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EVOLUTION AND RECOVERY OF SELF-ADAPTIVE ABILITY OF BARRIER- LAGOON SYSTEM IN DONGSHUI HARBOR

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Abstract: The evolution of a barrier-lagoon system keeps rapidly, and each part of the system is sensitive to the change of environment of dynamic and sedimentary conditons. As a relatively independent system, a barrier-lagoon system keeps itself balance based on the recovery ability under special conditions. Under the natural environment, it is common that the system loses its balance by rapid development of human activity, then the system loses its recovery ability of self-adapting. From a viewpoint of dynamic geomorphy, the article analyzes the ability of self-adaptaton of a barrier-lagoon system and the limitation of the ability which keeps the system in balance. The effect of waves, longshore sediment transportation, runoff, barrier and lagoon in the system is analyzed in detail by studying on the process and trends of the barrier-lagoon system in Dongshui Harbor under the action of nature and human beings. And engineering methods were carried out to recovery the ability of self-adaption and to keep the system in balance when the system lost its balance and only relied on the ability of self-adapting.

Key words: Barrier-lagoon system, Self-adapting ability, Geomorphic process, Dongshui Harbor

1. INTRODUCTION

The Dongshui Harbor is located at ChenMai Bay on the south of the West QiongZhou Channel, China. (Fig.1). The Dongshui Barrier-lagoon system is composed of the Dongshui barrier, the Dongshui lagoon and the river-mouth bar near the entrance of the lagoon. The coast near the Dongshui Harbor is arc-shaped and is controlled by the Xinhai Basalt Rocks and the Machun Basalt Rocks. The Dongshui Barrier is 15km long, 5-15m high, 500m-1000m wide, and extends from northeast to southwest. Inside the Dongshui Barrier is the Dongshui lagoon, which is 12km long, 100-1000m wide, 2.0-5.0m deep at the talweg and the mouth is in the west The main river which run into the Lagoon is Chen Mai River, whose basin area is about 240 km^2. The area of river-mouth bar is 7.7 km^2, and evenly distributes at the area which is 15m deep. The volume of the bar is about $1\times 10^8 m^3$。

2. ENVIRONMENTAL CHARACTERISTICS NEAR THE DONGSHUI HARBOR AREA

2.1 DYNAMIC ENVIRONMENT

2.1.1 Wind and Wave Condition

The area of Dongshui harbor is of tropic monsoon area, where the wind is inclined to S-SE in summer and NNE-ENE in winter. The survey data on 1960-1969 at the Yubaojiao, west to the Dongshui harbor, shows that the frequency of N-ENE direction is 54%, ESE-SSE is 18%. The dominated direction is consistent with that of normal.

