

A Study on the Stability of Three Tidal Inlets of Southern China

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Abstract

The stability of three tidal inlets along the coasts of Southern China are evaluated using the relationship between P/Ac and \sqrt{agT} by considering the ratio of M/Q_{max} . Because of less littoral drift or sediment discharge from the interior, Yangpu Harbor and Sanya Harbor have relatively greater cross-sectional areas and are relatively stable. While Jieshi Harbor is silting by littoral drift due to the decrease of tidal area with land reclamation. The study shows that it is useful to assess the stability of tidal inlets intuitively with graph on P/Ac and \sqrt{agT} by combining with the M/Q_{max} value.

I Introduction

There are many tidal inlets along the coasts of Southern China, and the tidal types are complicated. In this paper a semidiurnal tide(e.g., Jieshi Harbor), an irregular diurnal tide(e.g., Yangpu Harbor), and a regular diurnal tide(e.g.,

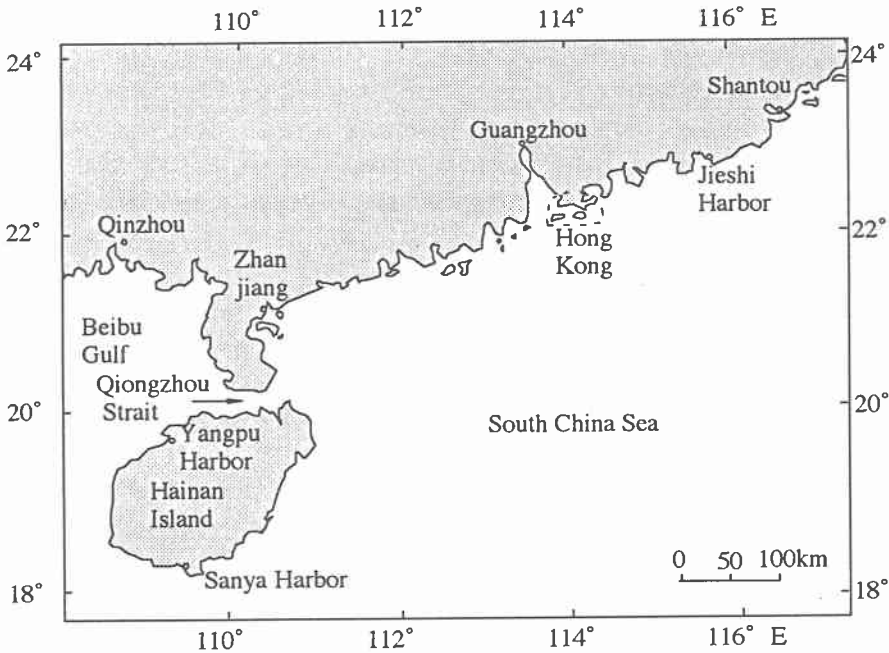


Fig.1 Location of three harbor along the coasts of Southern China

Sanya Harbor) are observed(see Fig.1). The mean tidal ranges are small. The mean wave height is about 1.0m along the coasts of East Guangdong and West Guangdong, 0.6-0.8m along Hainan Island¹⁾.

The stability of tidal navigation channel is of importance for satisfying the evolution of economics. Stability of the inlet cross-sectional area has been defined by Escoffier²⁾ and clarified by Van De Kreeke³⁾. The cross-

section of a tidal channel locating on sandy coast changes ceaselessly with scouring action by tidal currents and silting by littoral drift or sediment discharge from the interior. It is some ambivalence from the simply linearized relationship between the tidal prism \mathcal{P} and cross-sectional area A_c below mean sea level proposed by O'Brien⁹ and later verified by Per Bruun⁹ and Yoshitaka⁶ based on the data of Europe, U.S.A. and Japan, respectively. Moreover, because the complexity of the factors such as geometries, wave conditions, scale range, and human activities affecting the tidal inlet, too small successful example of physical model describing the inherent behaviors of a tidal inlet, to widely apply by instinct in practice. Hence the senior writer has proposed the stable condition for tidal inlets which can simply indicate the erosion or siltation of a tidal inlet on sandy coast.^{7,8} In this paper the relationship between \mathcal{P}/A_c and $\sqrt{a_g T}$ by considering the \mathcal{M}_t/Q_{max} value is applied to assess the stability of three tidal inlets along the coasts of Southern China.

