Morphological Studies on Yenliao-Fulong Beach

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Abstract

After Typhoon Nari attacked the northeastern coast of Taiwan on 6. September 2001, the sand spit where famous Fulong Sea Bath located was cut off and could not be naturally restored even after 2 years. People questioned that this situation was caused by the breakwaters of the nearby Nuclear Power Plant. In order to clarify this viewpoint, the morphology of Yenliao-Fulong beach is studied. It is found out that Yenliao-Fulong beach is a wave dominated micro-tidal beach, cross shore sediment transport dominates the nearshore process, and this feature stayed similar before and after the construction of the breakwaters. Therefore, it is concluded that most of the shoreline of Yenliao-Fulong beach is still stable. The influence of breakwaters to the beach is limited to 150~200m of range near the south breakwater. Besides, the sand spit was naturally restored since February 2006 which also support this point of view. However, attention must still be paid to the influence of typhoon event since it causes the major risk of coastal erosion.

1 Introduction

In September 2002, after the typhoon event of Sinlaku, the Yenliao-Fulong Beach was severely eroded and the sand spit of Shuangsi River mouth was cut off again. It was not a single event but happened before, like during typhoon Xangsane(2000) and Nari(2001). In fact, the sand spit cut off by the flood during Typhoon Nari could not be naturally restored even after 2 years. However, at the end of 2002, Taiwan Environmental Protection Union(abbreviated TEPU hereafter) and the local anti-nuclear power plant organization claimed that the constructing breakwaters of cooling water intake of the nearby Nuclear Power Plant was the major cause of the coastal erosion of the Yenliao-Fulong Beach nearby. They finally expressed their complain to the Prime Minister. The Prime Minister then asked the Atomic Energy Council to organize an Investigation Committee consists of many professors of coastal engineering to investigate this issue and to write down an investigation report. Several meetings and site visits were then hold and the conclusion was drawn in the investigation report. In that report, three reasons were mentioned as follows for being responsible for this issue. The probable reasons were 1.
Construction of Breakwaters for the cooling water intake of the nearby Nuclear Power Plant. 2. The Influence of Typhoon attack. 3. The decrease of sand resource of Shuangsi River. Based on this report, the Executive Yuan authorized the Public Construction Commission to supervise Taiwan Power Company to find a final solution for this issue. In 2003, after 6 meetings and several site visits with additional experts and professors, the Public Construction Commission asked Taiwan Power Company to suggest a final solution from the following 3 alternatives: 1. Beach Restoration. 2. Fully demolish of the breakwaters and construct a submerged cooling water intake instead. 3. Partly demolish of the breakwaters. The Taiwan Power Company therefore chose Sinotech Engineering Consultants Ltd. to study this issue. This paper is part of that study and focuses only on the morphological characteristics of Yenliao-Fulong Beach.

2 Background Information

2-1 Geographical Location

Yenliao-Fulong Beach is located at the northeastern coast of Taiwan. Due to its long sand spit landscape which separates the river flow and the ocean, Fulong Beach is a very famous and popular sea water bath since long time ago. Fig. 1 is a satellite image of Yenliao-Fulong Beach indicating its geographical location. The beach faces the Pacific Ocean, with the total length of about 2.5 km. The breakwaters of the cooling water intake of the nearby nuclear power plant is on the north end of the beach, and is extended from the original coastal reef. The construction of the Breakwaters started in 2000, and is completed in 2004.

2-2 Bathymetry

A further hydrographical survey was done around the end of 2003. The survey trajectory of echo sounding was around 20 m apart with less than 10 m a survey point in order to resolve the specific nearshore features. Fig. 2 shows the bathymetry of this area. The breakwaters of the nearby Nuclear Power Plant are located between two reef areas. The northern reef is partly exposed over the sea surface and the southern reef is mostly submerged. A navigation channel is between the two reefs. Near Fulong beach are several crescentic bars around -5m contour, this can be shown in the colored contours of Fig.3.
2-3 Seastate

2-3-1 Tide

One tidal station is set up in this area since 1981, it was first put in the Aodi Fishing Harbor and was moved out to the nearby abalone pond from June 2000 to Aug. 2003, and was moved into the wharf inside the breakwater of the nearby Nuclear Power Plant. The statistical tidal table from 1981 to 2002 is shown as Table 1. The mean tidal difference is smaller than 50 cm, even the mean tidal difference in spring tide is smaller than 80 cm.
Table 1 The Statistical Tidal Table of Yenliao Tidal Station (1981~2002)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HHWL</td>
<td>+2.43 m</td>
</tr>
<tr>
<td>HWOST</td>
<td>+0.36 m</td>
</tr>
<tr>
<td>MHWL</td>
<td>+0.29 m</td>
</tr>
<tr>
<td>MWL</td>
<td>-0.01 m</td>
</tr>
<tr>
<td>MLWL</td>
<td>-0.26 m</td>
</tr>
<tr>
<td>LWOST</td>
<td>-0.34 m</td>
</tr>
<tr>
<td>LLWL</td>
<td>-1.18 m</td>
</tr>
</tbody>
</table>