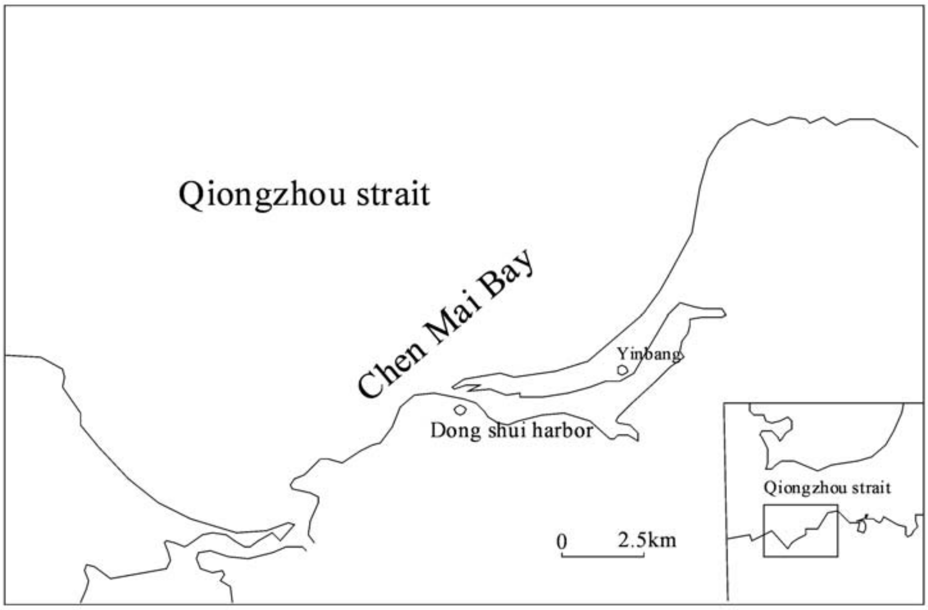

Fig. 1 Map of Dongshui Harbor

Even more, the typhoon occurs of high frequency and the survey data of 1951-1980 shows that the Dongshui harbor is affected by typhoon for 128 times, average for 4.3 times and the maximum is 8 times. Generally, the typhoon season is from June to October and typhoon is much often in August to September.

The wave of Dongshui area is mainly generated by wind and the frequency is 99%, which is supported by survey data from 1960-1969 at the Yubaojiao(the survey spot is 14.0m depth). The normal direction of wave is N-ENE, which is 55% of all the survey data. The dominated direction is almost the same as the normal direction. The surveyed highest wave height is 7.7m, and is on NE direction. The average height of a year is 0.5m, and the average period is 2.55. So that the Dongshui harbor is evidently affected by wind-generated wave can be concluded.

2.1.2 Tidal Current

The tide near the Dongshui harbor is of abnormal concurrent mixed. The average tidal range is 1.59m, while the maximum is 2.36m.

The tide near the Dongshui harbor is abnormal concurrent mixed tide which have four act forms: the flood in west direction, the flood in east direction, the ebb in west direction, the ebb in east direction. The east current turns to the west at mid-tide. At the mid-tide, the above runs to the east, while the lower runs to west. The west current dominates during the flood time and lasts longer, while the east current dominated during the ebb time. The dynamic of current is very different in the east and west direction. The maximum velocity of the current in the east direction is evident, while that of the west can not be identified. The maximum velocity of the current in the east is 1.09m/s, while that of the west is 0.54m/s. The maximum value of velocity often occurs at higher low water level.

The current near the Dongshui harbor is determined by the difference of water level between the lagoon and the sea area outside. When the sea level raised, the current runs from outside into the lagoon. The rate of sea level rise is small, and the largest number occurs at moderate level, which makes the current run into the lagoon at maximum velocity. When the water level outside keeps rising and the rate of sea level rise turns small , the velocity also turns small. When the sea level descend, the maximum velocity of current outside is the largest. The phrase of level and velocity of tidal current characterized stationary wave. The maximum velocity at the outlet occurs at slack water time of the sea outside. The survey data at June,1963 shows that the tidal current outside Dongshui Harbor run inside much longer and the velocity is much larger. The residual current velocity is about 0.1m/s and point to the inlet of the habour.

2.1.3 River

The main river that run into the lagoon of Dongshui Harbor is ChenMai River, which run-off volume is small. The average volume is less than 10 m^3/s , which is almost useless to strengthen the tidal current. It should be noticed that the run-off volume is large when it is rainstorm. The maximum amount of rainfall is 199.7mm in 1985, which means the run-off volume is 277.4 m^3/s at that day. The rainfall volume with the tidal current volume will produce current velocity as much as 1.08m/s when neap and 1.21m/s when spring.

2.2 SEDIMENTARY ENVIRONMENT

101 sediment samples got from sea area and sands were analyzed. There are 14 type of sediments , from gravel to sandy silts, distributed at the surface of Dongshui Harbor. The main body of river-mouth bar and area near the outlet is composed of sandy gravel. It turns smaller as it is run inside the lagoon. The area outside the river-mouth bar distributes fine sediments.

The erased gravel and medium sand from north-east is the source of the sediments of river-mouth bar and beach and is strongly affect by wave force, which is supported by analyses on median particle size, sorting coefficient, deviation coefficient and sediment content from the surface. And the river carries most of the sediments of lagoon, and run-off flow and tidal current transport it. The area out of the sea is mainly influenced by tidal current.

2.3 SEDIMENTS

2.3.1 Source

The source of the active sediments near the Barrier- lagoon System in DongShui Habour is the followings:

1) The erosion along the seashore is the main source of sediments on the river-mouth bar and modern beach, and the wave is the main force moving the sediments along the seashore to the river-mouth bar.

