A Study on the Environmental Impact Assessment of the Garolim Tidal Power Project

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Without a robust guideline for environmental impact observation and prediction, many development projects near coastal and estuarine areas have been conducted. The reason is that each project has its own characteristics, and so it is impossible to apply a single guideline to all of different projects. Thus, the purpose of this study is to present a guideline for the appropriate evaluation of environmental impact from the tidal power project at Garolim Bay. The guideline is focused on three essential subjects (hydrodynamics and water quality, sediment, and estuarine biota) and describes environmental impact observation and prediction for each subject.

For hydrodynamics and water quality, the important factors include changes in intertidal area, flow patterns inside the bay area, water exchange time(or residence time), exposed time of intertidal area, salinity and temperature, water quality deterioration (eutrophication and oxygen depletion) etc. For sediment, core issues contain short—and long—term sedimentation inside the bay area, seasonal bathymetry change, sediment transport at the entrance of the bay, sedimentation and suspended sediment outside the bay areas, erosion and deposition rate at the intertidal area, development of the muddy area, distribution of sediment type, and movement of sediment after the project. The range of estuarine biotic communities is very broad including primary producers, benthic communities, shallow water communities, communities at intertidal areas. These estuarine biotic communities are affected by change in flow pattern, intertidal areas, salinity, residence time, turbidity in the water column, exposed time of intertidal areas, sedimentation, and water quality. Therefore, the environmental impact prediction for estuarine biota shall be conducted by considering hydrodynamics, sediment, and water quality, and so that uncertainty is likely to be substantial.

Key words: Garolim Bay, Tidal Power Project, Environmental Impact Prediction, Environmental Impact Observation, Estuarine Environment

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1. Introduction

The 254MW-class tidal power plant has been completed and operated at Sihwaho (Lake) in South Korea, and the plan to build the 520MW-class tidal power plant at Garolim Bay, which is located at the northern coast of Taean Peninsula in South Korea, is being discussed. Tidal power generation is a method of power generation that the potential energy generated at the sea level is converted into electricity. It is more eco-friendly than fossil fuels in terms of greenhouse gas emission, but it has the serious problem of damaging the coastal ecosystem because it requires the construction of a tide embankment. However, there has been not enough study to predict the impact of constructing a tidal power plant and to determine an appropriate method of environmental impact assessment(EIA). In relation to Garolim Bay, three rounds of EIA meetings have been held, but still the discussions like seasonal changes in water quality and sedimentation after construction of the embankment, have been carried out. In addition, the EIA process has not produced positive results due to factors such as a lack of research on legally protected species (mongolian racerunners and spotted seals), the issue of the accuracy and reliability of reported data, conflicts among local residents, uncertainty in future environmental changes, and others. Against this backdrop, there is a need to guide the estuarine environmental impact observation and prediction for EIA of the tidal power project at Garolim Bay. The study aims to suggest a guideline for the environmental impact observation and prediction of three essential subjects(hydrodynamics and water quality, sediment, and estuarine biota)..

2. Methods

2.1 Overview of Garolim Bay Area

Garolim Bay is located at the northern coast of the Taean Peninsula in South Korea. The sea penetrates into the south of the Taean Peninsula, which is opposite to Cheonsu Bay. Garolim Bay has an area of about 100km^2, and the width of the bay entrance is about 2.2km. The length from south to north is about 22.4km, and the width from east to west is about 10km. The length of the coastline is 161.84km, and the bay is a typical bottle-necked type (Ministry of Ocean and Fisheries, 2006). There are large inhabited islands including Gopa Island and Wung Island as well as small uninhabited islands including Yul Island, Pi Island, Jo Island, and Daewu Island. There are a group of islands, Deokjeokgundo, which serves as the center of the fishing industry. The area is renowned as a major spot for oyster and laver farming, as well as a spawning ground for fish (Woo et al., 2009). Fishing is particularly excellent when the warm current goes to north in spring and summer. In addition, natural salt is produced at various salt ponds along the bay area.

