第 48 卷 第 5 期
2021 年 5 月

湖 南 大 学 学 报（自 然 科学版）
Journal of Hunan University（Natural Sciences）

Vol. 48. No. 5.
May 2021

Open Access Article

Measurement of Alongshore Sediment Transports at the Swash Zone of Teluk Nipah Beach

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Abstract: Teluk Nipah Beach of Pangkor Island, Malaysia, experienced severe erosion ever since 2017. One of the factors causing beach erosion is the change of alongshore sediment transport behavior at the site. In this study, an attempt was made to measure the alongshore sediment transport rates at the swash zone of TelukNipah Beach using an array of streamer traps. Three cycles of measurement were undertaken at the selected transects along the beach between February and September 2020. Three units of custom-made streamer traps were installed seaward, mid-point, and shoreward of the swash zone, respectively. Each streamer trap was attached with seven units of 50-microns nylon monofilament bags at different levels along its height. These bags were placed normal to the alongshore current within the swash zone of the study area. Overall, the streamer traps could capture the alongshore sediment transport at different heights of the water column within the swash zone. The sediment collected in September 2020 was courser than that collected in February 2020 due to the increased wave activities at the surf zone of Teluk Nipah Beach in September. The alongshore sediment fluxes were subsequently computed based on the measurement results, and the relationship between sediment fluxes and wave height is determined in this study. In summary, the streamer traps proposed in this study is a viable tool for measurement of alongshore sediment transports within swash zone that is subjected to mild to moderate wave conditions.

Keywords: alongshore sediment transport, water column, wave height, streamer traps, swash zone.

1. Introduction

The dynamics of wave climate and human intervention are the primary factors causing shoreline instability. Natural beaches are always dynamic, and the shorelines change according to wave climate conditions. For instance, beach materials are lost during the stormy seasons, but they are often replenished during the mild seasons [1]. The littoral and onshore-offshore drift activities configure the beach landscape along the coasts, and the beach form tends to achieve equilibrium in the long term. Good monitoring of the shoreline conditions by implementing coastal zone management plans and sustainable development practices is important to ensure the coastal ecosystem and socio-economy of the community are subjected to minimal disturbances [2].

Alongshore sediment transport is a movement of beach sedimentary materials parallel to the shore under the action of alongshore currents produced by the breaking waves [3]. The sediment transport processes are governed by the nearshore current resulted from the breaking of waves [4]. Various empirical formulae have been proposed for the estimation of alongshore sediment transports for a beach. These formulae include the CERC formula [5], Kamphius equation [6, 7], and Walton & Bruno equation [8]. The alongshore sediment transport rates computed using these empirical formulae may largely vary from one another. Hence, it is important to validate the computed alongshore sediment transport rates [9, 10, 11] with the measured results or numerical simulations [12, 13, 14]. The latter is often rather challenging due to the

Received: February 14, 2021 / Revised: March 16, 2021 / Accepted: April 12, 2021 / Published: May 28, 2021

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difficulty of measuring the alongshore sediment transports at sites. There are numerous measurement systems developed to measure the alongshore sediment transport rates at the site. These measurement systems include impoundment, fluorescent tracers [15, 16, 17] and streamer traps [18, 19]. Among the mentioned technologies, a streamer trap is the most economical measurement system [20]. [21] have utilized streamer traps of various configurations to collect the alongshore sediment at the surf zones of their respective study sites. Despite the good capability of streamer traps in collecting the alongshore sediment transports, they are subjected to several limitations, such as scouring the seabed, disturbance of fluid flow, and the heaviness of the trap.

The erosion of Teluk Nipah Beach of Pangkor Island, Perak, Malaysia, has been a pain point to the local community and the relevant stakeholders. The historical shoreline changes in Teluk Nipah were reported by [22]. One of the courses of erosion might be due to a change of the alongshore sediment transport behavior within the study area. Estimation of the alongshore sediment transports at Teluk Nipah Beach using the established empirical equations [5, 6, 7, 8] is relatively easy; nonetheless, the estimation might be subjected to large discrepancies when compared with the actual measurement values. Physical or site quantification of alongshore sediment transport using measurement systems is highly recommended, even though the measurement operation is laborious and costly. This study has been undertaken to measure the alongshore sediments at the swash zone of Teluk Nipah Beach using streamer traps and to determine the transport rates along the coast.

