FIELD INVESTIGATION OF SEASONAL VARIATIONS IMPACT ON FLOW DEPTHS AND VELOCITIES IN THE SWASH ZONE

Norasman Othman[1], Ahmad Khairi Abd. Wahab[2,3],
Mohamad Hidayat Jamal[2,3] and Shairul Rohaziawati Samat[1]

[1] Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang

E-mail: norasman@ump.edu.my, shairul@ump.edu.my

[2] Faculty of Civil Engineering, Universiti Teknologi Malaysia

[3] Center for Coastal and Ocean Engineering (COEI), Universiti Teknologi Malaysia

E-mail akhairi@utm.my, mhidayat@utm.my

Most studies of the hydrodynamics and sediment transport in the swash zone in recent years have stressed the importance of swash processes in terms of science advancement and practical applications in this field of study. Clearly, the hydrodynamics of the swash zone are complex and not fully understood. The hydrodynamics of the swash zone characteristics likes swash water depth and velocity will affected the sediment transport mechanisms that mostly control beach face morphology especially under dry and wet periods in east coast region of Peninsular Malaysia. Field monitoring works at Desaru beach for data of rainfall distribution, morphological changes and swash characteristics likes flow depths and velocities have been conducted and analysed for both different periods (dry and wet). From observation, it is believed that rainfall distribution during the seasonal variation of dry and wet seasons in Malaysia affects the swash characteristics mainly by the infiltration processes in beach areas and significantly controlled the morphological changes in the swash zone.

Keywords: beach morphology, swash zone characteristics, uprush, backwash, infiltration

Introduction

The swash zone is commonly defined as the part of the beach area between the minimum limit of backwash and maximum limit of up-rush. A detailed schematic illustration about the swash zone area in coastal area was shown in **Figure 1** and most studies clearly found that the swash zone also recognised as the most energetic area of beach sediment movement, characterized by strong and unsteady flows, high turbulence levels, large suspended sediment concentrations, high sediment fluxes and relatively rapid rates of morphological change (Baldock et al., 2005; Longo et al., 2002; Masselink and Puleo, 2006). Bakhtyar (2009) also reviewed and concluded that the swash zone hydrodynamics are poorly understood if compare to the surf zone. This is happen by the complexities of data collecting in intermittent, shallow, bubbly and rapidly varying flows, which makes data analysis and critical comparisons between theory and observations difficult. As a result, there are only limited field measurements and experimental data on swash zone study. So, there is an urgent need to improve the currently available equipment or tools in order to conduct a high quality study in the swash zone. Swash processes are totally forced by surf zone waves and are controlled by factors such as the beach morphology, sediment characteristics and beach groundwater (Hughes and Turner, 1999). Due to its complexity and difficulty of making field measurements, the swash zone remains one of the least understood regions of the nearshore (Hughes et al., 1997). Also the understanding of swash hydrodynamics likes bed levels, flow depths and velocities during wave uprush and backwash in the swash zone is becoming very important mechanism in the beach morphological development (Jensen et al., 2010; Baldock, 2009).

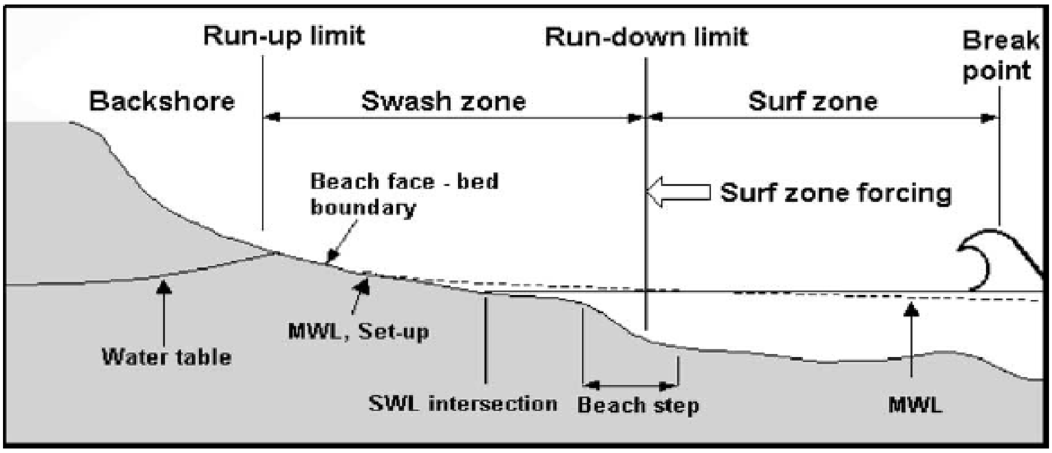

Figure 1: Schematic illustration of swash zone (Elfrink and Baldock, 2002)

