TIDAL POWER GENERATION IN GAROLIM BAY, KOREA

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Regarding ocean energies, tidal power generation has a great advantage on large development possibilities despite of its huge construction cost and difficulty in finding an applicable location. Furthermore, once tidal power generation is developed, various developmental benefits are expected such as semi-permanent energy production, a bridge role, tourism resource effects, an adjustability of flood inundation at inner bay and other multi-development effects(Roger H. Charlier.,2003, John Twidell, 2006). Nevertheless, unfavorable impacts on bay environments have also been pointed out. The environmental problems include mud flat extinction and marine eco-system disruption. The participation of local residents is essential to resolve ecological and socioeconomic issues. In this study, the feasibility of tidal power generation is examined by reviewing the hydraulic characteristics of a target area in the Garorim bay on the west coast of Korea.

Keywords: Ocean Energy, EFDC Model, Tidal Power Plant, Garolim Bay

INTRODUCTION

With the global warming and depletion of fossil energy, the world is focusing on natural energy development and most of the advanced countries are competitively directing their interests on its research and development. Among new renewable energies, the ocean energy has inexhaustible energy potentials with comparatively less risk causing the secondary environmental problems as a non-polluting natural energy which leads to higher expectation. Korea, surrounded by oceans, has a very beneficial topographic trait of taking an advantage of environment-friendly ocean energy such as wave-power and tidal energy generation at the eastern and western coasts.

In particular, since the West Sea of Korea has a large tidal range, it has a favorable condition for creating a large-scale of new renewable energy from tidal-power generation that leads to continuous studies on it in Korea. There are validities for tidal-power generations at Garolim Bay, Saemangum, Chonsu Bay and Incheon Bay, all of which have larger tidal ranges and stronger tidal currents than any other area.

According to the results of previous studies, the requirements for efficient tidal-power generation are a large tidal range, big water-reserving area and narrow mouth. Garolim Bay has a tidal range of 7.9m at the maximum, comparatively bigger water-reserving area and only 2km wide mouth, all of which have made it a first choice for building a tidal-power plant with high expectations. Although the availability of tidal energy at Garolim Bay has been reviewed, more reviews are still necessary to find the validity of a concrete location of the plant, tidal range and locations of sluices for more efficient tidal-power generation. In this study, using EFDC Model easily applicable to the West Coast with a large intertidal zone owing to the design to deal with the three-dimensional intertidal zone in neritic region, the validity of building a plant at Garolim Bay was reexamined. Moreover tidal ranges and the locations of sluices for efficient tidal-power generation was reviewed by identifying external forces of coastal hydraulics which provides a high degree of comprehension of the characteristics of ocean circulation in Garolim Bay.

STUDY AREA

Garolim Bay is located in the northern area of Taean Peninsula, Chungchong Province. The mouth of the bay is 2.2km wide and the distance from the mouth to the inner bay is 22.4km. Its mouth is narrow with the shape of gourd bottle, i.e., a semi-enclosed back bay (Ministry of Land, Transport and Marine Affairs, 2006). The length of the coast line is 161.84km and there are big islands at the inner bay such as Gopa Island and Ung Island and small deserted islands such as Yul Island, Pi Island, Jo Island and Daeu Island, surrounded by Seosan City and Taean County.

Garolim Bay reserves a natural state mud field of 70km^2 created by a large tidal range of 7.9m with abundant biota. From the viewpoint of fisheries science, the region is vital for fish spawning and habitats as much as Cheonsu Bay(Park, etc., 2009). It is generally known that an available head is needed for

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efficient tidal power generation which is determined by the water-level changes in the reservoir, the open sea tides, and a relatively large volume of reservoir area(Baker, 1991). From this point of view, Garolim Bay consisted of 112.57km^2 reservoir area which is the largest reservoir in Korea with a mouth less than 2km suits the best for a tidal power plant location and is an effective area for installing generating facilities(Yu, Yee, 2008).

