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INFLUENCE OF COASTAL RECLAMATION IN ZHANGZHOU PORT ON COASTAL EVOLUTION OF NEIGHBORING SEA AREA

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Abstract: Based on the accretion of sediment in harbor areas because of coastal reclamation nearby, the paper analyzes the landform, hydrodynamic factors, sediment and coastal evolution. According to topographic varieties before and after construction, the amount of the coastal backfill and the sediment transport data of the Jiulongjiang River are studied, and the influence on coastal evolution and siltation in the harbor are analyzed. The research shows after the coastal reclamation, the sediment deposition in the nearby harbor is due to natural silt deposition, beach accretion and muddy current caused by coastal backfill. When the coastal reclamation is finished, the new coast will reach a new balance gradually, and the deposition in the dock will also return to the natural level gradually.

Key words: Coastal reclamation, Coastal evolution, Deposition

1. INTRODUCTION

It is a rigorous problem facing mankind that land resources run short. It is estimated that in 21 century the population of our country will increase 2−3 hundred millions, but the total amount of farmland will reduce 1,800 km^2, by that time our country will be in need of 4−5 hundred million population’s existing space. Lots of maritime country and region regard coastal reclamation as an important path of solving land resources lack. Coastal reclamation also is a valid path to increase the resources of shore line and harbor tract. But after the engineering of coast reclamation is constructed, the circumjacent landform and condition of fluid and sediment will be changed accordingly, and the sum of silt deposit of neighboring sea area will increase unconventionally. For instance, half-year coastal reclamation of Ma Bay Port increases deposit intensity of nearby sea route of Chi Bay Port 0.4m in 1985; In 1989 the engineering of blowing sand of three months also made the deposition intensity of channel to increase 0.6 m. The study on influence of coastal reclamation on siltation in nearby harbors and distinguish the natural siltation from siltation caused by coastal innings is the important aspect of sediment deposition research under human effect.

Zhangzhou port is located at the combinative place of the entrance of Jiulongjiang River and the entrance of west seaport of Xiamen. The 35,000-tone wharf (3# berth) in the Zhangzhou port was finished in 1994. The engineering of coastal backfill in the manner of parallel forward was constructed near 3# berth after 1995. It is detected that the deposition intensity of 3# berth is bigger greatly than calculation. The deposition intensity reaches 2−3m/a, the max intensity is about 4m/a. the sediment deposition of Haida dock near 3# berth also unusually enlarge. With the analyses of sediment deposition in harbor area, the paper studies the influence of coastal reclamation on nearby harbor.

Fig. 1 Xiamen Sea Area Situation Diagram

2. THE NATURAL SITUATION OF ZHANGZHOU PORT SEA AREA

2.1 HYDRAULIC CONDITION

Based on survey data of this area, the mean difference of tidal level is 3.99m, the average current velocity of perpendicular line of spring tide and ebb tide are 0.55-0.66m/s and 0.6-1.3m/s respectively. The dominating wave influencing Zhangzhou port is ESE-SE direction ground swell diffusing from outside sea and WNW-E direction short wind district The calculating data of wave factor depended on survey wind data of Xiamen ocean observation station shows that the wave intension of this area is small.

Table 1 Wave Data of Project Area

	$H_{1/10} \leqslant 0.35$m	$0.35 < H_{1/10} < 1.0$m	$H_{1/10} \geqslant 1.0$m
f (%)	96.9	1.97	0.1
$\overline{H}_{1/10}$	0.3	0.6	1.0
$\overline{T}$	1.96	3.6	7.8

2.2 SEDIMENT CHARACTERISTIC

The main sediment resource of this sea area comes from Jiulongjiang River. According to datum of the sum of sediment transportation of Jiulongjiang River from 1980 to 1997, the average sum of sediment transport per-year is about 3.27×10^6t. In addition, because the coast and beach of Jiyu Island is eroded, the erosive sediment also influences this area.

The capacity of suspending sediment of the area varieties from 0.01 to 0.184 kg/m^3 considering survey datum. the capacity of ebb tide is larger than that of flood tide, and the capacity of spring tide is larger than that of neap. The direction of net sediment transportation is towards outside sea.

