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A Study on the Water Gate Operation in the Canal System by MIKE 3 FM

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Abstract

Water Circulation system in canal has a great importance in Songdo Waterfront. There is a need to ensure that consistent water flows occur in the canal. In this study, MIKE3 FM was setup and used to investigate the circulation system with respect to the operation of the water gates will present at the ends of the canal system. The model was computed under various tidal conditions in Incheon coastal. The numerical modeling of the water flow helped to determine the gate operation that will play an important part in the water circulation in the canal.Water gate operation was possible to maintain the specific water level. Optimal water gate operation was decided for the Songdo waterfront canal system.

Keywords: *Gate operation, MIKE 3 FM, Water circulation, Songdo waterfront*

1. Introduction

Songdo Waterfront is a project supported by IFEZ (Incheon Free Economic Zone) with maintains the water circulation system. The main focus of this project is to develop a canal system with a continuous water circulation that will guarantee a higher water quality but also an easily manageable water level. Songdo city is currently developing the waterfront near the coastline which is in line with its goal of being a world class eco-friendly green city in Incheon area [1]. The city planned to have a canal systemsurrounding it where clean seawater will flow. This proposed canal will be managed by 4 water gates which will regulate the flow inside the system. In this study using a MIKE 3 FM, analyze the water gate operation possibility. Using a water gate and weir structure module, we implement water circulation system in the Songdo city canals. The Songdo's canal system is shown in Figure 1.

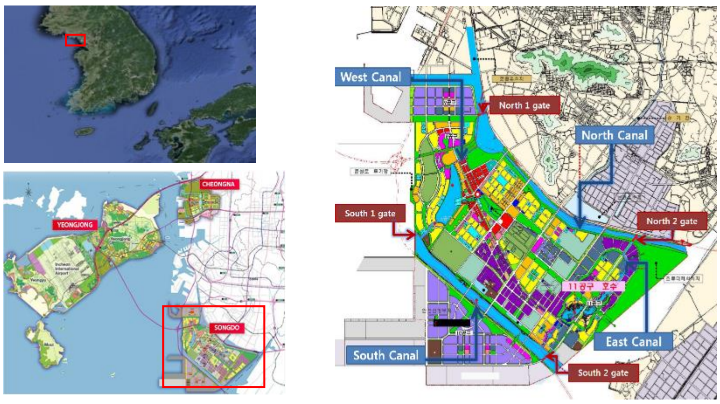

Figure 1. Location of Songdo Waterfront's Canal

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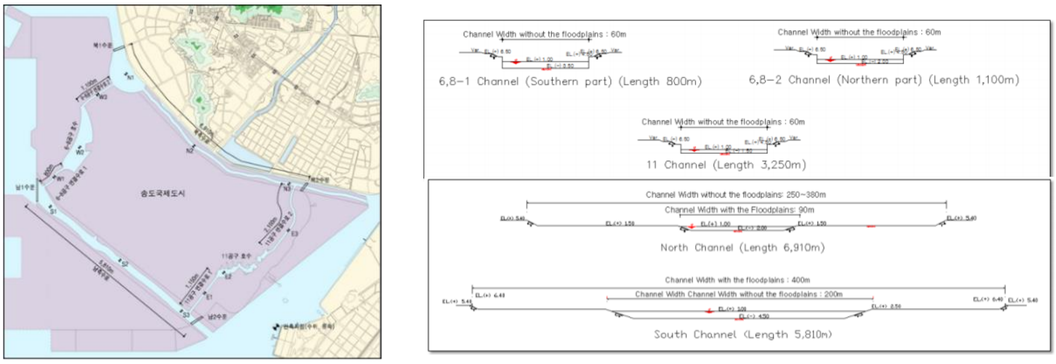
Figure 2 and Table 1 shows the specifications of the Songdo waterfront's canal. The length of the south channel length is 5.8km and North channel length is 6.9km, there is a lake locatedmiddle of the west and east canals. The width of the south canal is 400m and north canal is 90m. Bed level is El. (-) 4.5m at south canal.



