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The Changes in Hydraulic Characteristics due to the Topographic Changes in the Estuary

—In case of Downstream of the Kum River—

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Abstract□The topographic influences for the hydraulic characteristics in the estuary were studied by the hydraulic model test. The upstream boundary is set up at the Kumkang estuary dike and the downstream boundary at the Kunsan outer port. The geometrical model scales in horizontal and vertical are 1/300 and 1/100 respectively so that the distorted ratio is 3. If there is no or little river flow through the gate, the highest water levels are varied with ±5cm compared with those before the project. If there is a flood flow through the gate, the highest water levels in front of the estuary dike are reduced 5~20cm depending on the frequency of flood compared with those before the project. This means that there is no important risk of excessive water level rise after the dredging.

Keywords□Kumkang estuary, hydraulic model test, immovable bed, tide water level

I. Introduction

The downstream area of the Kumkang estuary dike has a large tidal fluctuation(±3m at the outer port). During the flooding period much suspended load and sediment are transported in this area. To maintain the functions of the passage and the inner port, about 200,000m^3 of sediment is dredged annually from 1975. The dredged sand is thrown away near the inner port, and a small island whose area is about 1km^2 is created. The Kunsan city has a plan to construct an artificial island by enlarging this small island. The area of the artificial island will be about 3.93km^2. At the same time as the reclamation of the artical island, a large scale dreging of the passage is planned, and the artificial island will be reclaimed by using the dredged sand.

When the dredging of the passage and the reclamation of the artificial island are completed, the topography of the downstream area of the estuary dike and the hydraulic characteristics will be changed. In this paper the topographic influences on the hydraulic characteristics are studied by means of hydraulic model test. The main subjects of the study are as follows.

1) In case of no river flow from the upstream (the gates of estuary dike are closed) the water

level and the velocity and direction of the flow around the artificial island are studied through the results obtained under the topographies before and after the project. The results are examined by comparing them with the data *in-situ* so that the hydraulic model is verified.

2) The same study is made assuming that the upstream flow is the runoff in 2 year and 100 year frequencies.

3) We presuppose the hydraulic situation in the future in this area and suppose some counterplan for the negative aspects of the project.

II. The Methods of Experiments

1. Facilities and Hydraulic Model

The study is excuted by an immovable bed model tests, and the facilities and the plan of the hydraulic model are shown in the Fig. 1. The hydraulic model is set up in the tidal model basin, whose dimension is 60m×60m. There are a tide generator, a littoral current and a wave generator in the basin. There is also a river flow generator for the experiments of the estuary. Therefore it is possible to reproduce synthetically the hydraulic situations.

The upstream boundary is set up at the Kumkang estuary dike and the downstream boundary

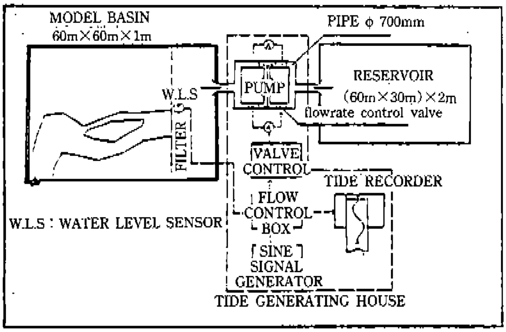


Fig. 1. Hydraulic model test facilities

Table 1. Transforming factors of some physical quantities in the hydraulic model

Physical quantities	Symbol	Transforming factors	Transforming factors in the model
Horizontal length	l_h/l_h'	λ_h	300
Vertical length	l_v/l_v'	λ_v	100
Velocity	v/v'	$\lambda_v^{1/2}$	10
Discharge	Q/Q'	$\lambda_h\lambda_v^{3/2}$	300,000
Time	T/T'	$\lambda_h\lambda_v^{-1/2}$	30
Froude number	1	1	1

at the Kunsan outer port, and the distance between the two boundaries in the longitudinal direction is about 15km. The model scales in horizontal and vertical are 1/300 and 1/100 respectively so that the distorted ratio is 3. The table 1 is the transforming factors used in the hydraulic model.

2. Experiment Conditions and Cases

First of all, the experiments for the topography before the project were carried out to examine the pertinence of the model and the boundary conditions by comparing the experiment results and the data *in-situ*. In the next step, the experiments for the topography after the project were carried out. From these two results the change of tidal level and flow velocity can be presupposed.