2) Parts of the sediments at the –5m depth bottom east of river-mouth bar is the east transportation of the river-mouth bar, while some others is from west faraway and is carried by tidal current.

3) The erosion of basaltic terrace at the west is the main source of west area of the river-mouth bar.

4)Source of the area at –7~–20m depth outside of the outlet is complicated. It should be the sediments spread from ad littoral area or deep area, while it also can be the sediment from west and east carried by tidal current.

5)The area of residual sands –20m depth out of the shore is also the main source of sediment transportation along the shore. Tidal current, the tidal to east, is the main carrier.

6)The sediment set down inside the lagoon is mainly from Chenmai River. Parts of them is caused by sands deposits, while the main parts is carried by wind. And another parts of sands is from the river-mouth bar through the outlet or through the beach carried by wave.

2.3.2 Sediment Transportation Caused By Tidal Current

Under common weather, the suspended sediments is generated from the sea bottom by wave. Mass of thick water can be watched because sea bottom was washed by rapid current to the east.

Without the affect of typhoon and great wave, the sediment content of water body at Dongshui Harbor is very small as much as 0.007−0.082km/ m^3 . The wave that moves in cycles and enduring transportation are very important to the development of Barrier- lagoon System in DongShui Habour and especially to the river-mouth bar outside the outlet. Regarded on the plane position, the sediment discharge and water delivery per unit width at the east of the river-mouth bar is bigger than that at west. Effect on water and sediments of the east-directional tidal current is bigger than that of west. The net sediment transportation points to the east.

2.3.3 Sediment Transportation Caused By Tidal wave

Because the medium particle size of sediments at Dongshui Harbor is 0.17−0.9mm, wave is the main force of sediment transportation at coast and shoal area. The longshore sediment transportation caused by wave is the main factor of scouring and silting at the seashore. It is also the main factor of evolution of the Barrier- lagoon System in DongShui Habour.

Calculation on sediments discharge under the wave condition near Dongshui Habour is taken using CERC formula, Formula of National hydraulic modeling in Xiadu of France and Formula of Marine hydrologic code for seaports. The result is shown as Table 1.

All results of the three methods figure out that the net sediment transportation points to west. And the amount to west is 15−20 times more than that to east, which is mainly caused by the normal and dominated wave direction to ENE and NE. Above all the net sediment transportation to the west is the main environmental factor which affects the evolution of the barrier- lagoon System in DongShui Habour.

Table 1 The longshore sediment transportation of Dongshui Harbor（$10^4 m^3$）

Direction		ENE	NE	NNE	N	NNW	NW	WNW	W
CEXC Formula	To East					0.49	0.87	0.43	0.21
	To West	12.26	14.48	3.5	0.96				
	Totally	31.2				2.0			
	Net	29.2(to west)							
France Formula	To East					0.24	0.36	0.27	0.22
	To West	11.49	8.62	1.77	0.47				
	Totally	22.35				1.09			
	Net	21.26(to west)							
Formula of Marine hydrologic code for seaports	To East					0.34	0.47	0.13	0.14
	To West	8.22	10.1	2.49	0.62				
	Totally	21.43				1.25			
	Net	20.18(to west)							

3. THE DYNAMIC GEOMORPHIC PROCESS OF THE BARRIER-LAGOON SYSTEM IN DONGSHUI HABOUR

3.1 THE FORMATION OF THE BARRIER-LAGOON SYSTEM

Dongshui Harbor is a secondary bay appeared after middle Holocene epoch. After the Ice Period, the sea level raises rapidly. About 8000 years ago, a bar appears at the sea bottom, on which generated groups of sand ripple. With the sea level keeps raising, the barrier keeps moving to continent. About 6000 years ago, the bar moves up to the position as today, and the modern bar appears. The residual lowland at the south of outlet is submerged to be a lagoon. About 3000-6000 years ago, the west part of the barrier is near to Qing Mount, out of which is the seashore at right-side. The outlet of the lagoon is west to QingMount. (Fig. 2)