(a) Floor Plans View (b) Cross Section View

Figure 2. Design of the Songdo Waterfront Canal

Table 1. Each Canal Dimensions

	Length(m)	Width (m)	Elevation
North canal	6,910	90	El. (-) 1.5m
South canal	5,810	200	El. (-) 4.5m
West canal	800 / 1,100	60	El. (-) 4.5m ~ 1.5m
East canal	1,150 / 2,100	60	El. (-) 1.5m
Ponds	-	-	El. (-) 1.5m

There are several aspects in contemporary gate management for which an informed view on discharge and flow properties around gates is essential [2]. Like stability of bed material and scour prediction: local erosion behind the bed protection [3] as well as larger scale morphological changes of surrounding bathymetry [4], ecological issues: fish migration, salt water intrusion and mobile fauna [5], dynamic forces associated with flow-induced gate vibrations [6].

Open channel flow software modeling has become standard design tools for irrigation canals [7]. In this study, numerical hydraulic analysis was conducted. Water gate operated throughout the water level difference between sea and canal area.

2. Methodology

2.1. Numerical Model Description

A process-based modeling approach is adopted by applying the MIKE 3 flexible mesh (FM) suite developed by DHI Water and Environment, in which an unstructured grid provides an optimal degree of flexibility in the representation of complex geometries and smooth boundaries. The modeling system consists of a number of modules integrated together to perform the simulation of hydrodynamic flow, wave generation and propagation, sediment transport and morphological changes. It has been successfully used for complex applications within oceanographic, coastal and estuarine environments [8].

The hydrodynamic model in MIKE 3 is a general numerical modelling system for simulation of flows in estuaries, bays and coastal areas as well as in oceans. It simulates unsteady three-dimensional flows taking into account density variations, bathymetry and external forcing such as meteorology, tidal elevations, currents and other hydrographic conditions.

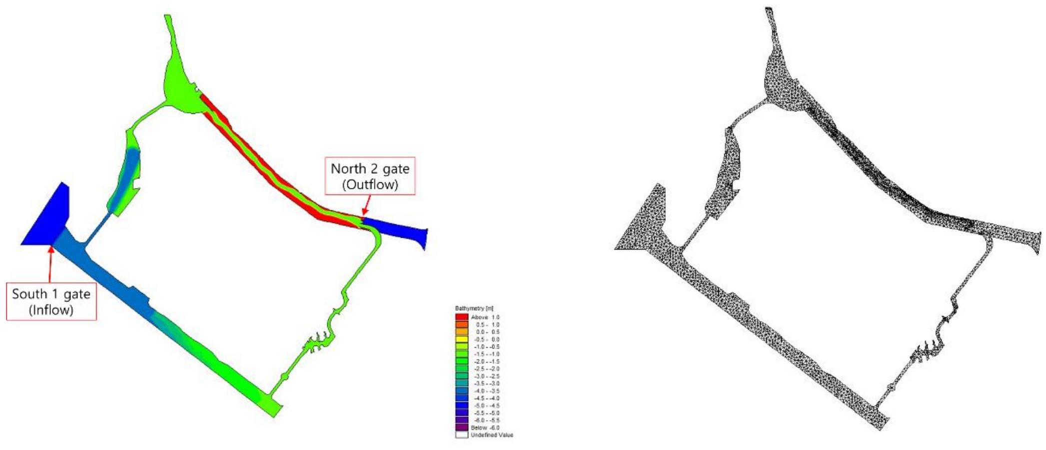
In a three-dimensional hydrodynamic model for flow of Newtonian fluids, the following elements are required mass conservation, momentum conservation, conservation of salinity and temperature, equation of state relating local density to salinity, temperature and pressure [8].

2.2. Model Set-up

The bathymetry of the channel system was built with the Mesh Generator from MIKE 3 FM using as input values the coordinates taken from elevation given for each channel.

In the Mesh Generator by Mike Zero, the UTM-52 projection was selected. The boundaries were imported from designed map from 'Songdo waterfront project' and the arcs that are connecting the nodes were created in the Mesh generator. After importing all the arcs that are compiling the outline of the mesh, the boundaries at each inflow and outflow are set. Each one is given a different name so that it can be easier to distinguish them in MIKE3 FM, when the boundary conditions are added.

The unstructured mesh and bathymetrywere built in the model. Each canal of outside boundary is tidal change. The tidal wave for 15 days was provided by KHOA and tidal harmony is considered M2, S2, K1, O1 which is available only for the Incheon costal area. Tidal elevation is change from El. (+)4.45m to (-)4.45m. This is normal tidal condition in Incheon costal. And canal water level controlled from El. (+) 1.3m to El. (+) 1.0m by the gate operations. Figure 3 is showing bathymetry and unstructured mesh for the study area.



