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Original Research

Numerical modeling of sedimentation control scenarios in the approach channel of the Nakdong River Estuary Barrage, South Korea

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ABSTRACT

The effects of sedimentation reduction at the Nakdong River Estuary Barrage (NREB) in Korea were quantitatively analyzed with respect to different sediment control methods using the calibrated and validated two-dimensional model. The countermeasures of sediment dredging, sediment flushing, channel geometry change, and a combination of flushing and channel geometry change were examined for the approach channel of the NREB. The flood event and channel geometries of the 3.8 km section upstream of the NREB surveyed before and after dredging in 2007 were used for modeling conditions. As a result, the half of sediments dredged in 2007 could be eliminated naturally by floods without dredging. The numerical simulation of sediment flushing indicated that the deposition height decreased in the entire simulation section with the minimum and maximum reductions from 0.3 m to 1.3 m in deposition height. The channel contraction method produced quantitatively the largest amount of sedimentation reduction and sediment flushing and dredging followed. Sedimentation reduction by a combination of flushing and channel contraction was up 10% compared to the individual method of channel contraction.

1. Introduction

An estuary barrage is generally constructed to prevent salt water intrusion, to provide a sustainable water supply, or to control floods. However, the incoming sediments from the upstream channel could be deposited after the construction of an estuary barrage and cause problems such as bed elevation increase and reduction of water storage volume (Ji et al., 2011a). In reservoirs, the methods of sediment routing, sediment flushing, and sediment excavation or dredging are generally applied to remove deposited sediments (Woo et al., 2015). Studies on the reduction of sedimentation in rivers or reservoirs have been performed by various researchers to provide the solution. Liu et al. (2004) developed the one-dimensional numerical model for predicting changes in concentration of suspended sediment and bed elevation due to sediment flushing in rivers. The model was verified using field data obtained from the Kurobe River in Japan. Martin and John (2001) simulated the removal of deposited sediments by sediment flushing in the Lake Sharpe using the HEC-6T model. Shen (1999) also performed a comprehensive examination of reservoir flushing techniques. Chollet and Cunge (1980) developed a finite difference model for the simulation of reservoir sedimentation, and performed the simulation for sedimentation and sediment flushing of the Setit River in Sudan and the Padma River in Bangladesh regarding the presence of a dam.

However, sedimentation reduction methods for reservoirs such as sediment flushing and sluicing cannot be directly applied to the approach channel of an estuary barrage because there are difficulties in the control of water surface levels due to the tide effect. Compared to studies on sedimentation reduction in reservoirs, there have not been many studies or applications of sedimentation reduction in the upstream channels of an estuary barrage. In previous studies on resolving sedimentation problems in estuary barrages, Holz and Heyer (1989) verified that the sedimentation

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problem could be mitigated by the control of water levels through gate operation in the estuary barrage of the Eider River in Germany, based on numerical simulations. For the Nakdong River Estuary Barrage in Korea (NREB), Ji (2006) performed a study on the changes in flood levels when dredging is not carried out, using the one-dimensional quasi-steady state model. Referring to the same one-dimensional quasi-steady state model, Ji et al. (2008) analyzed sedimentation characteristics of the Lower Nakdong River and sediment dredging effects at the NREB, and examined the feasibility of a sediment flushing method (Ji et al., 2011a). In 2011, the channel geometry change (channel contraction) for the NREB was analyzed as an additional method for sedimentation reduction with two-dimensional numerical modeling (Ji et al., 2011b). The possibility of the flood level and bed elevation increase in the Lower Nakdong River due to the channel contraction near the NREB was examined using the HEC-6 model. Park et al. (2013) performed numerical simulation and volumetric analysis of bed changes using field surveying data for the Lower Nakdong River with and without dredging operation. To apply the most appropriate method in the field for the NREB, the quantitative effect of sedimentation reduction for sediment dredging, flushing, channel contraction, and a combination of flushing and channel contraction should be analyzed using a two-dimensional numerical model for the same section of the approach channel based on the same hydraulic condition.

Therefore, the objectives of this study are (1) to quantitatively analyze and examine the effect of the dredging method currently used in the NREB, (2) to analyze the feasibility of the sediment flushing method which uses the water level difference between the inner and outer sides of the estuary barrage, and (3) to examine the effect of the channel contraction method that removes deposited sediments by increasing velocity due to decreased channel width, using a two-dimensional numerical simulation. The ultimate goal of this study is to provide the quantitative and volumetric results of sedimentation reduction and removal effects of the suggested methods for practical uses.