According to Elfrink and Baldock (2002), during the up-rush or backwash processes, water will infiltrate or exfiltrates the beach surface depends on groundwater elevation, beach material permeability and degree of soil saturation. This all conditions will be significantly affected the flow depths and velocities during up-rush and backwash processes, resulting the changes of beach morphological profiles.

In Malaysia especially in east coast region of Peninsular Malaysia, the annual variations of seasonal period during dry (March until June) and wet (November until January) period will significantly controlled the condition of the beaches. During the dry period, there are very limited of rainfall events and this situation will be significantly dropped the water table and moisture content in the beach area which is enhanced the infiltration process and resulting the accretion of the beaches.

Meanwhile, during the wet period due to the northeast monsoon season effect, the exposed areas like the east coast of Peninsular Malaysia experience heavy rain spells and contribute increasing level of water table and moisture content. This unique condition will enhanced the erosion rate at the near shore area. At the same time, it believed that the seasonal variation (dry and wet season) factor in Malaysia have significantly influence on the sediment transport processes especially in the swash zone. This paper aims to investigate the swash zone characteristics likes flow depths and velocities during two different periods in order to help the understanding of sediment transport processes impact from both characteristics in beach morphology changes.

Field Site

Desaru beach has 25 km of white and sandy beach plus lush tropical greenery which has made it as the well-known beach in Johor. It is approximately about 2° above the Equator, located at the east coast of Peninsular Malaysia, 98 km northeast of Johor Bahru; capital city of Johor and about 460 km from Kuala Lumpur; federal capital of Malaysia. **Figure 2** shows the location of Desaru beach in the Peninsular Malaysia maps. The beach is composed of fine sand with a median diameter, D_{50} of 0.2 – 0.4 mm. The beach experiences semidiurnal tide, with tide ranges of approximately 1.2 m. The upper beach is quite steep (tan $\beta \approx 0.11$) and the lower beach is gentle (tan $\beta \approx 0.03$)

