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TIDAL FLUSHING AT ENTRANCE OF TIDAL BAY IN KOREA

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ABSTRACT

Tidal Flushing at the entrance channels of tidal bay or estuary in the central western coast of Korea; Gum River Estuary, Garorim Bay, Asan Bay, and Yeomha Estuary were studied with the recent data of current surveys measured by current meter at three or five anchored stations along the section for one or two tidal periods at mean spring tide. Equilibrium relationship between tidal prism at mean spring tide and minimum flow area below the mean sea level of the channel in alluvial material was found as of O'Brien's (1931, 1969) study. Bed load transport in the tidal channel is balanced with the tidal flushing ability having a mean velocity of about 0.75m/sec or maximum velocity of about 1.25m/sec for a half tidal cycle over the section at mean spring tide which fairly agree with Brunn's study (1955, 1957). Flushing actions for different hydraulic depth (mean depth) and bed material size in the channel were reviewed and found that it depend to a minor extent on the factors.

INTRODUCTION

Tidal flushing ability in the entrance channel of a tidal inlet on a sandy coast was studied by many authors. O'Brien (1931, 1969) described an equilibrium relationship between the cross-sectional area of an inlet or the bay and tidal prism. Brunn (1955, 1967) demonstrated the unique mean velocity for a tidal cycle at the entrance of an inlet. General dimension of the entrance to a tidal estuary or bay along a sandy coast arranges itself in the most practical way by providing the highest flushing ability at the least loss of energy to bottom friction. In other words, in the tidal channels in alluvial materials there appears to be a balance between the scouring action of the tidal currents that tend to keep the channel open and the deposition of alluvial materials that tend to reduce the channel cross-section. A better understanding of the tidal flushing ability in the channel is necessary in order to improve capabilities in the design

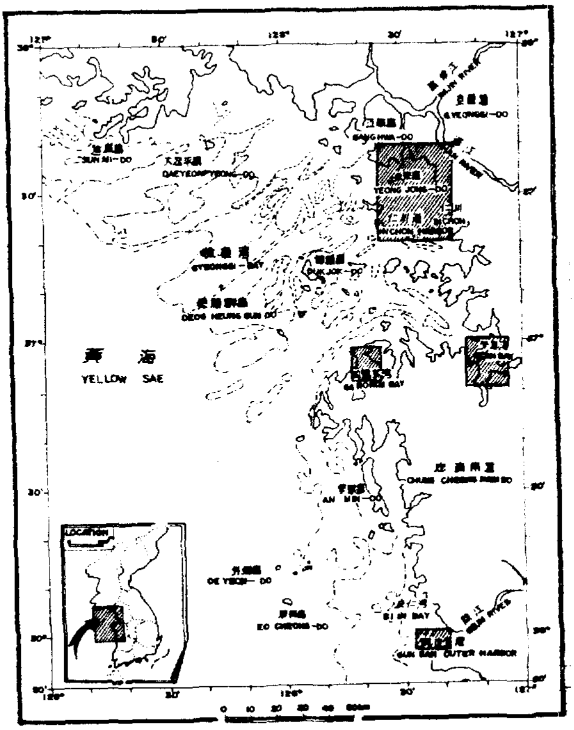


Fig. 1-1. Central Western Coast of Korea

and maintenance planning of the coastal features. This paper presents the tidal flushing at two estuaries and one channel of tidal bay in the central western coast of Korea: Han River-Yeomha Estuary where located at Incheon Harbor, Gum River Estuary where located at Gunsan Outer Harbor and the entrance channel of Garorim Bay.

Environment

The Central western coast of Korea, located on the east of Yellow Sea is composed of numeral islands, bays and estuaries. Yellow Sea is a shallow sea with a depth of about 70 m enclosed by China Continent and Korea Peninsula except on the south where it communicates with the East China Sea. The semi-diurnal tidal wave of M_2 tide progresses to the north along the west coast of Korea and rotates counterclockwise around the nodal point at west central part of Yellow Sea. The M_2 waves arrives at the central western coast of Korea at

