CHAPTER 232

Flow Area Prediction of Tidal Inlets After Sea Level Rise

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Abstract

An approach to predict flow area of constricted tidal inlets due to a mean sea level rise is developed. Increase of bay surface area is found to be the most dominant factor to increase the flow area due to SLR. A case study is conducted for an entranse channel of Lake Notoro in the Okhotsk coast.

1 INTRODUCTION

The trend of excessive sea level rise (SLR) has brought several crucial problems to coastal engineers, above all the beach erosion due to it. Studies until now have been restricted to the problems at an open coast affected by waves and the resulting sediments (e.g. Bruun (1983), Everts (1985), Dean(1987)).

The problem at a shore along a tidal inlet is somewhat complex. The tidal amplitude in an inlet does not always conincide with that at sea, since the former is dominated essentially by the tidal discharge through the constricted entrance between sea and inlet. This means the effect of SLR on the flow area is a key problem to be solved in advance of estimating the inlet level rise. A change of the flow affects navigation, water quality, maintenance of coastal facilities, etc. besides beach erosion.

In the present study a prediction approach is proposed for the equilibrium flow area of tidal inlets after SLR in coasts with littoral drift.

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2 EQUILIBRIUM FLOW AREA OF TIDAL INLETS

The minimum flow area of a stable or equilibrium tidal inlet (see Fig. 1) Ae has long been extensively studied by many researchers such as O'Brien (1931), Bruun (1958), Shigemura (1974) and Jarrett (1976). In 1975 the writer had proposed a relationship between the flow area Ae and the tidal prism P of inlet as in the following.

$$P \;/\; Ae \;=\; Ks\sqrt{a_s g}\cdot T \qquad \cdots\cdots\cdots\cdots\cdots \quad (1)$$

where a_s is the amplitude of tide at sea, T is the predominant tidal period and g is the gravitational accerelation. Ks is a dimensionless coefficient depending mainly on the littoral drift at sea M_l and entrance configuration. Eq. 1 had been deduced from an analysis of the maximum tidal current velocity of inlet and the data of P and Ae about inlets in US and Japan as shown in Fig. 2.

Ks had been given as;

$$\left.\begin{aligned} Ks &= 0.22, \quad for \quad M_l/Q_m > 300 \\ &= 0.15, \quad for \quad M_l/Q_m < \ \ 30 \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots \quad (2)$$