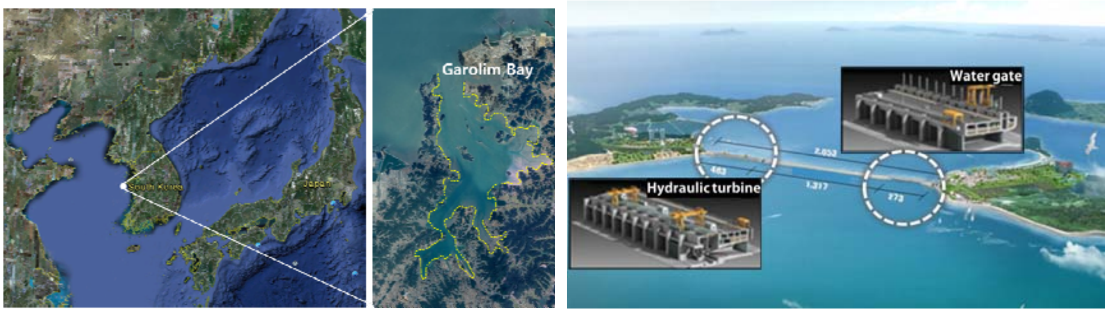

Figure 1. Study Area and Bird View

Considering the requirements for tidal power generation, Garolim bay has a large tidal range with a gourd bottle shape as shown in Figure 1. Its narrow bay entrance and broad surface extent of the inner bay indicate one of the best geographical conditions in the world for tide power generation.

The annual maximum tidal range at the bay entrance reaches 851cm and the tidal range amplifies towards the inner bay. The tidal current is observed to have noticeable semidiurnal tide components with its maximum flow speed of approximately 1.5m/s during flood tide.

Field observations were carried out to understand hydraulic characteristics of the target area and select the location of a water gate and a hydraulic turbine for tidal power generation development with its anticipated influence on the environment. Particularly, high quality data have been obtained by Ocean TMS(Telemetric Monitoring System) which is planned for continuous acquisition of real-time data(Figure. 2).

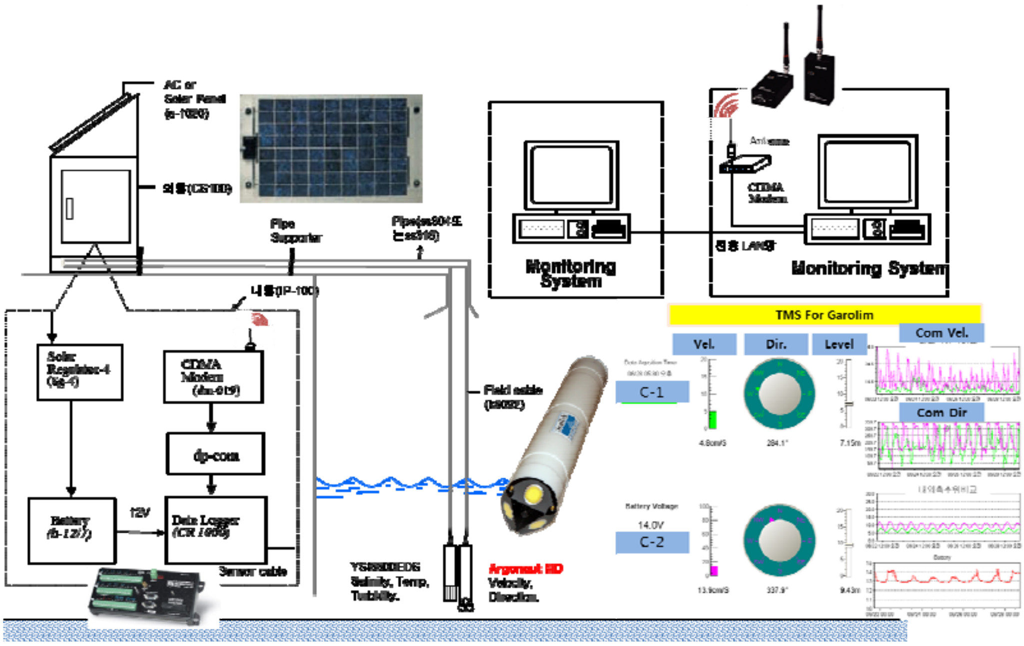

Figure 2. Field Observation: Tide & Tidal Current using TMS

NUMERICAL MODEL

The EFDC Model, developed by VIMS(Virginia Institute of Marine Science), is a numerical model for multi-variable finite difference simulating transport and flow which is authorized by Environmental Protection Agency. EFDC Model is very suitable to measure two or three dimensions vertically and horizontally. In particular, it is designed to deal with a three-dimensional intertidal zone in neritic region by using mass-conserving scheme. It can be easily applied in the western coast where a large intertidal zone exists. However, there are weaknesses of the model along with the easy application. First, a lot of calculation data is required considering with the multiple processes of hydrodynamics, sediment transport, water quality and toxics. Second, it requires a length of time to calculate which needs to be resolved in future.