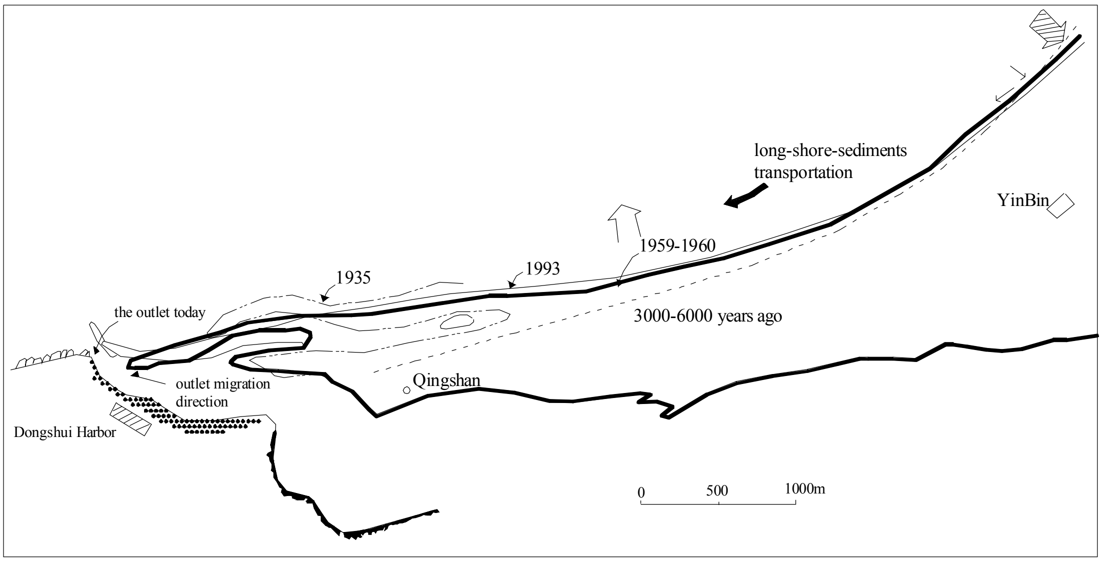

Fig. 2 The Evolution of Sand Spit of Dongshui Harbor

The appearance of lagoon and barrier make a part water pass through the channel, which restrain the barrier to move west any more. The water also combine with the strong current from the east and the cape at the west, which makes the outlet at a weak current environment and sediments can set down to be a river-mouth bar. The barrier-lagoon system is composed by the barrier, the lagoon and the river-mouth bar.

3.2 THE EVOLUTION OF THE BARRIER

About 3000−6000 years ago, the forming of arc barrier at Dongshui Harbor extending from east to west was completed。Affected by the wave force, the coastline of barrier keeps on under adjustment. The northeast part of the barrier is under erosion, and the erased sediments is moved to west, which made the bar extend west.

Affected by the alongshore sediment transportation from the east to west, the barrier have extended west for 1500m from Qingshan at 3000 years ago. The average velocity to west is 0.5m/a. About 30 years ago, the barrier is keeping on erosion at the northeast parts and siltation at the west parts. The Yingbing Chun is maybe the equilibrium point between scour and depostion.(Fig. 2). During this time, the man-made activity keep on cutting down the water area of the lagoon inside the barrier. The tidal current force in the channel is weaken, and the barrier is extend west in the average velocity of 4m/a, and the lagoon, narrow and long, is appeared to EW at the inside part of barrier. The topographic data at 1993 shows, that the narrowest width at the outlet is 83m, the sectional area is only 288 m^2 , and the total length of lagoon in the branch is 6500m.

3.3 THE EVOLUTION OF LAGOON

Under natural condition, the lagoon of Dongshui Harbor, where the tidal area reduced and the water turns shallower, will be gradually filled up. In recent years, the activity of human beings accelerated the lagoon to die out, which is supported by Table 2. The reduced number of tide-absorbing area because of human beings bank building and lake filling is astonishing.