II Relationship between \mathcal{P}/A_c and $\sqrt{a_g T}$

The inlet channel characteristics depend upon the balance between longshore sediment transport and wave acting to choke the inlet and the scouring action of tidal flows and river discharges acting to erode the inlet channel. When the depth of entrance channel ℓ or the cross-sectional area A_c is varied, the peak current velocity \mathcal{U} changes. Since too small ℓ makes the bottom resistance greater and much greater ℓ does the water surface gradient along the channel more gentle, \mathcal{U} must take the maximum value of it at some depth. That means in the channel with a stable cross-sectional area A_c for a long time, the deposition and the erosion are counteracting or in an equilibrium. Based on the ratio of the annual littoral sediment transport and river sediment discharge \mathcal{M}_t to Q_{max} , the peak tidal current discharge, the following fomula^{7,8} can be plotted in Fig.2.

$$\left(\frac{\mathcal{P}}{A_c}\right)_{max} = \frac{\mathcal{U}T}{\pi} = K_s \sqrt{a_g T}$$

The value of K_s is examined analytically by Kondo⁷ as

$$K_s = \frac{1}{2} \sqrt{\frac{3\sqrt{3}}{2\pi} \frac{\sqrt{\left(\frac{n_s}{n}\right)^2 - 1}}{\left\{f\left(\frac{n_s}{n}\right)\left(\frac{3}{4}\left(\frac{n_s}{n}\right)^2 + 1\right)\right\}^{\frac{1}{4}}}}$$

Where

$$n_s = n \left(1 + \frac{f_c \mathcal{R}^{4/3}}{2g\ell n^2}\right)^{\frac{1}{2}},$$

\mathcal{R} : Hydraulic Radius, n : Roughness coefficient of Manning formula; $f_c = 1+f$; Loss coefficient due to inflow or outflow from entrance; ℓ : Length of tidal channel; a_g : The amplitude for simple harmonic tides in the bay; g : Acceleration of gravity. T: Tidal period.

By examining the data of tidal inlet in both Japan and U.S.A., K_s can be obtained from Fig.2 as

If $\mathcal{M}_t/Q_{max} < 30$, $K_s = 0.15$

and if $\mathcal{M}_t/Q_{max} > 300$, $K_s = 0.22$

K_s , the slope of the oblique line can be defined as a relative current velocity (In fact, velocity is the product of the slope K_s and $\sqrt{a_g T} / \pi$). For a tidal inlet, if $\mathcal{M}_t/Q_{max} > 300$, and the data is under the line of $K_s = 0.22$, that means the deposition is stronger than the erosion. Whereas, If the data is over than the line of $K_s = 0.22$, the erosion will be dominant. Similarly, the line of $K_s = 0.15$ can be interpreted as above, but only different in the ratio of \mathcal{M}_t/Q_{max} .

Although it is difficult to coincide the \mathcal{M}_t with \mathcal{P}/A_c within a graph concretely, but the stability scope of tidal inlets is provided semi-analytically with this graph.