The river flow passing the Kumkang estuary dike is set up for the upstream boundary condition and the mean tide level for the downstream boundary condition. In case of the topography before the project there is no problem to use the tide level of the Kunsan outer port. From the report of the Korean Ocean Science and Engineering Corp. for the numerical modelling experiments (1989. 12.), the tide level of the Kunsan outer port in cases of normal and flooding time goes down 2cm and 1cm respectively. Therefore the boundary condition after the project at the Kunsan outer port is set up with the same value as that

Table 2. Boundary conditions of tide level(Kunsan outer port)

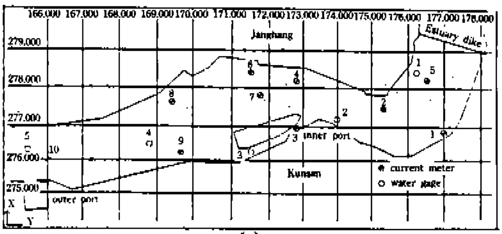
Tide condition	Tidal range		Period		Remarks
	Prototype	model	Prototype	model	
Sping tide	603.4cm	60.3cm	12.5hr	25min	Vertical scale : 1/100 Time scale : 1/30

Table 3. Boundary conditions of river flow(Kumkang estuary dike)

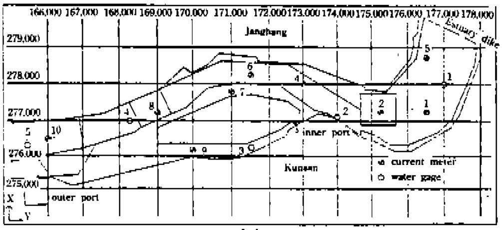
No flow (CMS)		2yr freq. (CMS)		100yr freq. (CMS)		Remarks
Prototype	Model	Prototype	Model	Prototype	Model	
0	0	4,700	0.0157	13,000	0.0433	Flow rate scale : 1/300,000

Table 4. Experiment cases

Topography	Tide	River flow	Cases
Before the project	Spring tide	No river discharge	Case 1
Before the project	Spring tide	2yr freq. discharge	Case 2
Before the project	Spring tide	100yr freq. discharge	Case 3
After the project	Spring tide	No river discharge	Case 4
After the project	Spring tide	2yr freq. discharge	Case 5
After the project	Spring tide	100yr freq. discharge	Case 6



(a)



(b)

Fig. 2. Sensor positions of current meter and water gage : (a) before the project, (b) after the project

before the project. The Tables 2 and 3 show the boundary conditions of the tide level and the river flow for the prototype and the hydraulic model respectively. Using the boundary conditions shown in the Tables 2 and 3 the experiment cases are decided and they are shown in the Table 4. The measuring positions of tide level and flow velocity are shown in the Fig. 2(a), (b).

III. Results of Experiments and Analysis

1. Analysis of the Data *in-situ*

Some important hydraulic characteristics of this area can be summarized as follows.

a. The ebb tide time is about 6.6 hours and is 0.8 hour longer than the flood tide time 5.8 hours.

b. The mean spring tide range is 6.0m at the outer port and 5.7m at the inner port, and normally the high tide water level at the inner port is 5~10cm lower than at the outer port.

c. In normal season the high tide water levels at the outer port and at the estuary dike are generally not much different each other.

d. During the ebb tide the maximum flow velocity at the cross section near the inner port is

115~136cm/sec depending on the depth, and the maximum velocity during the flood tide is about 30cm/sec greater than that during the ebb tide at this cross section.

2. Experimental Results for the Topography before the Project

1) Tide Water Level Characteristics

The Fig. 3 present the variations of the tide water level depending on the time variation at the sensor position 2 and 5 for the case 1 and 3, and the Table 5 presents the high and low tide water level characteristics for the case 1, 2 and 3. The important things for the tide water levels are as follows.