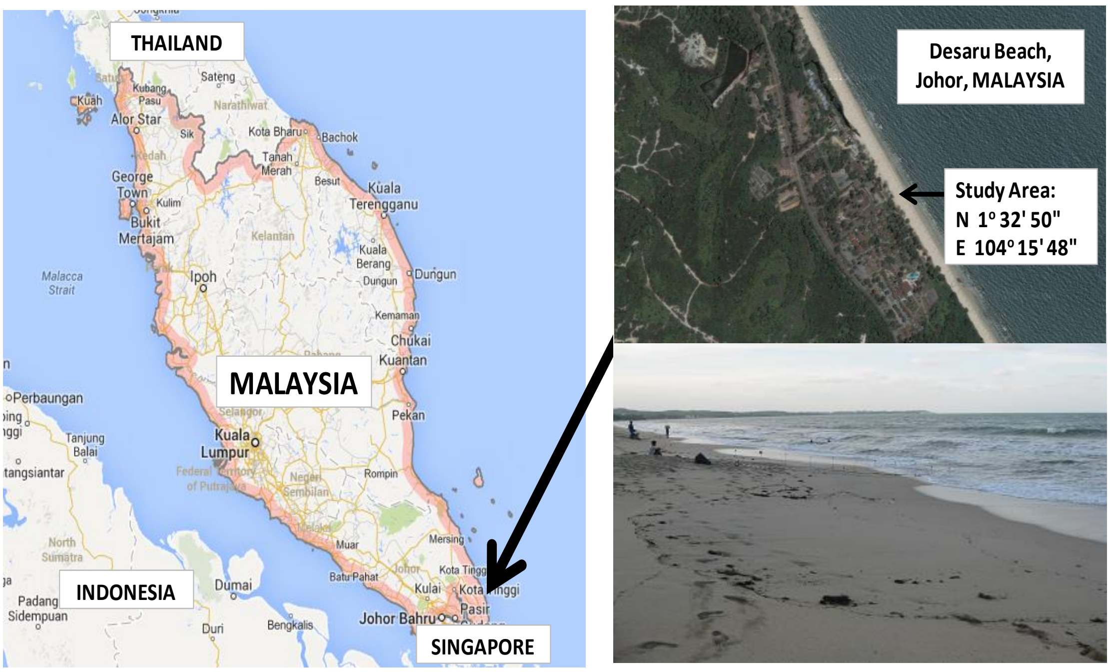

Figure 2: Location of Desaru beach

Methods and Instrumentations

There are several of field experiments were conducted during selected dry and wet period at Desaru beach in order to monitor and investigate the effect of seasonal variations on sandy beach profile changes. All data for swash zone characteristics for this field investigation likes flow depths and velocities were collected during the high tide.

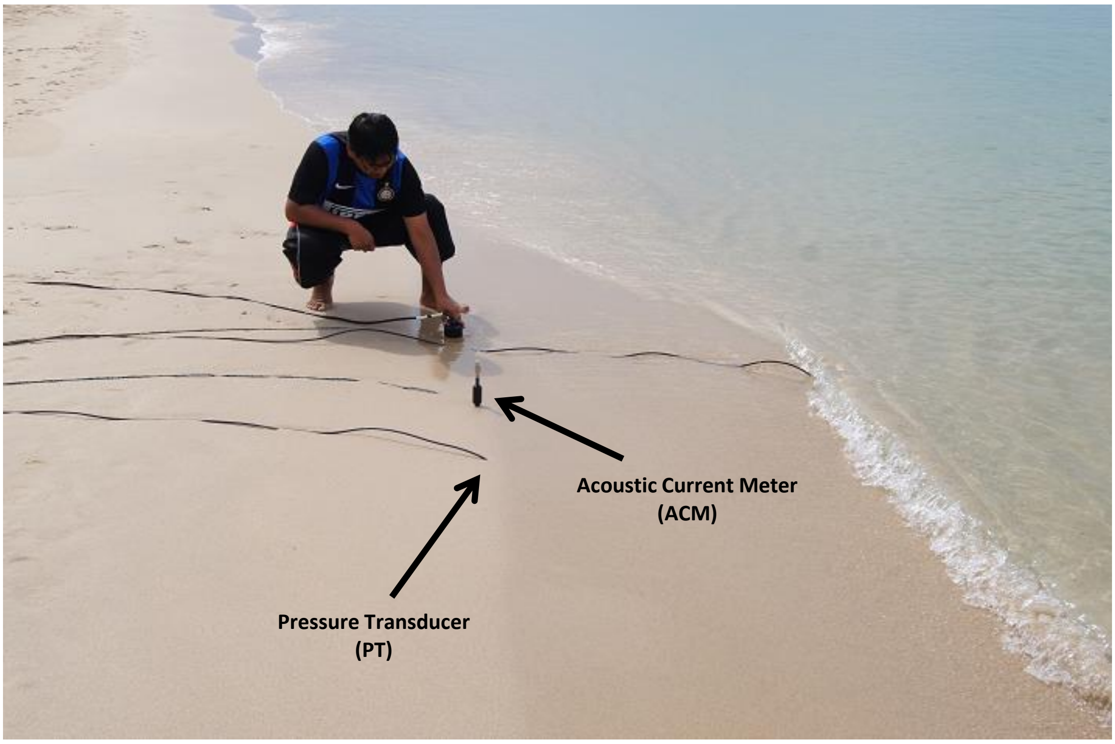

Figure 3: Photograph showing the PT and ACM were installed at the swash zone

For the swash zone characteristics monitoring as shown in **Figure 3**, two types of equipment were used for this study. Data on swash flow water depths were obtained using a pressure transducer (PT), which is two PTs buried 30 cm below the sand surface were deployed during this monitoring in the upper part of the swash zone area at a separation distance about 5 meter. This method has been used by Baldock et al., (2005) to measure swash flow water depths changes over a time frame of several hours or inter-swash changes. More on that Jensen et al., (2010) concluded that the deployment of self-logging pressure transducers in the swash zone is an accurate, easy and flexible method to acquire highly detailed data on water levels and bed elevations.