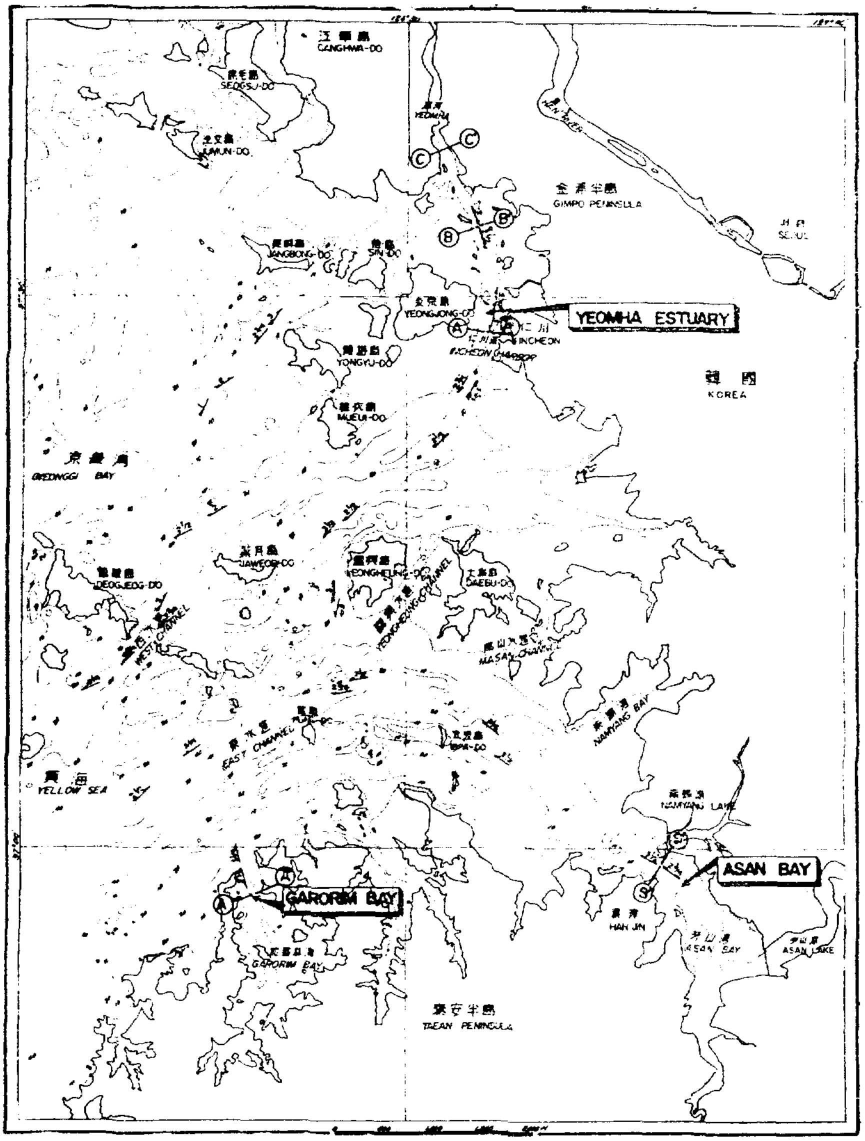


Fig. 1-2. Geonggi Bay-Yeomha, Asan Bay and Garorm Bay

Table 1-1. Tide Data

Location	M.H.W.I.	Spring Range	Neap Range	Ratio $\frac{O_1+K_1}{M_2+S_2}$	Remarks
Gunsan Harbor	3h 10m	5.7m	2.3m	0.20	
Deogjeong Is.	4 17	6.9	3.0	0.22	
Garorim Bay	4 04	6.6	2.8	0.21	
Asan Bay	4 24	8.1	3.5	0.16	
Incheon Harbor	4 28	8.0	3.5	0.16	

