Reprinted from Coastal Dynamics '97: Proceedings of the International Conference on Coastal Research through Large Scale Experiments Plymouth, UK – June 23-27, 1997

# **Rip Channels and Nearshore Circulation**

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## Abstract

Results from an experimental investigation into the effects of rip channels on the nearshore circulation system are presented. The results show that periodic channels in an otherwise longshore uniform bar induce longshore pressure gradients that drive pairs of counter-rotating circulation cells. Dense measurements of wave height, wave setup, and induced currents are presented. In addition, evidence of secondary circulation cells close to the shoreline is also given. Finally, the rip current is shown to contain low frequency oscillations probably due to jet instability and also tends to meander back and forth in the rip channel.

# Introduction

Previous researchers have addressed the question of what mechanisms regulate the flows near a longshore bar. Dalrymple (1978) indicated that small longshore pressure gradients (neglected in most models of longshore currents) can drive strong longshore currents if the bathymetry is longshore varying. Putrevu *et al.* (1995) extended Mei and Liu's (1977) work to develop a semi-analytical solution to study the effect of alongshore bathymetric variability on longshore current predictions. These results again confirmed that longshore pressure gradients can substantially alter longshore current predictions. Recently, computational results (Sancho *et al.*, 1995) for the wave-induced flow over a rip-channel and barred beach showed that the longshore pressure gradient strongly contributes to the longshore momentum balance. However, it is still an open question as to which mechanisms govern how much water flows over the bar (Hansen and Svendsen, 1986), how the mean water level varies, and how rip currents in rip channels through the bar are influenced by these factors.

The concept of the rip current was first introduced by Shepard (1936) and since then many researchers have made qualitative observations of rip currents and their effects on nearshore morphology and circulation (e.g. Mckenzie, 1958; Short, 1985). Additionally, in the field, rip currents tend to be transient and they tend to elude investigators intent on measuring them with stationary instrument deployments, though some quantitative measurements do exist (Sonu, 1972; Bowman,

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1988; Tang and Dalrymple, 1989). Therefore, the laboratory is very conducive to the study of nearshore circulation in the presence of rip currents since the environment is more easily controlled.

### Physical Model

The results presented herein are from an ongoing experimental investigation being conducted in the  $20m \times 20m$  directional wave basin at the Center for Applied Coastal Research at the University of Delaware. The basin (Figure 1) contains a planar concrete beach of 1:30 slope, along with a steeper (1:5) toe structure. A discontinuous longshore bar made of molded plastic was attached directly onto the beach slope. The crest of the bar is 6cm above the planar beach and it has a parabolic shape in the cross-shore. The discontinuities result from the two gaps in the bar which act as rip channels and tend to fix the location of offshore directed rip currents depending on the wave conditions. These rip channels are located at 1/4 and 3/4 of the width of the basin and are each 1.8m wide with sloped sides.



Figure 1: Plan view and cross-section of the experimental basin.

Separate arrays of ten capacitance wave gages and 3 acoustic-doppler velocity meters (ADV) were used to measure the generated wave fields, mean water levels  $(\overline{\eta})$ , and circulation patterns ( $\vec{u} = (u, v)$ ). The measuring procedure consists of simultaneously initiating monochromatic wave generation and data collection and then collecting approximately 27 minutes of data sampled at 10 Hz. The relatively long recording time allows us to observe the development of the circulation system as it evolves to a steady state. Because of the limited number of measuring instruments available, the measuring procedure is to repeat the test for multiple runs of the same wave conditions in order to achieve a dense coverage of the nearshore region. Figure 2 shows the measurement locations for the 29 runs described in this paper. The location of wave measurements was chosen such that the mean water surface elevations governing the flow through one of the rip channels would be resolved. The location of ADV measurements spanned a wider area in the basin in order to evaluate any asymmetry in the circulation. The ADV measurements taken shoreward of x=10.85m were taken 3cm from the bottom and, for the present discussion, it is assumed that the measurements approximately represent the depth-averaged flow below wave trough level. The offshore ADV measurement lines at x=10m,9m were taken 4cm and 5cm from the bottom, respectively. The still water line was at x=14.89m, the wavemaker at x=0m, and the water depth at the bar crest (x=12m) was 3.6cm.



Figure 2: Measurement locations for wave gages  $(\times)$  and ADVs  $(\circ)$ .

#### **Results - Wave transformation**

The measured rms wave heights are shown in Figure 3a. The offshore wave height measured at the stationary gage (x=4m,y=13.2m) was  $H_{rms}$ =4.8cm with a frequency of 1 Hz and the waves were generated normally incident to the beach. The wave height at the offshore location was very repeatable and had a standard deviation of 0.6mm over the 29 runs. The wave heights measured in the nearshore were slightly more variable from run to run with most of the variability taking place in the region of the rip current. The spatial variation of wave heights indicates that as the waves approach the bar they are fairly uniform in the longshore direction except for near the rip channel (y=12.9-14.7m). Due to the presence of the opposing rip current, the waves are much higher through the rip channel and the breaking process is less dramatic as the waves that travel through the channel decay at a slower rate and remain higher than elsewhere until very near to the shoreline.