For swash velocities monitoring, about two Acoustic Current Meters (ACMs) were deployed for data of swash velocities during uprush and backwash were recorded at the same point as for PTs. The ACMs were installed as close to the bed as possible, about 1 cm above the bed. Both the PTs and ACMs were synchronized at a same sampling time at 1 Hz or every 1 sec per data and operated continuously during the experiment were running. For this paper, only the data from the upper swash point will be discussed here. From this monitoring station, the data for swash water depths and velocities were separated and analyzed for every single uprush and backwash events during high tide. All these experiments also recorded by a video camera as a backup for next data analysis processes. This separation processes for every single uprush or backwash activities were separated and analyzed by the direction of fluid velocities and also rechecked by using recorded video for every experiment. The position of sampling based on the beach face point (x = 35 m) and the tidal elevation (MHWS at 1.56 m LSD) at the field work were selected at approximately as the same high tide condition during the dry and wet periods. This condition setup is very important for this experiment in order to get clear view about the effect of difference period in Malaysia at the same position on the swash flow water depths and velocities.

For the effect of Malaysia's seasonal variation especially for dry and wet periods, one rain gauge station (**Figure 4**) was installed close to the study area to record rainfall data for every 10 min during the observation period. This rainfall data is very important for this study in order to relate the contribution of seasonal variations during the dry and wet periods to the swash zone characteristics. This station was checked monthly by a researcher in order to make sure this rain gauge operated successfully and the data from this station was downloaded at the same time by using a laptop. This data also was double-checked with a data taken from the nearest rainfall station from Malaysia's local agency, Department of Drainage & Irrigation (DID) at Bandar Penawar rainfall station, which is about 10 km from the study area.

Figure 4: Rain gauge station at Desaru beach

Data Analysis

In order to determine the variation of different periods, rainfall data from the study area was used to determine the most suitable monitoring time for dry and wet periods at Desaru beach. Based on recorded rainfall data, month of March 2014 was identified as suitable dry period time due to lowest monthly rainfall occurred in February 2014. Meanwhile for the wet period, month of November 2013 was straightly selected based on the heaviest rainfall distribution on that month due to the significant effect from Northeast monsoon. For data analysis of swash characteristics, the aim is to compare and analyze the 300 seconds of selected swash characteristics likes flow water depths and velocities for this field study under different seasonal variations (dry & wet periods). In order to investigate the effect of local seasonal variations to swash zone characteristics, the flow water depth and velocity profiles were selected and analyzed for the same highest tidal elevation during the dry and wet periods in the study area as shown in **Figure 5** and **Figure 6** respectively.