Table 2 The Change of the lagoon area at Dongshui Harbor（km^2）

Time(year)	1935	1959	1986	1993
Tide-absorbing area	7.7	6.6	5.0	3.2

Analyzed by ^{210}Pb , the average deposition rate in the lagoon of Dongshui Harbor is 0.6cm/a, while the rate before 1983 is 0.53cm/a. After 1982, the human beings activity effect on the lagoon deposit increased, which caused the rate is 1.0cm/a. If based on the lagoon area before 1986, the sediments carried by river make the average deposit rate 0.3−0.5cm/a, which is the same as analyzed result of ^{210}Pb. Above all, the area decreased rapidly because of the human beings activity, and the deposition rate increased relatively, which will accelerate the lagoon in Dongshui Harbor die away.

4. ANALYZE ON SELF-ADAPTATIVE OF SYSTEM

4.1 SELF-ADAPTATIVE OF THE BARRIER-LAGOON SYSTEM

As the dynamic topographical system, the barrier-lagoon system has its own substance, energy, information input and self-adjustment controlling and feedback ability. When the environment outside influence on the system, which means the substance flow, energy flux, information flow changes and the system departs from balance, the system can organize its action and adjust its own structure, which developed itself to a balance gradually, from out-of-order state to in-order. For example, when the tidal absorbing area is changed, the outlet can adjust the boundary condition to adapt to tidal current force and make the outlet profile change to balanced state. That means that the outlet can ‘understand’ the change of tide-absorbing area and then adjust the size of profile as a response. The factors inside the system can understand and response each other, and then keep all of the system balanced, which means the system can self-adapt to the environment in a certain extent.

Under a definite condition, the self-adaptive ability of the barrier-lagoon system can maintain the system to keep balance. But the factors are so complicated and changeful that the balance is so weak. Above all, the self-adaptive ability is limited.

After summarized all the factors, the sea, outlet, tide-absorbing area, that influence on the barrier-lagoon system, Keulegan carried out a term—“Satiation Coefficient ”—to identify the balanced states. He regarded that there should be a critical satiation coefficient, K*, to a barrier-lagoon system. When the actual coefficient K>K*, the profile area should decrease and the current velocity will increase which can resume the profile. In contrast, when K< K*, the friction effect is so apparent, that the profile area decrease, and the velocity will decrease. Then the area of outlet profile decrease again. Esooffier use a closed curve to describe two critical balanced state at the barrier-lagoon system, which also prove this point. Research shows that balanced barrier-lagoon system have the self-adaptive ability and can use the ability fully. But, once it loses its balance, the self-adaptive ability will disappear and it cannot keep balance only with its own ability. For example, if the outlet area is less than the critical area for some reasons, the velocity at the outlet will keep decreasing, and the deposition at the outlet will increase, which cannot resume only by its own ability.

4.2 ANALYSES ON THE SELF-ADAPTIVE ABILITY OF BARRIER-LAGOON SYSTEM AT DONGSHUI HARBOR

With the west extension of the outlet bar, the tide-absorbing area of the lagoon at Dongshui Harbor is long and narrow. Even though, there is still a outlet that connect with the outside sea and the lagoon, the narrow outlet cannot satisfy the water exchange between the inside and the outside. Two times in-phrase tidal survey was taken at June-July, 1993. The survey data shows that the slack water time is unsuitable for about 40-50 minutes between the outside and inside, and the arrearage angle is 11.6° . The survey data show that the narrow outlet have baffled the water exchange between the inside and outside.

4.2.1 P-A relation

P-A relation is an important method to research the balance of the barrier and lagoon system:

Mayor Mora found the P-A relation have obvious scale effect by model experiments. The P-A relation of small-scale barrier-lagoon system is: $A=7.61\times10^{3}P^{0.68}$($A{\cdot}m^2$, $P{:}m^3$).

After considering the narrow and shady tide-absorbing area characteristic of Dongshui Harbor, the equilibrium profile area is calculated 345.7m^2 using Mayor Mora's method. But the area of outlet profile is only 288m^2, which is much less than the area of equilibrium profile for about 16.7%. Considered together with the tidal arrearage, the tide-absorbing ability is not fully used because of the narrow outlet, and the actual volume is very less than the ability of calculated result.