The spatial variation of  $\overline{\eta}$  is shown in Figure 3b. The variation of  $\overline{\eta}$  is essentially opposite to that of  $H_{rms}$  (note the change in figure orientation). As expected, the setup is highest shoreward of the bar due to the breaking process and, in the longshore direction, the setup is greatest away from the channels (except for very near to the shoreline). The induced longshore setup gradient shoreward of the bar drives the flow towards the rip channels where the flows converge and are driven out through the rip channel.



Figure 3: a) Measured rms wave heights b) measured setup/setdown. Note the change in horizontal orientation between the figures. Still water shoreline located at x=14.8m.

Figure 4 compares the cross-shore variations of  $H_{rms}$  and  $\overline{\eta}$  measured through the channel and in the center of the basin. Notice the largest measured longshore gradients are at x=12.3m which is just shoreward of the bar in what would be considered the bar trough. It is also interesting to note that at x=14m, near the shoreline, the longshore gradients are reversed which drives a reverse flow away from the rip channel close to shore.



Figure 4: Cross-shore profiles of a) $H_{rms}$  b) $\overline{\eta}$ . Solid lines represent y=9.2m (bar), dashed line y=13.65m (rip channel); c)bathymetry profile.

### **Results - Circulation**

Figure 5 shows the general circulation pattern induced in the basin. The current vectors represent the measured mean currents computed from a time average of

the last 819s of each data record. It is evident from the measured flows that there is a primary and secondary circulation and each circulation consists of a pair of counter-rotating cells. The primary circulation consists of the converging feeder currents, the rip current, the diverging flow at the exit of the channel, and the return flux driven shoreward over the bar. Since the ADVs were deployed below trough level, the mass flux brought shoreward over the bar in the wave crests is not represented by these measurements. The maximum flow rate  $(\vec{u})$ was 17.5cm/s and occured in the rip channel at x=12.25m, y=14.15m. The secondary circulation is driven by the breaking near the shoreline of waves that have shoaled through the channels. Here the breaking process creates a local maximum in the setup which drives a divergent flow away from the channel. This flow travels along the shoreline and eventually turns and joins the feeder currents of the primary circulation. As a consequence of the two circulations, the longshore current behind the bar contains a strong shear near the channels and is likely to be unstable.



Figure 5: Induced circulation in basin. Vectors represent time average of last 819s of each ADV record.

Figure 6 shows the evolution of the longshore current profile as it establishes itself near its starting point in the center of the basin and grows towards the channel. The center of the basin is in cross-shore balance which means the flow carried shoreward by the waves is returned directly offshore in the undertow and no longshore current exists. However, towards the channel the longshore current gains in strength with the strongest longshore current located just shoreward of the trough at x=13m. Correspondingly the reverse current located near the shoreline also gains in strength with the strongest cross-shore shear in the current profile located at y=12.2m.

Figure 7 shows the longshore variation of the cross-shore flow measured near the shoreward edge of the central bar section. Negative u velocities indicate offshore flow or undertow and the variation of u indicates that the strongest offshore flow occurs in the center of the basin (y=9.2m) and decays to zero near the channel (y=12.2m). Assuming that the flow below trough level is fairly depth uniform and since the wave field is longshore uniform along the bar, the



Figure 6: Longshore current profiles. Longshore current is assumed to be zero at the still water shoreline (x=14.8m).



Figure 7: Longshore variation of cross-shore velocities along the central bar. ADVs located 3 cm from bottom (x=12.3m).

decrease in undertow towards the channel implies that flow is being entrained in the shoreward directed mass transport over the bar and further strengthens the longshore mass flux behind the bar.

#### **Results - Low frequency motion**

In addition to the general circulation pattern measured during the tests, another interesting aspect of the experiment was the presence of fluctuations and meanders in the rip current. Figure 8 shows three 1638s records of velocities (u, v)measured simultaneously by three ADVs spanning 1m in the longshore direction and centered near the channel exit. The time series show that the rip becomes relatively steady at about t=800s. As the offshore flow first begins to strengthen at y=13.15m (t=1050s), distinct fluctuations appear in both the u and v velocities. Notice that the strengthening of flow and the onset of oscillations occurs first at y=13.15m and then at y=13.75m and y=14.15m at successively later times. The strengthening of the flow from one sensor to the next represents a meandering of the entire rip in the positive y direction and this occurs at a slower time scale than the oscillations present within the rip itself. The oscillations seem to have a relatively regular frequency during t=1050-1638s and are more easily visible in the longshore velocities since they do not contain the wave induced oscillations.