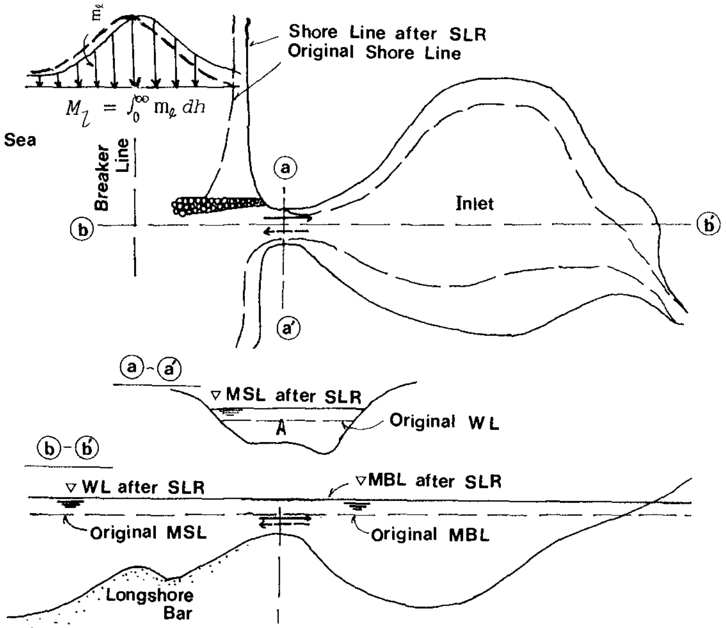

Fig. 1 Sketch of Tidal Inlet before and after SLR

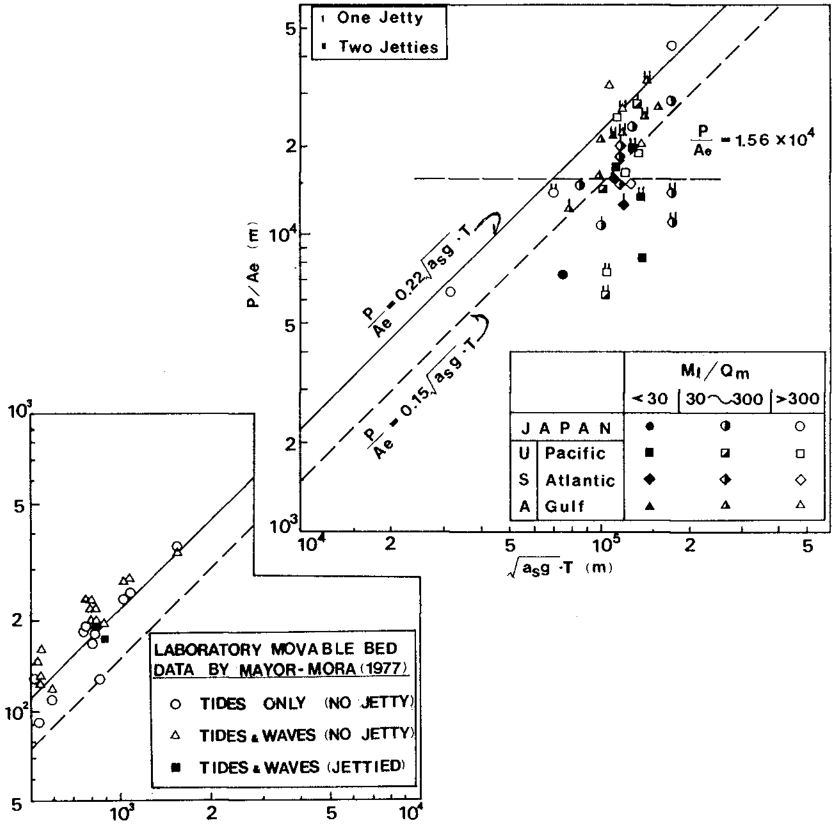

Fig. 2 P/Ae versus $\sqrt{a_s g}\,T$ and M_l/Q_m for Prototype and Model Tidal Inlets

In Fig.2, computational results for the movable bed laboratory data by Mayor-Mora (1973) are added. They fit well with Eq.1.

In order to determine effect of M_l on Ae, Ks must be determined more quantitatively. A dimensionless parameter $P/(A_e\sqrt{a_s}\,gT)$ is plotted against M_l/Q_m as Fig. 3.

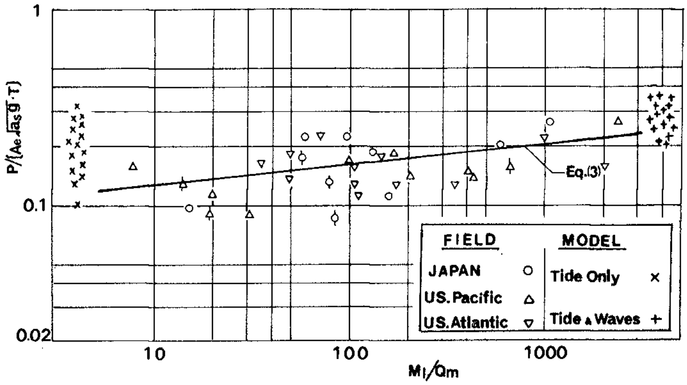

Fig. 3 $P\ /\ [Ae\sqrt{a_s}\,g\cdot T]$ versus M_l/Q_m

The solid line drawn as an average in the figure brings a relationship as in the following :

$$P\ /\ (Ae\sqrt{a_s}\,g\,T)\ =\ 0.1\ [\ M_l/\ Q_m\ ]^{0.1} \qquad \cdots\cdots\cdots\cdots (3)$$