The grid system of the model deals with Cartesian and curvilinear coordinate system horizontally and indicates a proper topography with the minimum number of grids through vertical coordinate system. It enables to get the numerical solution effectively and decreases the calculation time.

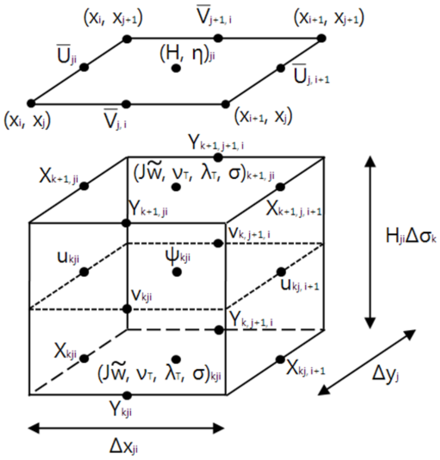

Figure 3. Coordinate and Grid System

The theory of EFDC Model and its numerical analysis are similar to those of Chesapeake Bay of US Engineer Corps. The governing equations are the three-dimensional Reynolds average continuity equations (1), (2), motion equations (3), (4), (5), equation of state (6) and mass conservation equations (7), (8), (9) (Hamrick, 1992).

Continuity equations

$$\partial_t(m\zeta)+\partial_x(m_yH\int_0^1 udz)+\partial_y(m_xH\int_0^1 vdz)=0 \tag{1}$$

$$\partial_t(m\zeta)+\partial_x(m_yHu)+\partial_y(m_xHv)+\partial_z(mw)=0 \tag{2}$$

Motion equations

$$\partial_t(mHu)+\partial_x(m_yHuu)+\partial_y(m_xHvu)+\partial_z(mwu)-(mf+v\partial_xm_y-u\partial_ym_x)hv$$

$$=-m_yH\partial_x(g\zeta+p)-m_y(\partial_xh-z\partial_xH)\partial_zp+\partial_z(mH^{-1}A_v\partial_zu)+Q_u \tag{4}$$

$$\partial_t(mHv)+\partial_x(m_yHuv)+\partial_y(m_xHvv)+\partial_z(mwv)-(mf+v\partial_xm_y-u\partial_ym_x)hu$$

$$=-m_xH\partial_y(g\zeta+p)-m_x(\partial_yh-z\partial_yH)\partial_zp+\partial_z(mH^{-1}A_v\partial_zv)+Q_v \tag{4}$$

$$\partial_zp=-gH(\rho-\rho_0)\rho_0^{-1}=-gHb \tag{5}$$

State equations

$$\rho=\rho(p,S,T) \tag{6}$$

Mass conservation equations

$$\partial_t(mHS)+\partial_x(m_yHuS)+\partial_y(m_xHvS)+\partial_z(mwS)=\partial_z(mH^{-1}A_b\partial_zS)+Q_S \quad (7)$$

$$\partial_t(mHT)+\partial_x(m_yHuT)+\partial_y(m_xHvT)+\partial_z(mwT)=\partial_z(mH^{-1}A_b\partial_zT)+Q_T \quad (8)$$

$$\partial_t(mHC)+\partial_x(m_yHuC)+\partial_y(m_xHvC)+\partial_z(mwC)$$

$$=\partial_z(mH^{-1}K_b\partial_zC+wC)+mHR_c+Q_c \quad (9)$$

The horizontal turbulent viscosity coefficient at the horizontal turbulent viscosity term and the turbulent diffusion term used to express the turbulent mixing of a smaller scale than the model grid is calculated through the equation determined by the gird size and the velocity gradient. In general, considering the horizontal turbulent viscosity coefficient and the horizontal turbulent diffusion coefficient are the same, as the calculated grid size and the velocity gradient gets smaller, the horizontal turbulent viscosity coefficient decreases and can be ignored if the grid is small enough.

Application and Simulation

The data of the depth of Garolim Bay waters to conduct an ocean circulation experiment by using the numerical model is shown in Figure 3. It shows the variable grids used for more detailed review of interesting areas and decrease of calculating time.

For the experiment, the waters of east to west 27km and north to south 39km were selected for the grid, and the grid was made of variable grid-net of up to 750m to the minimum of 40m for a specific review of the circulation characteristics at the targeted area for a tidal power generation.

