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Yanliao Beach Nourishment Methods

Hsing-Yu Wang[1], Hui-Ming Fang[2] and Yun-Chih Chiang[3]

1 Ph. D. Candidates, National Taiwan Ocean University, Keelung, Taiwan
2 Assistant Professor, National Taiwan Ocean University, Keelung, Taiwan
3 Associate Professor, Tzu Chi University, Hualien, Taiwan
E-mail: hmfang@email.ntou.edu.tw

Abstract. Yanliao Beach, part of Taiwan's Northeast Coast National Scenic Area, is a major sightseeing and recreation spot. In recent years, the number of tourists has increased, and maintaining the beach's recreation function has become crucial. In 2007, Typhoon Krosa caused substantial beach erosion at Yanliao Beach; sand dunes collapsed, resulting in a beach scarp and endangering facilities toward the back of the beach. To protect the sand dunes and beach scarp of the post-typhoon topography, based on long-term Yanliao Beach topographic survey information and long-term tidal water level records, this study conducted an integrated artificial beach nourishment method that comprised replenishing the coastal beach and dunes. The planned areas for sand replenishment were those above the mean high water line. This beach nourishment measure protected the dunes from collapsing further and mitigated the risk of beach nourishment polluting the water in front of the beach. Topographic survey results revealed that the large amount of sand deposited in the intertidal zone resulted in the 0 m shoreline advancing toward the seaside. The width of the beach increased, indicating the success of this integrated beach nourishment method.

1. Introduction

Regardless of developing the area or constructing engineering projects under the purpose of coastal disaster prevention, human activities inadvertently influence coastal areas. Changes in coastline occur because of coastal area development involving various coastal constructions and are often attributable to the overdevelopment of coastal areas. Beach erosion, especially in sandy beaches or seaside resorts, has received public attention in Taiwan, notably, that of the receding shoreline in areas of the west and northeast coasts. Natural beach erosion has resulted in heated arguments. Moreover, aggravating greenhouse effects have resulted in extreme weather worldwide and in the increased frequency of abnormal climate. This has led to broad discussions as well as emphasis on coastal restoration and disaster prevention. Both artificial and natural factors contribute to sand erosion in coastal areas; one result is receding shorelines, which sometimes even involve their disappearance. Commonly adopted coastal protection methods include hard and soft engineering methods. Hard engineering methods mainly comprise constructing coastal structures that protect the coast. From the viewpoint of energy conservation, this measure only shifts the focus elsewhere and does not fundamentally solve the problem of coastal protection. When attempting to reestablish a new balance in the nearshore dynamic systems, other coastal protection problems may occur. By contrast, soft engineering methods mainly rely on nourishing the beach by artificially replenishing sand to increase the beach's width, thereby restoring the beach's original function: reducing and eliminating wave energy to protect the coast. Artificial beach nourishment has some strengths; it does not involve hardware construction that protects the coast but destroys the view, and it does not restrict people from visiting the beach or prevent them from engaging in water recreation or sports by the seashore.

Viewpoints on coastal protection no longer stem purely from the perspective of protective engineering. Instead, factors such as the coastal landscape and ecosystem have gradually been included in coastal engineering designs and coastal education thinking. In Taiwan, ideas on coastal protection lean toward employing ecological methods that protect the ecology and landscape. Some relevant studies are as follows. From the perspective of environment sustainability, [1] discussed domestic and foreign coastal protection methods that had the dual functions of disaster prevention and ecology promotion. They examined the design factors to be considered in coastal engineering designs and the importance of their effects. [2] studied the feasibility of employing geotextile tubes in coastal protection planning design. [3] discussed the potential problems of adopting ecological engineering methods in coastal engineering and their solutions. [4] investigated the application of an environmentally friendly coastal protection method combining headland control and beach nourishment for the Nanbin and Baibin coasts in Hualien. [5] demonstrated that a shore-term change of the beach profile was due to significant meteorological events such as typhoon passages, and the long-term evolution of the beach profile was dominated by monsoon waves. To summarize the evolution of coastal protection engineering methods, traditional sea dikes have been replaced by gentle slope-type dikes; conventional detached breakwaters have been replaced by submerged breakwaters or artificial reefs; and straight-type groins have been replaced by T-type or anchor-type groins. These features combined with methods such as artificial beach nourishment constitute the integrated coastal protection engineering methods of today, and the two-dimensional protection methods traditionally applied to coasts have been replaced by three-dimensional protection engineering methods. Fulong Beach in Yanliao, Northeast Taiwan is a major coastal recreation and sightseeing spot visited by numerous tourists every year. In recent years, Taiwanese people's demand for coastal recreation activities has been increasing, and thus, maintaining the leisure and recreation functions of Fulong Beach has gained more attention, especially the post-typhoon beach restoration problem in summer. Therefore, this study set off from the point of view of coastal disaster prevention and coastal preservation, and with the post-typhoon preservation problem as the focus, investigated Yanliao Beach nourishment mechanisms and researched beach nourishment engineering methods as references for future beach restoration projects.