2. Study Area

Teluk Nipah Beach is located in the western part of Pangkor Island (coordinates: Latitude: 04°13'50" N; Longitude: 100° 32'43" E). The natural coastal features are depicted in Fig. 1. Teluk Nipah Beach is confined by two offshore islands, i.e., Giam Island and Mentagor Island, which provide some level of protection to the beach. The recreational beach is currently lined by shore-based infrastructures and buildings with a very limited buffer zone between the shoreline and the development. The beach was subjected to extreme storm waves between November and December of 2017, in which the offshore significant wave height recorded was as high as 1.76 m. The intrusive waves of high energy damaged the landscape of the beach and resulted in beach lowering of 1 m from the original level.

Fig. 1 Location of study area covering the entire Teluk Nipah: Northern Cell (Transect 1) and Southern Cell (Transect 2 & 3)

3. Methodology

3.1. Streamer Traps

In this study, three units of streamer traps were fabricated. Each unit of the streamer trap was made of a rectangular frame (with a cross-section of 0.25 m x 0.25 m) using solid steels. The height of the streamer trap was 1.9 m. There were seven rectangular openings of 10.5-cm height and 20.5-cm width at one side of the streamer trap. These openings were separated from each other at 1.5 cm. The openings were attached to a series of 50-microns nylon monofilament bags of various lengths, i.e., 70, 100, and 120 cm. 70-cm bags were attached to the first three openings from the top, 100-cm ones were connected to the fourth opening, and the bottom three were attached with the 120-cm bags. It was anticipated that the sediment transport would be maximal close to the seabed [11]. Each streamer trap weighed 50 kg.


Fig. 2 Setup of streamer traps at Transect 3

Three cycles of alongshore sediment transport measurement exercises were conducted at TelukNipah Beach in different seasons of 2020. The sampling periods of the three measurement cycles are the 10th-12th of February 2020 (Cycle 1), 17th-18th of February 2020 (Cycle 2), and 22nd-24th of September 2020 (Cycle 3). The wave condition of Cycle 3 was more severe than the first two cycles. Fig. 2 demonstrated the installation of two units of streamer traps at Transect 1 (measurement points 1A and 1B are given in Fig. 1) during measurement cycle 1. The streamer traps stood firm by their weight regardless of the wave conditions when the legs penetrated the seabed. For ensuring structural stability and functionality of the streamer traps, the bottom-most opening was located 35 cm from the stoppers attached to the respective streamers' legs. First, the flow direction of the water was ascertained using dye and drogues. The streamer traps were then erected at the swash zone of Transects 1, 2, and 3. The openings of the streamer traps were placed normal to the flow direction. The nylon monofilament bags would retain the suspended sediment and drain the water through the porous material. The sampling duration varied from 10 to 20 minutes, depending on the wave conditions. A smaller sampling duration was adopted for rough wave conditions. The streamer bags were closely monitored to ensure that none of the bags were tangled. Upon completing the sampling exercise, each of these streamer traps was towed to the shore for sample collection. The sediment samples entrained at the respective nylon bags were retrieved through water rinsing, and the samples were labeled and kept in sealed bags. The moisture content of the sediment samples was then removed using an oven before weighing the sediment. Apart from alongshore sediment sampling, bed sampling was also conducted at each measurement point of Transects 1, 2, and 3 for each sampling cycle. Sieve analysis was undertaken to determine the particle distribution of the bedload collected at the site.

3.2. Calculation of LST Rates

The point sediment flux Q, which is measured in terms of weight within a time interval, at a measurement point can be calculated using [12]:

$$Q(f) = \frac{S(f)}{wht} \tag{1}$$

where S is the weight of the dried sediment samples in a streamer bag, and w, h, and t are the width and height of the streamer’s opening and sampling duration, respectively. The unit of sediment flux is $kgs^{-1}m^{-2}$.

The sediment flux between two adjacent streamer bags ΔF_i can be calculated using linear integration [12]:

$$\Delta F_i = \frac{\frac{F_{i+1}}{w_{i+1}} + \frac{F_{i-1}}{w_{i-1}} \Delta Z_i}{2} \tag{2}$$

where F_{i+1} and F_{i-1} are fluxes between the upper and lower bags, respectively; w_{i+1} and w_{i-1} are vertical widths for both upper and lower bags, respectively; and ΔZ_i is the vertical distance between two streamer bags. The sediment flux for a unit of streamer trap, *I*is obtained by the combination of the sediment fluxes on each of the seven bags and sediment fluxes that occurred between the subsequent upper and lower bags within a trap array:

$$I = \sum_{i=1}^{N} (F_i) + \sum_{i=1}^{N-1} (\Delta F_i) \tag{3}$$

where N is the number of streamer bags within a streamer trap.

