RIP CURRENTS AND THEIR SIGNIFICANCE IN THE NEAR-SHORE CIRCULATION SYSTEM

by

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Abstract

Near-shore circulation system on a barred beach was discussed with reference to shore-parallel and rip currents. Laboratory measurements of wave field, mean water elevations and 2D current system on a typical bar-trough beach profile is used for the discussion. After identifying the significance of rip currents in the near-shore coastal dynamics, it is attempted to find out a quantitative relationship between rip currents and the incident wave field. It is found that the strength of the rip current is very sensitive to the incident wave conditions and the position of wave breaking.

1. Introduction

1.1 Near-shore circulation currents

The area between the breaker line and the shoreline known as 'surf zone' is characterised by near-shore currents, moving in both along-shore and cross-shore directions. Currents that are moving in the shore-parallel direction are known as along-shore currents while those that are moving perpendicular to the shoreline are known as cross-shore currents. The generating mechanism of both along-shore and cross-shore currents is wave breaking in the surf zone. The strength and the direction of both types of currents depend on sea bottom bathymetry and incident wave characteristics such as wave height, wave period and wave direction. In addition to wave induced along-shore and cross-shore currents, strong off-shore directed currents concentrated in narrow channels in the near-shore zone are well known for a long time, especially to fisherman and skilled swimmers. These currents are known as 'rip currents'.

Near-shore water movement could be described in terms of circulation cells. These cells consist of a shoreward mass transport due to incoming waves carrying water in the direction of wave propagation, along-shore currents and seaward flow along rip currents. A typical near-shore circulation system consisting wave induced along-shore currents, cross-shore currents and rip currents is shown in Figure 1.

A rip current is a narrow seaward flow of water from the beach to the outside of the surf zone. They are fed by along-shore currents. The ideal form of rip current is symmetrical with equal feeder currents joining to form a rip current. Usually, when two along-shore currents that flow in opposite directions merge together, they turn abruptly towards offshore as a rip current as schematically shown in Figure 2.

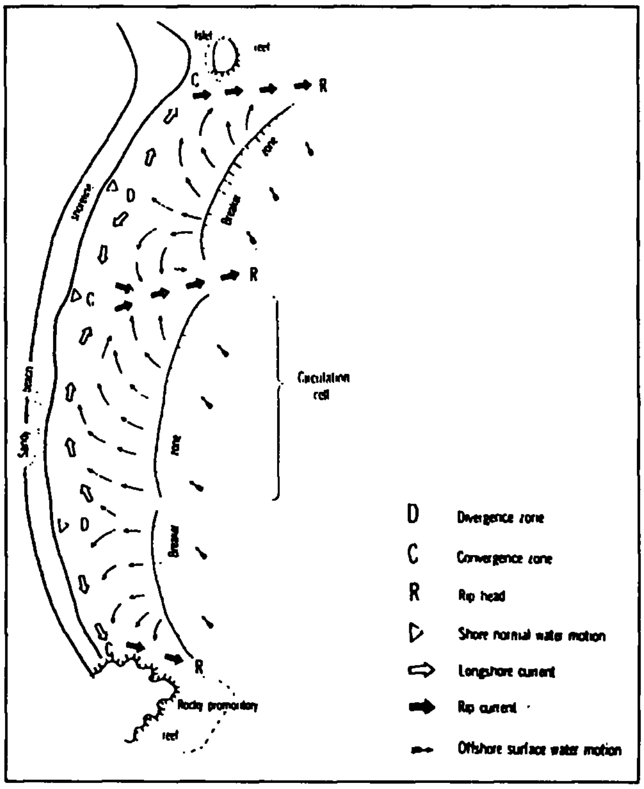

Figure 1 - A typical near-shore circulation system.