4.2.2 The Average Velocity at Outlet Profile at Spring Tide

The maximum mean velocity in section at flood, Vmax, is the main steady criterion of equilibrium state of flow section at outlet，p'Bruum carries out Vmax as：

$$\text{Vmax}=(R\frac{1}{8}-a)\text{m/s} \qquad (4\text{-}1)$$

The R is hydraulic radius; a is factor，when R<5，a=0.1，and when R>5，a+0.2。

The Vmax, calculate by Formula 4-1, is 1.07m/s at outlet of Dongshui Harbor. But the survey mean velocity at the outlet is 0.64m/s at greater ebb time, which is only 60% of the Vmax. All these means the barrier-lagoon system doesn't have enough energy to maintain the narrow outlet.

4.2.3 Satiation Coefficient

Keulegon's Satiation Coefficient is an important symbol if the self-adaptive ability of the barrier-lagoon system is carried out. The formula is:

$$K=\frac{T}{2\pi Q}\frac{A}{Ab}\sqrt{\frac{2ga}{F}} \qquad (4\text{-}2)$$

The **K** is satiation coefficient, a is tidal range of the outlet; A is the profile area; A_B is the tide-absorbing area; T is the tidal current cycle; F is the impedance; $F=1+\frac{0\cdot032}{4R}$; L is the length of lagoon; R is the hydraulic radius.

D'Brien's research proved further that the critical satiation coefficient K* is 0.64.

The calculation satiation coefficient of Dongshui Harbor *K* is 0.48, which means that the self-adaptive ability is lost. The profile at the outlet cannot enlarge itself according to itself self-adaptive ability, the outlet incline to closing.

4.2.4 Run-off Discharge

Chengmai River is the main river that fills in the lagoon of Dongshui Harbor. Though the average value is not big, the discharge at storm is big. Under the discharge, in addition to the neap or spring ebb, the velocity can be the same as or a little bigger than the critical velocity. But the discharge at storm is not the main force that can maintain the profile form.

Based on the long-termed survey data at the Borwon River Estuary of Australia, the discharge area at the outlet will change with the largest peak discharge. The outlet area often act as a function of largest peak discharge, which only occurs when the average discharge is bigger than a certain critical discharge. The critical discharge often equals the 0.23 times of maximum tidal current. When the discharge is smaller than the critical value, the run-off's effect on the area can be ignored.

The common run-off discharge of Chengmai River is only 1/30 of the largest peak discharge. Even there is one or two storm, no more than 1−2 times/a and 1−3 days/times, when the discharge will be bigger than the critical value.

Based on the survey data on the Borwon Estuary, the profile at the outlet will adjust quickly to the tidal condition, prevailing wind-wave after the flood peak passed. Above all, the dominated factor is the tide-absorbing volume in a long term, and the flood run-off at storm can change a little on the outlet area.

5. CONCLUSIONS

Though the lagoon can absorb a certain tide volume, the lagoon outlet is so narrow and small that the tide-absorbing ability is limited. The average velocity at the outlet in spring tide is much less than the critical value. The whole barrier-lagoon system has lost its self-adaptive ability on shape and dynamic force. Under the strong longshore transportation environment, the self-adaptive ability can not maintain the system stable. The runoff also could not be the endurance force to maintain the stability of the outlet. Now, the system is developing to a closed system, and the human beings' activity, which has diminished the area rapidly, accelerates the dying process.

A mount of longshore sediment transportation from east to west extends the barrier to west and reduce the outlet. The human beings activity reduced the tide-absorbing area. Both these two main environmental factors caused the barrier-lagoon system of Dongshui Harbor going to dying out. If the dying process is stopped or slowed down, the disadvantageous environment should be changed and the self-adaptive ability should be resumed. But it is impossible to change the wave force that brings the longshore sediment transportation. To avoid the influence of longshore sediment transportation, sediment-retaining dike can be built, and the longshore sediment can be retained outside of the outlet.

After avoiding the influence of the longshore sediment, the outlet can be enlarged manually to satisfy the water exchange between the sea and the lagoon. The tide-absorbing ability can be fully used and the self-adaptive ability can be resumed. Of course, the scale that the outlet can be enlarged depends on the tide-absorbing ability. During this process, the tide-absorbing area should be enlarged as large as possible to develop and use the barrier-lagoon system in the future.

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