It is worthy of remark, that the capacity of suspending sediment is not only related to water depth, current dynamic, sediment characteristic, but also related to wave dynamic. The survey capacity of suspending sediment under ordinary condition only stands for the weather of no wind or small wind. Under the condition of storm, the capacity of suspending sediment will increase. The average survey capacity of suspending sediment of this area is 0.08 kg/m^3. This capacity stands for normal weather. If the affect of storm is considered, the average capacity under interaction of current and wave can be calculated as following. (Table 2)

Table 2 Calculation on the capacity of suspending sediment (kg/m^3)

$H_{1/10}$≤0.35m		0.35<$H_{1/10}$<1.0m		$H_{1/10}$≥1.0m		Average capacity of suspending sediment per-year
capacity of suspending sediment	frequency	capacity of suspending sediment	frequency	capacity of suspending sediment	frequency	
0.084	96.9	0.084	1.97	0.09	0.1	0.084

According to the result of calculation, the average capacity of suspending sediment pre-year of Zhangzhou port is 0.084kg/m^3, therefore because of deep water depth and small wave, the wave's affect on capacity is limit.

3. THE EVOLUTION OF BEACH AND COAST NEAR PORT AREA UNDER NATRUAL SITUATION

The entrance of Jiulongjiang River is a gulf of a drowned vale. The entrance is small, but the inside is big. The topography of this area is very complex, and the variation of landform in different district is also difference. Because the mainstream of spring tide and ebb tide of Jiulongjiang River leans to the north, the beach in the north part of the entrance is stability, but the beach in the south is deposited tiny. Despite the decrease of acreage of accepting tide in upside of this area, the average deposition range is less than 1.0m in this half century.

According to the contrast among four relief maps of different period of 1904, 1938, 1976 and 1993, the beach and coast near engineering area is in the dynamic balance in more than 70 years from 1904 to 1976, and the area near Yuzaiwei is eroded. Since 1976, the 5m-isobath and 10m-isobath of the engineering area have turned towards outside sea. It shows that the beach is deposited during this period.

Based on the analysis of geography diagrams of 1989 and 1993, during the period from 1989 to 1993, the beach shallower than 10m-isobath is in dynamic balance, and is even eroded. Especially the beach apart from the coast no more than 400m is eroded, and the erosion intensity is about 0.3m/a. The beach apart from the coast more than 400m is in equilibrium, some local area is even deposited.

In despite of slightly deposition of this area since 1970's, the beach is equilibrium relatively since, the sea area shallower 10m-isobath is not deposited, and the area alongshore is even eroded.

4. THE VARIATION OF BEACH AND COAST AFTER COAST BACKFILL

The engineering of coast backfill between the coast of Dashiken and the east of Nanpaotai has been constructed since 1993. The coast line has been pushed towards sea about 300m till July 1998 (Fig.2). The west coast line of the Haida dock is pushed forward 550m. The coast line between Haida dock to 35,000-tone wharf (3# berth) is pushed forward 100−500m. The coast line of 3# berth is pushed forward 200m or so.