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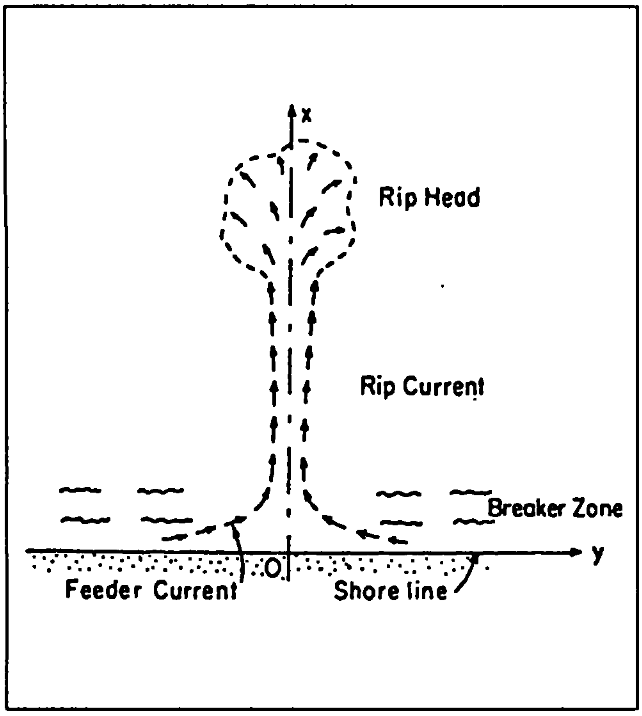

Figure 2 - Schematic view of a rip current.

The main factors affecting the occurrence of rip currents are the size and irregularity of incident waves, incident wave direction and wave breaking characteristics. The strength of flow of a rip current is directly proportional to the potency of wave activities. The coastal configuration and the sea bottom bathymetry are also of major importance in determining wave refraction, the angle of wave approach and wave breaking and hence rip characteristics.

Rip currents are commonly found in sandy beaches characterised by off-shore sand bars. The reason for this is the generation of strong along-shore currents due to the irregularity of wave breaking on the bar crest.

Rather than an isolated single rip current, they occur as regularly spaced system of rip currents along the shore. A standard pattern of each rip system is mainly referable to a particular wave field, bottom bathymetry and coastal configuration. The strength, direction, spacing, extent and the number of currents in a rip system vary both spatially and temporally with the change in incident wave field. Rip currents commonly tend to turn diagonally across the surf zone into the direction of wave approach. The spacing of the rip currents in a rip system are much larger than the width of a single current in the system. The length of a rip current varies depending on the strength of the current but, usually extends beyond the breaker zone. The general understanding is that the strength of the current reduces in the direction of flow. Therefore, after some distance of travel, they form so called rip heads and expand dramatically in width accompanied by a rapid reduction in velocity. Beyond the rip head, the current becomes well mixed with the surrounding wave motion and loses its identity.

When rip currents are well established, the sea bottom in the surf zone is characterised by rip channels which line across sand bars through the surf zone.

Despite their primary function of returning seawater carried inshore by incident waves, rip currents carry large volumes of sediment from the beach towards offshore in suspension. Therefore, they play a very significant role in sediment dynamics of the near-shore area and hence beach stability.

Rip currents were first described by Shepard et al. in 1941. His paper, which appeared in Journal of Geology, carries a general description of rip currents. A comprehensive series of field investigations on rip currents have been then carried out by Shepard and Inman in 1951. Putnam et al. (1949) and Inman and Quinn (1952) attempted to perform mathematical and statistical studies on rip currents. Bowen (1969) formulated an equation of motion of rip currents in terms of stream function. His study indicated that the driving force of near-shore circulation currents was provided by a characteristic distribution of wave stress in the near-shore zone known as 'radiation stress'.

Sonu in 1972 carried out an extensive series of field investigations on rip currents in Florida. He measured rip velocities, rip current patterns and velocity profiles across water depth to find that rip currents occur in the upper layers of the water column. Dalrymple (1975) discussed the causes of rip currents. He also discussed types of rips that occur with different beach states through an analysis of long-term field observations. In 1985, Short observed short term temporal variations of rip currents in Narrabeen beach, Australia. Zyserman (1989) determined the spacing and dimensions of rip currents on bar-trough beaches through numerical modeling. He also studied the overall stability ~~of a~~ beach with rip currents considering the overall sediment balance.

1.2 Objective of the study

After identifying the importance of rip currents in the near-shore circulation systems and associated sediment dynamics, numerous theoretical and field investigations have been reported over the last few decades. However, despite all the scientific advances so far, several aspects of rip current hydrodynamics and sediment dynamics associated with them are not fully understood quantitatively.

The objective of the present study is to look at the insights of rip currents quantitatively and their role in the near-shore circulation system through laboratory investigations. A series of experiments were done on a bar-trough beach profile with an artificially formed rip channel. The current field including alongshore and rip currents and wave drift were measured together with the incident wave field. The experimental programme is described in detail in section 2. Section 3 is devoted to present and discuss the results. Section 4 gives conclusions.