(a) Bathymetry and QateLocation (b) Unstructured Mesh

Figure 3. Bathymetry and Mesh

It was decided before that at each entry/exit should be placed a weir. The weir height was set as follow:

Weir level of South 1 gate is El. (+) 0.5m and North 2 gate is El. (-) 1.0m. In order to keep the management water level at 1.0m, South 1 gate and North 2 gate has to be implemented. South 1 gate will block the water inflow when the inside canal water level reaches 1.3m at the tidal increase duration. Also stop the water outflow in the North 2 gate when the inside water level at 1.0m in tidal decrease duration.

The mode of flow associated with gated structures is often complex under real-time conditions but there hydraulics fall into two regimes of: (i) modular flows when discharge is independent of the tail water depth; and (ii) submerged flows when there is dependency [9]. Figure 4 and 5are showing the gate operation in South 1 and North 2 gate.

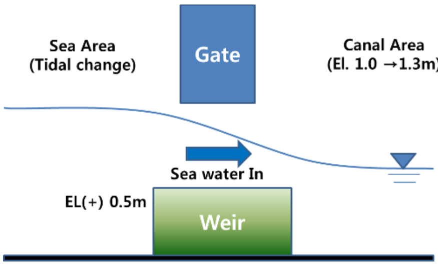


Figure 4. Flow Condition at the South 1 Gate

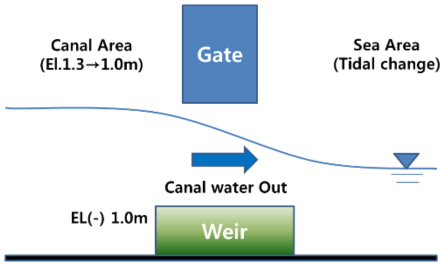


Figure 5. Flow Condition at the North 2 Gate

Water level managed fromEl. (+) 1.0m toEl. (+) 1.3m in canal. As shown in Figure 6, inflow duration is shorter than outflow duration. Inflow and outflow discharge must be same, so weir width at the inflow location designed longer than outflow weir width.

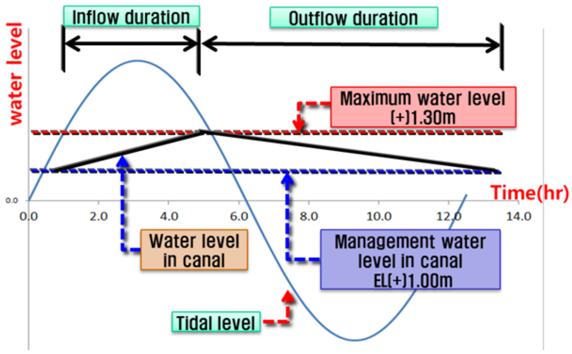
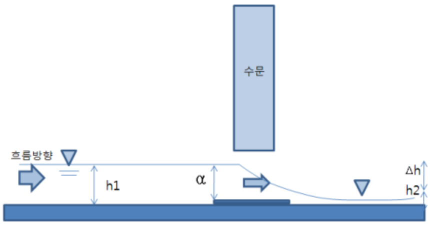
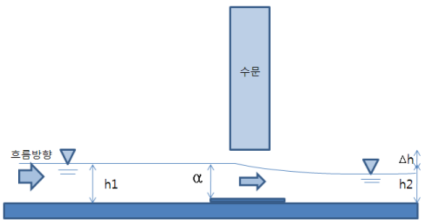


Figure 6. Relationship with Canal Water Level and Tidal Level

Weir discharge equation at the model is shown Table 2. Depending on the water level conditions, divided into two characteristics flows.

Table 2. Discharge Equation at the Model[10]

Flow condition		Discharge Eq.
Free Weir		$Q = 1.704CBH_1^{3/2}$
Submerged Weir		$Q = Ch_2B\sqrt{2g\Delta H}$

Where, c = discharge coefficients, B= weir width, H_1= upstream water level (m), H_2= Downstream water level (m), ΔH=$H_1 - H_2$, α =water level at the weir

The tidal wave for 15 days was provided by MEIS(http://www.meis.go.kr/) which is available only for the South Korea peninsula. The levels are varying to different maximum and minimum tidal conditions, each tidal having a duration of 12.4 hours and a 10 minute time step. The 15 days tide waves can be seen in Figure 7.