4. Results and Discussions

4.1. Hydrodynamics and Beach Characteristics

In this study, three measurement cycles were conducted at the swash zone of TelukNipah Beach at the respective transects, i.e., Cycle 1 (10–12 February 2020), Cycle 2 (17–18 February 2020), and Cycle 3 (22–24 September 2020). Table 1 presents the measured wave height, wave period, median grain size, beach slope, and water depth across three transects on different swash transitions during the field measurements conducted in Cycle 1, Cycle 2, and Cycle 3. The mean wave heights recorded at Transect 1 and Transect 3 were 0.10 and 0.21 m. The wave heights at Transect 3 were particularly high (reaching 0.40 m) on the 23rd – 24th of September 2020 due to the strong wind effect. Hence, measurement of Transect 2 could not be performed due to safety reasons. It is also observed from the table that the slopes of the swash zone at three transacts were relatively steep, and they varied with sampling days and tidal conditions. The mean swash zone slopes for Transect 1, Transect 2, and Transect 3 were 0.20, 0.24, and 0.19, respectively. The swash zone slope of Transect 2 was the highest among the others. In terms of the bedload median grain size, the D_{50} largely varied from one transect to another transect for a specific measurement cycle, and the seasonal variation was also observed. The D_{50} range for Transect 1, Transect 2 and Transect 3 were 0.47 – 0.95, 0.64 – 0.85 and 0.93 – 1.12 mm. Overall, the bedload at Transect 3 was the largest. It is also noticed that the D_{50} recorded in Cycle 3 was the largest compared to Cycle 1 and Cycle 2. This is due to the influence of rough wave conditions during the measurement. Hence, it is safe to deduce that the bedload at the swash zone of TelukNipah Beach increases with the intensity of the wave action. The finding is sensible because the fine sediment is relatively easy to be disturbed (suspended) by the wave action and drifted by the swash motions along the shoreline. The larger sedimentary materials will prone to stay at the swash zone with a little movement.

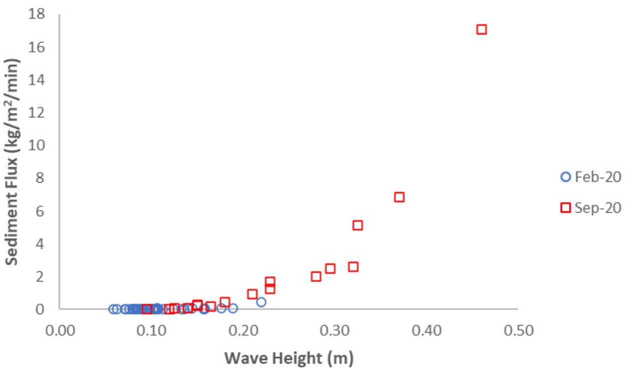
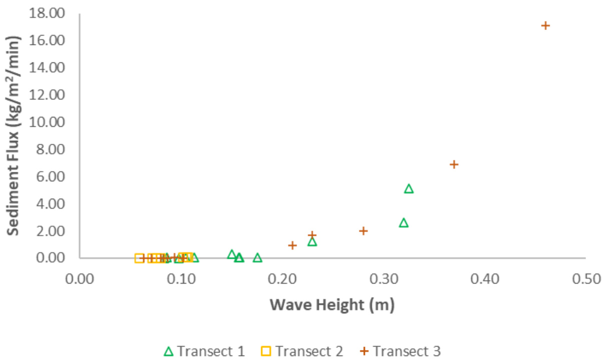


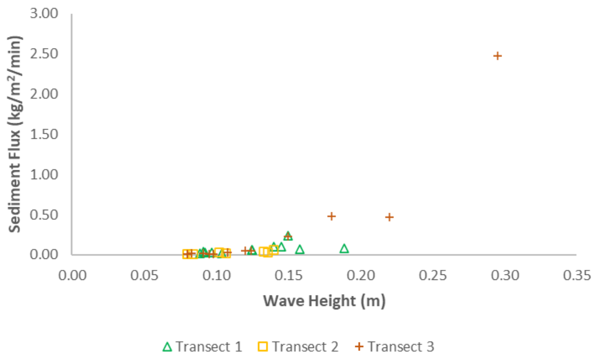
Fig. 3 Relationship between sediment flux and wave height for different seasons