2. Experimentation

2.1 Experimental setup

The focus of the experiments was to investigate the near-shore circulation system including rip currents on a barred beach. The experiments were designed to explore the changes in the circulation pattern in detail with respect to change in incident waves and depth of submergence of the bar crest in a quantitative manner.

Experiments were carried out in a 30.0 m long, 4.0 m wide and 1.0 m deep wave flume in the Technical University of Denmark. A physical model beach with a characteristic bar and a trough with a rip channel was constructed in the flume using concrete blocks and cement-sand mortar. The scale of the model was in the order of 1:20. The offshore bar had a seaward slope of 1:20 while the slope of the beach was 1:14. The rip channel which ran across the bar from the trough was 1.0m wide. The trough was 1.9m wide and 0.13m deep. Model dimensions were selected to represent a typical barred beach with rip channels. The model setup is shown in Figure 3.

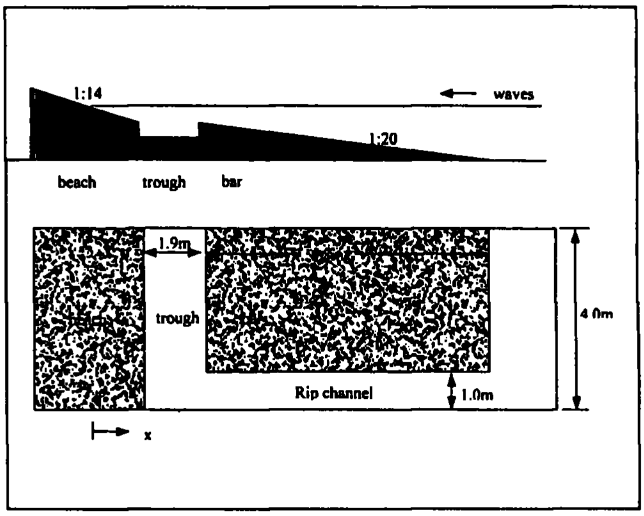

Figure 3 - Experimental setup

2.2 Experimental procedure

Experiments were done using regular waves. Incident waves were carefully selected to represent typical wind wave conditions. Waves were generated using a piston type wave generator. The whole test programme was divided into two phases. Aiming at investigating wave characteristics and associated current dynamics two test runs were carried out during the first phase of the test programme. Incident wave period and water depth at offshore were kept constants for both runs at 1.5sec and 0.52m respectively. The incident wave height was the only variable where 0.21m and 0.17 m high waves were used for test cases 1 and 2 respectively. At the selected offshore water depth, the bar crest was submerged by 0.1m.

It was decided to measure wave and the velocity fields in a 2D array of measuring points covering the whole experimental domain. Wave measurements were done at 72 points while currents were measured at 60 points as shown in Figures 4 (a) and (b) respectively. Capacitance type high precision wave gauges were used for wave measurements while velocities were measured by a laser doppler anemometer with a bust spectrum analyser at back scatter mode. The wave and current at any given point were measured simultaneously.

The objective of the second phase of experiments was to quantify effects of incident wave conditions and bar submergence on rip strength. This set consisted of four test runs under conditions given in Table 1. Each test run covered twelve offshore incident wave heights in the range of 0.06-0.24m.

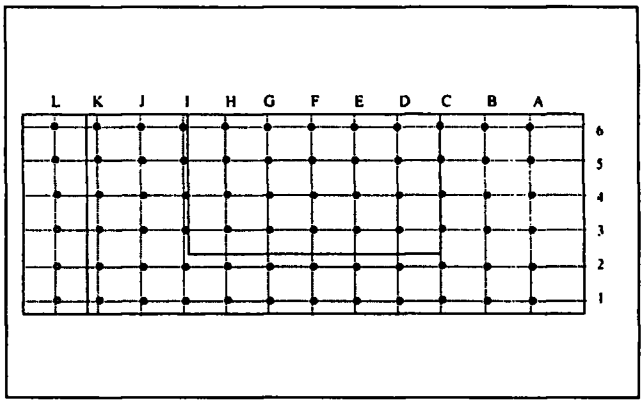

Figure 4(a)- Measurement points of waves.