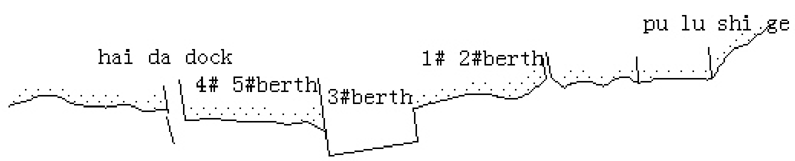

Fig. 2 Position of Berths of Project Area

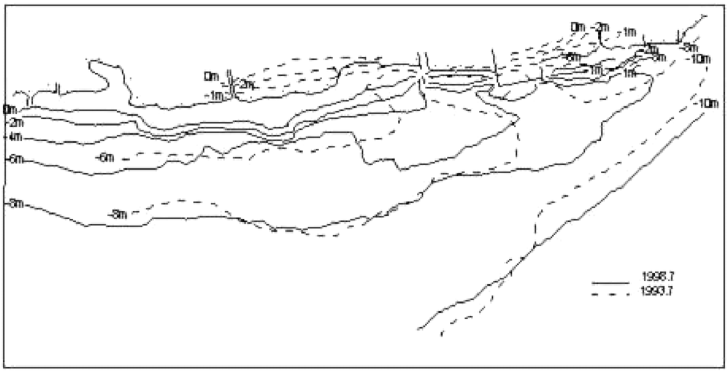

Fig. 3 Contour Line Variety of Project Area

According to the Comparison between underwater-relief map of research area between Dashiken and Nanpaotai of July 1993 and July 1998, in the west of Haida dock (Fig.3), 0m-isobath, 2m-isobath, 4m-isobath are all pushed outside parallelly. The pushed outside distance is about 275m in 5 years, and the average pushed outside rate is 55m per-year. The max pushed outside distance is 360m, and the pushed outside speed is 72m/a. But 6m-isobath and 8m-isobath move little in this 5 years. The contrast shows that the beach shallower than 6m water depth is in the process of deposition, and the beach near the coast is driven up generally. The coast for 1# berth to 5# berth is located in the east of Haida dock. In this area, 0m-isobath, 2m-isobath and 4m-isobath are also pushed outside parallelly, and the average pushed outside distance is 150−200m. 6m-isobath, 8m-isobath are also pushed towards outside sea. 10m-isobath keeps stability. The result shows that the beach shallower than 10m water depth is all deposited in the east of Haida dock after coast backfill. The isobathes of 0m, 2m and 6m are pushed outside parallelly, but the distance of pushed is shorter than in the west of Haida dock. The area, of which the water depth is between 6m and 10m, is deposited generally, because the lower topography is propitious to the sediment filled up. The beach deeper than 10m keeps stability, and is influenced by coast backfill little.

Based on the landform variety of project area during the period from 1993 to 1998 (Fig.4), the beach which is apart from the coast within 1000m is filled up after coastal reclamation. The seabed outside the deposition area is still in dynamic balance. In deposition area, the deposition intensity of the beach apart from the coast within 400m is less than 1m. The distance of 1m-deposition-line to the bank is 300m in the west of Haida dock, in the east the distance is about 600m. The average distance of 2m-deposition-line to the bank is 200m. The average distance of 2m-deposition-line is 125m. Influenced by coast backfill, the seriously deposition area is within 200m apart from the bank, especially within 125m.

5. ANALYZE ON BEACH DEPOSITION

5.1 THE RELATIONSHIP BETWEEN BEACH DEPOSITION AND COASTAL RECLAMATION

It is calculated that the sum deposition of this area during the period from 1993 to 1998 is 6.521×10^{6} m^3. The sum deposition between Dashiken dock and Haida dock is 4.326×10^{6} m^3, the average deposition thickness is 1.53m. The sum deposition between Haida dock and 3,500-tone wharf is about $6.08\times10^{5}m^3$, the average deposition thickness is 1.84m. The sum deposition between 3,500-tone wharf and Gangjichang dock is 1.587×10^{6} m^3, the average deposition thickness is 1.35m.

Based on the contrast of underwater geography data of 1989 and 1993, the beach keeps stability, even eroded under natural situation. The beach near bank is filled up markedly since

1993. It is obviously connected with coast backfill. The special landform of 0m-isobath, 2m-isobath, 4m-isobath and 6m-isobath caused by coast backfill proves the direct relation between beach deposition and coast backfill further.

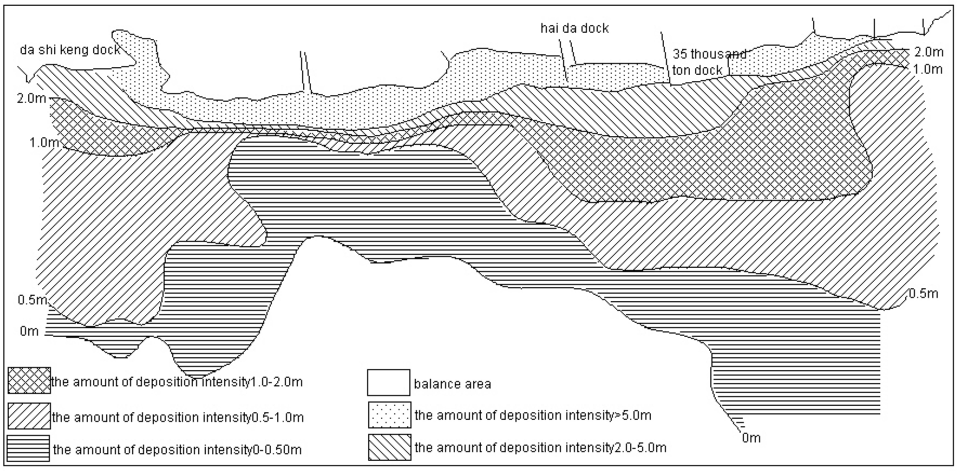

Fig. 4 Current Situation of Landform Variety of Project area

The coast of this area is backfilled in succession since 1993. The basic style of backfill construction is pushing parallelly, and a few engineering has local cofferdam. During the process of engineering, muddy flow of high suspending sediment runs everywhere, and sediment is filled up near the bank. The relation between beach deposition and the sum of coast backfill is in Table 3 and Fig.5.