HHWL: High High Water Level
HWOST: High Water Outer Sea
time
MHWL: Mean High Water Level
MWL: Mean Water Level
MLWL: Mean Lower Water Level
LWOST: Low Water Outer Sea
time
LLWL: Low Low Water Level

Fig. 2 The Bethymetry of Yenliao-Fulong Beach
Because Yenliao-Fulong beach faces the open sea, the sea state is quite rough especially during winter monsoon. Besides, since typhoons appear frequently during summer and most of the typhoons originated in west Pacific and moved westward, Northeastern Taiwan is therefore becoming an area easily affected by typhoons. The winter monsoon dominated the winter climate and the waves were mostly rough unless the front weakened occasionally. The waves were normally very calm during summer unless typhoon passed by or even attacked directly. Although there is no longterm wave measurement within this site until April 2006, there is one wave buoy about 8 km away northward of Fulong sponsored by the
Central Weather Bureau. The water depth of the wave buoy is around 30 m. Table 2 shows the seasonal average significant wave height and period of year 2001~2003 for example. It is obvious that the wave condition in winter is rougher than in summer. On the other hand, the wave condition during typhoon events are even rougher than the normal winter monsoon. Significant wave height could even reach 8 m.

Table 2 Seasonal Wave Condition

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>$H_{1/3}$ (m)</th>
<th>$T_{1/3}$ (sec)</th>
<th>Effective sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Feb.-Apr.</td>
<td>1.22</td>
<td>6</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>May-July</td>
<td>0.79</td>
<td>5.67</td>
<td>87%</td>
</tr>
<tr>
<td></td>
<td>Aug.-Oct.</td>
<td>1.35</td>
<td>6.5</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Nov.-Jan.</td>
<td>1.53</td>
<td>6.17</td>
<td>63%</td>
</tr>
<tr>
<td>2002</td>
<td>Feb.-Apr.</td>
<td>1.26</td>
<td>5.9</td>
<td>78%</td>
</tr>
<tr>
<td></td>
<td>May-July</td>
<td>0.74</td>
<td>5.64</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Aug.-Oct.</td>
<td>1.04</td>
<td>6.01</td>
<td>86%</td>
</tr>
<tr>
<td></td>
<td>Nov.-Jan.</td>
<td>1.31</td>
<td>6.44</td>
<td>91%</td>
</tr>
<tr>
<td>2003</td>
<td>Feb.-Apr.</td>
<td>1.26</td>
<td>5.92</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>May-July</td>
<td>0.81</td>
<td>5.86</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Aug.-Oct.</td>
<td>1.31</td>
<td>6.44</td>
<td>91%</td>
</tr>
<tr>
<td></td>
<td>Nov.-Jan.</td>
<td>1.92</td>
<td>6.35</td>
<td>93%</td>
</tr>
</tbody>
</table>

2-3-3 Current

The current system outside surfzone is dominated by tidal current, at the location where the water depth is around 20 m, the current direction during flood is toward NW and toward SE during ebb and there is no apparent seasonal variation, the current speed of flood tide is stronger than ebb tide and it ranges 15~65 cm/s. Nearshore current is dominated by the wave induced current.

2-4 Hydrological Information

There are three creeks and one river in this area. Shi Ding Creek is just in the north of the nearby Nuclear Power Plant and the creek mouth is located directly on the north side of the breakwater. The estimated mean annual sediment transport is around 26,000 m$^3$ with around 10.5 km$^2$ of watershed area. Yenliao Creek is the smallest creek in these 4 creeks, its mouth is about 200 m away from the southern breakwater. The estimated mean annual sediment transport of Yenliao Creek is only around 8,000 m$^3$ with around 3 km$^2$ of watershed area. Shuangshi River is the major flow in this area with around 200,000 m$^3$ mean annual sediment transport rate and with around 141 km$^2$ of watershed area. The fourth creek is the Longlong creek with around 16,000 m$^3$ of mean annual sediment transport rate and with around 11 km$^2$ of watershed area. Longlong creek flows toward the river mouth of Shuangshi river and flow out together. With a total amount of more than 85% of the averaged annual sediment transport, Shuangsi River and Longlong creek should be the major sand resources of the Yenliao-Fulong beach. Fig. 4 shows the watershed of the aforementioned rivers.
3 Image Records and Field Observation