2. Environmental Background Information of the Research Site

2.1. Research Site

This study's research site was the Yanliao Beach Park in the Northeast and Yilan Coast National Scenic Area, adjacent to Aoti and Fulong Beach. It is one of the most famous recreation spots along the Northeast Coast. The topographical features of the Yanliao Coastal region are characterized by the coexistence of sandy shore and reef rocks with bedrock as the seabed foundation. Because of the waves caused by the northeast monsoon and by typhoons in summer, the ocean in this region supplies plenty of sand. Sand drift deposits cover the coastal area, forming a sandy terrain. Because the sand is mainly fine quartz sand from the Shuang River and is of a light yellow color, this area is also called the Gold Coast. Figure 1 shows the research site of this study: in the north is the southern breakwater for the intake of Taiwan Power Company's Lungmen Nuclear Power Plant; in the south is a large reef at the southern end of the beach; in the east, the sea water is 3 meters deep; and in the west, is the junction of the dunes behind the beach windbreak. The research site was approximately 20 hectares in area, as indicated in green in the figure.

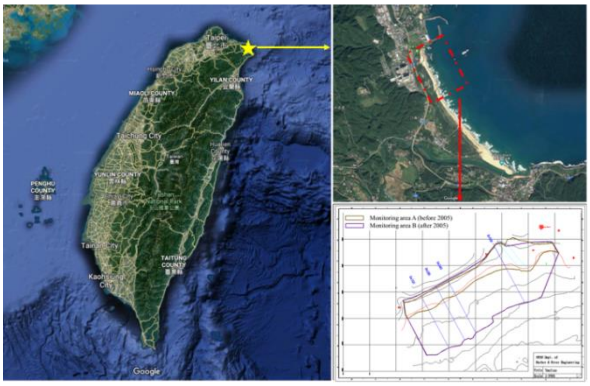

Figure 1. Schematic of relevant locations in the research site

Figure 2. Relevant observation stations near the research site

2.2. Marine Weather Condition

The background information that this study collected for analysis (Fig. 2) was mainly marine weather information from the neighboring Longdong and Yanliao observation stations of the Central Weather Bureau (CWB). Relevant background information is detailed in the following section. Table 1 presents the statistical results from the CWB Longdong Tidal Observation Station and from Yanliao Station. The mean tidal level at the Longdong Tidal Observation Station was -0.01 m, and the mean high water springs was 0.34 m. The mean tidal level of Yanliao Tidal Station was -0.01 m, and the mean high water spring was 0.36 m. Table 2 presents the tidal information from the CWB Longdong Tidal buoy station. During summer (May to July) in the research site from 1998 to 2017, the mean significant wave height was $H_{1/3}$ = 0.63~0.82 m, and the mean significant wave period was $T_{1/3}$ = 5.25~5.75 s. During winter (November to January), the mean significant wave height was $H_{1/3}$ = 1.58~1.80 m, and the mean significant wave period was $T_{1/3}$ = 6.06~6.24 s. Table 3 presents the current observation results from the Yanliao sea area observed by this research team between 2008 and 2012. During spring and summer, the average flood tide velocity was between 0.13 and 0.35 m/s, and the current direction was mainly between north-northwest and north. The average ebb tide velocity was between 0.11 and 0.21 m/s, and the current direction was mainly between west-southwest and north. During autumn and winter, the average flood tide velocity was between 0.16 and 0.42 m/s, and the current direction was mainly between northwest and north. The average ebb tide velocity was between 0.13 and 0.34 m/s, and the current direction was mainly between south and north-northwest. During spring and summer, the stagnation-point flows during flood tide and ebb tide were toward the same direction, between west-southwest and north, whereas during autumn and winter, the flow directions during flood tide and ebb tide were less consistent. Them, according to the CWB database, typhoons affected Yanliao Beach 45 times from 2004 to 2016. Among typhoon occurrences, the most frequent routes were Type 2 and Type 3 with 9 typhoon incidents each, accounting for 40%, followed by Type 1, which occurred seven times (16%). These typhoon invasion routes were referenced from Hsiao et al. (2010). The results indicated that typhoons with Type 2 and Type 3 routes had more noticeable effects on erosion and deposition at Yanliao Beach. Figure 3 illustrates the typhoon routes.

