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WIDENING RATE OF ESTUARINE REGULATION AND ITS PRELIMINARY CALCULATION IN THE TRAINING LINE OF NORTH DEEP-CHANNEL OF THE CHANGJIANG RIVER ESTUARY

Zhaosen LUO
Nanjing Hydraulic Research Institute, Nanjing 210029, China

Abstract: Based on the morphological relationships of rivers and estuaries, a formula for calculating widening rate of training works in estuaries has been derived. The widening rate is related to dimensions of tidal range, tidal period, tidal discharge, sediment content, width and depth etc. at the beginning and following cross-sections of a channel to be regulated. By using of coefficients and experiences concerned with estuarine regime in China and the corresponding values of the Changjiang River Estuary, the widening rate of training line with jetties and spur-dikes inside the north channel of the Changjiang River Estuary is calculated. The values obtained are in a quite agreement with the project design and model test results.

Key words: Widening Rate, Changjiang River Estuary, Estuarine Regulation

1. WIDENING RATE AND WIDENING RATIO OF ESTUARIES

A river emptying upland runoff and combining the effect of tides forms an estuary in which flood-discharge and ebb-discharge gradually increase from the upper to lower toward the sea. Estuaries, generally shaped as a funnel, have a definite widening rate, which is one of the essential parameters for the estuarine regulation. It is defined as follows:

Assume the width along the river course with 1 km-distance is widened e times of its original width (e<<1.0), the width at the beginning cross-section is B_0 (m), and the followed widths per 1 km are B_1 (m), B_2 (m), …, B_x (m), etc., it follows that

$$B_1 = B_0(1+e),\ B_2 = B_1(1+e),\ \ldots,\ B_x = B_{x-1}(1+e)$$

Then

$$B_x = B_0(1+e)x \quad (1)$$

where e is expressed as the widening rate of a channel to be regulated whereas B_x is the width of x km downstream the position of B_0.

As regards the widening rate, in the earlier years it was applied in the estuarine regulation in Western States. In China, for the regulation of Huangpujiang River Estuary and Haihe River Estuary, the parameter was also used.

In *Chinese Technical Codes of Regulation Works for Navigation Channels*, the same definition is described, i.e., $B = B_0(1+\Delta B)^x$. In this paper, the widening rate is expressed by e instead of ΔB so as to keep away from the confusion of $\Delta B/\Delta X$. $\Delta B/\Delta X$ or dB/dX is widening ratio or widening dimension and different from e.

2. DERIVATION OF THE FORMULA OF WIDENING RATE

A normal estuary should be conformed to the relationship of the morphology of rivers and estuaries. Each estuary, under the action of ebb-discharge including upland runoff has its own cross-sectional area, width and depth. By use of the minimum-activity theory of river processes, one group of formulas for calculating the dimension of plain rivers and estuaries derived by Dr. Dou are as follows:

$$B = K_1 Q_e^{5/9} S_e^{1/9} \tag{2}$$

$$H = K_2 (Q_e / S_e)^{1/3} \tag{3}$$

$$A = K_3 (Q_e^8 / S_e)^{1/9} \tag{4}$$

in which B, H and A represent the width, depth and cross-sectional area of rivers, respectively, K_1, K_2 and $K_3 = K_1 \cdot K_2$ are parameters related to sediment characteristics, relative activities between riverbeds and banks. For a relatively stable estuary or an estuary required to be regulated, all the parameters must be the same or of little discrepancy. Based on this viewpoint, if an estuarine channel is recommended to have a relatively stable reach (Its depth and width naturally accommodate the requirements of navigation.), it can be chosen as a predominant reach.

Suppose the average tidal range is ΔH (m), the average ebb-tide period is Te (s), the average sediment concentration is Se during ebb period, the cross-sectional width and ebb-discharge (including upland runoff) at the beginning cross-section are B_0 and Q_0, the depth required in the channel to be regulated is H, ebb-discharge of 1.0 km downstream is Q, according to the theory of continuity , the following formula can be obtained:

$$Q - Q_0 = 0.5(B_0 + B) \cdot \Delta H \cdot 1000 \cdot \eta\lambda / Te \tag{5}$$

in which η is the ratio-coefficient of tidal discharge to the tidal prism. According to the data measured in tidal rivers, it is 0.95−0.98; λ is the coefficient of storage water diverted by the actual project layout, and it may be determined as follows:

λ=1.0 when the top elevation of training work reaches high-tide level;

λ=0.5 when the top elevation of training work reached mid-tide level; and

λ=0.25 when the top elevation of training work reaches slightly higher low level.