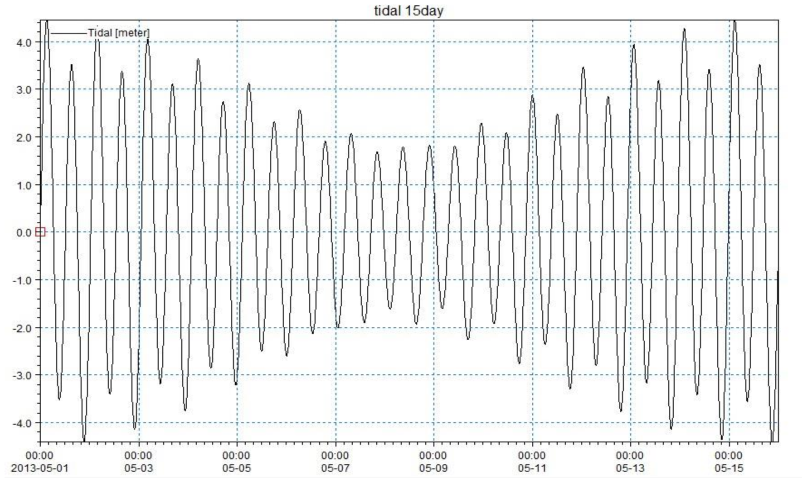
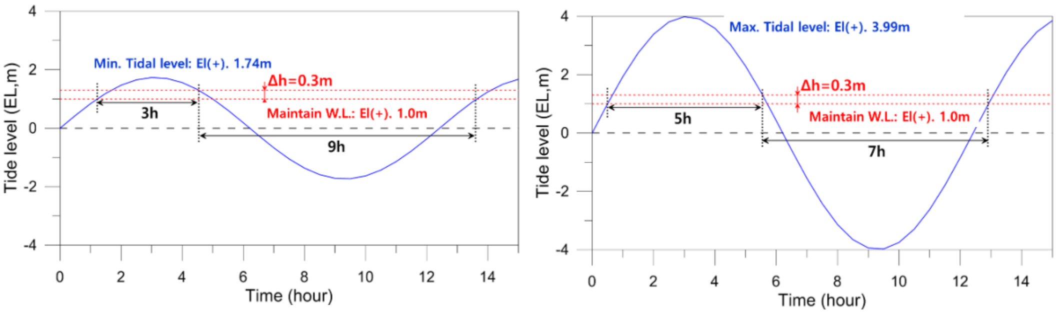


Figure 7. 15 Days Tidal

In order to do the simulations for the water exchange ratio and flood condition, the 15 days tidal was divided in a maximum tidal and minimum tidal. From the 15 days tidal condition, the smallest and highest peak were selected and two different time series were created, so that the simulations can have extreme input conditions for the boundaries. The Figure8 is representing the two separated tidal, with a 10 minute time steps.

Inflow duration is required 3 hours and outflow duration is required 9 hours in the minimum tidal condition. Inflow duration is required 5 hours and outflow duration is required 7 hours in the maximum tidal condition.



(a) Minimum tidal. (b) Maximum tidal.

Figure 8. Relationship with Tidal Level and Canal Flow Duration

3. Simulation Results

The simulation for the water gate operation was run for maximum and minimum duration and it was analyzed for each channel main points. The result of MIKE 3 FM hydrodynamic module, we can see the water level and velocity changed in the canal system.

The following graph is showing how the water level changed at the canalduring maximum tidal condition. It shows that in tidal increased duration, sea water was in flowed from sea; the canal's water level increased until El. (+) 1.3m. And tidal is lower than canal water level; the canal's water level was decreased by El. (+) 1.0m.

In this experiment more simulations were performed using different gate openings, so that the management level can be maintained fromEl.(+) 1.3 m toEl. (+) 1.0 m, according to tidal level change from each time steps. The initial water level inside the channels was set to 1.0 m.

To collect the results, different coordinates were used along the inside of canal. The main points of each canal for the velocity and water level analysis was selectedas shown in Figure 9. The canals which are W1, W3, E1 and E3 located are expected to high velocity cause of narrow canal width. Also S1, N3 is located near the gate, inflow and outflow location. So if inflow and outflow duration by the gate operation, the velocity in the S1, N3 point will be increased.