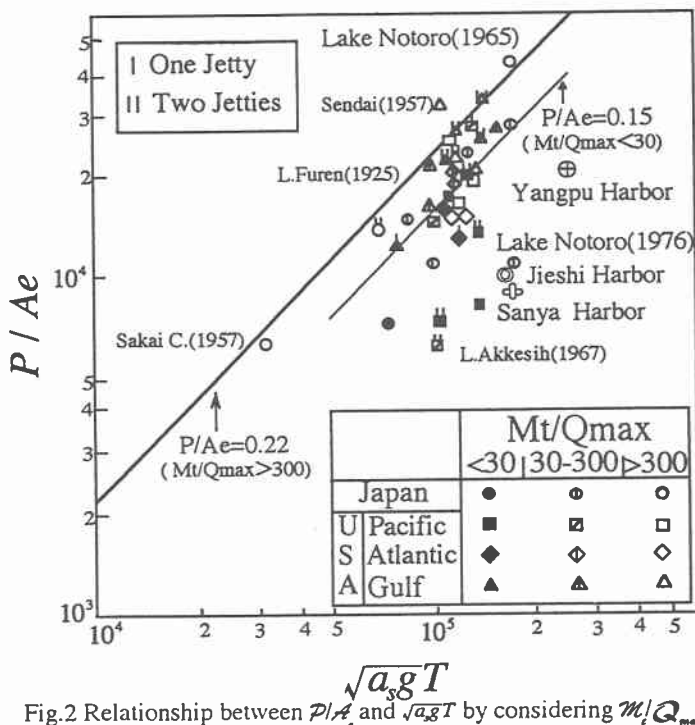


Fig.2 Relationship between P/A_e and $\sqrt{a_s g T}$ by considering M_t/Q_{max}

III Yangpu Harbor

Yangpu Harbor is located in a larger tidal inlet in the northwest part of Hainan Island(Fig.3). It is composed of an outer harbor, called Yangpu Bay and inner harbor, called Xinying Bay. Xinying Bay is a tidal embayment

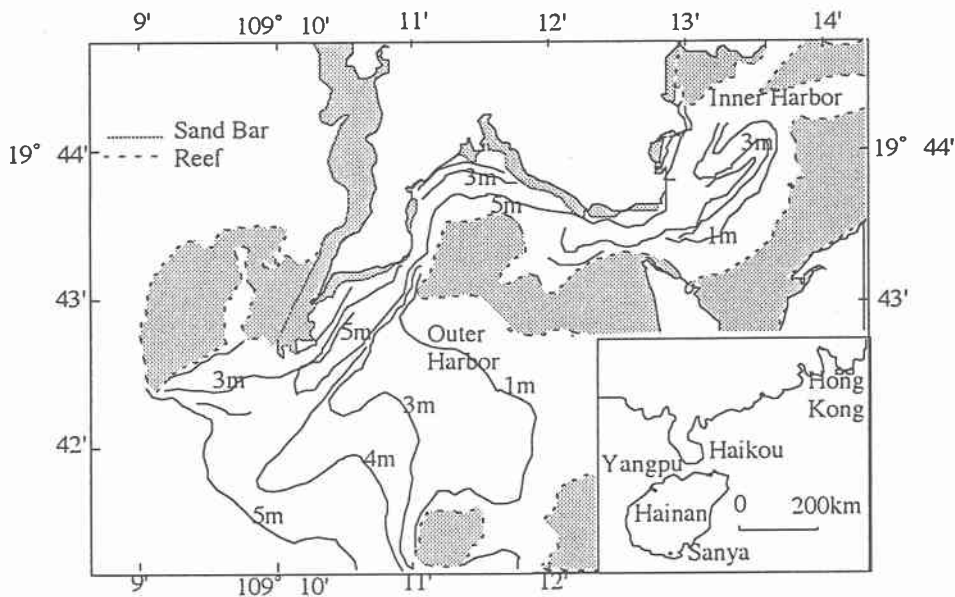


Fig. 3 Bathymetry of Yangpu harbor

with an area of 50km^2 . Two rivers enter the embayment from the east [Dashui Jiang], and from the southeast [Chun Jiang], respectively. The outer of the embayment, referred to as Baimajing Strait is 550m wide, and has a cross-sectional area A_s below mean sea level of about 5000m^2 .

