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A PRELIMINARY ANALYSIS OF THE STREAM CHARACTERISTICS OF THE WATER AREA SURROUNDING MACAO IN THE PEARL RIVER DELTA

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Abstract: With the hydrological data and results obtained in recent years，this article analyses the effect of the runoff and tide in the water area surrounding Macao，describes tides，stream motion and the characteristics of their changes，and briefly analyses different elements of the silt subsidence.

Key words：Water Area Surrounding Macao, Tide and Stream Characteristics, Analysis

1. INTRODUCTION

The water area surrounding Macao in the Pearl River delta，lying in the area on the south of Zhuhai and Macao at the southern end of the economically developed Pearl River delta，facing the South China Sea，has a superior geographical position and good natural environment. Since China's reform and opening to the outside world，especially since the beginning of 1990's，this area has become a hot spot for investment and exploitation，and achieved a rapid development in the economic construction. Thus an issue on how to plan，regulate and develop the area more reasonably has been put forward. This article，with the hydrological data and result obtained in recent years，briefly probes and analysis the stream formation of the area and its characteristics of stream motion changes so as to provide some references for the comprehensive planning and exploitation of it.

2. GEOGRAPHICAL SURVEY OF THE AREA

The water area surrounding Macao lies between from 22°05′ to 22°15′ north latitude and from 113°15′ to 113°37′ east longitude at the west side of the outer fringe of the Pearl River delta，between the Pearl Rivers mouth bend and the Modaomen Rivers mouth bend，with the east side of the mouth of the Pearl River facing Hongkong. Wanzai，Macao，Taipa Island，Coloane Island and Hengqin Island form a cross pattern alternating with water and land. The Hongwan Waterway，the Wanzai Waterway and the Shizimen Waterway run vertically and horizontally to different directions(See Fig. 1). Situated at the mouth of the Peral River，influenced by the tides from the South China Sea and the runoff from both the

Peral River and the Modaomen Waterway， in addition to the convergence of several waterway，the stream motion of the area become more complicated.

With a subtropical maritime climate， mild and rainy， this area is often hit by typhoons. It has plenty of rain and the rainfall density is large with an average annual rainfall of 1989mm in Zhuhai，2016.1mm in Macao and the rainfall mostly concentrates during the period from June to August.

