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Application of tidal energy for purification in fresh water lake

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ABSTRACT: *In order to preserve the quality of fresh water in the artificial lake after the reclamation of an intertidal flat at the mouth of a river, we suggest two novel methods of water purification by using tidal potential energy and an enclosed permeable embankment called an utsuro (Akai et al., 1990) in the reclaimed region. One method uses an inflatable bag on the seabed within an utsuro, while the other uses a moored floating barge out of a dyke. Each case employs a subsea pipe to allow flow between the inside and outside of the utsuro. The change in water level in the utsuro, which is pushed through the pipe by the potential energy outside, caused circulation in the artificial lake. In this paper, we analyzed the inflatable bag and floating barge motion as well as the pipe flow characteristics and drafts as given by a harmonic sea level, and compared the theoretical value with an experimental value with a simple small model basin. The numerical calculation based on theory showed good agreement with experimental values.*

***KEY WORDS*:** Water purification; Reclamation; Inflatable bag; Floating barge; Utsuro.

INTRODUCTION

Reclamation of land from the sea at a river mouth is an important issue to secure farmland and to expand valuable economic zones. In order to sustain the area to be utilized, costal environmental issues such as water purification and circulation, sluice gate control and environmentally-friendly engineering solutions should be carefully addressed. However, these issues are not well addressed in many cases in the world.

After the construction of a dyke in Isahaya Bay in Japan, the water quality did not achieve the marine environmental target value (Yokoyama et al., 2003). Haringvliet dam with sluice gates in the Netherlands was intended to shut off incoming seawater, but the water quality inside was worse than before due to lack of water circulation (Stuyfzand et al., 2004). The Tuckombil waterway in Australia has deteriorated rapidly since a water gate was constructed for flood protection (Richmond River County Council, 2007). Further, Shihwa lake in Korea was planned for agricultural water use, however, an industrial zone was constructed in the vicinity of the estuary before the wastewater treatment plants, which control pollutants, was built, so that the fresh water process accelerates the salinity gradient in the water column and results in a low oxygen layer on the bottom of the water (Park et al., 1997). In the case of Semangeum, the sluice gate opening caused benthic organisms to develop around the gates and reduced coastal circulation as well (Suh et al., 2006).

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Nature-friendly reclamation should be accompanied by water quality management. The prevention and/or reduction of water pollution and eutrophication due to contamination by large pollutant effluent from the land should consider the surrounding marine environmental situation. As a self-purification system, a rockfill-type enclosed embankment in the dyke can be introduced. This rubble seawall, dubbed an "utsuro" (Akai et al., 1990), functions like a rubble mound breakwater introduced by Palmer et al. in 1998 to protect a coastal area from excessive waves. The Japanese word utsuro means a calm space enclosed by permeable embankment, and it is known that the water is purified after passing through the utsuro. An additional part is a system to generate water current across the dyke using tidal potential energy. Consideration of water level management is important because the water level pattern in the reclamation area is dramatically changed from running water before the dyke to stagnant water after dyke construction. Therefore, the water current in the lake is significantly reduced. This can result in degradation of water quality, since nutrient concentration in stagnant water is largely determined by external pollution such as supply via streams, rivers, and wastewater discharge. Heretofore, several researchers have studied the function of the "utsuro at sea" from physical (Akai et al., 1993), ecological (Otsuka et al., 1996), and experimental viewpoints since Akai's initial research in 1981.

In 2001, the first utsuro was constructed in the estuary of Kinokawa in Japan to improve the water quality in the region. The area of the utsuro is about 30,000 m^2, and the tidal height is about 1.5 *m*, so that the capability of purification will be approximately 90,000 *tons* per day. As for the bio-function of the utsuro, the surface of the rock in the rockfill embankments serves as a bio-film, in which many marine microbes live. Oxidation of organic matter and decomposition of the nitrogen and phosphorus containing compounds occur at the surface due to biological processes. Ocean benthos and seaweeds take part in the food chain so that the rock filter effect shows not only lower Chemical Oxygen Demand (COD) and higher Dissolved Oxygen (DO) but also more photosynthesis. For example, the quality of the water is improved with respect to several parameters, namely, 0.56 *mg/l* to 0.2 *mg/l* for turbidity, 4.64 *mg/l* to 3.7 *mg/l* for COD, and 6.06 *mg/l* to 4.61 *mg/l* for Suspended Solid (SS) as measured by Akai et al. (1990) in and out of the utsuro, respectively. Also, after installation of an utsuro downstream of the Yellow River in China, SS and turbidity values improved tremendously (Akai, 2008).

An option we suggest in this paper is to use the potential energy to circulate the water tidal differences outside the dyke. A connecting pipe is used for the connection between the inside of the utsuro and outside of the dyke in order to transfer the potential energy. There are two possibilities employing a pipe connection device at the both ends. First, an inflatable bag is placed inside the utsuro with an outside opening. A second option is an inside opening accompanied by a floating barge outside, which elevates due to the tide. Two kinds of tidal energy transfer systems to be used during the reclamation process are first introduced. Then, utilization of an utsuro in a fresh water lake is discussed, where an innovative idea is required to use tidal energy. We developed theories to analyze the systems and conducted numerical simulations. The results seem to accurately explain the performance of these systems.

REPRESENTATIVE RECLAMATIONS IN JAPAN AND KOREA

Isahaya reclamation

Seventeen years have passed since 1997 when Isahaya Bay in the Ariake Sea, Japan was separated from the sea with a dyke about 7 *km* length. The planed area of reclamation was about 9.42 km^2. During the reclamation period, environmental changes have occurred in this area causing a red tide that led to a decrease in fish and marine products and a decline in the seaweed harvest. In 2002, the government changed the Isahaya Bay Project to reduce the reclamation area by half and to conduct more marine environmental assessments. The scientific field data show that most water contamination parameters such as COD and TP (total phosphorous) grew worse after closing the dyke. Annual mean COD concentration in the Isahaya Bay changed from 2.2 *mg/l* in 1987 to 7.7 *mg/l* in 2000, while TP changed from 0.067 *mg/l* to 0.234 *mg/l* (Teiichi, 2001). Thus, the government decided in 2010 to open the sluice gates at the end of December 2013 to see whether it would affect the environment in the Ariake sea or not.