Tides in Yangpu Harbor are of an irregular diurnal type and have a mean range of 1.82m^{11} . But the maximum range can reach 3.8m . The maximum velocity of ebb current can reach 1m/s . As different researcher proposed different tidal prism^{11,9)}, in this paper the tidal prism of $100 \times 10^6\text{m}^3$ is used on average by combining the different data from many researchers.

The components of total wave climate include wind-generated waves(78%) and sea swell waves(12%). The waves entering the harbor is predominantly from southwesterly direction. The average height of waves from SW direction is 0.83m with an average period of $4.5\text{s}^{9)}$.

The three major sources of sediment are, in order of importance, river transport, coast line erosion and coral reef erosion. The total discharge from all river sources is a sediment volume of about $6.2 \times 10^4\text{m}^3/\text{yr}$. Sediment derived from the southern coast of the outer harbor, each year is approximately $2.2 \times 10^4\text{m}^3$. The northwest basaltic coastline of outer harbor, is also being eroded, but at significantly slower rate compared to the southern coast. Its annual contribution of sediment is about $0.2 \times 10^4\text{m}^3$. Hence, the total coastline erosion is $2.4 \times 10^4\text{m}^3/\text{yr}$. Sediment from barrier coral reefs outside of the bay is $4000\text{m}^3/\text{yr}$. Combing river sediment discharge, coastline erosion and coral reef erosion, the total sediment is $9.1 \times 10^4\text{m}^3/\text{yr}^{7)}$.

By using the data above we obtain $P/A_s = 2 \times 10^4\text{m}$, $\sqrt{ag}T = 2.57 \times 10^5\text{m}$, $M/Q_{\text{max}} = 18.2$. And plotting it into Fig.2 the data of Yangpu is under the line of $K_s = 0.15$. That means the sediment transport from sea or interior is relatively small. As studied before¹⁰⁾ and shown in Fig.2 difference of two data of Lake Notoro in 1965 and 1976 apparently originates from the different M_s quantities since the artificial entrance channel is furnished with two jetties which interrupting the littoral drift heavily. Hence it is corresponding in Yangpu Harbor and Lake Notoro that entrance affected by less littoral drifts have relatively greater cross-sectional areas.

IV Sanya Harbor

As shown in Fig.4, Sanya Harbor is part of lagoon-embayment system that forms one of the large harbors