Tide level and velocity component at the open boundary of the open sea were assumed to be represented around the targeted waters. In addition, coordinate system was comprised to include the numerical traits by layers since the inner water of Garolim Bay consists of intertidal zone due to different water depths between the edge and the center. Table 1 shows the conditions of ocean circulation numerical model experiment.

Table 1. Simulation Conditions.

Model	Grid System	Grid Size 40 ~ 750m 189 × 256 (Grid Number 26,493)
	Layer	3Layer(surface, middle, bottom)
Condition	Tide	M2, S2, K1, O1
	Duration	16day
	Time Step	2sec
Simulation Cases		Spring tide, Neap tide

Verification of Numerical Simulation

T-1(the standard tide at the targeted area, Korea Hydrographic and Oceanographic Administration, 2010) is used to verify the tide and current which are the major characteristics for numerical simulation, shown in Figure. 4. Also, a current observation data (Garolim Tidal Power Plant Co. Ltd. 2011) at the mouth of Garolim Bay is used for the target area.

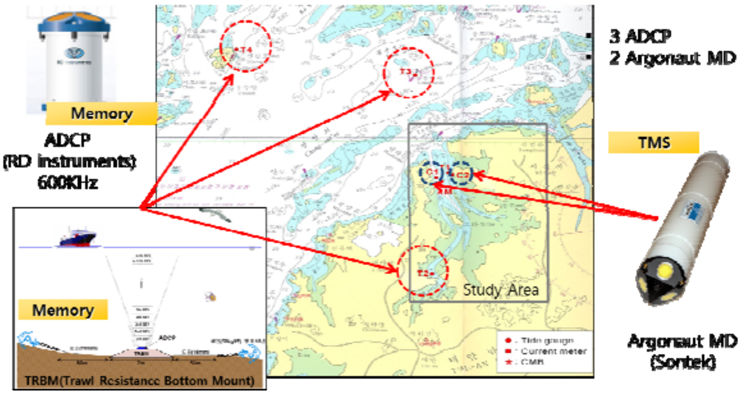

Figure 4. Field Monitoring

Table 2 shows the verification results of the tide. There was a relatively small error in between the spot observation and the numerical experiment and the relative error was verified in the numerical model experiment to those of the spot observation. As shown in Figure 6, a consistency between the two results is drawn which represents the circulation status of the target area.