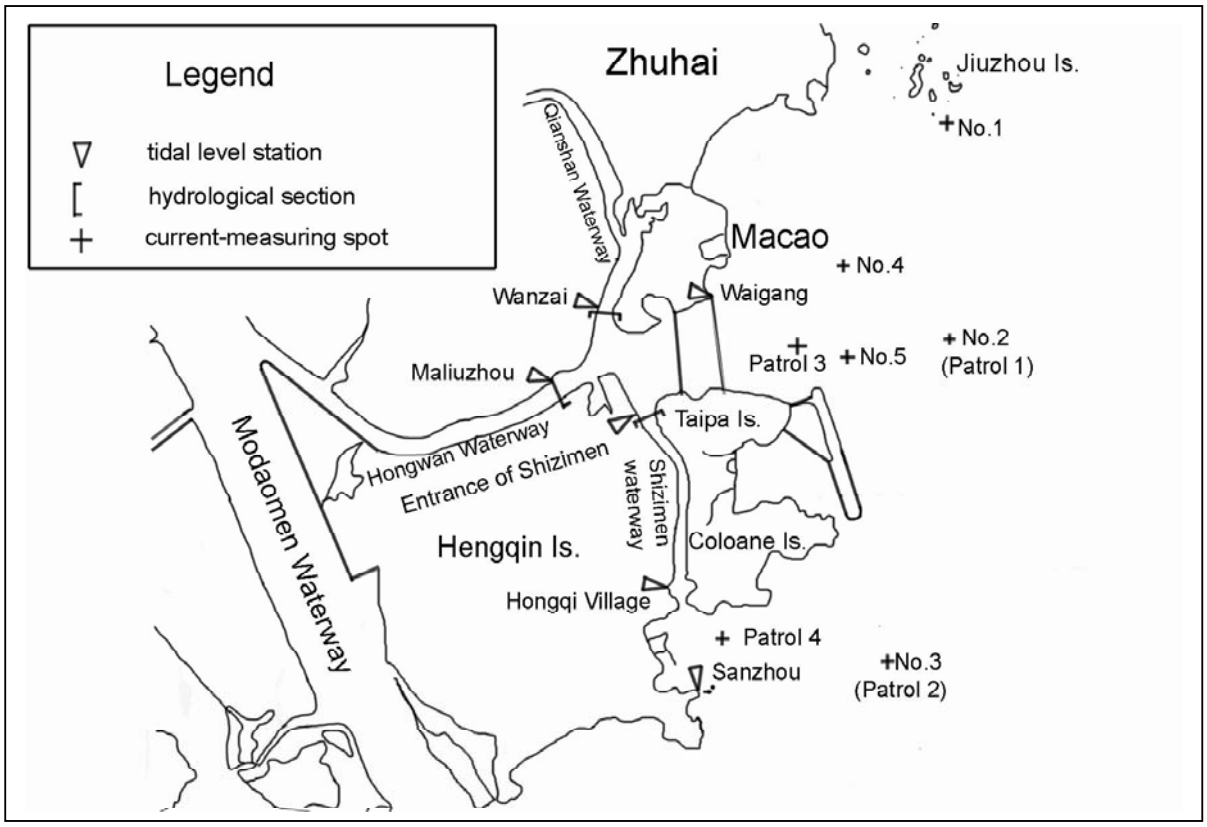

Fig. 1 The brief map of the water area surrounding Macao

3. TYPES OF THE TIDES AND THE CHARACTERISTICS OF THEIR CHANGES

The tides of the area mainly come from the Pacific tide waves via the South China Sea. Both restricted by astronomical phenomena and influenced by such elements as runoff of the upper reach and the terrain，the tide waves here become deformed and the phenomena of tide with diurnal inequalities. It is analyzed that the tides in this area belong to the type of irregular semidiurnal tides.

According to the analysis of the hydrological data，whether in drought period or in flood period，the tendency of the changes of the high and low tidal level positions all decrease progressively from north to south and from west to east，i. e. the high and low tidal level of north-south direction decrease progressively to the entrance of Shizimen，Hongqi Village and Sanzhou from Wanzai while the east-west direction decrease progressively to Waigang from Maliuzhou. The changes of the tidal range is not evident in drought period，but opposite to the change tendencies of the high and low tidal level positions in flood period. The largest tidal range emerges in Waigang while the smallest tidal range in Maliuzhou. Usually，the highest tidal level emerge in Maliuzhou and the lowest tidal level in Waigang.

Whether high or low tidal level，the range of tidal level at east-west direction from Maliuzhou to Waigang is larger than that from Wanzai to Sanzhou. This phenomenon is more evident in flood period than in drought period，more evident in high tidal level than in low tidal level. For instance，in flood period，the average high tidal range from Maliuzhou to Waigang is 0.07m，the average low tidal range is 0.21m；while in drought period，the average high tidal range is 0.07m，the average low tidal range is only 0.12m. However，as for the tidal range south to north from Wanzai to Sanzhou in flood period，the average high tidal range is 0.07m，the average low tidal range is 0.09m，but in drought period the average high tidal range is only 0.03m and the average low tidal range is only 0.04m.