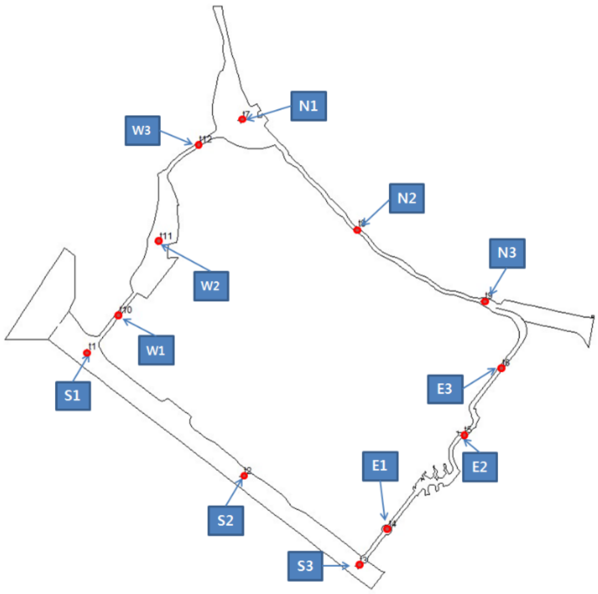


Figure 9. Analysis Points

3.1 Weir Width Decision

Prior to the water gate operation analysis, weir width decision experiments were performed. Considering the inflow and outflow of water due to the tidal difference. When determining the minimum width of South 1 gate for maintain the critical water level at canal by 1.3m in inflow condition, the maximum tidal condition need a20 meter width and minimum tidal condition need a 80meter width.

Also outflow conditions in canal, we determine the minimum width of North 2 gate for maintain the water level at 1.0m, the maximum tidal condition need a 20 meter width and minimum tidal condition need a 10 meter width.

Table 3 is showing maximum velocity at Maximum tidal and minimum tidal conditions. On average, the high velocitywas generated in the western channel and the east channelwhich has small canal width, and maximum tidal condition has a high velocity than minimum tidal condition. Maximum velocity of 33cm/s occurs in N2 point.

Table 3. Surface and Bottom Maximum Velocity at Each Point (Unit: cm/s)

Tidal	Layer	W1	W2	W3	N1	N2	N3	E1	E2	E3	S1	S2	S3
Max.tidal	Sur.	25	4	28	3	33	28	13	29	30	7	6	4
	Bot.	18	3	19	3	23	19	10	21	21	5	4	3

Min.tidal	Sur.	19	4	24	2	17	15	8	14	16	6	6	2
	Bot.	14	3	16	1	12	11	7	11	11	5	4	2

Figure 11and Figure 12shows the water level change at main points of canal in maximum and minimum tidal conditions.

When a tide level increased, water in flowed from sea. Inside of the canal water level was increased until El. (+) 1.3m from the management water level (El. (+) 1.0m) by S1 gate operation. Also when a tide level lower than inside of canal water, canal water level was decreased gradually at management water level (El. (+) 1.0 m) by N2 gate operation.