Although there are many historical aerial photos of this site taken by the Aerial Survey Office, Forestry Bureau which can give a very clear view about the site and its morphological specialities. We are here only able to use some other material with lower resolution to present the coastal feature of this coastal area. First considered is the satellite image. Although there are recently high resolution satellite images like Ikonos with 1m resolution, there are only Spot 1 or Spot 4 images with only 10 m resolution before the construction of the breakwaters. Fig. 5 and Fig. 6 are the satellite images of 1996 and 1999, which were taken before the construction of breakwaters. It can be seen from Fig. 5 that there was nearshore circulation in front of the coastline. From the satellite image of 1999, the crescentic bars can also be easily seen.

Fig. 7 and Fig. 8 are the high resolution Ikonos satellite image taken on Aug.18 and Nov.11 2002 when the breakwaters are under construction. The resolution of the two satellite images are as high as 1 m. In Fig. 7, beach cusps appear in the Yenliao beach, and the crescentic bars with circulation cells and megacusps in the southern part of beach appear clearly in Fig.8.
Besides, in order to help understanding more about the morphological characteristics of the Yenliao-Fulong Beach, more than 50 site visits especially before and after typhoon events were arranged, and series of photos were taken at about the same standing point from the many site visits which might also give some important hints. Two series of photos are arranged from July 2005 to July 2006, experienced 5 typhoon attacks and winter monsoon period. Fig. 9 is the first series taken on the sand dune near the huge rock which is about 800 m away from the breakwater and shows the change of the north part of the Fulong Beach. Several rocks on the beach can indicate the height of the beach. Fig. 10 is the second series taken in front of a small temple near the breakwater and shows the change of Yenliao Beach. The big rock at the end of Yenliao Beach can be a reference for comparison. The beach was not continuously eroded, but could be recovered naturally. The typhoon event caused an immediate erosion and shoreline retreat.
Fig. 6 Spot 4 Image of Yenliao-Fulong Beach (1999)
Fig. 7 Ikonos Satellite Image with beach cusps appeared in Yenliao (Aug. 18 2002)
Fig. 8 The Ikonos Satellite Image of Yenliao-Fulong Beach (Nov. 11 2002)
4 Morphological Features

From the various image information and the site investigations, the rhythmic shoreline forms like beach cusps, megacusps, crescentic bars and circulation cells appeared frequently in the Yenliao-Fulong Beach which indicating a near-zero longshore sediment transport feature, in other words, cross-shore sediment transport dominated feature(Komar, 1998). That is because the waves approaching this area are mostly normal to shore due to wave refraction, the longshore current induced by oblique incident waves is not big. Even during winter monsoon when the northeastern monsoon wind prevails, the wave direction approaching the beach is also nearly shore-normal. Besides, since the tidal range is smaller than 2 m, therefore, the Yenliao-Fulong Beach is a wave dominated micro-tidal beach according to Short(1999). The beach type changes with the wave power level.
The most severe impact to the beach is then the typhoon events. Combining with storm surge and wave setup, the huge waves ride on the elevated water level can erode the dune face easily and cause severe retreat of beach. This kind of erosion was also described by Nishi et al. (1994). Typhoon Tokage was a typhoon even did not attack Taiwan, it passed by the northeastern offshore of Taiwan with its center about 400 km away from Taiwan. However, the waves sent to northeastern coast of Taiwan could reach 5.5 m of significant wave height with 9.2 sec of wave period. After this typhoon event, beach scarps appeared at the dune foot with about 1.5m height for about 200 m in length was experienced in Oct. 2004. Fig. 11 shows the beach scarp observed just after the typhoon event. Beach scarp with height smaller than 1 m often happened near foreshore during winter monsoon.

On the other hand, fortunately due to the cross-shore sediment transport dominated feature of Yenliao-Fulong Beach, the eroded sediment is brought not quite far offshore and becoming deposited sand bar which can dissipate wave energy and reduce the impact of typhoon. Besides, if it rains hard in the Shuangsi watershed during typhoon, the flood of Shuangsi River might cut off the sand spit on the river mouth. For example, Typhoon Nockten landed near Fulong on Oct. 25 2004 around midnight caused a severe flood event in Shuangsi River, the road direct on the north side of river near the river mouth with elevation around +3 m was even flooded by the river flow. The sand spit on the river mouth was cut off again,
but the sand spit recovered gradually and the rainbow shaped bridge connected to the sand spit since February 2006 again (see Fig.12). Fig. 13 shows the pictures of river mouth taken on 21. Oct., 27. Oct., 10. Dec. 2004 and 16. May 2005 respectively. In comparison with Fig.13, the similar event happened before during Typhoon Nari is shown in Fig.14.