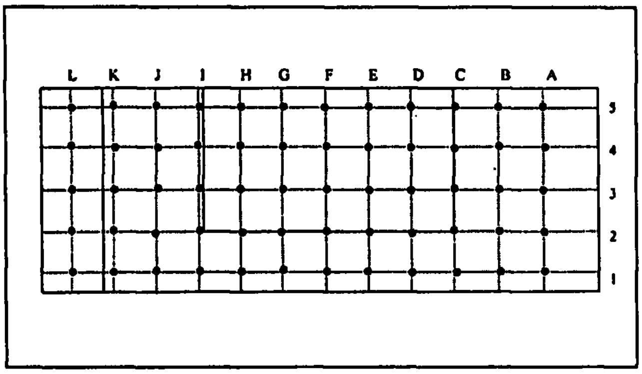

Figure 4(b)- Measurement points of currents.

In this case, maximum rip velocity was measured under different combinations of wave heights, periods and depths, of submergence of the bar crest. During this series of tests, only the current velocities within the rip channel were measured to detect the maximum rip velocity resulting from any given condition.

Table 1- Experimental conditions for test series 2.

Test case	T (sec)	Dc(m)
1	1.5	0.05
2	1.5	0.10
3	1.5	0.15
4	2.5	0.15

3. Results and discussion

This chapter is devoted to present some selected results obtained by the laboratory testing programme described in Chapter 2 and discuss them in detail with special emphasis to characteristics of rip currents.

Figure 5 shows wave height distributions along longitudinal sections through the bar-trough profile. The figure corresponds to the test case 1 of series 1. Channel 1 in the figure corresponds to the section along the rip channel. (Refer Figure 4 for channel numbers.)

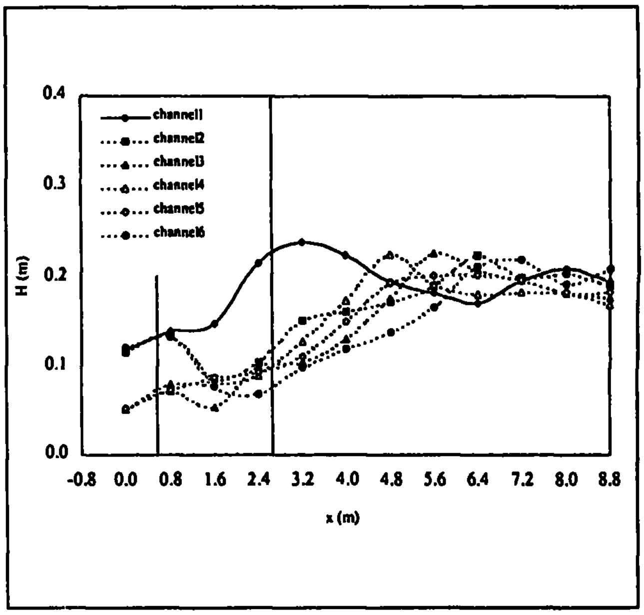

Figure 5 - Wave height distribution across the bar-trough profile.

A pronounced difference in wave height decay over the bar and in the rip channel is observed. Over the bar, wave breaking occurred at a significant distance offshore from the bar crest while in the rip channel, waves broke near its mouth. This phenomenon could be attributed to the difference in water depth on the bar and in the rip channel where the rip channel offers a greater depth than the bar. It is noticed that the rip channel creates a significant non-uniformity of waves in the along-shore direction.

Figure 6 shows mean water elevations in the presence of the wave field discussed in Figure 5. It is noted that even though there is a pronounced non-uniformity in the incoming wave field in the along-shore direction around the bar crest, such a non-uniformity could not be seen in the distribution of mean water levels. Mean water level gradients that should otherwise occur in the along-shore direction may have been balanced by the shore-parallel water flow. However, mean water levels in the cross-shore direction follow a very typical pattern where a water level depression (wave setdown) occurred near the breaker line followed by wave setup on the beach.

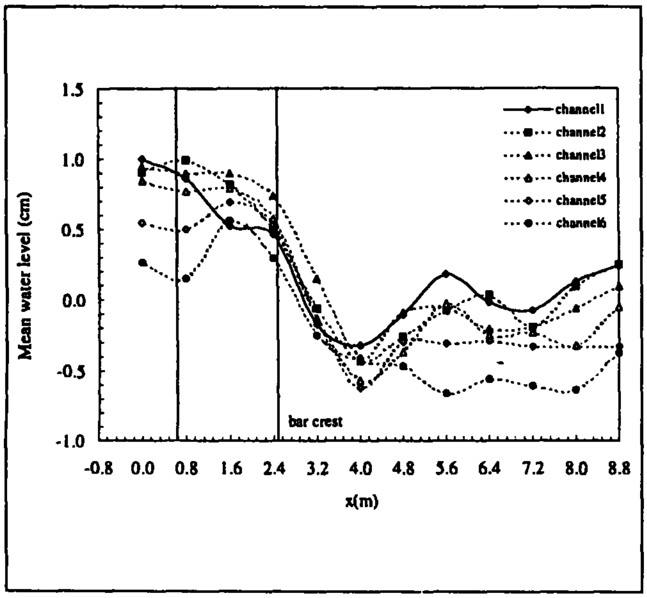

Figure 6 - Mean water level across the beach profile.