As far as a simle harmonic tides concerned, P is expressed

$$P\ =\ Qm\ T/\pi\ =\ Ae\,U\,T\,/\,\pi \qquad \cdots\cdots\cdots\cdots (4)$$

From Eqs. 3 and 4, Ae is derived as,

$$Ae\ =\ 1.02\ Q_m^{1.1}\ a_s^{-0.5}\ M_l^{-0.1} \qquad \cdots\cdots\cdots\cdots (5)$$

a simplified analytical solution of the peak current velocity U and the tidal amplitude at bay a_b is (Kondo,1972),

$$U = \frac{1}{p}\sqrt{\frac{1}{2}\ [-\{(\frac{\alpha}{\sigma^2})\ -1\ \}^2 + \sqrt{\{(\frac{\alpha}{\sigma^2}\ )\ -1\}^4\ +\ 4\cdot(\frac{\beta p}{\sigma^2})^2}\ ]} \qquad \cdots\cdots (6)$$

$$a_b\ =\ a_s\ (\frac{\alpha}{\sigma^2})\sqrt{\frac{1}{2}\ [\{(\frac{\alpha}{\sigma^2}\ )\ -1\}^2 + \sqrt{\{(\frac{\alpha}{\sigma^2}\ )-1\}^4 + 4\ (\ \frac{\beta p}{\sigma^2}\ )^2}\ ]} \quad \cdots (7)$$

where

$\alpha = Ag/lS$ ...... (8) $\quad n_r = n\sqrt{1 + (f_c R^{4/3}/2gln^2)}$ .... (10)

$\beta = a_s g\sigma/l$ ..... (9) $\quad p = 4\pi\, n_r^2 g T$ .... (11)

and l is channel length $\sigma = 2\pi/T$ and n is Manning roughness coefficient of it.

3 PREDICTION PROCEDURE

By making use of Eq. 4 we can estimate A_e after SLR with the procedure as shown in Fig. 4. Several causions in the course of calculating procedure are:

(1) Make use of a dominant simple harmonic tide to compute tidal discharge Q_m and P employing an analytical approach.

(2) Initial value of bay surface area S and A inlet flow area are those at the MWL simply raised by $\bar{\eta}_s$ from the original one and neglecting effect of the other factors.

(3) Neglect effect of SLR on M_l itself, as we have presently no substantial knowledge about it. The distribution of m_l only shifts due to SLR.

(4) Due to the fact of (3), increment of trapped littoral drift by SLR ΔM_t may be evaluated as,

$$\Delta M_t = \int_h^{h+\bar{\eta}_s} m_l \, dh \quad \dots (12)$$

referring to Fig. 1.

Thus the effective littoral drift rate M_l' is given as,

$$M_l' = M_l - \Delta M_t \quad \dots\dots (13)$$

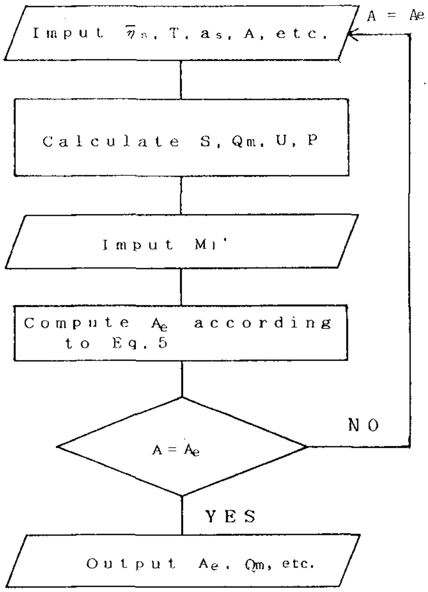

Fig. 4 Procedure to Estimate A_e after Sea Level Rise

4 TREND OF CHANGE OF FLOW AREA

From Eq.4 the rate of change of the flow area is

$$\frac{\Delta A_e}{A_e} = 1.1\left(\frac{\Delta Q_m}{Q_m}\right) - 0.5\left(\frac{\Delta a_s}{a_s}\right) - 0.1\left(\frac{\Delta M_l}{M_l}\right) \quad \dots\dots\dots\dots (14)$$