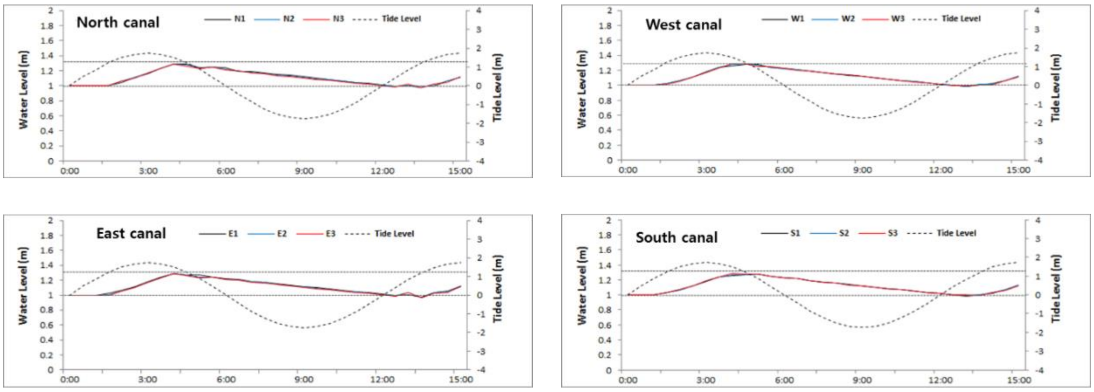


Figure 11. Water Level Change at Canal in Min. Tidal Condition

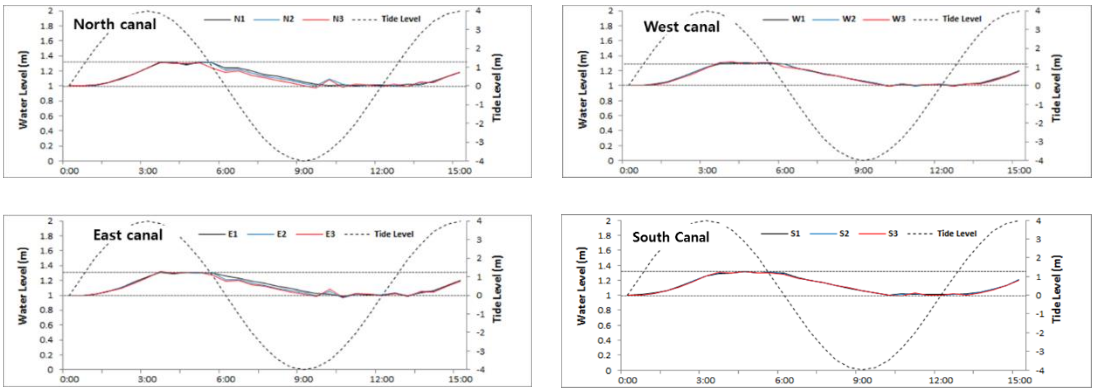


Figure 12. Water Level Change at Canal in Max.Tidal Condition

Figure 13 and 14 shows the velocitychange at main points of canal in maximum and minimum tidal conditions. When the water inflow conditions, western canal can be seen that the velocity is increased rapidly. In the outflow duration, north and east canal maintain a constant velocity. Time series velocity was analyzed by inflow and outflow duration by water gate operations.