4. ANALYSIS OF RUNOFF AND TIDE CURRENT EFFECT

4.1 ANALYSIS OF RUNOFF SOURCE FORMATION

The runoff of the area mainly comes from the transit runoff of the upper reach while the local runoff is tiny. The main source can be divided into two parts：one is the runoff rushing down to the Hongwan Waterway from the Modaomen Waterway，which takes up about 85% of the total runoff and the other comes from Qianshan Waterway including the runoff of the Modaomen Waterway entering via some tributaries and parts of the mountain runoff from Zhongshan and zhuhai，which takes up about 15% of the total runoff. Besides，the runoff from the Lingding Sea also，in a certain sense，influences the stream motion on the east of the mouth of the Hongwan Waterway.

4.2 ANALYSIS OF THE STRONG-WEAK TIDE CURRENT EFFECT

The area is one outlet of Modaomen Waterway to sea，and it is an interacting area of runoff and tide current. Restricted and influenced by the terrain，runoff and tidal flow power，the tidal flow force of the south-north Shizimen Waterway is evidently stronger than that of the east-west Hongwan Waterway. It is analyzed according to the main parameter of the proportion of discharge to flood tide to measure the strength or weakness of the runoff and tidal current：in drought period，the proportion of Maliuzhou and Waigang in the Hongwan Waterway are 0.48 and 0.63 respectively while that at the entrance of Shizimen Waterway is only 0.16；in flood period，the proportion in the Hongwan Waterway is 100 times larger than that in the Shizimen Waterway. This shows that the tidal current force in the Shizimen Waterway is evidently stronger than that in the Hongwan Waterway.

5. CHARACTERISTICS OF THE STREAM MOTION

In both the Hongwan and the Shizimen Waterway，the stream basically flows reciprocally in the direction along the coastline；at No.4 and No.5 Current-Measuring spots at the mouth of the Hongwan Waterway，the stream flows in the direction of northwest；at No.2 Curren-easuring Spot，the flood-tide flows upward toward north by west while the ebb-tide flows downward towards south；at No.1 Spot near the Jiuzhou Island，whether in flood or drought period，stream basically flows in the direction from south to north；whereas at No.3 Spot in the mouth of Shizimen Waterway，the flood-tide flows upward towards north by east，and the ebb-tide flows downward towards south by west(See Fig. 2).