Table 1. Tidal information

	Longdond (2004~2017)	Yanliao (1981~2002)
H.W.O.S.T.	0.34 m	0.36 m
M.H.W.L.	0.27 m	0.29 m
M.W.L.	-0.01 m	-0.01 m
M.L.W.L.	-0.33 m	-0.26 m
L.W.O.S.T.	-0.34 m	-0.34 m

Table 2. Wave information statistics

	1998~2000		2002~2005		2008~2017	
	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$
Summer	0.69 m	5.74 s	0.82 m	5.75 s	0.63 m	5.25 s
Winter	1.80 m	6.24 s	1.60 m	6.11 s	1.58 m	6.06 s

Table 3. Current information statistics

		Avg. Spd.	Main Dir.			Avg. Spd.	Main Dir.
2008/10/10	Flood	0.29	N-NW	2011/07/05	Flood	0.27	NNW
	Ebb	0.13	WNW-NNW		Ebb	0.11	NNE
2009/07/06	Flood	0.35	NNW	2011/11/26	Flood	0.42	NNE
	Ebb	0.11	NNW-SSW		Ebb	0.15	S
2009/12/07	Flood	0.16	NNW-S	2012/09/01	Flood	0.3	NNW
2010/07/15	Flood	0.33	N		Ebb	0.13	NNW
	Ebb	0.21	N	2012/11/21	Flood	0.3	NNW
2010/11/30	Flood	0.31	NNW		Ebb	0.13	NNW
	Ebb	0.25	NNW				

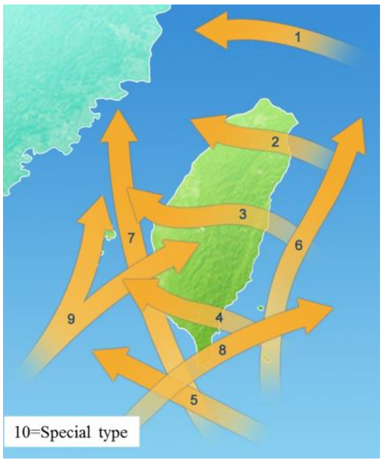

Figure 3. Typhoon route classifications (Central Weather Bureau: Typhoon Database)

3. Topographic Surveying Method

3.1. Beach Topographic Surveying Method

This study conducted a beach topographic survey in the research site that was divided into topographic surveying on land and at sea. A total station laser light theodolite—Leica TC703—was used for land mapping. The coordinates and elevations of the control points were first measured before conducting a beach topographic survey, the results of which are presented in Fig. 4. The mean-section method was employed to calculate the erosion and deposition volumes, with the goal of assessing changes to the beach. For the topographic survey of the sea, remote control vehicles that carried echo sounders were mainly used to map the depth of the topography. This surveying system comprised three parts: a survey vehicle, a total station theodolite, and a navigation integration operation unit. Fig. 5 illustrates the operating principles of the surveying vehicle.