The average duration of flood and ebb of Garolim Bay are 6 hours 16 minutes and 6 hours 9 minutes, respectively. The mean tidal range at the entrance of the bay is 4.72m, and the spring range is 6.56m. The flood current is 1.4m/s and the ebb current is 1.1m/s, and both of them are weakened at the inner bay. The mud flat with an area of about 70km^2, which is over 60% of the total area of the bay, has been formed due to the large tidal range of up to 7.9m and maintained properly (Park et al., 2009). Garolim Bay has active water exchange with the outer sea, and the quality of water is maintained as Class I or II that indicates good quality (Nam et al., 2012).

2.2 Environmental Impact Observation and Prediction for Hydrodynamics and Water Quality

The scope of observation for Hydrodynamics and Water Quality can be determined based on predicting results of change in flow pattern, water temperature and salinity, and water quality caused by a tidal power plant. It is also possible to determine the scope of observation throughout the results of previous studies. After considering hydrodynamics and water quality conditions, the optimal observation points must be selected. To clearly identify spatial and temporal characteristics of changes in tide, current, waves, water temperature, salinity, and water quality, as many points for monthly or seasonal observation should be selected as possible. In addition, the observation should be conducted at each level (surface, middle, bottom) to investigate the vertical profile. The changes of the intertidal zone seriously affect the estuarine environment of Garolim Bay, so it is recommended to select enough points at the intertidal zone. Table 1 shows the detailed contents of observation, the scope of observation, the period of observation, and the method of observation.

2.3 Environmental Impact Observation and Prediction for Sediment

Even though the sediment layers of natural state may have remarkably been eroded or deposited throughout the seasonal weather or the typhoon, but it has reached a state of equilibrium through interactions with dynamic factors, including tide and wave, for an extended period of time. But structures like embankment and breakwater destroy the state of equilibrium and transform the local or large sedimentation environment, such as seasonal bathymetry, sediment transport at the entrance of the bay, sedimentation and suspended sediment outside the bay area, erosion and deposition rate at the intertidal area, development of the muddy area, and distribution of sediment type. These alternations directly affect water quality and eco-environment in the area. Therefore a complete study of present sedimentation environment should first be conducted, and furthermore it is necessary to fully utilize existing measured data. If there are not enough data available, the feasible plan needs to be set up to additionally acquire reliable data considering contents of observation, the scope of observation, the period of observation and the method of observation (Table 2). The prediction tool for sediment transport classifies sediments according to sizes of particles, considers the mechanism of sediment transport(bedload and suspension), and needs to be verified as comparing with measured data.

2.4 Environmental Impact Observation and Prediction for Estuarine Biota

An EIA for estuarine biota considers the characteristic of project, the project operation process, and the diverse ecological structures and functional characteristics of the habitat. In case of a tidal power plant, the EIA should cover the environmental impact of an embankment, turbine operation on the ecosystem, and changes in the tidal level on the mud flat and intertidal zone. In addition, the benthic system and pelagic system of the intertidal zone at low water and high water should be carefully considered. In particular, the benthic system includes diverse types of estuarine habitat including salt marshes, unvegetated tidal flats, sand flats, oyster beds, mussel beds, and zostera beds, and each type of habitat has a completely different ecological structure and function. As mentioned to the previous subjects, the short-term, mid-term and long-term changes in estuarine biota should be investigated, so the environmental impact observation plan for estuarine biota is carefully choosen (Table 3). First of all, as the estuarine environment is quite different to the land environment, the adaptive management plan is a key factor to make the estuarine system sustainable.

3. Conclusion

This paper focuses on the environmental impact observation and prediction for EIA of the Garolim Bay tidal power project and represents three key factors related to the estuarine environment (hydrodynamics and water quality, sediment, and estuarine biota). The Hydrodynamics is a base of the estuarine environment, and the key factors for tidal power project include changes in intertidal areas, flow patterns inside the bay area, water exchange time(or residence time), exposed time of intertidal area, salinity and temperature alternation, etc. The prediction should be conducted for at least a year, and the results of prediction should be verified. It is necessary to predict the various environmental impacts for many different scenarios. In relation to water quality, there is concern over the deterioration of water quality, including eutrophication and the low-oxygen phenomenon, as the water flow will be reduced after the construction of tidal power plant. Therefore the present water quality should be investigated. After that, the impact of organic matters accumulated at the bottom layer as well as changes in water quality in the water columns after the operation of tidal power plant must be predicted.