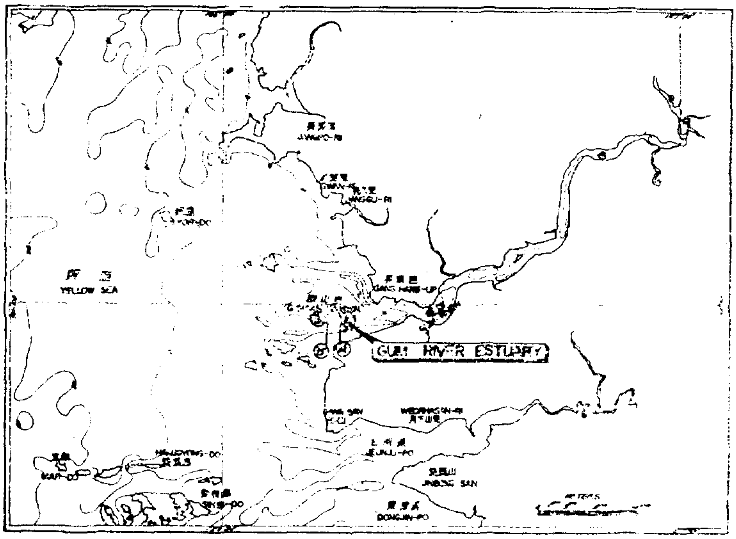


Fig. 1-3. Gum-River Estuary

3 to 5hour of co-tidal hour with a spring tidal range of 5.5 to 8.0m, as shown in Fig. 2-1 and 2-2. Tide data for five locations in the area are listed in Table 1-1. The tidal currents at the channel in the area flow parallel to the coast with a maximum velocity of 1.0 to 1.5 m/sec at about mid tide in the direction of landward and seaward during flood and ebb, respectively. The central western coast of Korea is well sheltered from waves due to many islands scattered in the area during winter month the strong winds from the north but the waves produced by the winds are not significant, because of its short fetches. River drifts from Han River-Yeomha and Gum River are estimated as approximately 200×10^3 m^3/year, respectively, which seem to be transproted to open sea through the estuaries.

DATA

Method

The volume of water accumulated in a tidal bay or estuary during a flood tide or discharged during ebb is the integral of the product of the flow area and averaged velocity expressed as

$$\text{Tidal Prism } (P) = \int_0^{T/2} aV\, dt \qquad 1)$$

in which a=instantaneous flow area, V=velocity averaged over area a, T=period of full tidal cycle: aV=rate of volume transport. The flow area varies with the stage of the tide. And average velocity over this area is a function of the range, the stage of the tide and flow area.

In the tidal prism calculation the observed velocities for three layers at a half hour or an hour interval from slack to slack during a tidal cycle at three or five stations along the each section were used. The averaged velocity along each cross section at a given time was calculated by current profiles where equal current velocities were drawn. The instantaneous