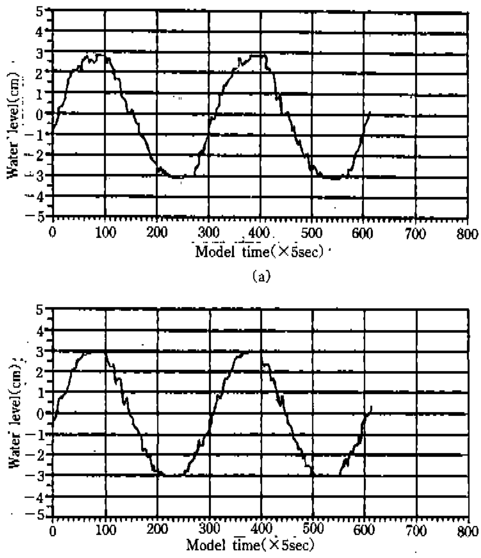


Fig. 3. Water level before the project, no river flow (a) sensor position 2, (b) sensor position 5

a. In the case 1 the highest water level near the Kumkang estuary dike(sensor position 1) is about 5cm higher than that of the inner port, and the highest water level of the outer port is about 15cm higher than that of the inner port. It is coincident with the data *in-situ* that the highest water level of the inner port is lower than those of the Kumkang estuary dike and the outer port.

b. In the case 1 the flood tide time and the ebb tide time at the outer port are same each other, but the latter is one hour longer than the former at the inner port. The difference is greater in the case 2 and 3, and it closes to 2.5 hours. It is observed in the field that the period during the ebb tide is longer than that during the flood tide.

2) The Flow Velocities and Directions

The Fig. 4 and 5 show the flow velocities and directions at the sensor position 1 and 4 respectively, and the Table 6 gives the maximum velocities at the sensor positions. In the figure the flow velocities are expressed in absolute values and the flow directions are expressed in the clockwise angle between the north direction and the flow

Table 5. High and low tide water level(before the project)

Sensor position	Case 1				Case 2				Case 3			
	High water level (cm)	Low water level (cm)	Flood tide time (min)	Ebb tide time (min)	High water level (cm)	Low water level (cm)	Flood tide time (min)	Ebb tide time (min)	High water level (cm)	Low water level (cm)	Flood tide time (min)	Ebb tide time (min)
1	290	−320	11	14	300	−250	10	15	325	−65	10	15
2	285	−310	11.5	13.5	300	−255	10	15	305	−165	10	15
3	285	−315	12.5	12.5	300	−280	10.5	14.5	310	−130	10	15
4	295	−315	12.5	12.5	300	−295	11	14	305	−190	12.5	12.5
5	300	−305	12.5	12.5	305	−295	12.5	12.5	305	−300	12.5	12.5

(the real flood and ebb tide time=the flood and ebb tide time in the table×30)

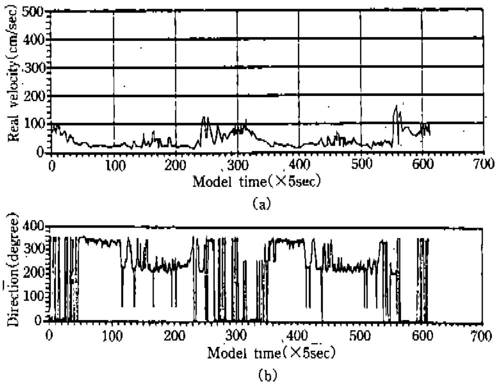


Fig. 4. Flow velocities and directions at sensor position 1(before the project, no river flow)

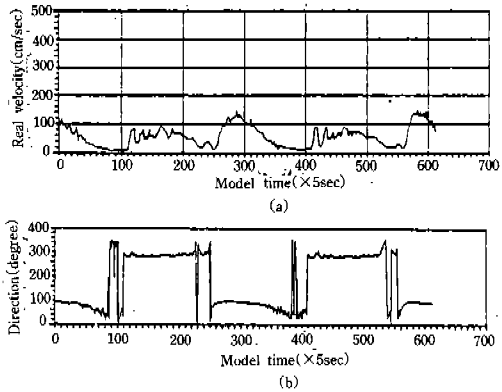


Fig. 5. Flow velocities and directions at sensor position 4(before the project, no river flow)

Table 6. Maximum flow velocities(before the project)

Sensor position	Case 1		Case 2		Case 3	
	Flood tide (cm/sec)	Ebb tide (cm/sec)	Flood tide (cm/sec)	Ebb tide (cm/sec)	Flood tide (cm/sec)	Ebb tide (cm/sec)
1	80	40	30	140	10	220
2	80	80	70	230	140	350
3	140	80	60	150	40	240
4	120	60	30	100	80	220
5	80	60	50	200	120	260
6	100	60	15	120	60	280
7	80	80	50	140	140	260
8	50	90	50	140	60	190
9	90	60	60	100	30	130
10	240	160	160	250	100	460