This means the effect of change of discharge is much larger on the change of flow area. The discharge is approximated for common tidal entrances as,

$$Q_m = a_s \sigma S \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

since they satisfy the following condition in Eq. 6,

$$\frac{\alpha}{\sigma^2} \gg \sqrt{\frac{\beta p}{\sigma^2}} \gg 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Thus for those inlets, Eq.14 becomes

$$\frac{\Delta Ae}{A_e} = 1.1\left(\frac{\Delta S}{S}\right) - 1.1\left(\frac{\Delta T}{T}\right) + 0.6\left(\frac{\Delta a_s}{a_s}\right) - 0.1\left(\frac{\Delta M_l}{M_l}\right) \quad \ldots \quad (17)$$

Applying the procedure above mentioned, it is found that the rate of variation of the flow area to SLR, $\Delta Ae/Ae$ behaves roughly as shown in Fig. 5 provided sea tide unchanged with SLR. Remarkable change of Ae which refers to $(\Delta Ae/Ae) > 0.5$ occurs for inlets of $\Delta S/S$ is larger than 0.4 due to SLR. It is deduced that those tidal entrances of inlet with low and flat beaches will suffer scouring troubles.

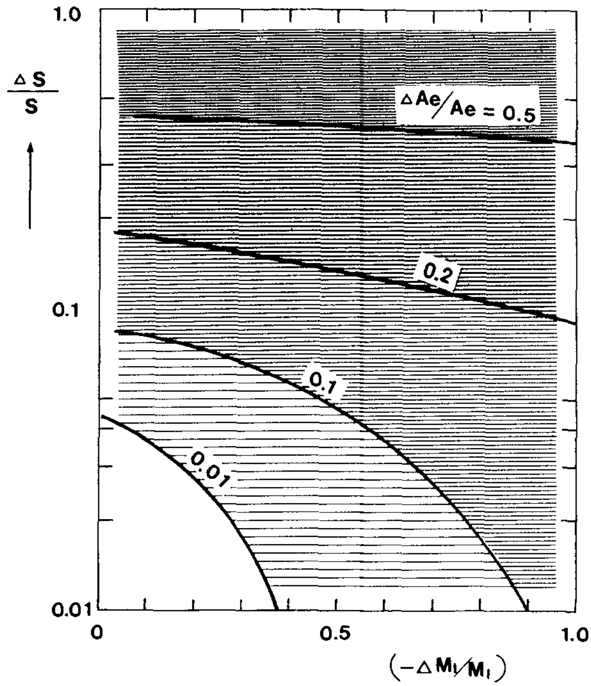

Fig. 5 Trend of Change of Stable Flow Area

4 A CASE STUDY

Lake Notoro in the Okhotsk coast, Japan has the surface area of 58 km^2 of an elliptic form. It had a shallow natural entrance with width of 100m and the mean depth of 2 m below MWL as shown in Fig. 6. An analytical computation by Kondo (1978) had shown that the depth bringing the maximum tidal current was about 4 m for the width of 150 m. Since the entrance had had the depth less than 2 m, the flushing power of tidal current had been decreased with shoaling of the depth due to the drift sand by storm waves. An artificial entrance channel had been cut with a sheet piled side wall at the spring of 1974. After 16 years had passed, the entrance is 200 m wide between two side walls and protected with two long jetties (Kondo et.al, 1988) as shown with the broken line in the figure.

Estimation of A_e after SLR, has been performed for the present condition, and for the cases of $\bar{\eta}_s$ up to 2 m, according to the procedure explained in Chapter 3.

Computational conditions in the present case are;

(1) Sea tide ; $T = 8.94 \times 10^4$ (sec), $a_s = 0.3(m)$

(2) Channel ; $B = 200$ (m), $l = 200$ (m)
$n = 0.02$, $f_c = 1.5$

Estimation of A_e for case of each $\bar{\eta}_s$ is performed with the aid of topographical maps. M_l at the coast approximated to be about 100,000 m^3. At the present case which the entrance being protected with breakwaters as shown in the figure, the effective littoral drift rate $M_l{}'$ is estimated to be 50,000m^3. And it is assumed to decrease linearly with the value of $\bar{\eta}_s$.