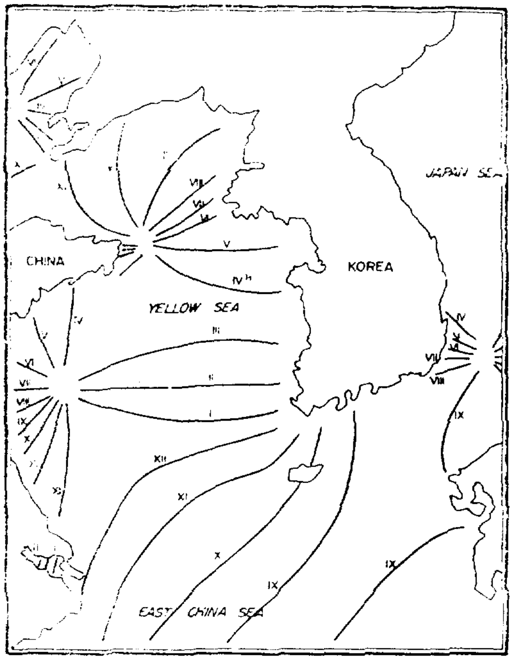


Fig. 2-1. Co-tidal Line of M_2 Tide in Yellow Sea

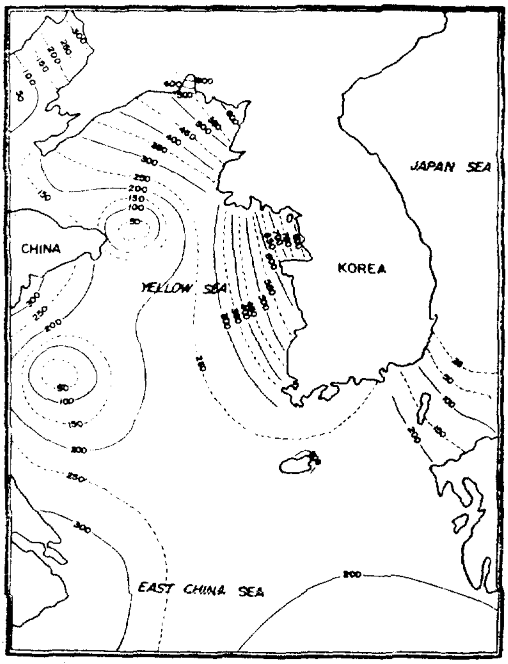


Fig. 2-2. Spring Tidal Range in Yellow Sea

Table 2. Values of A.P. Qmax. Vmax. and Vmean

Estuary or Bay	Section	Bottom d50 mm	A $\times 10^3 m^2$	P $\times 10^6 m^3$	Qmax. $\times 10^3 m^3/s$	Vmax. m/s	Vmean. m/s
Gum River Estuary Gunsan Harbor	A	Sandy silt 0.02-0.3	11.35	174.6	13.55	1.235	0.735
	B	Silt 0.01-0.02	12.05	196.6	15.60	1.38	0.745
Garorim Bay	A	Sandy silt 0.04-0.3	26.90	463.4	38.6	1.348	0.739
Asan Bay	S	Rock	38.25	768.7	46.4	1.42	0.92
	A	Sandy silt	29.89	(748.8)[a]	52.6	1.15	(0.73)[b]
	B	Sandy silt	26.99	(664.8)	46.7	1.01	(0.64)
	C	Sandy silt	22.93	(529.6)	37.2	1.00	(0.64)
Yeomha Estuary Incheon Harbor	A	Silt 0.02	30.26	521.0	38.1	1.127	0.717
	B	Silt 0.02-0.03	14.03	261.0	14.8		
	C	Silt 0.01-0.03	6.67	108.0	7.6		

Note: a) P were calculated by Eq. 3)
b) Vmean. were calculated by 0.573 Vmax.

flow area at a given time was obtained from the flow area graph as a function of tidal level for each section. The product aV or the rate of volume transport for a half or an hour interval during a tidal cycle were plotted and the integrals of the product aV or the tidal prisms were obtained by the measuring of the area bounded by the rate curve and $aV=0$ axis on the graph.

If it is assumed that the flow area is constant and equal to A, the minimum area below mean sea level and the duration of both flood and ebb are equal to T/2, then average velocity across the section is a sinusoidal function of time.

$$V = V_{max} \, \mathrm{Sin} \frac{2\pi}{T} t \qquad 2)$$

Applying these relationship to Eq. 1) the tidal prism (P) would be

$$P = \frac{A V_{max}}{\pi} T \qquad 3)$$

Data

In this study, the values of tidal prism (P) and flow area (A) of the channels as well as maximum rate of transport Qmax., maximum velocity Vmax. and mean velocity Vmean over the section for each channels at mean spring tide were used. Table 2 listed those values reproduced from the report of current survey at Gunsan Outer Harbor (1974,) Garorim Bay (1974), Asan Bay (1974) and Incheon Outer Harbor (1970).

The vertical profiles of each cross-section are shown in Fig. 3-1 and 3-2, in which the current stations are also indicated.

DISCUSSION

Flow Area (A)-Tidal Prism (P)

The tidal prisms versus flow area at the sections were plotted with the data of Table 2 as shown in Fig. 4-1 and 4-2. By the least square method the relation ship between flow area (A) and tidal prism (P) was obtained. The data used are those of A and P at three sections along the Yeomha Estuary at Incheon Harbor, two sections along the Gum River Estuary at Gunsan Harbor and one section of Garorim Bay listed in Table 2. The result is

$$A = 1.81 \times 10^{-4} \, P^{0.9424} \qquad 4)$$

where A=minimum flow area bolow mean sea level in m^2 and P=tidal prism in m^3 at mean spring tide. Fig. 4-2 shows the relationship between tidal prism and flow area by O' Brien (1969) and also the A-P data at six sections mentioned above are fairly agree with the study of O'Brien's curve.

The relationship, shown in Eq. 4) and Fig. 4-1 and 4-2 means that the change of tidal prism may be associated with the change of flow area.