The construction of a tidal power plant at the entrance of the bay, which is a path for sediments in Garolim Bay, is expected to cause major changes in sedimentation patterns in the bay. Accordingly, the concrete observations such as transported net sediment volume, flow pattern, sediment type, and bedload at the entrance of the bay should be conducted. The prediction tool for sediment transport classifies sediments according to sizes of particles, considers the mechanism of sediment transport (bedload and suspension), and needs to be verified as comparing with measured data. The tool can be applied to the bay to understand the status of sedimentary caused by the construction of tidal power plant. Hydrodynamics, sedimentation, and water quality are closely related, so there is a need to conduct observation and prediction at the same location and period. It is very important to identify the impacts of the tidal power plant on estuarine environment.

Estuarine biota, which includes algae, fish, zoobenthos, eggs and larvae, zooplankton, seagrasses, benthic algae, and mammals, is largely affected by the embankment due to by change in flow pattern, intertidal areas, salinity, residence time, turbidity in the water column, exposed time of intertidal areas, sedimentation, and water quality. As a result, the environmental impact prediction for estuarine biota shall be conducted by considering hydrodynamics, sediment, and water quality, and thus uncertainty is likely to be substantial.

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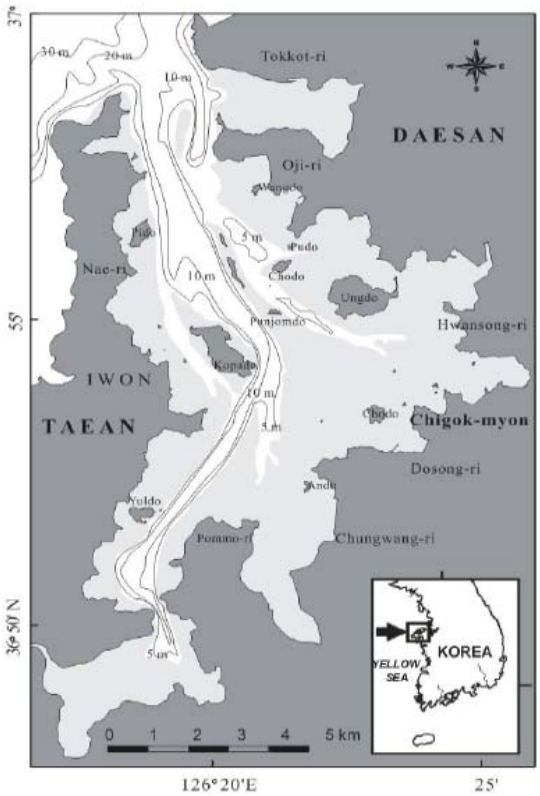

Figure 1. Garolim Bay (Woo et al., 2009)

Table 1. Environmental impact observation for hydrodynamics and water quality

Contents	Scope and location	Period and duration	Method
Water circulation in inside bay (tide, tidal current, wave)	· Multiple points · Multiple points including inside and outside bay · Stratified observation (surface, middle, bottom)	· Tidal current: seasonal observation more than four times a year (every 10 minutes for 15-day serial observation) · Wave: seasonal observation more than four times a year (every 1 hour for 15-day serial observation) · Year-round serial observation on representative point	· Tide and tidal current: every 10 minutes or 1 hour · Flow velocity: using ADCP, stratified observation over water layer · Wave: serial observation using pressure type tide gauge (AWH-16), ultrasonic tide gauge (ADCP)
Salinity and temperature	· Multiple points · Multiple points including inside and outside bay · Stratified observation (surface, middle, bottom)	· At least 3 years · At least 3 years in case of existing data · Monthly observation · Year-round serial observation on representative point	· Instrumentation(CTD) and observation sensor(CT) · Serial observation
Water depth and topographical changes	· Overall water depth and topographical changes (including intertidal and subtidal zone)	· Seasonal observation more than four times a year	· Intertidal zone: precision deepsea recorder for shallow sea, multibeam echo sounder · Subtidal zone: onshore leveling, lead leveling, LiDAR
Water quality	· Multiple points including inside and outside bay · Stratified observation (surface, middle, bottom)	· At least 3 years · At least 3 years in case of existing data · Monthly observation	· Observe standard regulation for marine surveying
Sediment quality	· Multiple points including inside and outside bay	· Seasonal observation	· Sampling and analyzing sediment · Elution test using core sample