From formula (4), Qe can be obtained as:

$$Q_e = (BH)^{8/9} S_e^{1/4} \Big/ (K_3)^{9/8} \tag{6}$$

From formula (1) when x = 1 000 m, it follows that

$$B / B_0 = 1 + e \tag{7}$$

Substitution of formulas (6) and (7) into (5) and simplification lead to

$$\frac{(1+e)^{9/8} - 1}{2 + e} = \frac{500\eta \cdot \lambda\Delta H}{Te} \quad \frac{K_3^{9/8}}{H^{9/8} S_e^{9/8} B_0^{1/8}} \tag{8}$$

Formula (8) is the formula for calculating the widening rate of a channel to be regulated in estuaries and e can be calculated simply by a simple program with any computers.

It is demonstrated that: the larger ΔH, the greater e; the deeper H, the smaller e; the smaller the ebb-sediment concentration; the larger e; the larger the initial cross-sectional width, the smaller e; and in contrast, the less width of B_0, the greater e. Such knowledge is conformed to the characteristics of river processes. Fig. 1 gives different values of e varied owing to different parameters and shows that e basically reflects the laws of river processes.

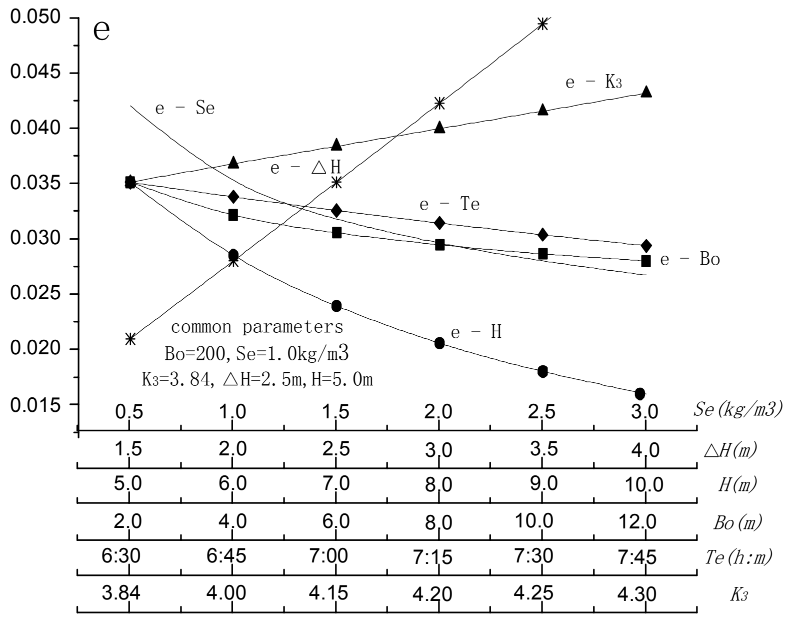

Fig. 1 e versus B_o, H, $\triangle H$, S_e, T_e and K_3

3. APPLICATION OF THE WIDENING RATE IN THE TIDAL RIVER ESTUARIES

3.1 HISTORICAL BACKGROUND

That there should be an appropriate widening rate in an estuary was known in the earlier years in France from the regulation of Seine Estuary where tidal range is large and tidal action is extremely strong, and two long training jetties had been constructed primarily to attempt to deepen the navigation channel. Although the depth of channel regulated succeeded in somewhat increasing, due to the widths between two jetties were too narrow it was unable to accept enough influx, and a very wide sand-bank occurred downstream of the dikes. Hereafter, another cannel was dug to connect the port in the upper Seine River. Later, for regulation in other estuaries, it was considered the requirement of widening rate. In China, Huangpujiang River and Haihe River Estuaries were designed with definite widening rates for their regulation as shown in Table 1.

Table 1 Width, length and widening rate of Huangpujiang River and Haihe River Estuaries

Name of Estuary	Name of Reach	River Length (km)	Width in the Upper (m)	Width in the Lower (m)	e	Remarks
Huangpujiang River	Gaochangmu-Wusong	31.0	400	700	0.018	
Haihe River	Jiefang Bridge-Lvdeng	70.9	100	250	0.013	Prior-to sluice construction

3.2 LAWS OF THE MORPHOLOGICAL RELATIONSHIP OF ESTUARIES

In fact, estuaries with regular widths are seldom. Most of them are wide and narrow. A plain-fluvial estuary, under the control of flood- and ebb-discharges and sediment movement would develop a smooth meandering course, narrow wide at the bend and wide at the transition. For example, Yongjiang River Estuary in Zhejiang Province, within which there are six meanders from Beisa to Zhenghai, the widening rate of the strait reach is e = 2.4%; and that of the bend e = 3.0%. The river has a definite relationship between the depths at the straight reach and at the bend reach. At Huangpujiang River Estuary in Shanghai, the North Port-Convex had been dug in the thirtieth of 20th century, desirable to fit the width under the regulating line. However, the more it was dug, the more amount the dredging, because North Port-Convex is located in the convex bend, siltation always took place, later dredging gradually decreased even stopped, influx decline and depth becoming shallow in the inner river reach didn't occur. Depth at the bend in estuaries is generally sufficient.