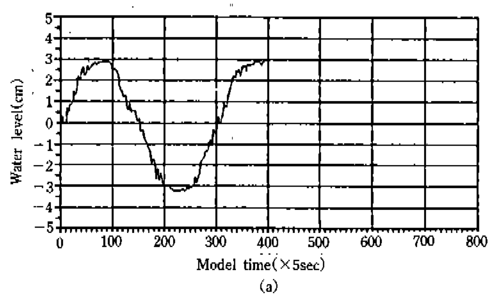
direction vector. The important things about the flow velocities and directions are as follows.

a. In the case 1 the maximum velocity is 120 cm/sec at the position number 4, between the inner port and the Janghang port, which is similar with the data *in-situ* at this position.

b. In the case 1 the maximum velocities at all the sensor positions except the position 8 occur in the period of flood tide, which is coincide with the data *in-situ*.

c. When there is no river flow(case 1), in almost all the section the maximum velocities in the period of flood tide are greater than in the period of ebb tide, however when the river flows(case 2, 3), in all the section the maximum velocities in the period of ebb tide is much greater than in the period of flood tide.

From the experimental results for the topography before the project we can conclude that the hydraulic characteristics such as the tide water level, flow velocities and directions are coincide with the data *in-situ* and it is possible to reproduce the main phenomena in the hydraulic model.



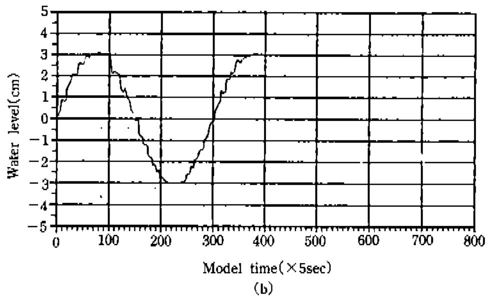


Fig. 6. Water level after the project, no river flow (a) sensor position 2, (b) sensor position 5

3. Experimental Rusults for the Topography after the Project

After the project the artificial island occupy a part of the river flow section. In spite of the dredging, the flow section area is reduced by 20~25% at the point of time of the spring tide, but it is largely increased in the other sections. Especially in the large area between the estuary dike and the inner port the flow section is increased more than two times so that the large storage capacity will contribute to control the water level in this area.

1) Tide Water Level Characteristics

The Fig. 6 present the variations of the tide water level depending on the time variation at the sensor point 2 and 5 for the case 4 and 6, and the Table 7 present the high and low water level after the project, and the Table 8 shows the changes of the highest water level after the project.

Table 7. High and low tide water level(after the project)

Sensor position	Case 4				Case 5				Case 6			
	High water level (cm)	Low water level (cm)	Flood tide time (min)	Ebb tide time (min)	High water level (cm)	Low water level (cm)	Flood tide time (min)	Ebb tide time (min)	High water level (cm)	Low water level (cm)	Flood tide time (min)	Ebb tide time (min)
1	285	−335	13.0	12.0	285	−320	12.5	12.5	305	−260	11.5	13.5
2	290	−325	12.5	12.5	300	−320	12.5	12.5	305	−270	11.5	13.5
3	300	−310	12.5	12.5	300	−315	12.0	13.0	315	−280	12.5	12.5
4	295	−315	12.5	12.5	300	−315	12.5	12.5	305	−295	12.5	12.5
5	305	−300	12.5	12.5	305	−300	12.5	12.5	305	−295	12.5	12.5

(the real flood and ebb tide time=the flood and ebb tide time in the table×30)

Table 8. The change of the highest water level after the project(spring tide)

Sensor position	No river flow(cm)	2yr freq. flood(cm)	100yr freq. flood(cm)
1	−5	−15	−20
2	+5	0	0
3	+15	0	5
4	0	0	0
5	+5	0	0

The important things for the tide water levels are as follows :

a. In the area between the estuary dike and the inner port the storage capacity is much increased by dredging. On the other hand, in the section near the artificial island the flow section is decreased so that it hinders the flow and the water level