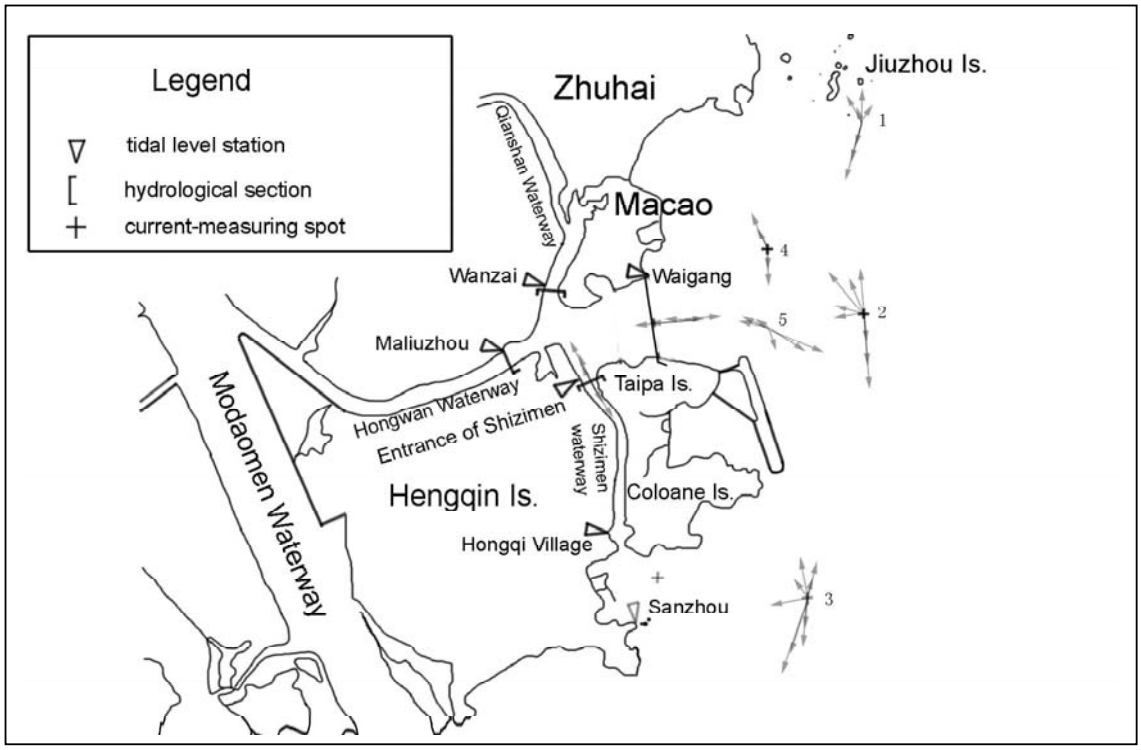

Fig. 2 Vectors of stream motion in the water area surrounding Macao

On the whole，the stream motion in this area have the following characteristics：

The flow of the ebb-tide：After the upper reach runoff enters this area from the Hongwan Waterway and Qianshan Waterway，the major part of it sluices through Waigang Section of the mouth of the Hongwan Waterway，which takes up about more than 92% of the fluicing，and the minor part of it sluices southward through the Shizimen Waterway，which takes up about 8% of the sluicing.

The flow of the flood-tide：After the Pacific tide waves enters this area through the South China Sea，part of it flows upward towards through the Shizimen Waterway and the rest flows northward from the east of the Macao Airport and then flows upward towards west via the mouth of the Hongwan Waterway.

As the tidal current force in the Shizimen Waterway is stronger than that of the east-west Hongwan Waterway，i. e. the runoff effect in the Hongwan Waterway is stronger than that in the Shizimen Waterway. When the tidal current upward along the Shizimen Waterway arrives the entrance section of Shizimen，the tidal current upward along the Hongwan Waterway is still on its way toward Waigang Section. Generally，the latter is about 30 minutes slower than the former in drought period and over an hour in flood period，Influenced by the interaction of the tidalcurrent and the flood，under certain circumstances of flow power，when the tidal current upward along the Shizimen Waterway arrives the entrance section of Shizimen，Maliuzhou in the Hoangwan Waterway，Waignag at the mouth of the Hongwan Waterway and No.5 and No.2 current-Measuring Spots are still under the condition of ebbing tidal current so as to make the tidal current entering from the Shizimen Waterway flow upward again along the mouth of the Hongwan Waterway and form the unique stream motion characteristics of this water area. The duration of the special stream motion depends on the runoff and tidal current effect，the longest time can reach as long as 2 hours. (See Table 1 and Fig. 3).

Table 1 Characteristics of the area surrounding Macao

Measuring Time：Sep．3．1997 Current Velocity：m/s， Direction：Degree

velocity/ direction time	spot positon	Maliuzhou	Wanzai	Entrance of Shizimen	Waigang V2	No.5	No.2	No.3
4:00	0.8	0.57/64	0.010/244	0.17/339	0.36/95	0.13/155	0.15/164	0.18/210
	0.6	0.63/64	0.030/231	0.030/330	0.57/85	0.19/164	0.24/159	0.42/210
	0.2	0.71/64	0.050/171	0.10/334	0.74/85	0.29/116	0.60/171	0.73/200
5:00	0.8	0.50/64	0.020/256	0.25/328	0.47/90	0.030/120	0.040/144	0.19/215
	0.6	0.59/64	0.020/261	0.25/338	0.63/83	0.080/200	0.12/162	0.42/205
	0.2	0.63/64	0.070/167	0.15/334	0.64/83	0.22/107	0.56/167	0.66/195