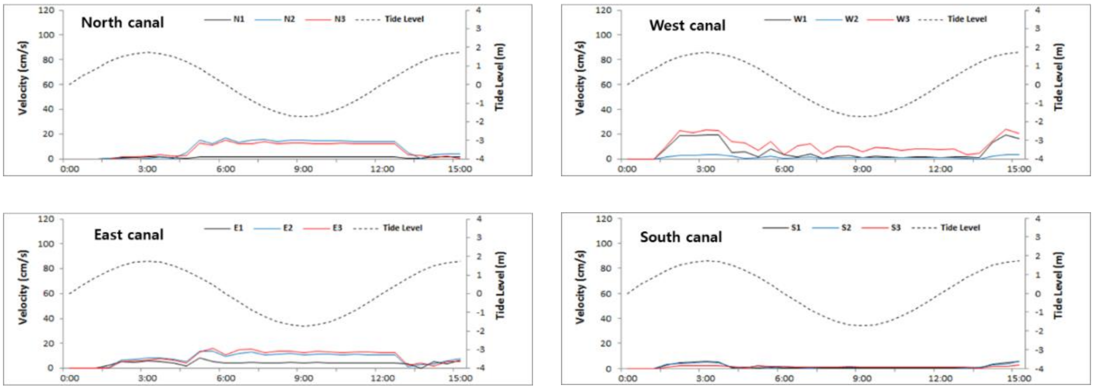


Figure 13. Velocity Change at Canal in Min. Tidal Condition

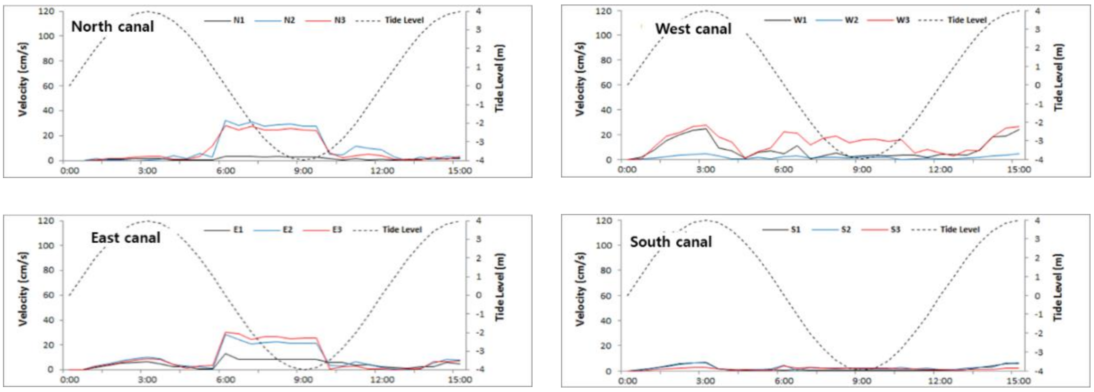


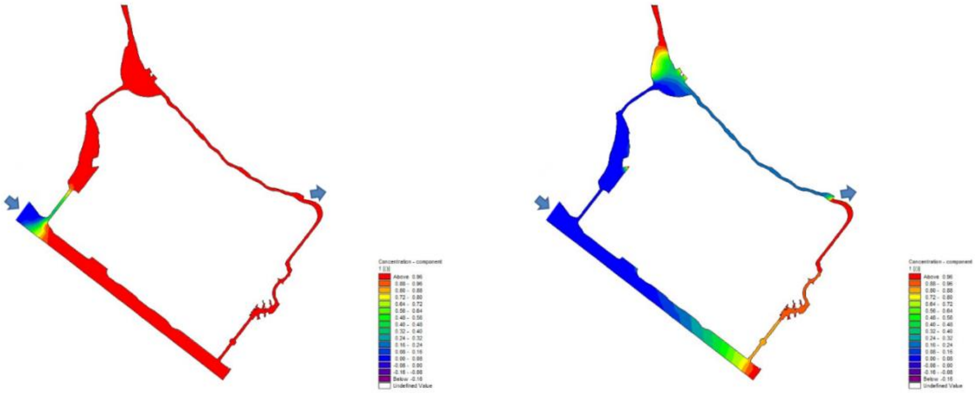
Figure 14. Velocity Change at Canal in Max. Tidal Condition

3.2 Exchange Ratio Test

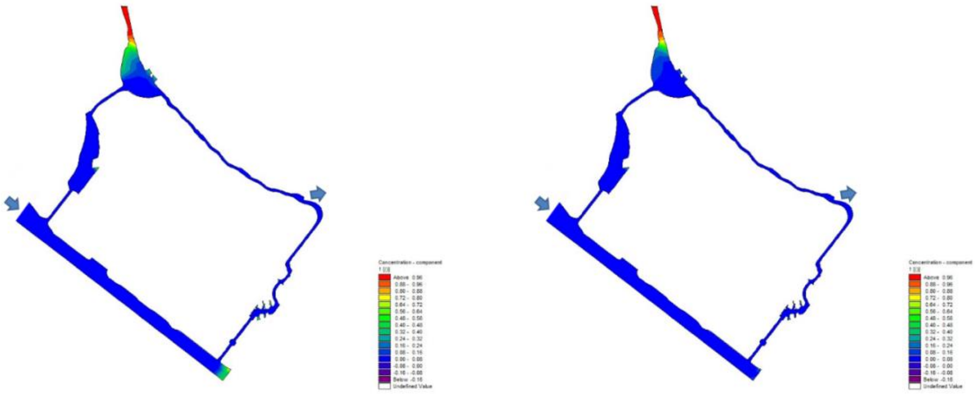
To determine the retention time of the water flowing from sea in the canal, the exchange ratio experiment was carried out. The initial condition was set to 1.0 mg/l across the entire canal while the input was 0.0 mg/l.The simulation was run for 15 days with a varying tidal condition.

The initial concentration of entire canal water was1.0mg/l while the inflow concentration of sea water was 0.0mg/l. We analyzed the concentration of canal water in 15 days. The used model was Transport module of MIKE 3 FM and Incheon coastal tide conditions were used for 15 days.Figure 16shows the concentration change in the canal according to the exchange ratio in each 5 days. The accepted values for the weir width were as 50 m for the inflow weir and 20 m for the outflow one. This weir width satisfying the economical construction fee and efficient operation for the flow in the weir.

Canal water exchanged by seawater andthe concentrationchange is showing well. 5 days after seawater had penetrated to all canals except the east canal. 10 days after, except for the some part of north canal, it can be seen that almost of the sea water is flowedin to the canal.