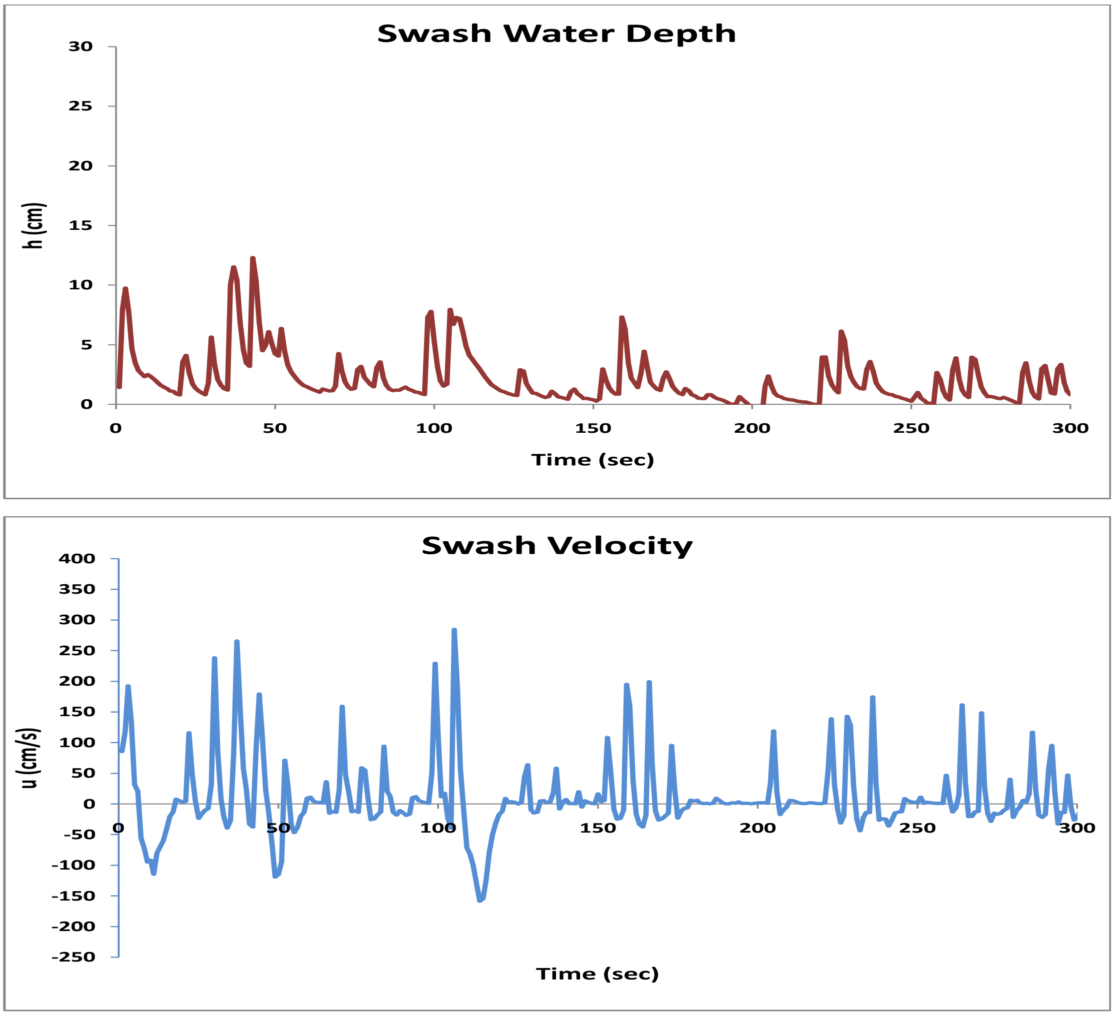

Figure 5: Profiles of flow water depths and velocities during dry period

In **Figure 5**, the profiles data for swash flow depths and velocities taken at the same high tide elevation on 16 March 2014 have shown the effect of seasonal variations on swash characteristics. During this month, the study area was experiencing the dry period and the end of the Northeast monsoon which has a lower wave attack and energy. This condition totally affected the swash water depth and velocity levels to become lower than during the wet season as shown in **Figure 6**. For the swash water depths comparison, it clearly showed that decreasing of swash energy happened during this period with an average depth was 2.1 cm with the maximum and minimum values were 12.3 cm and 0 cm respectively. This an important condition can explain why most berm was occurred at study area during the wet period before did not change due to wave attack with the limitation of observed uprush length occurred as far as at landward, which is shorter if compared with the furthest uprush length during the wet period. For the velocity data during this period, the highest values of uprush and backwash were detected at 2.85 m/s and 1.58 m/s respectively. It clearly found that the swash velocities was decreasing for the uprush and backwash flow but the backwash velocity was significantly reduced by greater infiltration effect due to believably high value of unsaturated beach surface during the dry period.