6. ANALYSIS OF THE CURRENT VELOCITY AND IT'S INFLUENCE ON SILT DEPOSIT

6.1 CHARACTERISTICS OF CHANGES OF THE CURRENT VELOCITY

The largest ebb-tide current velocity in this area appears at the Maliuzhou section in the Hongwan Waterway and the largest flood-tide current velocity of it in the section of Hongqi Village and the entrance of Shizimen in the Shizimen Waterway．As far as the average current velocity in tide periods is concerned (See Table 2)，in the east-west Hongwan Waterway，the changes of the current velocity assume the shape of a saddle，with two sides (Maliuzhou and No.2 Current-Measuring Spot) being high and the middle part (the old Aodang Bridge，Waigang and No.5 Current-Measuring Spot) low．On the contrary，in the south-north Shizimen Waterway，the middle part (the entrance of Shizimen and Hongqi Village) is high and the two ends (Wanzai and No.4 current-Measuring Spot) are low．However，in another south-nouth direction with No.1，No.2 and No.3 Current-Measuring Spots along it，the changes of the current velocity on different spots are very slight．

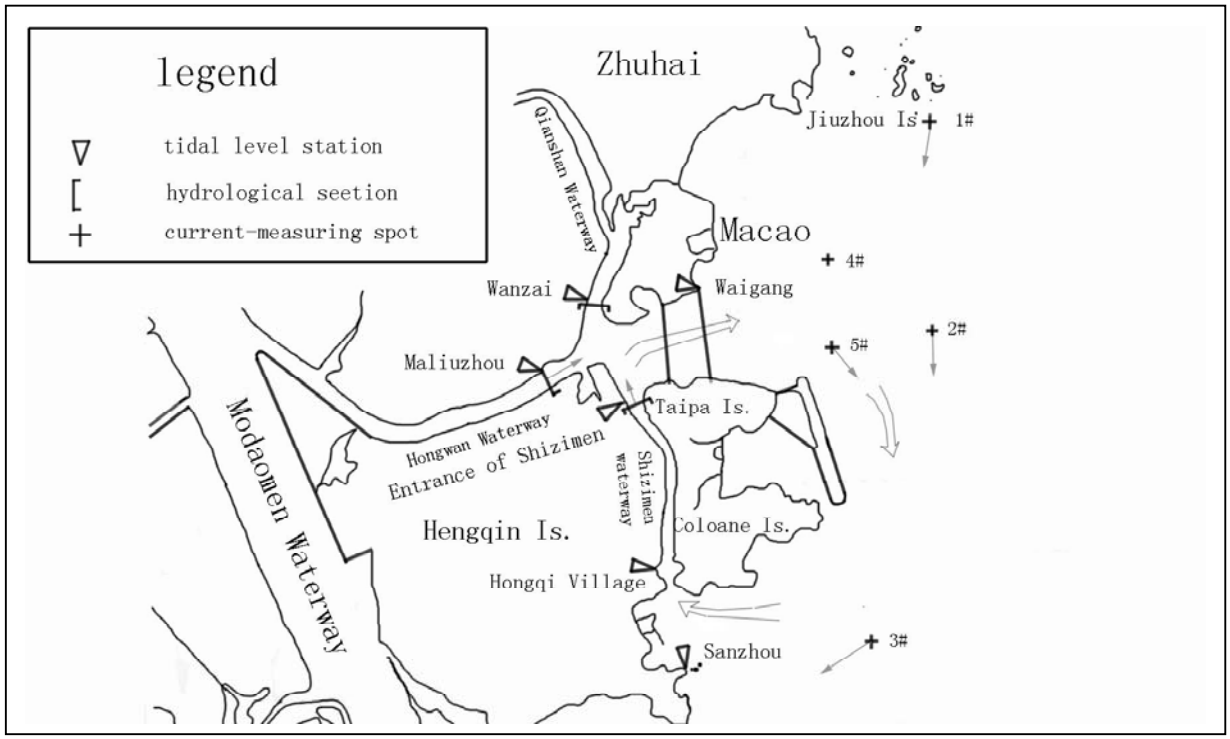

Fig. 3 Characteristics of stream flow in the area surrouding Macao

Table 2 Average current velocity during the tide periods at all measuring spots(m/s)

