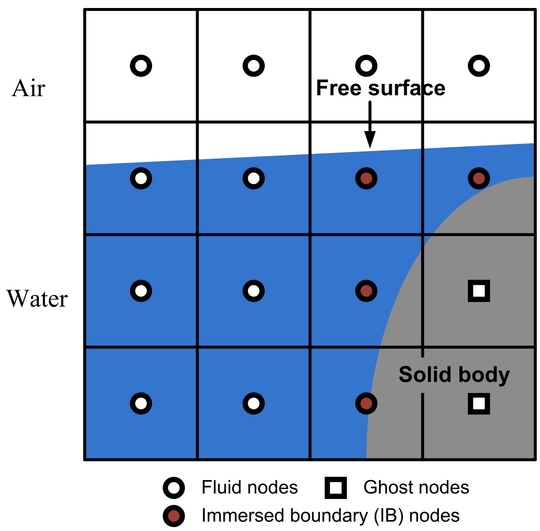

Fig. 1. Schematic description of the immersed boundary and fluid nodes.

final ground surface after reclamation. To estimate this, accurate prediction of the flood water level inside the barrier is essential since a slight change of the predicted flood level could result in a significant change of the landfill volume required for the future reclamation. The accurate prediction of the water surface elevation, especially, is not a trivial task because one needs to account for both the influence of the incoming flood discharge from the upstream rivers (Dongjin and Mankyung Rivers) connected to the lake and the discharge through the drainage gates. The discharge through the drainage gates, however, is difficult to estimate as it is influenced by multiple physical/geometrical parameters such as the inner and outer water levels, gate opening scenarios (partial or full opening), bed topography, etc. The discharge through the opening of hydraulic structures (e.g. weir, orifice, spillway, sluice gate, etc.) has been traditionally calculated using empirical formulas that relate the geometries of the hydraulic structures to the discharge. One way to estimate the discharge-water level relationship is to apply the Bernoulli equation to obtain the equation in the form of $Q = C\sqrt{2gh}A$ (Brater et al., 1996), where Q is the discharge, A is the area of the gate opening, g is the gravitational acceleration, C is the discharge coefficient, and h is the head. Another approach is to develop the so-called rating curve. A commonly used rating curve is in the parabolic form that is given by $Q = K(h \pm z_0)^{\alpha}$ (Gupta, 2001), where z_0 is the datum correction, K and α are constants, and h is the gage height. However, the water−level discharge relationship of the drainage gates of a tidal barrier cannot be represented by the equations like those mentioned above. Using those simple equations based on one or two parameters it is difficult to account for all of the important physical parameters such as the lake water level, sea water level, irregular bed topography, Reynolds number, Froude number, gate geometries, gate opening scenarios, etc, at the same time. For instance, the flows occurring near drainage gates could exhibit strong three-dimensionality due to the presence of irregular bed topography, complex structure geometries, or the interaction among neighboring gates, and

Fig. 2. Semangeum tidal barrier and two drainage gates − Sinsi and Garyok gates.