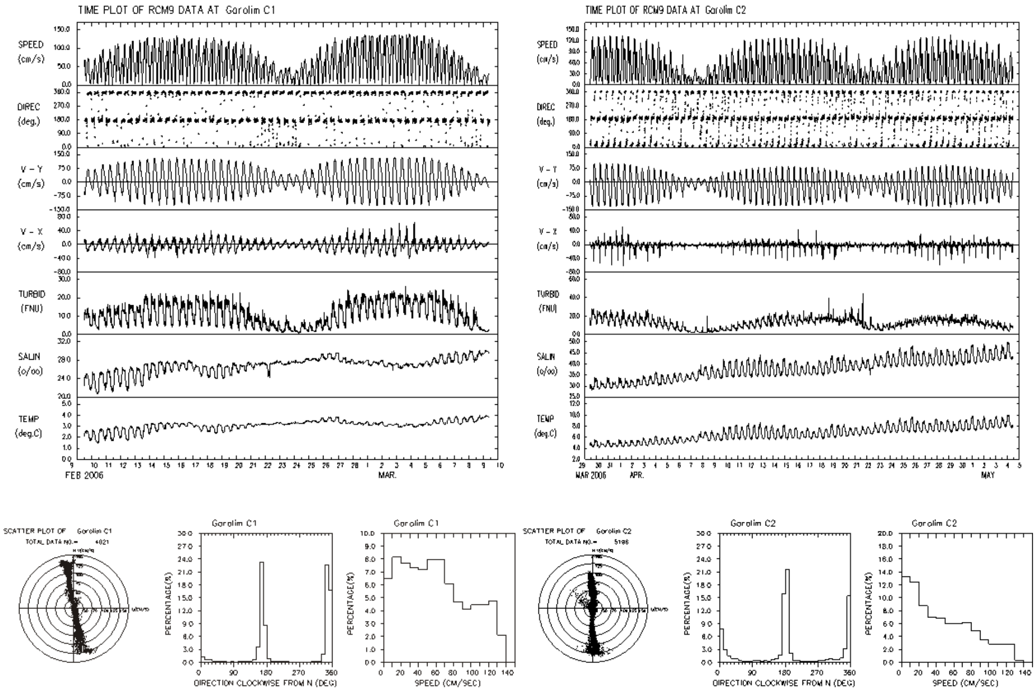

Figure 5. Results of Field Investigation

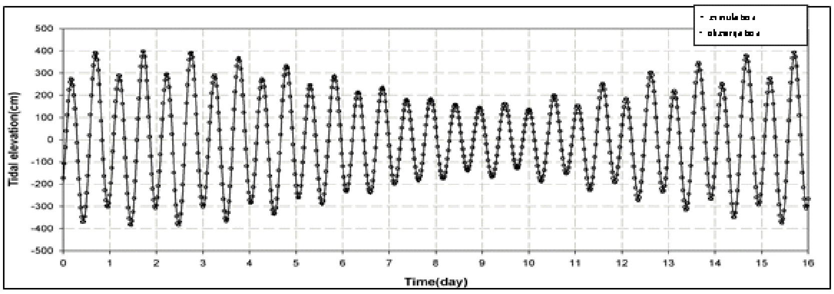

Figure 6. Tide level verification

Table 2. Tide level verification(middle layer)

Item		Observation		Numerical simulation		Relative Error (%)
Point	Constituent	Amplitude (cm)	Phase lag(deg.)	Amplitude (cm)	Phase lag(deg.)	
T-1	M_2	248.00	110.90	246.70	113.94	-0.5
	S_2	99.20	157.30	99.30	166.11	+0.1
	K_1	38.30	288.30	38.30	292.65	0.0
	O_1	28.40	259.50	28.50	256.51	+0.4
	SUM	413.90	-	412.8	-	-0.3

Furthermore, Table 3 shows the verification results of current velocity. It indicates the relative error of 0.7% between the observed values of PC-1 located at the west to the waterway and the result of the numerical model experiment. Even though the velocity at the east to the waterway shows a little difference(19.8%) between the observed and the result of numerical calculation, it is well represented regarding to the Deg. conditions applied to the numerical model experiment.

Table 3. Tidal current verification(middle layer)

Item		Observation		Numerical simulation		Relative Error (%)
Point	Constituent	Velocity (cm/sec)	Phase lag(deg.)	Velocity (cm/sec)	Phase lag(deg.)	
PC - 1	M_2	85.1	203.3	78.5	213.4	+0.5
	S_2	26.9	257.1	33.9	265.6	
	K_1	6.3	13.9	6.6	292.2	
	O_1	4.7	339.6	4.6	357.6	
PC - 2	M_2	52.4	205.7	58.3	213.4	+19.8
	S_2	16.9	257.5	25.0	265.6	
	K_1	4.5	14.1	5.7	292.2	
	O_1	4.1	322.5	4.3	357.6	

Result of Numerical Simulation

The numerical model experiment on the characteristics of ocean circulation in Garolim Bay was carried out at the time of the biggest difference between spring and neap tides. By representing the results of velocity vector and velocity distribution at the times of flood current and ebb current at middle stratum by the time of tide, the locations of sluices and hydraulic turbines for the efficient single-action tidal power generation were reviewed with the consideration of the regional trait of large reservoir area. As the result of the numerical model experiment, the ocean circulation of the target area flows from the northern waters of Taean Harbor to the east, passes Daesan Harbor and Daenanji Island, and partially passes the waterway between Naeri and Beolmal to flow into the inside of Garolim Bay, while it flows in the opposite direction at the time of falling tide (Figure.9, Figure 11).

Spring tide velocity (Figure 7) of open sea targeted for Bay-Mouth Tidal Power Plant was 31~157cm/s and 64~154cm/s for the velocity at the area for a tidal power plant, 35~97cm/s inside the bay, 46~136cm/s at the exterior waterway at the falling tide, 52~127cm/s at the bay mouth and 28~68cm/s inside the bay, respectively.