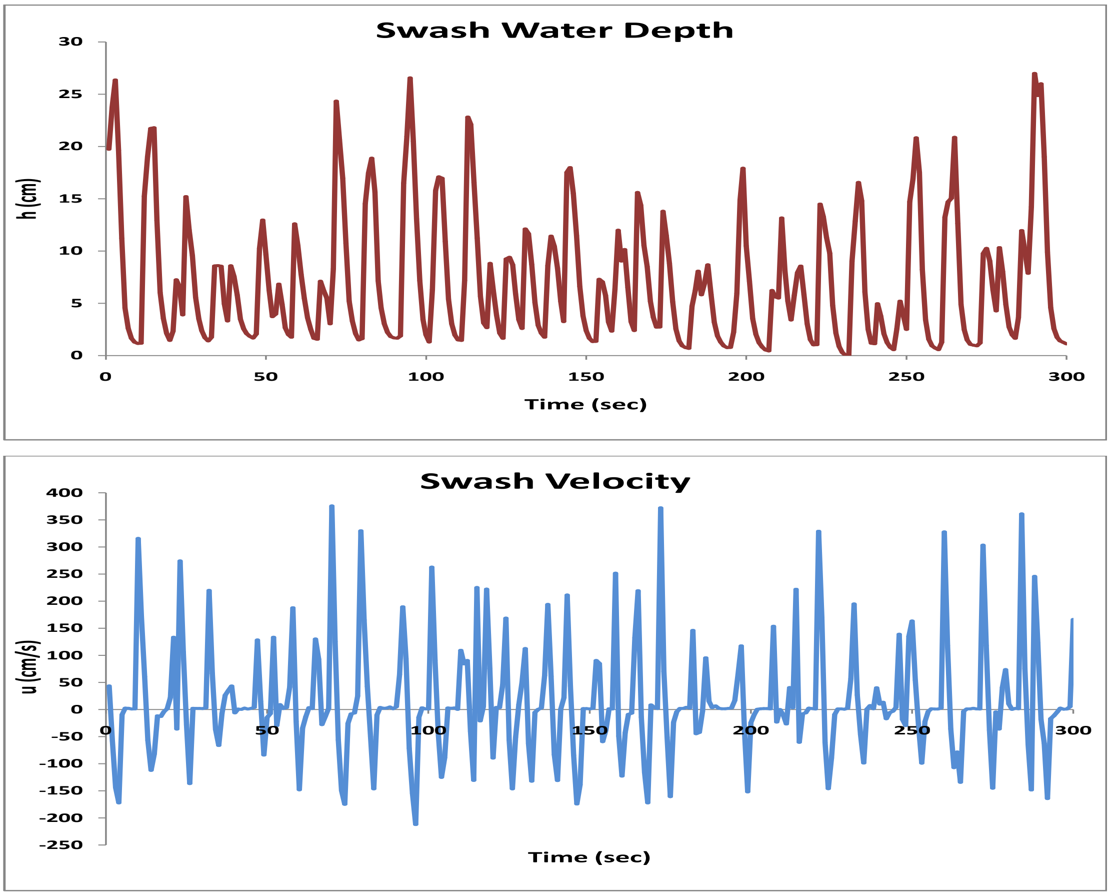

Figure 6: Profiles of flow water depths and velocities during wet period

During the wet period in **Figure 6**, the average depth was 7.1 cm with the maximum and minimum values were 27.0 cm and 0 cm respectively. For the velocity data, the highest values of uprush and backwash were recorded at 3.76 m/s and 2.13 m/s respectively. The sampling point for data profiles during the wet period, when the uprush flow came, there was always a maximum instantaneous acceleration in uprush velocity and followed by more steadily decrease until zero velocity at the end of the uprush flow. During this moment, it clearly showed that the maximum water depth always occurred when zero velocity reading at the end of uprush flow. In contrast, when the backwash flow took the action in the swash zone, the velocity increased gradually until it reached its maximum value. After that, the backwash flow depths and velocities decreased to zero until the new uprush flow came. This observation was consistent with other field study work done by Hughes (1997).

Table 1: Result Analysis of Swash Water Depth and Velocity

Swash Zone Characteristics	Parameters	Dry Period	Wet Period
Swash Water Depth	Mean Uprush, hu_{mean} (cm)	4.6	13.8
	Mean Backwash, hb_{mean} (cm)	2.2	10.4
	Ratio hu_{mean} to hb_{mean}	2.11	1.33
	Max Uprush, hu_{max} (cm)	12.3	27.0
	Max Backwash, hb_{max} (cm)	7.2	21.8
Swash Velocity	Mean Uprush, vu_{mean} (m/s)	1.30	2.00
	Mean Backwash, vb_{mean} (m/s)	0.35	1.08
	Ratio vu_{mean} to vb_{mean}	3.71	1.85
	Max Uprush, vu_{max} (m/s)	2.85	3.76
	Max Backwash, vb_{max} (m/s)	1.58	2.13

From **Table 1** as shown above, it is clearly shown that seasonal seasons at Desaru beach (dry and wet periods) have significantly affected the swash zone characteristics likes swash water depth and velocity. For every single swash event of water depth analysis, the ratio of mean water depth for uprush to backwash during dry and wet period is 2.11 and 1.33 respectively. These values are very important in order to explain the seasonal variations effect on beach morphological changes. For example, the ratio value during the dry period was higher than the wet period due to the effects of lower value of beach's moisture content and groundwater table. This phenomenon have promoted the higher infiltration rate of swash flow into the sand beach and it is also explained why the water depth of backwash have significantly reduced during dry period if compare during wet period. This unique phenomenon also explains why the ratio of swash velocity for uprush to backwash flows during dry period (3.71) higher than wet period (1.85). Still use the same mechanism such as swash water depth analysis, the backwash flow velocity during dry period was significantly reduced about 73.1% by greater infiltration effect and this phenomenon also have promoted the accretion processes in the swash zone area due to deposition of sediment transport especially during backwash activities. In contrast during wet period, the backwash flow velocity reduced only about 46.0% and this value contributed by the high degree of moisture content and created slightly decreased the flow volume and velocity in the swash zone area especially at the upper part.