Table 3 Amount of Silt Deposit and Relevant Amount of Coast Backfill

	Dashiken dock–Haida dock	Haida dock–3500-tone wharf	3500-tone wharf–Gangjichang dock
Sum of deposition(10 ^{4}m^3)	432.6	60.8	158.7
Sum of coast backfill(10 ^{4}m^3)	980	76	342
deposition/backfill	0.44	0.8	0.46
Deposition intension(m)	1.53	1.84	1.35

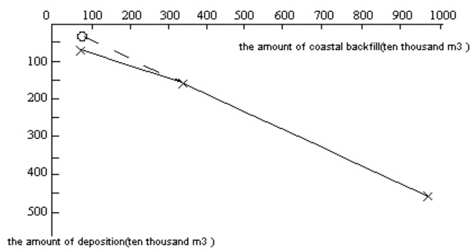

Fig. 5 The relation between amount of deposit and amount of coast backfill

From table3, there is a direct relation between the amount of deposition and that of coast backfill of corresponding bank from 1993to 1998. The ratio of deposition/backfill both in the bank between Dashiken dock and Haida dock and between 3500-tone wharf and Gangjichang dock is 0.45 or so. The result expresses that there is corresponding relation in quantum between deposition and backfill of corresponding coast, further more the deposition intension of these two sections is also same. The rate of deposition/backfill in the bank between Haida dock and 3500-tone wharf is about 0.8, and is more than the bank of both sides 0.44 and 0.46. Also the deposition intension is lager than both sides. There are several reasons about these phenomena: first, the landform of this area is lower than both sides, so the landform is favorite for sediment filled up during the process of coastal reclamation; second, 3500-tone wharf is in the east of this area, and Haida dock is in the west. The both sides extrude towards outside sea, so this area forms harbor shape with two sides standing out, and forms the slow current section. The slow current cause sediment to fill up here; third, the beach deposition is not only effected by coast backfill of this area, but also effected by coast backfill of both sides. Referring to the deposition of both east and west sides, the deposition caused by coast backfill is 45% of whole amount of backfill. So the deposition of this kind is 3.4×10^5 m^3, and the rest deposition 2.68×10^5 m^3 is caused by other factors.

5.2 INFLUENCE OF SEDIMENT TRANSPORT OF JIULONGJIANG RIVER

This area is the entrance of Jiulongjiang River. The sediment transport of Jiulongjiang is the main sediment resource of this area under natural situation. Based on sediment transport data of Jiulongjiang during the period from 1952 to 1997(Table 4), because of the erosion of land, the capacity of suspending sediment and amount of transport increase from 1960's to 1980's, but after 1980's, the amount of sediment transport keeps on 3.3×10^6t or so.

Table 4 Sediment Transport Data of Jiulongjiang River

	1952−1958	1959−1968	1970−1979	1980−1988	1989−1992	1993−1997
Amount of sediment transport per-year (10^4t)	121.3	294.23	286.8	315.26	348.25	331.8

Based on above analyses, the beach keeps stability, even eroded in 1989−1993, at the same time the general amount of sediment transport is 1.668×10^7t, so the sediment transport doesn't influence the variation of landform directly. In 1993−1998, the beach near the coast is deposited generally, and the whole amount of deposition is 6.74×10^6 m^3, but at the same time, the general amount of sediment transport is 1.659×10^7t, which is just equal to the amount of 1989−1993. It shows that the sediment transport from Jiulongjiang is not the reason of beach deposition.

5.3 MAIN REASON FOR BEACH DEPOSITION AT PRESENT

Before 1993, the beach near the coast keeps stability, and after 1993, the beach is deposited seriously. But during these two period times, the sediment transport of Jiulongjiang doesn't change in evidence. The fact indicates that the beach deposition is mainly caused by coast backfill, and sediment pile and fill up of backfill is the fundamental reason of landform variation. The rate of general amount of sediment deposition/amount of coast backfill is about 45%. The serious deposition section is the beach apart to the coast within 200m. It can be forecasted that when the engineering of coastal reclamation finish, the new stability beach slope will come into being after prophasic beach deposition. The muddy flow of high suspending sediment will scatter and disappear. Though the deposition of beach will continue, the intension will wear off. After a period of adjustment, the beach will reach a new dynamic balance.

6. ANALYSES ON EXCEPTIONAL DEPOSITION OF 3# BERTH AND HAIDA DOCK

6.1 ANALYSES ON DEPOSITION OF 3# BERTH

The 3# berth is located in the east of Yuzaiwei, and is a 3500-tone berth constructed apart from former coast 300m. According to the survey data of water depth in front of the wharf, the mean deposition intension in front of wharf is 3.2m from 1997 to 1998.