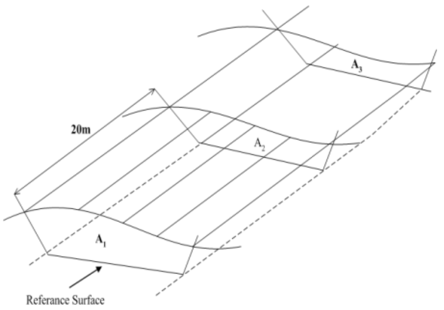

Figure 4. Schematic of earth volume calculation

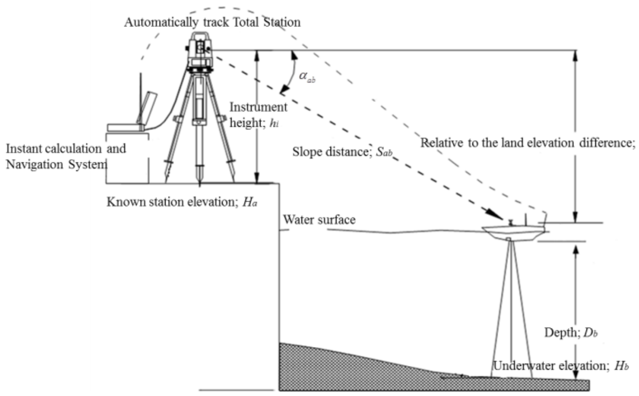

Figure 5. Schematic illustrating the surveying vehicle's operating principles

To record correlated time factors, the surveying vehicle's surveying result data comprised two types: sounding and plane positioning. Subsequently, the two types of data were integrated to become three-dimensional survey point data. The formulas for underwater elevation and position data are as follows:

$$H_b = h_i + H_a + \Delta h_{ab} - D_b - d_p \quad (1)$$

The vehicle's plane position calculation formula is as follows:
Coordinates in the N_b direction:

$$N_b = N_a + \Delta N_{ab}; \quad \Delta N_{ab} = (S_{ab} \cdot \sin\alpha_{ab}) \cdot \cos\phi_{ab} \quad (2)$$

Coordinates in the E_b direction:

$$E_b = E_a + \Delta E_{ab}; \quad \Delta E_{ab} = (S_{ab} \cdot \sin\alpha_{ab}) \cdot \sin\phi_{ab} \quad (3)$$

where H_a is the station elevation, h_i is the height of the total station, H_b is the underwater elevation, $\Delta h_{ab} = S_{ab} \cdot \sin\alpha_{ab}$ is the difference of elevation between the prism on the remote control vehicle and the total station on the ground, α_{ab} is the vertical angle (α_{ab} is the angle of depression; here its negative value is taken), D_b is the depth that the vehicle measured, d_p is the distance between the prism and the transducer, ϕ_{ab} is the azimuth angle (the north is set as 0°), and S_{ab} is the slant distance.

3.2. Discussion on the Reasons for Changes in Topography

From May 2004 to March 2017, the research team surveyed changes in topography. The survey results indicated that in the surveyed coastal area, the areas with relatively severe changes were concentrated near the cross sections in Fig. 6: STA:0+100, STA:0+180, STA:0+240, and the Little Stage STA:0+500. Fig. 7, the monitoring results revealed that as the northeast monsoon weakened, from March, sand was gradually deposited on the Yanliao Beach terrain. By contrast, abnormal marine weather such as typhoons in summer and autumn are short-term variation factors on the monitored beach topography, causing erosion. After typhoons hit and before the northeast monsoon arrived from the north, the beach topography again responded to the summer climate conditions and gradually sand was deposited. In winter, the northeast monsoon is strong. The beach topography in the monitoring area reflected this winter climate condition and was eroded. Later, as the northeast monsoon weakened, beginning the following March, the Yanliao sand beach survey area resumed reacting to the seasonal climate conditions and sand deposition gradually increased. The beach topography indicated the trend of a dynamic balance. This result is supported by the sand erosion and deposition change results in Table 4.