Conclusions

The patterns of swash water depths and velocities for every single uprush and backwash during the dry period have shown why the accretion processes significantly occurred in the swash zone due to high infiltration effect during dry period. In this condition, the sediment or sand carried by swash water during the uprush and backwash flow has settled down easily on the beachface due to high infiltration process and this situation put the beach in the accretion mode. However, in order to understand swash zone processes clearly and how these affect beach profile response, Horn (2006) stresses the importance of direct measurements of key parameters such as hydraulic conductivity, moisture content and infiltration rates which must be carried out in the field.

Field measurements or monitoring have been relatively few in numbers and surprisingly, in Malaysia, there has previously been no interest in such study or research of swash zone hydrodynamics if compare to the surf zone. This complicated nature of flow within the swash zone include intermittent, shallow, bubbly and rapidly varying flows, making data collecting and analysis comparison between theory and experiments difficult to achieve. As a result, there are only limited experimental data on swash zone study. There is an obvious need to attract academicians and researchers in our country especially from universities, government bodies and local agencies to study the swash zone sediment transport processes. The seasonal climatic factors that affect the coastal groundwater table levels experienced here also would present an ideal opportunity for ideal field experiments or site observations to be conducted here. Thus, the outcomes or findings of these studies at least would contribute to the knowledge of swash zone sediment transport and would be highly anticipated by the coastal engineering scientific community around the world.

Acknowledgements

The authors would like to acknowledge the financial support provided by the Universiti Teknologi Malaysia through Research University Grant No. 02H58 and 07J10. We also would like to thank the Desaru Development One Holding Sdn. Bhd. for the permission to use the beach as a study area and also for the support in the field especially during monitoring works. Norasman Othman is grateful to the Ministry of Higher Education Malaysia and Universiti Malaysia Pahang for the sponsorship of his research studies at the Universiti Teknologi Malaysia.

References

Bakhtyar, R., Barry, D.A., Li, L., Jeng, D.S., Yeganeh-Bakhtiary, A.Y., 2009. Modeling sediment transport in the swash zone: A review. Ocean Engineering 36, 767–783.

Baldock, T.E., Barnes, M.P., Hughes, M.G., 2005. Field observation of instantaneous cross-shore free surface profiles and flow depths in the swash zone. Proc. Coastal Dynamics 2005, Barcelona, ASCE.

Baldock, T.E., 2009. Discussion of "Measurement of wave-by-wave bed-levels in the swash zone" by Ian L. Turner, Paul E. Russell, Tony Butt, [Coastal Eng. 55 (2008) 1237-1242]. Coastal Engineering 56, 380-381.

Elfrink, B., Baldock, T.E., 2002. Hydrodynamics and sediment transport in the swash zone: A review and perspectives. Coastal Engineering 45, 149–167.

Horn, D.P., 2006. Measurements and modelling of beach groundwater flow in the swash-zone: a review. Continental Shelf Research 26, 622–652.

Hughes, M.G., Turner, I., 1999. The beachface. In: Short, A.D. (Ed.), Handbook of Beach and Shoreface Morphodynamics. John Wiley and Sons, pp. 119– 144.

Hughes, M.G., Masselink, G., Brander, R.W., 1997. Flow velocity and sediment transport in the swash zone of a steep beach. Mar. Geol. 138 (1–2), 91–103.

Jensen, S.G., Aagaard, T., Baldock, T.E., 2010. Swash zone bed level changes and sediment entrainment at the surf-swash boundary. Proceedings of 32nd International Conference on Coastal Engineering (ICCE2010), Shanghai, China.

Longo, S., Petti, M., Losada, I.J., 2002. Turbulence in the surf and swash zone: a review. Coastal Engineering 45, 129-147.

Masselink, G., Puleo, J.A., 2006. Swash-zone morphodynamics. Continental Shelf Research 26, 661-680.