(a) 0.5day (b) 5 day



(c) 10 day (d) 15 Day

Figure 16. Mike 3 FM Transport Module Results

In the maps above we can observe how the water is travelling through the channel and how fast it reaches the outflow. Table 4 shows 15days exchange ratio in each canal. More than 95% of all canal water exchanged with seawater except for the north canal.

In the upper side of North1 gate which has stagnant areas likely to be resolved through the North 1 gate operation.When the operation of South 1 gate and North 2 gate, there is need a North 1 gate operation which is located on the top of north canal.Canal water exchanged with more than 90% of seawaterduring the 6.9 days.

Table 4. Exchange Ratio Change at 15 Days

canal	0.5day (%)	5day (%)	10day (%)	15day (%)	90% exchanged date
All	9	77	95	96	6.9
North	0	58	79	84	-
West	4	97	99	100	3.5
East	0	6	95	99	8.6
South	15	85	99	100	5.5

Figure 17 shows the exchange ratio change during 15days.South canal water exchanged rapidly with sea water. East canal which arethe farthest away from inflow gate(S1 gate), the canal water exchanged by sea water after 5 days. In case of north canal, the exchange ratio has slowly changedcause of congestion area.

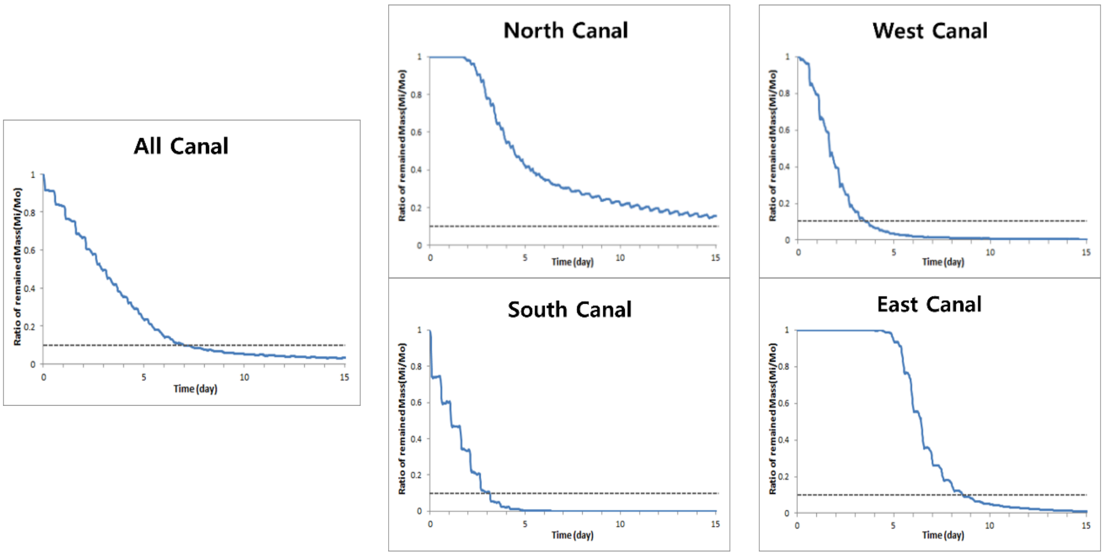


Figure 17. Exchanged Ratio Change in 15 Days

4. Conclusions

The purpose of this study was to applicate the gate operation in the canal system through the MIKE 3 FM simulation. Sea water can be inflow to the canal by gate operation. The numerical modeling of the water flow helped to determine the gate operation that will play an important part in the canal system. For each inflow or outflow boundary was set an opening and a closing level so that it can be used as a guide in the real situation.

South 1 and North 2 gate operation condition was appropriate to be implemented in Songdo waterfront area. Water level at canal was maintained by their design criteria.

The weirs played an important role in stopping the water going out of the channel but also not allowing water to go inside. The accepted values for the weir width were as 50 m for the inflow weir and 20 m for the outflow weir.

The transport module simulation showed that the water was exchanged 90 % in 7 days it was released through the South 1 gate and North 2 gate operation.

The results from this study will be used as a basis for a preconstruction plan of the canal system in Songdo. The water circulation results will be an important guide for further decisions that need to be taken for a prosperous and healthier water environment system.

Acknowledgement

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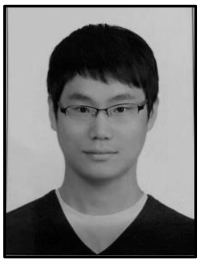

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