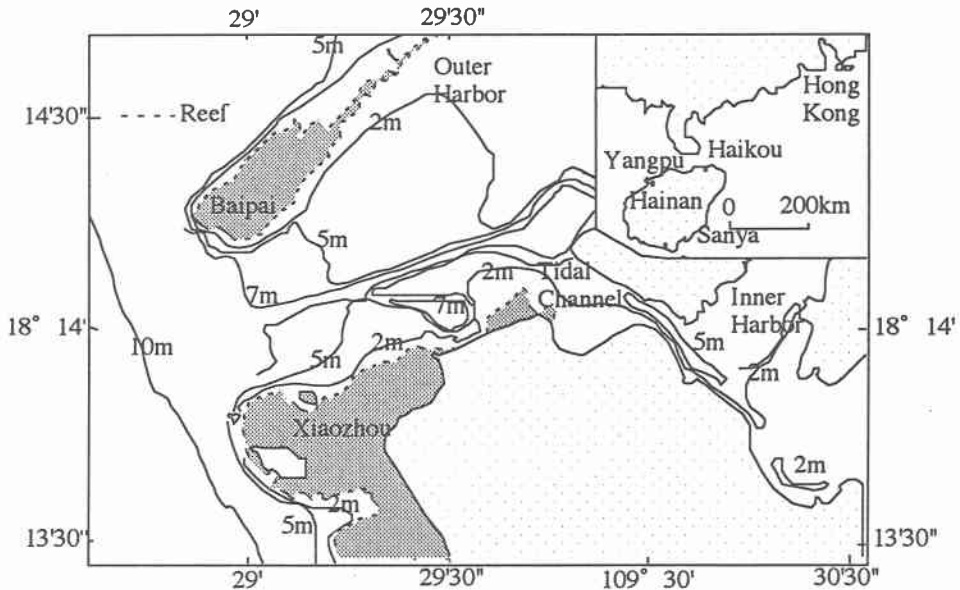


Fig.4 Bathymetry of Sanya Harbor

in the southern part of Hainan Island. Two islands are in the west and with nearshore reefs of Baipai and XiaoZhou, They decrease the wave energy from the west and southwest. Thus the wave energy is small in the harbor area.

The average height is less than 0.5m¹¹⁾ and the period is shorter than 4s. And the longshore supply has been being stopped by a submerged artificial bank with zero meter high since 1979 to connect the Baipai reef with the shoreline. Thus, the outer part of Sanya Harbor has little sediment supply and without serious wave power to stir the bottom sands. River sediment discharge is about 2417m³/yr¹²⁾.

The tides are of a regular diurnal type and the average tidal range is 0.82m. The average tidal area is 2.3km², and the average tidal prism is 0.00174×10⁶m³. The cross-sectional area is maintained by tidal currents and is 430m² on average¹⁾. During the short period of ebb tides, the maximum current speed is 1m/s which is twice of flood current speed.

Similarly, the data of Sanya Harbor also depart from the line of $K_s=0.15$ with a distance in Fig.2. And the same interpretation can be given as Yangpu Harbor and Lake Notoro.

V Jieshi Harbor

As shown in Fig.5, Jieshi Harbor is located on the Eastern coast of Guangdong Province (22° 49'N, 115° 47.5'E). The tides are of a semi-regular tide and the mean tide range is 0.8m. On average, its tide prism is 1.56×10⁶m³, and the cross-sectional area A_c is about 150m²¹⁾at present. Plotting the limited data into Fig.2, the data of Jieshi Harbor is also off the line of $K_s=0.15$ with a distance. It has been found that its tidal area had been reduced from 5km² to 2.2km² due to the land reclamation in 1969's field research¹³⁾. Thus, this phenomenon originated from the tidal area decreased due to land reclamation. Subsequently, the tidal prism had been reduced, while the cross-sectional area has been varying by a considerable slower speed than changes of tidal prism as well-known. The similar examples have been found in many other coastal areas of the U.S.A.^{14),15)}.

VI Conclusions

1) Because of less littoral drift or sediment discharge from the interior, Yangpu Harbor and Sanya Harbor have relatively greater cross-sectional areas A_c as almost the same as the case of Lake Notoro after jetties built.

2) Since land reclamation in 1969 in Jieshi Harbor, the navigation conditions and geological environment have been aggravated. Hence careful investigation and research, rational planning and healthy management should be undertaken before human activities for exploitation are implemented in the coastal zone.

3) It is useful to assess the stability of tidal inlets intuitively with relationship between P/A_c and \sqrt{agT} by considering the M/Q_{max} value.

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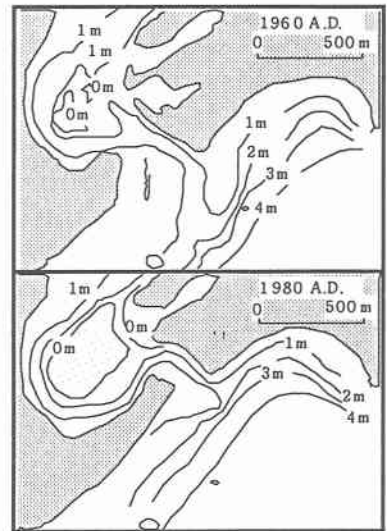


Fig. 5 The changes of geomorphic system before and after reclamation in Jieshi Harbor

provided useful data of tidal inlets along the coasts of Southern China.

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