If the affections of beach driven up caused by coast backfill and muddy flow of high suspending sediment on the deposition of 3# berth are not considered, the natural deposition of 3# berth caused by dug can be calculated as following:

$$P = \frac{K_1 s \omega t}{\gamma_0}\left[1 - (\frac{d_1}{d_2})^3\right] \tag{1}$$

In which: K=0.35; ω is sedimentation flocculation velocity; s is the mean capacity of suspending sediment; γ_0 is dry density of sediment, $\gamma_0 = 1750 D_{50}^{0.183}$; d_1 is average water depth near the berth; d_2 is water depth after dug.

Using formula (1), the deposition intension of 3500-tone berth is 0.42m/a caused by dug in front of the berth. The survey data shows that the deposition intension of same area is about 3.2m/a. The deposition depth of this area caused by coast backfill is 1.55m in 5 years, and the mean deposition intension is 0.31m. Besides the muddy flow of high suspending sediment also increase the sediment deposition. The deposition intension 3.2m/a is composed by three parts: natural silt deposition, beach accretion and muddy current caused by coastal backfill. Among them, the natural deposition is 0.42m/a, the depth caused by beach accretion is 0.31m/a, so the deposition caused by muddy current is 2.47m/a. Calculated using formula (1), the capacity of suspending sediment is 0.5kg / m^3 . If the natural capacity of sediment 0.084kg / m^3 is considered, the whole capacity is about 0.6kg / m^3.

6.2 ANALYSES ON DEPOSITION OF HAIDA DOCK

Based on the analyses of geographic data, the deposition intension is 1.8m/a or so. The natural deposition intension can be calculated in formula (2):

$$P = \frac{K_0 S \omega t}{\gamma_0}\left[1 - (\frac{d_1}{d_2})^3\right]\exp\left[\frac{1}{2}(\frac{A}{A_0})^{1/3}\right] \tag{2}$$

or:

$$P = \frac{K_0 S \omega t}{\gamma_0}\left[1 - (\frac{V_1}{V_2})^3\right]\exp\left[\frac{1}{2}(\frac{A}{A_0})^{1/3}\right] \tag{3}$$

in which: K_0=0.14~0.17; V_1、V_2 represents mean current velocity before and after dug separately; A/A_0 represents the rate of shallow area/ whole water area; the other parameters are just same as formula (1).

The result of calculation shows that the natural deposition intension of Haida dock area is about 0.26m/a. Just same as the deposition of 3500-tone berth, the sediment deposition in fact is composed of three parts: natural silt deposition, beach accretion and muddy current caused by coastal backfill. Among them, the natural deposition is 0.26m/a, the depth caused by beach accretion is 0.3m/a, so the deposition caused by muddy current is 1.24m/a. Calculated using formula (2), the capacity of suspending sediment is 0.45kg / m^3 . If the natural capacity of sediment 0.084kg / m^3 is considered, the whole capacity is about 0.55kg / m^3. The calculation data is almost equal to the capacity of 3# berth calculated above.

7. CONCULSIONS

1) Beach deposition of Zhangzhou Port is mainly caused by coast backfill, and sediment piled and filled up of backfill is the fundamental reason of beach accretion. The serious deposition section is the beach apart to the coast within 200m. The present large deposition is not caused by sediment transport of Jiulongjiang.

2) The deposition of 3500-tone berth and Haida dock is composed of three parts: natural silt deposition, beach accretion and muddy current caused by coastal backfill. According to calculation, in the area of 3# berth, the natural deposition is 0.42m/a, the depth caused by beach accretion is 0.31m/a, the deposition caused by muddy current is 2.47m/a; in the area of Haida dock, the natural deposition is 0.26m/a, the depth caused by beach accretion is 0.3m/a, the deposition caused by muddy current is 1.24m/a. Based on calculation, the capacity of suspending sediment of engineering area is 0.55−0.6kg / m^3 during construction period.

3) When the engineering of coast backfill finish, the capacity of suspending sediment of muddy current change from 0.45−0.5kg/m^3 in the period of engineering to 0 when the beach reach a new balance. The deposition intension of berth and dock also reduce gradually. When the beach adjusts to be equilibrium, the deposition intension will return to natural sediment deposition intensity.

4) When the influence of coast backfill on sediment deposition of neighboring sea area is discussed, it should be paid more attention to that the beach accretion and local capacity of suspending increase.

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