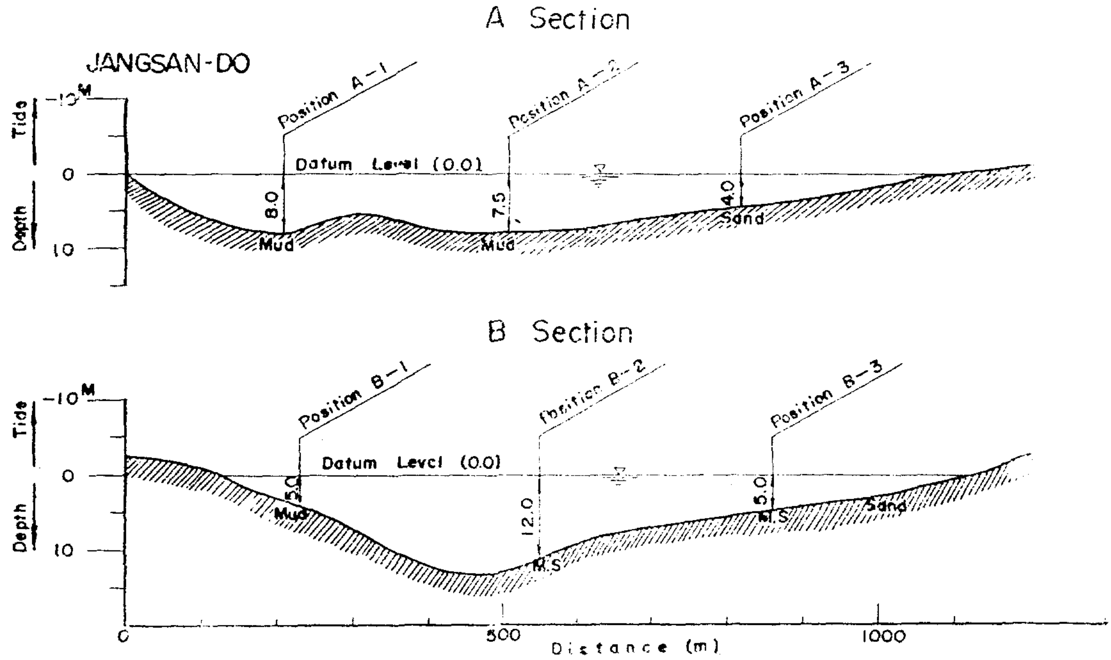
If the tidal flats were reclaimed or the bay were partially diked, the flow area of the entrance channel of the bay would be reduced by Eq. 4). In other words, for instance, a reduction of 10% of present tidal prism at mean spring tide will cause about 10% reduction of present flow area at the entrance.

Entrance flow area of the Asan Bay, the section at Hanjin has area of $38.25 \times 10^3 m^2$ with irregular rocky bottom. With Eq. 4) equillibrium tidal prism at S section was computed as $682.2 \times 10^6 m^2$ which is about 11.2% smaller than that of observed tidal prism 768.7×10^6 m^3. Recently the east inner part of the bay was diked and tidal prism was reduced, but the present flow area at the entrace is still smaller than the equilibrium flow area given by the A-P relation formula Eq 4).

Tidal Prism (P) Current Velocity (V)

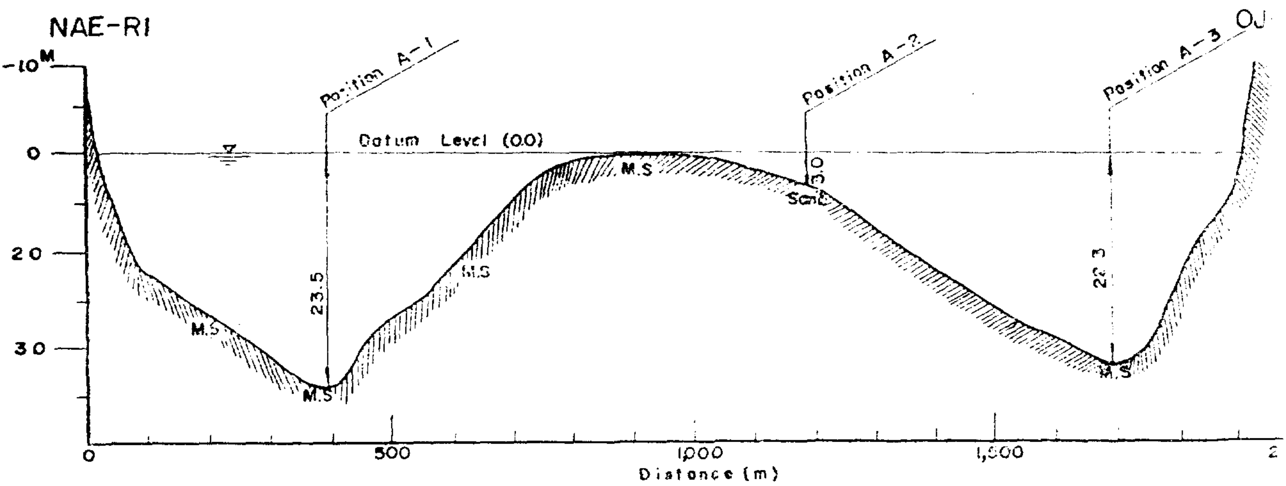
Tidal prism (P), the maximum rate of transport Qmax. and the period of the tide T are related as following expression.