In the processes of estuarine development, it may not be limited by the widening rate. When a river is regulated to a normal width, the narrower the width, the deeper the depth. However, it could not be unlimitedly narrow, otherwise, limitation of the upward-flood discharge would decrease the dimension of cross-sectional area.

As for strong-tidal-range estuaries, most of them shape as funnels, for instance, Qiantang River Estuary in Zhejiang Province in China.

4. PRELIMINARY APPLICATION OF THE WIDENING RATE TO THE TRAINING WORKS OF THE NORTH CHANNEL OF CHANGJIANG RIVER ESTUARY

4.1 REGULATION OF THE NORTH CHANNEL OF CHANGJIANG RIVER ESTUARY

Through yearly experiments, studies and model tests, the North Channel of the south waterway in south branch is chosen as a deep-water channel to be regulated. Two long jetties and several spur-dikes inside are used for the training works. Operation of the regulation is divided into two stages: first stage has come into force with depth of –8.5 m completed in 2000; the second stage will operate on the basis of the first stage. After physical and mathematical model experiments and analytical studies, there are five schemes for predominance (Fig. 2) with the same layout of the long jetties and spur-dikes located, however, their lengths are different. According to the coordinate of the head at spur-dikes of design schemes, widths as well as the radius at the head position and widening rate can be calculated. The widening rates of five schemes are shown in Table 2.

Table 2 Widening rates of design schemes

Scheme	1	2	3	4	5
B_o (m)	3,360	4,568	4,007	4,007	3,642
B_x (m)	4,321	5,450	5,450	4,729	4,364
$\triangle X$ (km)	38.503	38.625	38.608	38.430	39.494
e (%)	0.655	0.458	0.800	0.432	0.471

4.2 PRELIMINARY CALCULATION OF THE WIDENING RATE

For calculation of the widening rate of North Deep-Channel, the following parameters and factors should be considered and adopted:

(1) ΔH = 2.66 m and Te = 7:24' = 26 640'' at Zhongqiun station;

(2) Se = 0.80 kg/m^3 is used as the yearly average sediment content, because there is no exactly average statistic value to be referred, according to experiences from other estuaries, 3/5 of 1.33 kg/m^3 (in spring tide during flood season in North Channel) is employed;

(3) K_3 = 3.84 could be used because the corresponding statistic morphological coefficient of Changjiang River Estuary is lacked. Some reference data are considered: K_3 = 3.84 analyzed by Luo for estuaries with Se near 1.0 kg/m^3 in the coasts of Zhejiang and Jiangsu Provinces and 3.47 in Pearl River Estuary with small sediment content (Se<0.5 kg/m^3), and K_3 = 4.7 by Dai in Qiangtang River Estuary (Se>1.0 kg/m^3), etc.;

(4) λ :Through physical fixed-bed model, movable-bed model tests and mathematical model studies among five schemes, No. 5 scheme is the most predominant. As regards No. 5 scheme, the average length of spur-dikes is 1 605 m in the north and 1 560 m in the south, the widths between the head and head connecting line of spur-dikes at the beginning and end cross-sections are 3 642 m and 4 360 m respectively, the top elevation of jetties reaches 2.0 m (mid- tide level), the elevation at the head of spur-dikes is slightly higher than low tidal level, so the conversion coefficient of storage water from middle level to low level can be calculated as:

λ = 0.25+0.25×(1605+1560)/(0.5×(3642+4360)) = 0.25+025×0.79=0.25+0.198 = 0.498

(5)H:How to calculate H is a problem, however, these values can be determined by the actual condition of Changjiang River Estuary. From the topographic maps measured after completion of the first-stage-operation, especially at the initial cross-section–position of S1+000 and S2+000, the author obtained the ratio between the average depth and navigable depth is 0.75, so depths of 7.88 m, 9.38 m and 10.88 m correspond to those of -8.5 m, -10.5 m and -12.5 m (under the datum of Wusong) to be regulated for navigable channels, respectively.

Substitute the above mentioned values into formula (7), the widening rate e can be calculated as:

e = 0.644% for navigable channel depth -8.5 m(under the datum of Wusong);

e = 0.53% for navigable channel depth is -10.5 m, and

e = 0.448% for navigable channel depth -12.5 m.

These values are close to those of model tests of No. 5 scheme.

5. CONCLUSION

As an example of regulation of the Changjiang River Estuary, a formula for calculating the widening rate has been derived in this paper and applied to calculation of the North Channel. The widening rate is one of the main parameters for estuarine regulation, although calculation of e is primary in Changjiang River Estuary, the calculated results are in quite agreement with those physical model test and design ones. It reflects variation tendency in estuarine regulation. This knowledge is conformed to the historical data in the processes of regulating Mississippi River, i.e., water depth of the navigation channel is deepened yearly owing to that spur-dikes inside the jetties prolong and narrow the width of channel. In general, the present research results can be used for planning and design of channel regulation in estuaries.

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