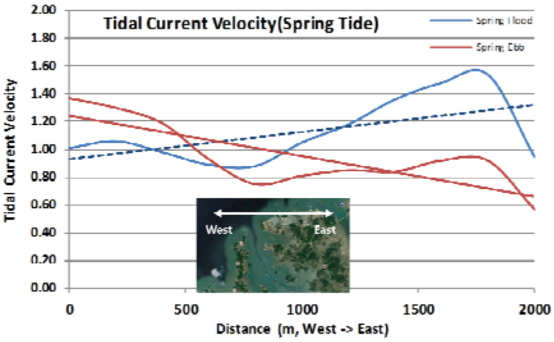

Figure 7. Tidal current velocity at the mouth of the Garolim Bay (spring tide)

During neap tide, the current velocity(Figure 8) of the waters at waterway of bay mouth at falling tide was 21~67cm/s and at the inside of the bay 11~40cm/s, respectively. Accordingly, at the velocity distribution at flood tide(spring tide) shown in Figure 8, the current velocity of the eastern waters was 154cm/s at maximum and the western waters 106cm/s, which shows the eastern waters was higher at falling tide, 92cm/s at the east and 137cm/s at the west.

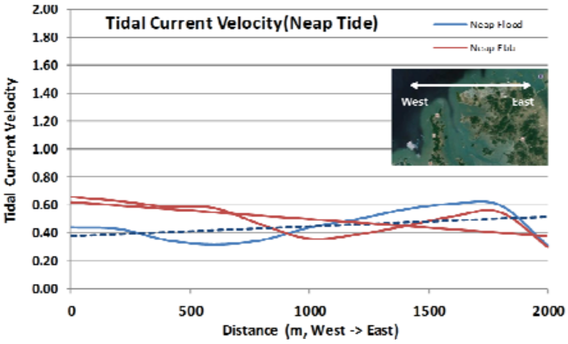

Figure 8. Tidal current velocity at the mouth of the Garolim Bay (neap tide)

As a result, when big sluices with high discharge capacity were installed at the eastern waterway where a dominant flood current flows through the mouth of Garolim Bay and hydraulic turbines were installed at the western waterway with strong current velocity at falling tide, the efficient tidal power can be generated.