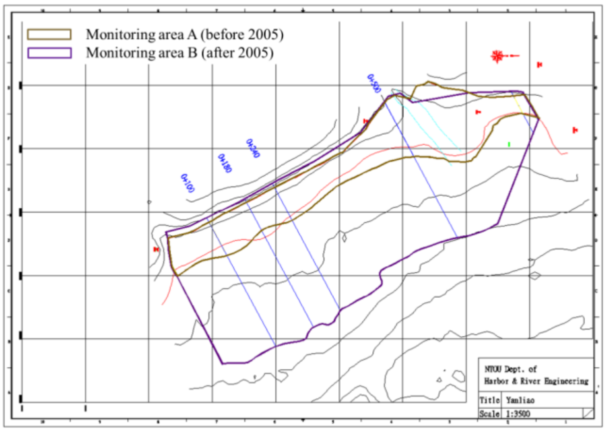

Figure 6. Schematics of the cross sections in the survey area (on site observation)

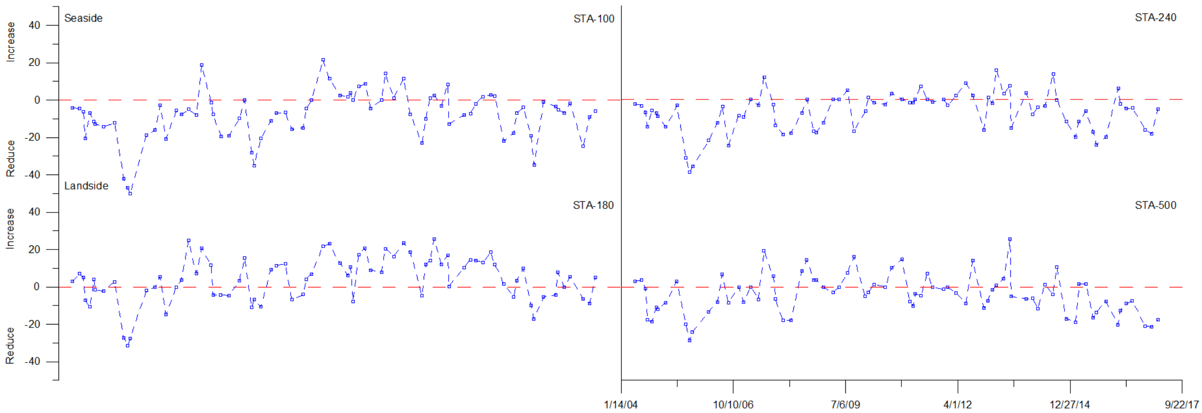

Figure 7. The contour line of each cross section's change over time (on site observation)

Table 4. Statistical information of the current

Year	Season impact	Typhoon impact	Year	Season impact	Typhoon impact
2004	0	-26,096	2011	+12,346	-707
2005[a]	+9,800	-53,582	2012	+4,489	-8,217
2006	+52,981	-4,240	2013	+6,589	-27,077
2007	+9,735	-19,181	2014	+10,491	-7,742
2008[b,c]	+28,357	-15,261	2015	+8,937	-30,715
2009	+20,102	-16,928	2016	+6,875	-30,578
2010	+21,525	-18,613	2017	+31,065	-

[a] 2005 input 25,000 m^3
[b,c] 2008/5/15 input 25,000m^3, 7/15 input 10,000m^3

4. General Discussion

4.1. Coastal Protection after Typhoon Krosa

After Typhoon Krosa hit on October 4, 2007, the width of Yanliao Beach was markedly reduced, and the dunes in the back beach collapsed to form beach scarp. Figures 8 depict Yanliao Beach's topography after Typhoon Krosa. After considering the strengths and weaknesses of hard and soft coastal protection engineering methods, this study determined that artificial beach nourishment would be effective in creating a coast with functions similar to a natural coast in terms of dissipating tidal energy, restoring the beach, and increasing the width of the beach. Moreover, the functions of beach recreation and disaster prevention could be achieved, and balance with the natural ecosystems maintained. To maintain the width of the beach, prevent the back beach from further collapsing and retreating, and satisfy the Yanliao Beach Park's recreational requirements, this beach required fast restoration through adopting soft coastal protection methods.

(a) (b) (c)

Figure 8. Yanliao Beach's topography after Typhoon Krosa, (a) topography near the north side of the reef area (b) topography in the central survey area (c) Topography near the south side of the large reef.