Figure 7 shows the 2D distribution of the near-shore current system resulting from the wave field given in Figure 5. Currents were measured at an elevation one third of the water depth above the sea bottom. Note that due to the prevailing inadequate water depth the currents on the beach could not be measured.

It could be seen that there is a net shoreward flow on the bar known as 'wave drift' or 'mass transport'. The current then turns into the shore-parallel direction in the vicinity of the bar crest finally forming a strong seaward flow in the rip channel. The location at which the shoreward flow converted to a shore-parallel flow was the location of wave breaking. It was noted that in most occasions, the flow entered into the rip channel without crossing the bar crest. The seaward flow in the rip channel is so strong such that its magnitude was found to be in the order of maximum water particle velocity induced by the incoming waves.

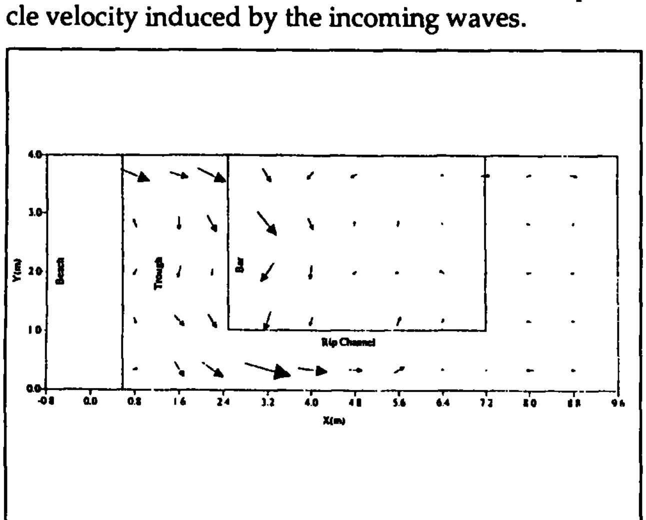

Figure 7 - Distribution of near-shore currents on the bar-trough profile.

The maximum rip velocity $[(V_{rip})_{max}]$ is drawn against wave height *(H)* in Figure 8 for two wave periods, 1.5 and 2.5 seconds. As could be seen in the figure, the rip strength increases with increasing wave period *(T)*. This could be explained by the fact that wave period is directly related to wave stress. Therefore, for a wave of a given height, stress released at breaking from a wave with a large period is higher than that of a wave with a small period. As a result, forcing available for the generation of a rip current will be larger for waves with larger periods.

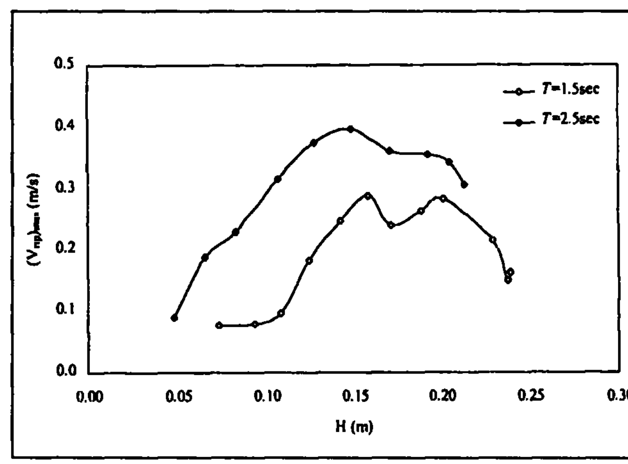

Figure 8 - Effect of incident waves on rip strength.

Rip velocities follow a rather complicated pattern with changing wave height. The strength of the rip current should theoretically increase with increasing wave height as a result of the increasing wave stress released at wave breaking. However, the figure shows that there is a limiting wave height beyond which rip strength diminishes despite the increase in wave height. This could be explained by the fact that large waves break far behind the bar-crest at offshore thus resulting weak along-shore currents in the surf zone. Therefore, rip velocities become smaller.