Table 2. Environmental impact observation for sediment

Contents	Details	Scope and location	Period and duration	Method
Coastal physics	· Tidal current, wave, longshore current, density current	· Representative points including inside and outside bay	· Seasonal observation more than four times a year · Flow velocity: every 10 minutes for 15-day serial observation · Wave: every 1 hour for 15-day serial observation	· Flow velocity: ADCP, stratified observation over water layer · Wave: serial observation through pressure type tide gauge (AWH-16), ultrasonic tide gauge (ADCP)
Sediment transport factors	· Critical erodible shearing stress, erosion rate constant, sedimentation rate, critical sedimentable shearing stress	· Representative points including inside and outside bay	· At least 2 times before and after operation	· Erosion and sedimentation: annular flume · Sedimentation velocity: lab test using settling tank accompanied by field test using owen tube, LISST-ST
Source and amount of sediment	· Net inflow quantities of sediment at estuary and bay entrance	· Bottom tracking: cross section of overall flow at bay entrance · Precise monitoring on driftsands: 2~3 representative points on cross section at bay entrance	· Monthly observation · High/mid/low tide · At least 1-hour serial observation considering nautical twilight (25-hour duration recommended)	· Vessel type using ADCP and bottom tracking with GPS · Seabed support type using ADCP, ADV and OBS to monitor driftsands
	· Net inflow quantities of sediment at coastal area	· Decide depending on river type	· Seasonal observation, four times a year · Every 10 minutes for 15-day serial observation	· Observe standard method for river sediment measurement · Surface current meter, grab to collect suspended load
Sedimentary facies	· Spatio-temporal variability on sediment facies, grain size · Sediment transport routes	· In- and outside bay · Every 500m for intertidal zone · Every 1km for subtidal zone	· Seasonal observation more than four times a year	· Intertidal zone: van Veen grab · Subtidal zone: direct sampling
Topography of seabed and	· Spatio-temporal variability on topography,	· Overall water depth and topographic changes (including	· Seasonal observation more than four times a year	· Intertidal zone: precision deepsea recorder for shallow sea, multibeam echo sounder

intertidal zone	sedimentation and erosion quantities	intertidal and subtidal zone)		· Subtidal zone: onshore leveling, lead leveling, LiDAR

Table 3. Environmental impact observation for estuarine biota

Contents	Scope and location	Period and duration	Method
Bird	· Supratidal to subtidal zone · Migratory bird land and habitat	· Consider occurrence season · Distribution status timely	· Line census, point census, point observation
Fish	· Supratidal to subtidal zone · Consider mudflat condition	· Consider life cycles of fish · Consider flood and ebb	· Sampling, diving, sample line · Use 1 or 2 method
Benthos	· Supratidal to subtidal zone · Consider mudflat condition · Consider onshore site during ebb tide	· High and low tide · Vessel inspection on water way and tide pool	· Quantative, qualitative investigation · Sieve after sampling · 0.04 ㎡ for four points
Fish roe and fry	· Supratidal to subtidal zone · Consider mudflat condition · Consider inflow and transport direction· Consider seaweed condition	· High tide period to retain constant depth	· Plankton net
Zooplankton	· Supratidal to subtidal zone · Consider mudflat condition · Consider flood and ebb tides	· High tide period to retain constant depth	· Plankton net (0.1~0.3 ㎜)
Phytoplankton	· Supratidal to subtidal zone · Consider mudflat condition · Consider flood and ebb tides	· High tide period to retain constant depth	· Water sampling
Seaweed	· Supratidal to subtidal zone · Consider distribution scope in advance	· Winter to spring, overgrowing season	· Scrapping or cutting
Microalgae	· Supratidal to subtidal zone · Consider mudflat condition, low tide	· Ebb tide during high tide	· Use quadrate