4.2. Planning and Implementing the Beach Nourishment Plan

After organizing and analyzing the aforementioned background information, this study reference the [6] adopted a dune nourishment method (depicted in Fig. 9). This method placed all of the beach nourishment sand along the area of the beach marked for nourishing, forming a continuous dune along the land side of the area. This beach nourishment method was adopted to resist the erosion caused by extreme waves and storm surges, and ensure the safety of buildings behind the coastal beach. Sand from dredging conducted elsewhere and leftover earth from construction sites can be placed near the beach in the form of dunes for maintenance or reconstruction after storms affect the beach. When storms occur, the dunes that serve as blocking facilities will be eroded; however, the dunes also serve to block the waves, thereby reducing costs incurred by assembling workers for emergency repairs. Therefore, some beach nourishment plans use dredged sand to form dunes, thereby reduce the need for emergency repairs when storms erode the coast. When the weather is dry, the dunes may be blown into the wind and cause air pollution, causing negative effects on nearby residences; thus, fences should be erected and vegetation should be planted to enhance the stability of the dunes.

Past topographic survey results revealed that the changes in topography of Yanliao Beach reflect seasonal climate factors and a dynamic balance. However, Typhoon Krosa caused severe erosion and the beach lost a large amount of sand. To prevent the back beach dunes from further collapsing and retreating, artificial beach nourishment through sand replenishment was conducted. According to the topographic change assessment results after Typhoon Krosa, adopting beach dune nourishment could form a continuous dune on the landward side, relying on natural forces to spread out the sand on the beach. However, natural forces would be slow in carrying the sand to form a natural beach, and be unable to immediately form a platform. By contrast, employing the coastal beach nourishment plan could rapidly restore the platform and create a beach for recreation. Therefore, considering the premise of protecting the post-typhoon beach scarp on the back beach as well as maintaining both the beach's recreation function and intertidal water quality, the artificial beach nourishment plan should combine beach dune and coastal beach nourishment. Specifically, this would involve beach nourishment sand being spread across the beach above the mean high water line for beach restoration. Comparing the topographic change observation results between May 2004 and late March 2017, reflected in the forms of the 0 m contour line of the beach cross sections STA:0+100, STA:0+180, STA:0+240, and STA:0+500, revealed that areas above the mean high water line where sand replenishment was conducted for beach nourishment in 2008 were not affected by the tidal water's constant impact. Waves brought by Typhoon Kalmaegi compacted the sand placed above the mean high water line, resulting in an extension of the 0 m shoreline toward the sea. This result satisfied the original beach nourishment plan and proved the effectiveness of this artificial beach nourishment project.

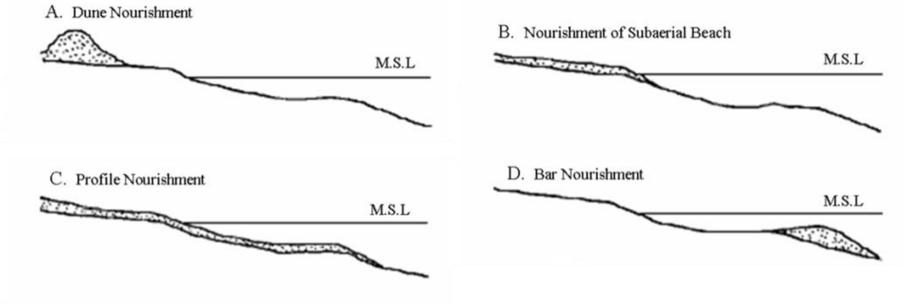

Figure 9. Schematic of artificial beach nourishment (NRC, 1995)

5. Conclusion

This study investigated coastal protection problems after Typhoon Krosa and their solutions. Based on the aforementioned discussion, the following conclusions were reached:

- Past observation results revealed that the survey area's beach topography reflected seasonal marine weather conditions and presented dynamic changes in erosion and position. Artificial beach nourishment through sand replenishment is recommended for maintaining beach width only if the beach has been affected by typhoons that resulted in large-scale changes to the beach topography.
- In 2007, Typhoon Krosa caused severe erosion to the dunes on the back beach of Yanliao Beach. The dunes collapsed and formed beach scarps. Beach nourishment plans for both coastal beach and dunes were adopted; the plans involved replenishing sand in areas above the mean high water line. They proved to be effective in protecting the dunes on the beach and maintaining the beach's width.
- Combining coastal beach and dune nourishment methods could protect beach and dune terrain. In addition, this combination could prevent coastal beach nourishment methods from degrading foreshore water quality. The results may serve as a reference for future beach nourishment plans.

6. References

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