Figure 9 gives the maximum rip velocity against wave height for three different depths of submergence of bar crest (D_c). The wave height at which the rip current is strongest increases with the increasing depth of submergence. But, the maximum rip velocity that could possibly occur for a given water depth is not significantly sensitive to changes in water depth.

During the test series 2, it was observed that the location at which the maximum rip velocity occurred varies with varying incoming wave conditions. Figure 10 shows the migration of the strongest rip position along the rip channel with changing wave height. x is measured in the offshore direction starting from the mouth of the rip channel. In this case, wave period and depth of submergence of the bar crest were kept constants. For a given wave period and depth of bar submergence, the strongest rip position migrated offshore with increase in wave height.

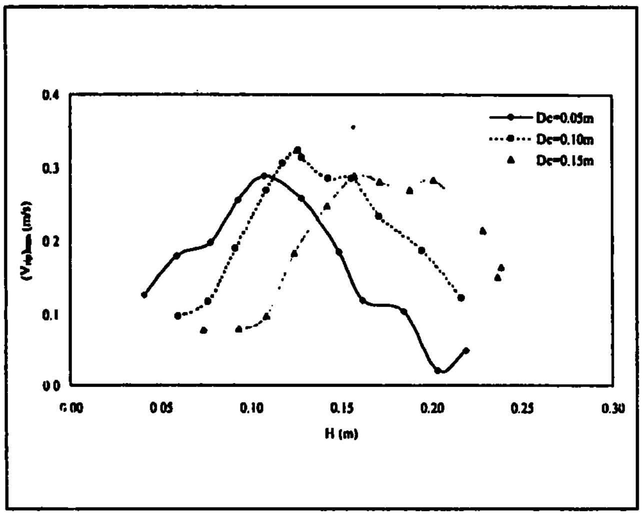

Figure 9 - Effect of bar submergence on rip strength.

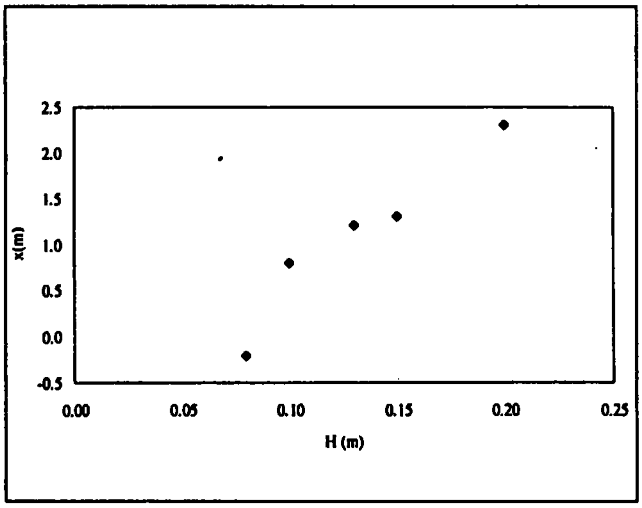

Figure 10 - Effect of wave height on strongest rip position.

4. Conclusions

It is seen from the above investigations, that the near-shore current system on a sandy beach with a typical bar-trough profile, is driven by the imbalance of wave forcing released at wave breaking. On the other hand, rip channels and rip currents play a very significant role in the generation of non-uniformity in wave forcing and hence the circulation system.

Rip strength varies with change in incident wave conditions. It increases with increasing incident wave height only up to a certain limiting wave height and then diminishes. Also, the region at which rip current is strongest for a given wave height migrates offshore when wave height increases. Therefore, extreme wave conditions such as monsoon waves or storm waves may not have a pronounced effect on the rip strength in the surf zone. However, stronger rip currents will be resulted by waves with large periods.

The depth of bar submergence also has a pronounced effect on rip strength. Therefore, at locations where tidal fluctuations are very large, rip velocities and maximum rip position may significantly vary with the tidal cycle.

Along-shore and shoreward directed currents induced by wave breaking, move sand particles in the surf zone in both shore-parallel and shoreward directions in suspension. Incident waves also carry sediment by mass transport either in suspension or as bed load. As rip currents travel in the seaward direction through the surf zone, they carry large volumes of sediment offshore from near-shore areas. As a result, rip currents act as sediment sinks.

When a beach consists of fine sands which is very typical in the tropics, volume of sand particles in motion under near-shore circulation system is extremely large thus creating very dynamic and unstable beaches.

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