Section	Width	Area	Mean depth
A	1,080^m	5,766$^{m^2}$	5.3^m
B	1,120	6,306	5.6



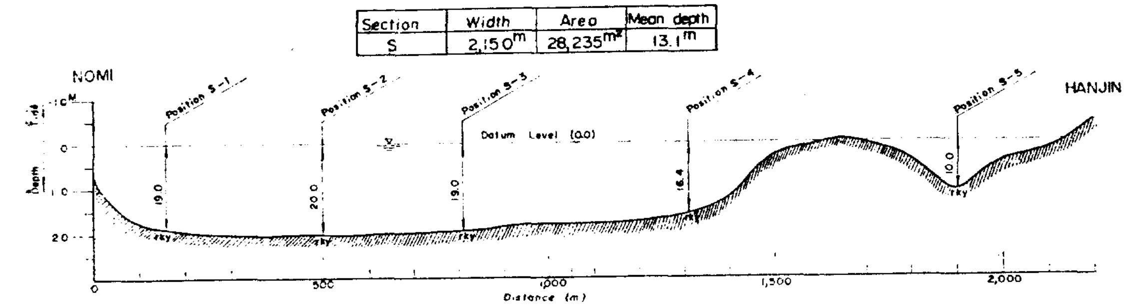
i) Gum River Estuary

Section	Width	Area	Mean depth
A	1,880^m	19,330$^{m^2}$	10.3^m

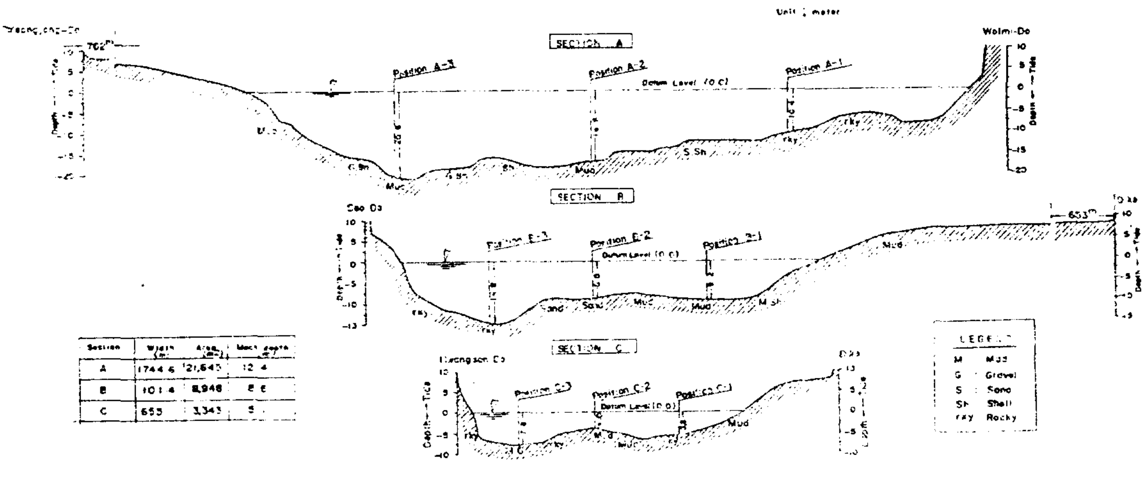


ii) Garorim Bay

Fig. 3-1. Cross-Section of Channels(I)



iii) Asan Bay



iv) Yoemha Estuary

Fig. 3-2. Cross-Section of Channels (II)