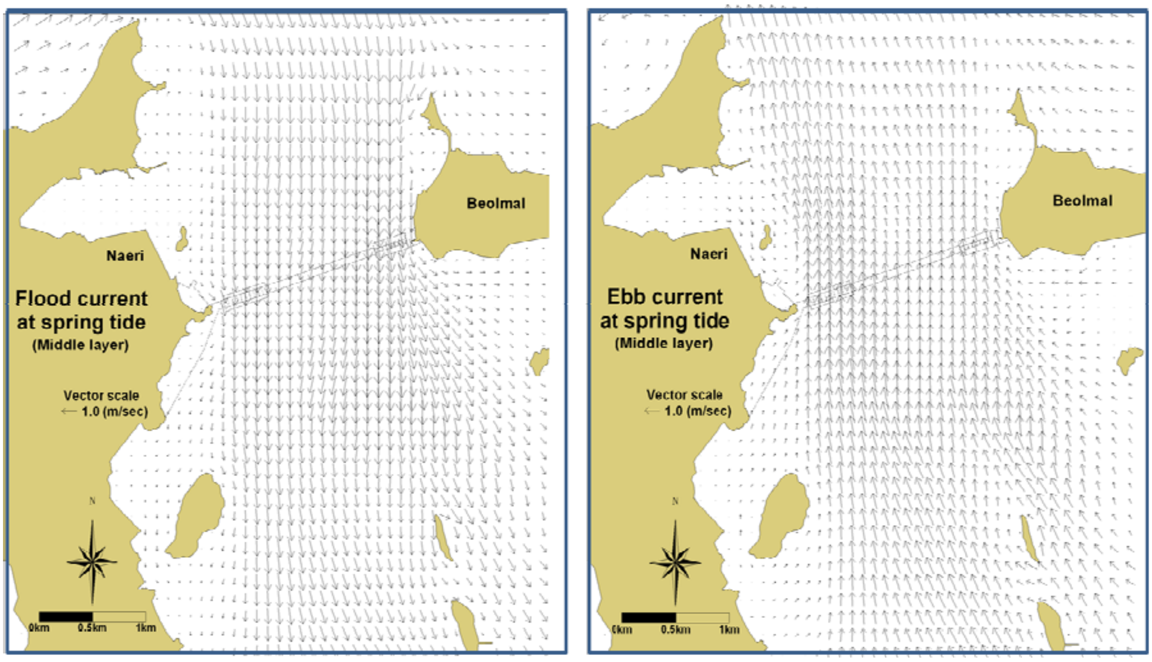

Figure 9. Maximum current vector at spring tide

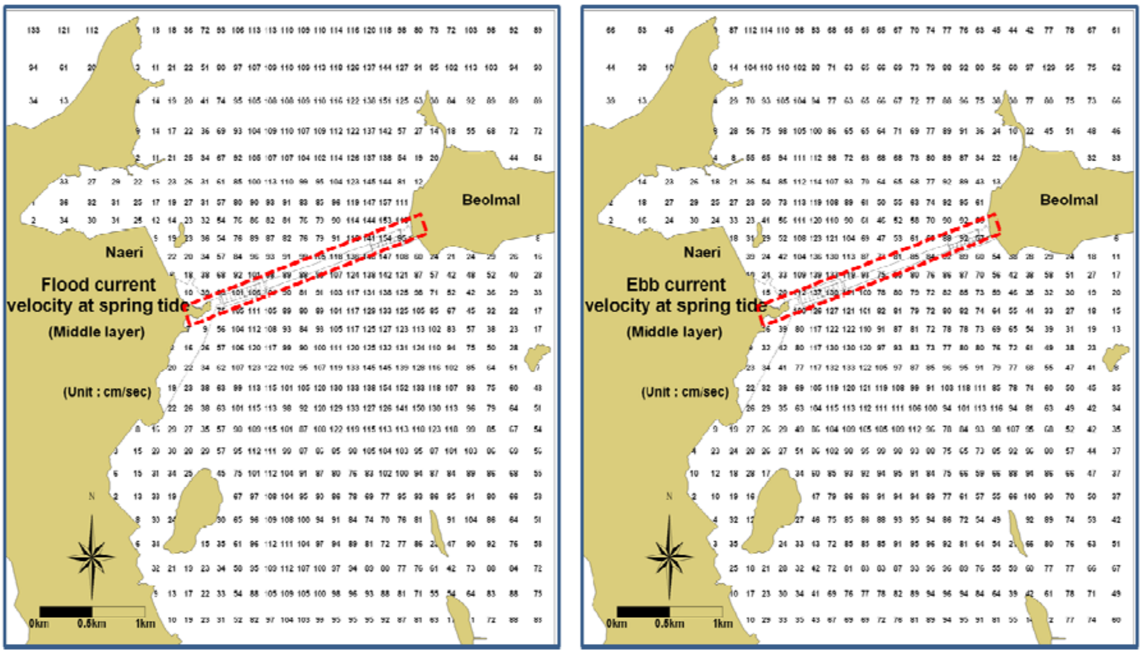

Figure 10. Maximum current velocity distribution at spring tide

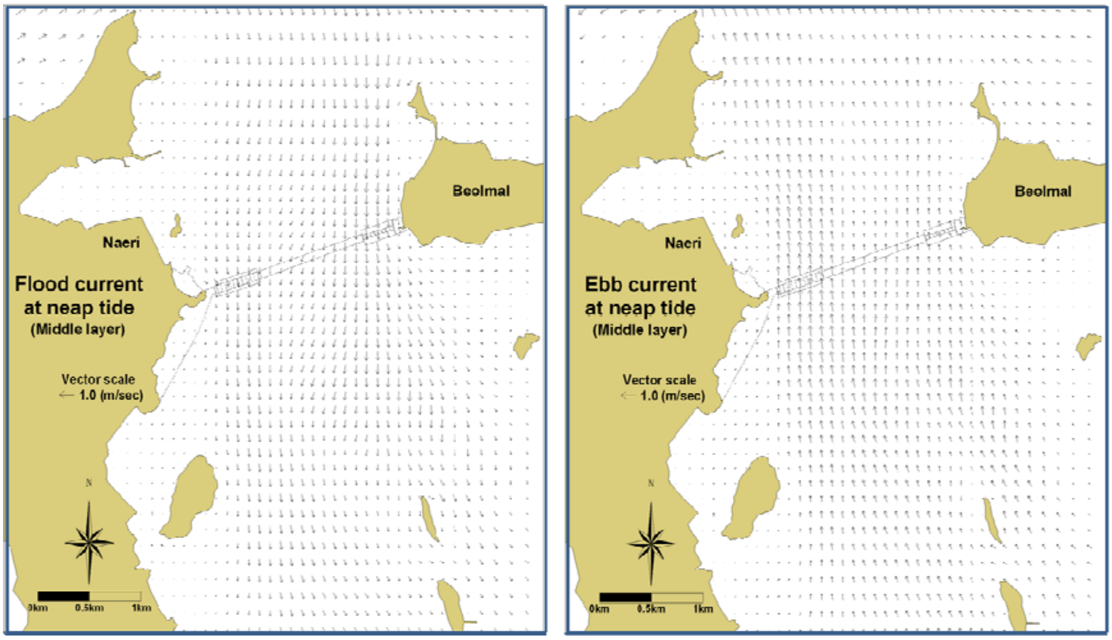

Figure 11. Maximum current vector at spring neap tide

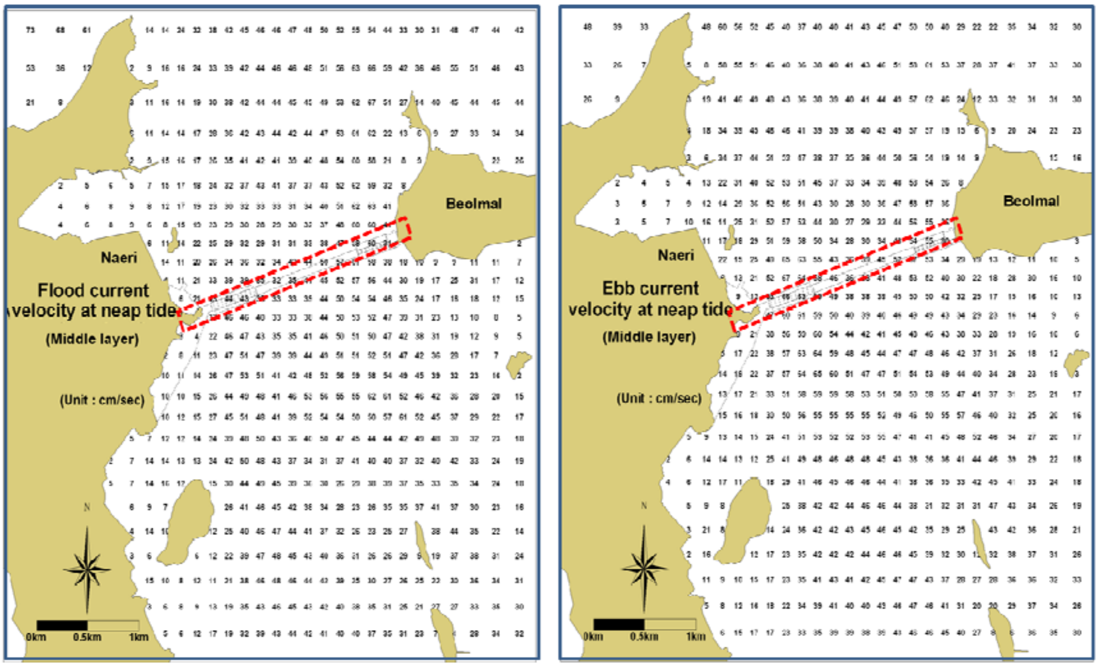

Figure 12. Maximum current velocity distribution at neap tide

CONCLUSION

For this study, a high level of interpretation on the traits of ocean circulation at the target area for a tidal power plant at the Garolim Bay's mouth by using the three-dimensional numerical model of EFDC was conducted, and the locations of hydraulic turbines and sluices for an efficient tidal power generation were reviewed through analyzing the characteristics of coastal hydraulic external forces.

The tidal power generation is to generate electrical energy by blocking the tidal bay with tide embankment to keep the ocean water inside, installing hydraulic turbine generators and utilizing the water level difference between the reserved water and the sea surface. To build an efficient tidal power plant, hydraulic turbines should be installed at an area with big current velocity created by the tide, and the locations for big sluices with big discharge capacity should be selected in order to secure the tidal volume flowing inside the bay.

The verification of numerical model experiment and the spot investigation data show that the results of the numerical model experiment are consistent with those of the spot investigation on the current and the tide relatively well. Also they made it possible to confirm the characteristics of ocean circulation.

According to the results of the numerical experiment, the flood tide at Garolim Bay flows towards the bay through the eastern waterway and it results a strong falling tide through the western waterway at falling tide. The results indicate the value of 125~140cm/s and the falling tide dominant against the flood tide.

For an efficient tidal power generation, accurate location selections for sluices and hydraulic turbines installation should be based on the results of the numerical experiment considering with the characteristics of ocean circulation. An efficient tidal power generation can be constructed with the installation of big sluices with high discharge capacity at the eastern waterway involving dominant flood tides toward the mouth of Garolim Bay and hydraulic turbines at the western waterway with a strong current velocity at falling tide.

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