4.2. Sediment Transport

Fig. 3 shows the sediment flux with respect to wave height for the respective measurement cycle, i.e., February 2020 and September 2020. During the September measurement cycle, the wave activity was more intensive than that of the measurement cycle in February 2020. Fig. 4 shows the effect of wave height on sediment flux for Transects 1, 2, and 3 during ebbing and flooding at Teluk Nipah Beach. The sediment fluxes were computed using equation (3) based on the measurements of suspended loads at each transect's swash zone. It is noticed that the sediment flux was more significant during ebbing, recording a maximum flux of almost 18 kg/m^2/min. During flooding, most of the measured fluxes were barely more than 3 kg/m^2/min. This implies that the alongshore sediment transports heading down south of Teluk Nipah are more dominant than those heading north. Based on Fig. 3, it is also learned that the sediment fluxes recorded at Transects 1, 2, and 3 are closely related regardless of the wave height variation. As wave height increases from 0.05 m to 0.50 m, the sediment fluxes increase exponentially. This signifies that wave height is the dominant factor influencing the magnitude of sediment fluxes.



(a)



(b)

Fig. 4 Effect of wave heights on sediment flux for Transects 1, 2, and 3 during ebbing (upper diagram) and flooding (lower diagram)

Fig. 5 shows the sediment flux measured at different sections of the swash zone at Teluk Nipah Beach, i.e., seaward swash, mid swash, and shoreward swash. A total of 65 sediment traps were installed at the swash zone for this study, i.e., 27 traps were located at the shoreward swash, 24 traps - at the mid swash zone, and 14 traps - at the seaward swash. A limited number of traps were located at the seaward swash zone due to the steep slope and intensive wave activities during the measurement. In Fig. 5, it is apparent that the highest sediment flux rate obtained was located at the shoreward swash, and the lowest sediment flux rate was recorded at the seaward swash zone. Higher wave heights were recorded at the shoreward swash zone because the waves experienced shoaling, breaking, and run up within a short distance when propagating on a steep beach slope.

Table 1 Hydrodynamics and beach profile characteristics across the study area on different tidal transitions and cycle of measurements

Date	Tide	Location	Wave height (m)	Wave period (s)	Bedload D_{50} (mm)	Swash zone slope, tan β	Water depth (m)
10th Feb (Cycle 1)	Flooding	Transect 1	0.11	4.69	0.47	0.24	0.82
		Transect 2	0.11	4.86	0.64	0.20	0.77
		Transect 3	0.13	4.63	0.93	0.22	0.73
11th Feb (Cycle 1)	Ebbing	Transect 1	0.13	5.90	0.47	0.18	0.82
		Transect 2	0.09	9.79	0.64	0.22	0.75
		Transect 3	0.08	7.24	0.93	0.22	0.73
	Flooding	Transect 1	0.09	8.80	0.47	0.13	0.82
		Transect 2	0.09	7.25	0.64	0.18	0.77
		Transect 3	0.09	5.50	0.93	0.22	0.73
12th Feb (Cycle 1)	Ebbing	Transect 1	0.09	9.20	0.47	0.15	0.82
		Transect 2	0.09	8.87	0.64	0.20	0.77

		Transect 3	0.08	8.64	0.93	0.24	0.73
17th Feb (Cycle 2)	Flooding	Transect 1	0.17	5.45	0.65	0.14	1.03
		Transect 2	0.13	6.00	0.85	0.17	0.98
		Transect 3	0.12	7.50	1.12	0.24	0.98
18th Feb (Cycle 2)	Ebbing	Transect 1	0.17	7.50	0.65	0.10	1.07
		Transect 2	0.08	8.57	0.85	0.23	1.00
		Transect 3	0.10	6.00	1.12	0.22	1.10
22nd Sep (Cycle 3)	Flooding	Transect 1	0.13	6.50	0.95	0.29	1.20
		Transect 2	0.17	8.30	0.71	0.31	1.25
		Transect 3	0.18	8.70	1.04	0.19	0.97
23rd Sept (Cycle 3)	Ebbing	Transect 1	0.28	8.80	0.77	0.11	0.60
		Transect 3	0.32	9.20	0.85	0.12	0.67
	Flooding	Transect 1	0.15	7.80	1.19	0.17	0.53
		Transect 3	0.15	8.30	1.27	0.17	0.75
24th Sep (Cycle 3)	Ebbing	Transect 1	0.24	8.10	1.19	0.15	0.57
		Transect 3	0.30	7.80	1.04	0.14	0.55