A summary of the result is shown in Fig. 7. The bed scouring depth reaches approximately to 0.6m for case of $\bar{\eta}_s = 1.5$ m, and to 1m for $\bar{\eta}_s = 2$ m. The scouring depth become considerably large with the SLR value.

5 CONCLUSION

A sea level rise gives incidentally an excess tidal discharge and a decrease of effective littoral drift for inlets on sandy coasts. The flow area increases with increase of SLR from the present approach. Thus an entrance with vertical side wall will probably suffer severe bottom scouring trouble at inlets with ample low and flat shores.

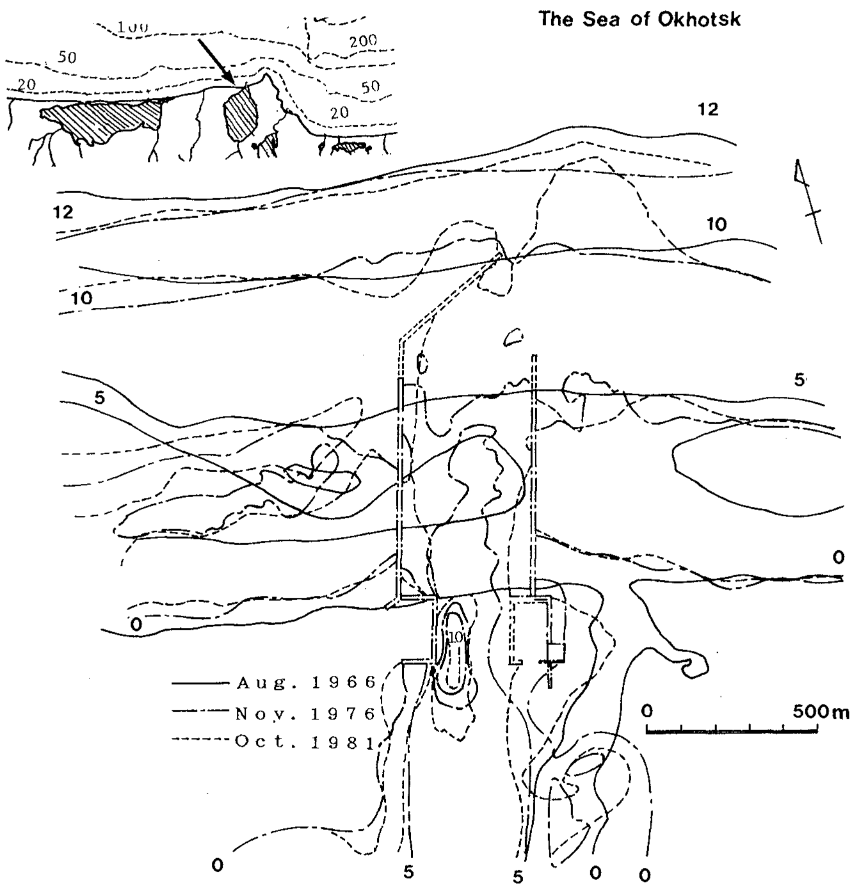

Fig. 6 Change of Under Water Topography around Entrance of Lake Notoro

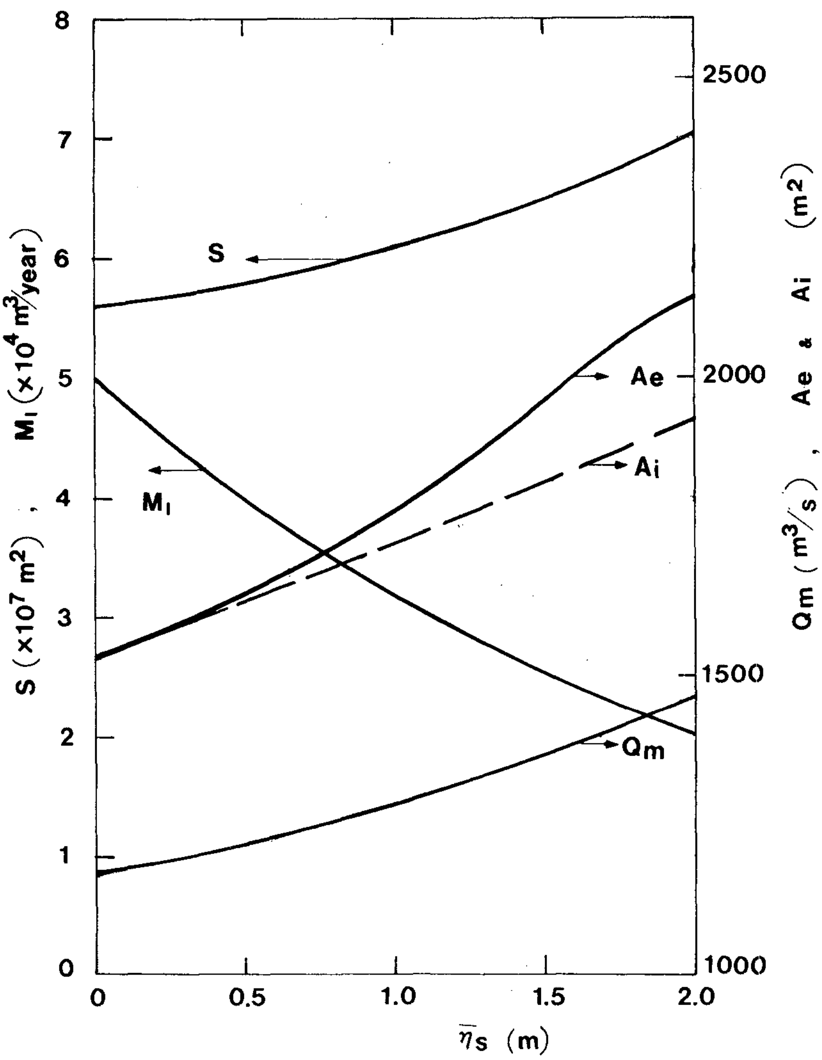

Fig. 7 Result of Prediction of Flow Area for Lake Notoro Entrance due to Sea Level Rise

REFERENCES

Bruun, Per. (1983): Review of conditions for use of Bruun Rule for erosion, Coastal Engineering, 7, 117-133.

Dean, R. G. (1987): Additional sediment imput to the nearshore region, Shore & Beach, Jul.-Oct., 76-81.

Everts, C. H. (1985): Sea level rise effects on shoreline position, Proc. ASCE, Vol.111, WW6, 985-999.