Figure 8: Time series of a)cross-shore velocity b)longshore velocity measured at exit of rip channel.

Spectral analysis of the longshore velocity records of the rip current are shown in Figure 9 (a and b). The spectra contain strong energy peaks near T=20s. In contrast, the longshore velocity spectra measured in the feeder currents and in the secondary circulation cells (Figure 9c,d) contain more energy at longer periods. Simultaneous visual observations and video recording of the rip current were made throughout the experiment with the aid of dye injected into the feeder currents. Besides following the dye patterns, it was also possible to track the location of the rip by watching the distinct breaking pattern (whitecapping) of the incident waves which was limited to the region of the strongest rip current (rip neck) (note: elsewhere wave breaking occurred at the bar crest). It was difficult to visually observe the 20s oscillations of the rip current. What was seen instead was the slower time meandering back and forth of the rip current in the channel. This supports the idea that the 20s oscillations are probably smaller scale vortices being advected with the current that are generated due to flow instability mechanisms. These oscillations are distinct from the larger scale, slower, side-to-side meanderings of the entire rip current which in turn cause the primary circulation cells to shrink and stretch along with it.



Figure 9: Measured spectra of longshore velocities from rip current a) and b) during t=1024s-1638s, D.O.F.=12,  $\Delta f$ =.00977Hz. Measured spectra of long-shore velocities from c)feeder current and d)secondary circulation, t=0-1638s, D.O.F.=8,  $\Delta f$ =.00244Hz.

### **Results - Wave-current interaction**

The presence of strong currents in the region of the rip channel greatly affected the local wave field. The most obvious visual effects were refraction around the rip leading to criss-crossed wave crests shoreward of the rip, wave steepening/breaking on the rip, and subsequent diffraction of the relatively higher waves that had shoaled through the channel. In order to assess the effects of the rip on the incoming waves, the spectra of the waves entering the rip channel are compared to the spectra of the waves which travel over the bar in the center of the basin (Figure 10).

Figure 10a shows that as the waves encounter the strong opposing current  $(u \sim O(10 \text{ cm/s}))$  energy is transferred to the sidebands (f=.95,1.05 Hz) of the spectral peak frequency. In addition, there is a low frequency peak located at f=.05 Hz.



Figure 10: Comparison of wave spectra measured in the channel (y=13.65m, solid line) and in the center of the basin (y=9.2m, dashed line), t=819-1638s, D.O.F=16,  $\Delta f$ =.00977.

This effect is not seen in the waves measured at the same cross-shore location (and same depth) in front of the central bar. As the waves shoal through the channel the sidebands decay (Fig.10b,c) and near the shoreline (Fig.10d) the spectra have a very similar shape. It is also important to notice that the low frequency energy (f=.05Hz) present in Figure 10a is two to three orders of magnitude smaller than that shown in the rip spectra (Fig. 9a,b). Since the oscillations in the rip at f=.05Hz are much larger than the low frequency wave energy measured near the rip it is unlikely that the current oscillations are a manifestation of resonant tank modes (seiching/standing edge waves). In addition, wave spectra measured very near to shore (x=14m) do not show any significant energy in the f=.05Hz frequency band further indicating that the wave energy at this frequency measured near the rip is not due to basin resonance.

### Discussion

The experimental results give a detailed description of the nearshore hydrodynamics existing on a barred shoreline with periodically spaced rip channels. The relatively dense set of measurements made during this experiment provide good resolution of the longshore variations in wave height and wave setup/setdown induced by the experimental bathymetry. A somewhat more extensive set of current measurements show that for the experimental wave conditions a complex circulation system exists. The circulation consists of primary and seondary circulation systems, each containing a pair of counter-rotating cells. It is expected that the data set will be very useful for the testing of computational models of nearshore circulation.

In addition, visual observations and data analysis of one of the rip currents present during the experiment shows that the rip tends to be unstable and contains oscillations of approximately 20s period. These oscillations are distinct from the larger scale, longer period meanderings of the entire rip current structure. These meanderings were observed to cause a shrinking and stretching of the primary circulation system associated with the rip. The feeder currents and secondary circulation cells are shown to contain long period oscillations related to the meandering of the rip current.

Finally, the experimental results indicate significant wave-current interaction occurs in the vicinity of the rip. Initially monochromatic waves propagating into the opposing rip current gain energetic sidebands. These sidebands disappear as the waves shoal past the rip neck. It is deemed unlikely that the low frequency energy (f=.05Hz) present in the waves near the rip and in the rip itself is due to resonant basin oscillations.

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