Fig. 13 The Photo series of Fulong Sand Spit after Typhoon Nockten

Fig. 14 The Photo series of Fulong Sand Spit after Typhoon Nari

Sources: Northeast Coast National Scenic Area Administration
5 Numerical Simulation

From the various information sources including satellite images, aerial photos and the photos taken in the site visits, it is not obvious that the breakwaters have a strong influence on the Yenliao-Fulong Beach. The coastlines and the morphological patterns stay similar before and after the construction of breakwaters of the nearby Nuclear Power Plant. It might because that the cross-shore instead longshore sediment transport dominates the coastal sediment transport process here due to almost shore-normal incident nearshore waves. Only during winter monsoon, the northeastern wind will cause weak but persistent longshore sediment transport toward the sand spit located at the river mouth. That is also the reason why the sand spit on the Shuangsi river mouth so formed. However, although Yenliao-Fulong Beach seemed stable from the past history even after the completion of breakwaters, it is still not quite sure what may happen in the future. Other tools should be taken into account for evaluating the probable influence of breakwaters on the Yenliao-Fulong beach in the future.

Fig. 15 The simulated crest line of wave propagation
Because of the increased ability of computer hardware, numerical simulation becomes to be a very useful tool for studying the coastal processes. The numerical model of Mike 21 developed by DHI (Danish Hydraulic Institute) was used to model the nearshore circulation system of Yenliao-Fulong Beach before and after the construction of breakwaters. The modules considered in the simulation including the PMS (Parabolic Mild Slope) Module for wave propagation, the HD (Hydrodynamic) Module for current simulation based on the Shallow Water Equation and the ST (Sediment Transport) module for coastal sediment transport.

First of all, wave propagation was numerically simulated with different offshore wave direction. The offshore wave directions chosen are ENE, NE and NNE which were the major direction during winter monsoon. Fig. 15 shows the result, the waves does show a shore-normal approaching pattern. The next is to simulate the wave induced nearshore current. Fig. 16 are the results without and with breakwaters, the offshore wave direction chosen is NNE. Both results show similar pattern. Besides, the nearshore current

![Fig. 16 The simulated nearshore currents under NNE waves](image1)

![Fig. 17 The simulated nearshore currents under ENE waves](image2)
shows a meandering current toward the river mouth, which shows a combination of weak longshore current and cell circulation (Sonu, 1972). Fig. 17 are the results with offshore wave directon ENE. It can be seen that the nearshore current shows a meandering current in the opposite direction because of the northward weak longshore current. If compared the current ve locity of the two cases in Fig. 16, the differences are not quite big especially further away from the breakwaters. The region with apparent difference is limited to a 200m region away from the southern breakwater. Similar results were also obtained by Yang and Hsu(2004). By using both of the Mike 21 model and the EEMSE model(Extended Elliptic Mild Slope Equation), they also stated in their report that the influence of the breakwaters is only limited to about 150 m south of the breakwater. But they also mentioned that it is worthwhile to pay attention to the erosion condition of the separation point found from the EEMSE result. Perhaps because that the wave direction on site was not so persistent as assumed in the model set-up, the erosion of the separation point in the Yenliao Beach was fortunately not observed within 2 years. However, it is still worthwhile to take this suggestion in mind. Countermeasures should be taken in case such situation happened.

6 Concluding Remarks

The Yenliao-Fulong Beach is a wave dominated beach due to its specific geographical condition that most incoming waves approach the beach perpendicularly through wave refraction. The most severe impact to the beach is the typhoon events. Combining with storm surge, the huge waves can erode the dune face forming beach scarps and cause severe retreat of shoreline. Besides, if it rains hard in the Shuangsi watershed during typhoon, the flood of Shuangsi River might cut off the sand spit on the river mouth.

The controversy encountered in Yenliao-Fulong Coast is not only a pure scientific issue but mixed with the antinuclear emotion. Therefore, although the shoreline position is again becoming stable this year, and the sand spit recovered again since February 2006, it is not yet admitted by all the people that the influence of the Breakwaters of the nearby Nuclear Power Plant to the beach is really limited. It is also found out that the sand spit movement of the Shuangshi river is mostly affected by the flood event which happened most of the time during or just after typhoon attack. However, attention must still be paid to the influence of typhoon event since it causes the major risk of coastal erosion.

7 Acknowledgements

This study is part of a project supported by Taiwan Power Company. Besides, some historical photos of the sand spit are supplied by Northeast Coast National Scenic Area Administration. Their assistance are gratefully acknowledged.
8 References