Jarrett, J.T. (1975): Tidal prism-inlet area relationship, GITI Rept. 3, U.S Army Corps of Engineers.

Johnson, J.W.(1973): Characteristics and behavior of Pacific coast tidal inlets, Proc. of ASCE, WW3, 325-339.

Kondo, H. (1975): Depth of maximum velocity and minimum flow area of tidal entrances, Coastal Engineering in Japan, JSCE, 18, 167-183.

Kondo, H. (1978): Design procedure of artificial channels for tidal entrances, Coastal Engineering in Japan, JSCE, 21, 191-199.

Kondo, H., N. Nitta and S. Touma. (1988): Tidal in the Okhotsk coast, Japan, Proc. of 9th Int. Symp. on Ice, IAHR, 2, 103-111.

Mayor-Mora, R.E. (1973): Hydraulics of tidal inlets on sandy coast, Hydraulic Eng. Lab., College of Engrg., Univ. of California, Berkeley, HEL 24-16, 241p.

O'Brien, M.P. (1931): Estuary tidal prisms related to entrance area, Civil Engineering, Vol.1, No.8, 731-739.

O'Brien, M.P. (1967): Equiribrium flow area of tidal inlets on sandy coast, Proc. of 10th Conf. on Coastal Eng., ASCE, 676-686.

Shigemura, T. (1976): Characteristics of tidal inlets on the Pacific Coast of Japan, Proc. of 15th Coastal Eng. Conf., Vol. IV, ASCE, 1666-1679.