Measuring spot / Date	Tide	Maliuzhou	Old Aodand Bridge	Waigang	Patrol 3	Patrol 1	No.4	No.5
1994-07-24	Flood	0	0.037		0.19	0.24		
	Ebb	0.76	0.40		0.34	0.35		
1997-09-03	Flood	0.26		0.13			0.18	0.12
	Ebb	0.46		0.20			0.20	0.37

Measuring spot / Date	Tide	Wanzai	Entrance of Shizimen	Hongqi Village	Patrol 4	No.1	No.2	No.3
1994-07-24	Flood	0.086	0.12	0.34	0.11			
	Ebb	0.14	0.23	0.28	0.11			
1997-09-03	Flood	0.091	0.24			0.27	0.29	0.15
	Ebb	0.11	0.26			0.31	0.35	0.42

6.2 ANALYSIS OF THE SILT DEPOSIT EFFECT

From the changes of the current velocity in Table 2，it can be seen that，because of the rapid increase of passing waters section，the flowing water slows down suddenly in the area from the junction of the Hongwan Waterway and the Shizimen Waterway to the old Aodang Bridge， Waigang and No.5 Current-Measuring Spot，and in the area from the mouth of the Shizimen Waterway to No.3 Current-Measuring Spot，so that its capacity of carrying silt decreases and the silt is liable to deposit．What's more，the suspending silt becomes flocculent when the water is in certain salty degrees so as to speed up its subsidence．When the water contains 3‰ of salt in it，the subsiding speed of suspendind silt begins to increase，and the subsiding speed of silt becomes the largest in both 4−6‰ and 14−20 ‰.Since the amounts of salt contained in the above two areas are both within this range (See Table 3)， under the joint effect of slowing down of water flow and floccule，silt subsidence is promoted to form a silt depositing area and the development of blocking silt is accelerated．

Table 3 Changing scope of salt-containing degrees in different measuring spots(‰)

Date	Entrance of Shizimen	waigang	No.4	No.5	No.2	No.3
Mar. 1997	1.1−8.1	1.0−6.4			6.1−9.8	5.1−10.3
Aug. 1997	0.1−6.5	0.1−5.3	2.8−6.7	1.2−7.5	2.7−7.6	3.0−9.2

7. CONCLUSIONS

The water area surrouding Macao in the Pearl River delta is a area influenced by runoff and tidal current. The tide belongs to the type of irregular semidiural tide．The tide range along the east west Hongwan Waterway is larger than that in the south north Shizimen Waterway.

The runoff mainly comes from the Modaomen outlet via the Hongwan Waterway and the flood rushes down mainly through the mouth of the Hongwan Waterway．The tidal current in the Shizimen Waterway is far stronger than that in the Hongwan Waterway．Influenced by the interaction of the tidal current and the flood，under certain circumstances of water flow power，when the tidal current upward along the Shizimen Waterway arrives the entrance section of Shizimen，it sluices along the mouth of the Hongwan Waterway so that the unique characteristics of the stream motion in this area forms.

The changes of the current velocity from Maliuzhou to No.2 Current-Measuring Spot along the Hongwan Waterway assume the shape of a saddle with both sides higher than the middle part. On the contrary, the changes of the current velocity from Wanzai to Hongqi Village and No.4 Current-Measuring Spot assume the shape of a peak with the middle part higher than both ends.

Because the current velocity of the tide slows down and becomes flocculent when meeting salty water in the area from the old Aodang Bridge to Waigang, No.4 and No.5 Current-Measuring Spots as well as in the area of the mouth of the Shizimen Waterway, the suspended silt speeds up its deposition and forms a silt depositing area.