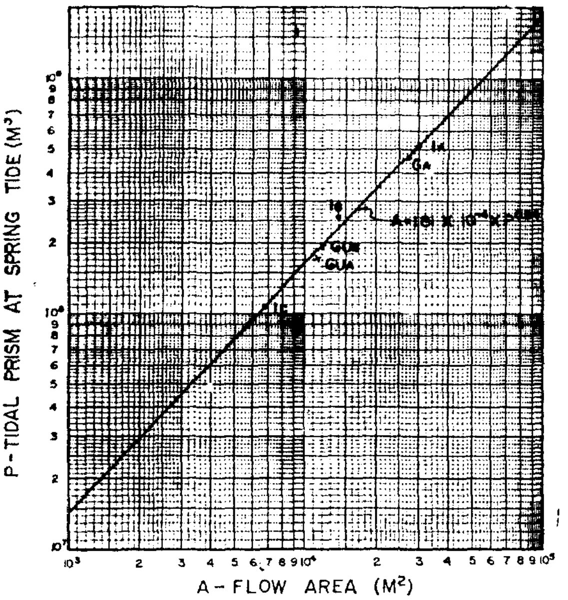


Fig. 4-1. Minimum Flow Area and Tidal Prism in the Tidal Channel in Korea

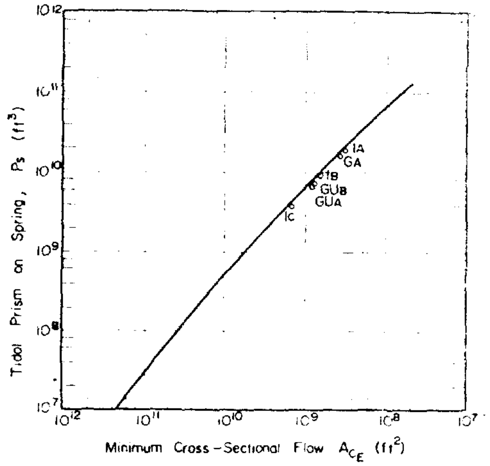


Fig. 4-2. Minimum Flow Area and Tidal Prism (From M.P. O'Brien 1969)

$$\frac{T}{\pi}\frac{Q_{max}}{P}=C_1 \qquad 5)$$

in which C_1 is a dimensionless number. On the other hands, $P=V_{mean}\cdot A\frac{T}{2}$ therefore,

$$V_{mean}=\frac{2}{\pi}\frac{V_{max}}{C_1} \qquad 6)$$

and with the data of Table 2, $C_1=1.1$ was obtained. This means that the mean velocity over the section during a half tidal cycle is 0.9 times of $2/\pi$ Vmax. or 0.573 max..

Looking at the Table 2, it is seen that mean velocity at mean spring tide in the four sections: two sections in Gum River Estuary, one section in Garorim Bay and one section in Yeomha Estuary is about 0.75m/sec and mean of maximum velocities is about 1.25m/sec regardless of the hydraulic radius(mean depth) which ranged from 5m to 13m and of the grain sizes of the bed material which ranged from 0.01mm to 0.4mm. This fact also demonstrated by P. Brunn (1967) as the flushing velocity of maximum 1.0m/sec and mean 0.7m/sec in the tidal inlet.

CONCLUSIONS

With respect to the cross sectional stability of a tidal channel in alluvial material on the central western coast of Korea, the following conclusions were drawn.

1. The equilibrium minimum flow area below mean sea level in a channel is controlled by the tidal prism with

A (in m^2)$=1.81\times10^{-4}\ P^{0.9424}$

A reduction of the tidal prism by reclamation of tidal flat or artificial closing of channel will reduce the flow area of channel.

2. Bed-load transport in the tidal channel is balanced with the tidal flushing ability having a mean current velocity of about 0.75m/sec or maximum velocity of about 1.25m/sec for a half tidal cycle over the section of channel at mean spring tide.

3. Equilibrium flow area of a tidal channel depends to a minor extent on the bad material and the hydraulic depth of the section.

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