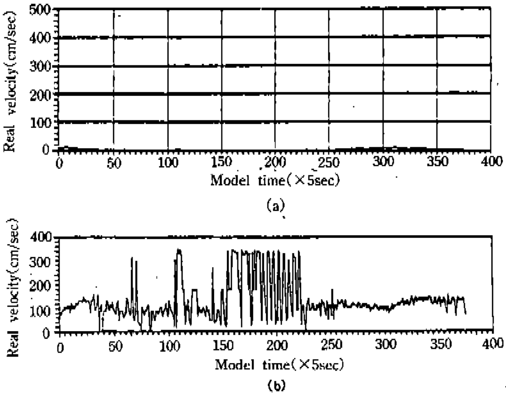


Fig. 7. Flow velocities and directions at sensor position 1(after the project, no river flow)

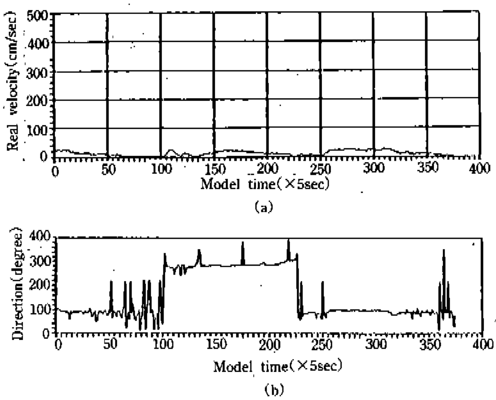


Fig. 8. Flow velocities and directions at sensor position 4(after the project, no river flow)

Table 9. Maximum flow velocities(after the project)

Sensor position	Case 4		Case 5		Case 6	
	Flood tide (cm/sec)	Ebb tide (cm/sec)	Flood tide (cm/sec)	Ebb tide (cm/sec)	Flood tide (cm/sec)	Ebb tide (cm/sec)
1	10	5	20	30	40	60
2	10	10	20	80	160	180
3	20	20	30	120	50	220
4	20	20	20	120	80	220
5	45	80	100	200	140	250
6	40	40	30	180	110	350
7	20	30	40	100	60	150
8	20	20	25	120	80	220
9	20	20	100	100	60	140
10	30	30	60	140	40	200

at the inner port becomes higher.

b. In case of the topography after the project, the highest water level always occurs at the position 3. This is because the narrow channel is elongated so that the tide flow is not passed smoothly.

c. What is specially northworthy under the topography after the project is the diminution of the water level at the estuary dike. The highest water level at the estuary dike(point 1) is reduced by 5~20cm. This means that there is no important risk of excessive increase of the water level.

2) The Flow Velocities and Directions

The Fig. 7 and 8 present the flow velocities and directions at the sensor position 1 and 4 when there is no river flow, and Table 9 gives the maximum velocities at the sensor positions.

The important things about the flow velocities and directions are as follows :

a. When there is no river flow after the project, the flow velocities are much reduced compared with those before the project. In the area between the inner and outer port the velocities are greater than those in the other positions because the flow section is reduced after the project.

b. In the case 6 the maximum velocities during the ebb tide period are increased in order of 2 compared to the case 5 in all the area, and the maximum value is 350cm/sec at the sensor position 6.

c. When there is no river flow(case 4) the flow velocities are reduced compared to those before the project so that the transport of the sediment, and the suspended load will be reduced, therefore the amount of deposit to be dredged will be reduced also.

IV. Conclusions

Our study is excuted to predict the change of the hydraulic circumstances after the construction of the artificial island and the dredging of the passage. First of all the hydraulic model experiments for the topography before the project were carried out and the pertinence of the model is proved by comparing the results with the data *in-situ*. In the next step the experiments for the topography after the project were carried out and the results were compared with those for the topography before the project.

Finally the changes of the hydraulic characteristics after the project were examined. The important things are as follows :

a. The dredging in the area between the estuary dike and the inner port much influences to the reduction of the water level so that the water level is reduced by the range of 5~20cm depending on the river flow. This means that there is no important risk of excessive water level during the flooding period.

b. The flow velocities after the project are generally reduced compared to those before the project. However the flow section except some part of the area largely increased so that the total tidal flowrate increase compared to that before the project.

c. After the project, the water depth becomes deeper and the flow velocities are reduced compared to that before the project so that the transport of the sediment and the suspended load will be reduced and the sediment deposit on the river bed will also be reduced.

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