Table 2 Summary of alongshore sediment transport at Teluk Nipah Beach

Date	**Tidal Transition**	**Longshore Direction**	**Location**	**Average Sediment Flux ($kg/m^2/min$)**	**Number of trap arrays**
10th Feb 2020 (Cycle 1)	Flooding	South	Transect 1	0.06	3
			Transect 2	0.04	3
			Transect 3	0.17	3
11th Feb 2020 (Cycle 1)	Ebbing	North	Transect 1	0.04	3
			Transect 2	0.05	2
			Transect 3	0.01	3
	Flooding	South	Transect 1	0.02	3
			Transect 2	0.01	3
			Transect 3	0.01	3
12th Feb 2020 (Cycle 1)	Ebbing	North	Transect 1	0.02	3
			Transect 2	0.04	3
			Transect 3	0.02	3
17th Feb 2020 (Cycle 2)	Flooding	South	Transect 1	0.08	2
			Transect 2	0.04	2
			Transect 3	0.04	2
18th Feb 2020 (Cycle 2)	Ebbing	North	Transect 1	0.06	2
			Transect 2	0.01	2
			Transect 3	0.01	2
22nd Sep 2020 (Cycle 3)	Flooding	South	Transect 1	0.06	1
			Transect 2	0.17	1
			Transect 3	0.91	3
23rdSep 2020 (Cycle 3)	Ebbing	North	Transect 1	1.94	2
			Transect 3	6.68	3
	Flooding	South	Transect 1	0.17	2
			Transect 3	0.27	2
24th Sep 2020 (Cycle 3)	Ebbing	North	Transect 1	2.71	2
			Transect 3	4.28	2

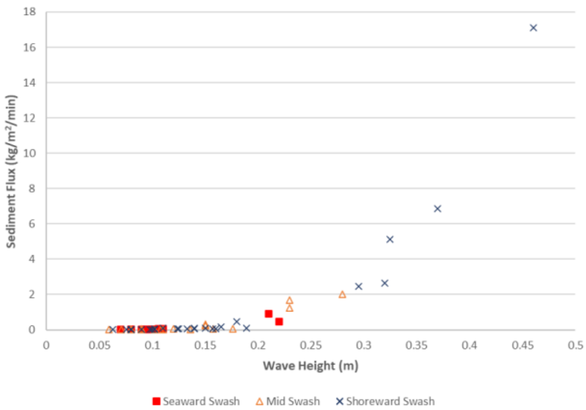


Fig. 5 Effect of wave heights on sediment flux across different swash zones

The effect of the seasonal wave effect is demonstrated in Table 2. The wave condition in February 2020 was relatively calm compared to that in September 2020. The alongshore sediment transport activities were almost invisible in February, but they became a dominant agent in transporting the beach sedimentary materials at the swash zone of Teluk Nipah Beach. Note that the September data were unavailable in Transect 2 (Fig. 6b) due to missing data sampling.

It is worth highlighting some of the limitations and challenges encountered during the sediment transport measurement at Teluk Nipah Beach. Streamer trapper is suitable for the measurement of alongshore sediment transport rate on a short-term basis. Although streamer traps are inexpensive and provide reliable measurements, the installation and removal of the traps were laborious and required a lot of manpower for the works. Operating the streamer traps in rough sea conditions is not recommended due to safety concerns and damage of the nylon monofilament bags by the wave action. The streamer trap is most suitable to be adopted in limited water depths (up to the height of the streamer trap) when the seas are subjected to mild to moderate wave conditions. Users need to ascertain the direction of the alongshore current before the installation of the streamer traps in the sea. The opening of the streamer traps should be facing the incoming currents. Close monitoring of the streamer bags is required during the measurement to ensure the bags are not entangled with other bags. It is also advised that the bottom-most sediment bag should be set above the seabed level to minimize interruptions to the bedload transports.

5. Conclusion

In this study, streamer traps were constructed to measure the alongshore sediment transports taking place at the swash zone of Teluk Nipah Beach, Pangkor Island, Malaysia. Based on the weights of the sediment collected at the respective streamer bags, the sediment transport rates were computed using the proposed equations. The alongshore sediment transports largely depended on the wave heights experienced at the site during the measurements. Based on the site measurement, the shoreward swash induced more sediment transports than the seaward swash within the swash zone. In short, the streamer traps adopted in this study were capable of capturing the alongshore sediment transports.

Acknowledgment

The authors would acknowledge Universiti Teknologi PETRONAS for funding this research through URIF grant (015LB0-042) and the technical assistance given by the research team members – Meor Asniwan Bin Mew Ghazali, Muhammad Nur Aiman Bin Roslan, Omar Abdelnaby Mohamed Hendawy Kishk, Altowayti Faris Ali Hamood, and the staff members from the Department of Irrigation and Drainage Manjung District.

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