2. Study reach and numerical modeling conditions

2.1 Nakdong River Estuary Barrage

The Nakdong River has a total river length of 525 km, and a basin area of 23,860 km^2 (Fig. 1). It is the second largest river in Korea after the Han River, and is a representative tidal river. The mean annual precipitation of the Nakdong River basin is 1167 mm, and the total annual discharge is 15.008 billion m^3. The Nakdong River basin is affected by a monsoon climate and an average of 26.7 typhoons have occurred every year according to the survey from 1971 to 2000 (Ji & Julien, 2005). Especially on September 12, 2003, Typhoon Maemi hit the Lower Nakdong River and caused extensive damage around the City of Busan with extreme precipitation over 400 mm and a 1.7-m storm surge (Ji et al., 2011a). The flood level exceeded both the warning stage of 4 m and the dangerous stage of 5 m, which corresponds to 70% of the design flood discharge (19,370 m^3/s) for the Nakdong River (Ji & Julien, 2005). The field data for water stage, discharge, and tide levels observed in 2003 during Typhoon Maemi are presented in the study of Ji et al. (2011a). The Lower Nakdong River is very gentle, with a channel slope of about 1/10,000. Therefore, before the construction of the NREB, the maximum saltwater intrusion went up to about 60 km upstream of the estuary, and during the spring tide of the low flow, the saltwater intrusion went up to about 44 km upstream of the estuary.

The NREB was completed in 1987, and is located 355 km downstream of the Andong Dam. The total length is 2230 m (510 m of gate sections, and a 1720 m closed dam section), and the gates consist of six main gates, four control gates, one navigation lock, and a tidal outlet in the right-bank (Park et al., 2008). Recently, three main gates and two control gates have been additionally constructed in the closed dam section in order to control extreme floods. After the completion of the NREB, fresh water supply was enabled at a number of water intake systems, and the difficulties in water supply were resolved.

In the NREB, deposited sediment is currently removed by hydraulic suction dredging with a cutterhead and a large pump to

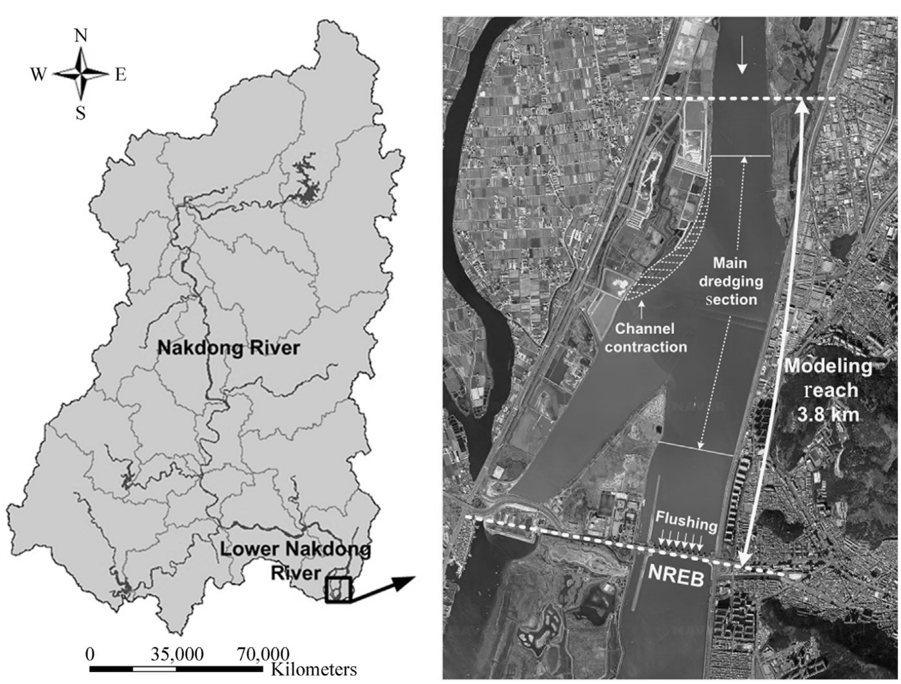

Fig. 1. Study reach and modeling section of the Lower Nakdong River and NREB.