seasonal beach changes and elevation sufficient to protect from a design wave or flood event (normally the 100-year storm or flood). These examples combine spatial concerns – bluff erosion and landslides, or beach erosion and flooding – over a temporal period – the anticipated life of the development. (City of Malibu, 2002)

A second planning option for hazards is a formalized program of removing the development potential of hazardous lands. In areas where there are undeveloped lots that would present a number of physical constraints to development – very small lots, lots on steep slopes, lots in sand dunes, and such. There can be programs where the owners of these properties can "market" the development rights from these constrained sites to other locations where the development scale is limited by other zoning elements. In the Santa Monica area, the available resources and infrastructure have been examined and used to establish limits on new housing starts. As part of this program, each new house is accompanied by the relinquishment of development rights on another property. (CCC, 1996; Johnson 1997)

Engineering Options to Coastal Hazards

Engineering covers the physical efforts to make buildings more hazard-resistant and efforts taken to protect both the people in buildings and the property. Engineering options cover such things as tie-downs, caisson foundations, shear walls, moment frames, breakaway walls, fire-retardant roofs, smoke detectors, and storm shutters. Some engineering options have improved over time – with new materials and improved understanding of building dynamics and hazard forces. In general, newer engineering tends to increase damage resistance and building strength over time.

State-wide, the 1982/83 El Niño storms destroyed 27 homes and 27 businesses, and damaged over 3,000 homes and 900 businesses, with a total cost of $100 million US. In Santa Monica, many of the damaged or destroyed buildings were small beach houses. By 1997/98, when the area was attacked again by major El Niño storms, most of the buildings were more robustly built. The level of destruction was far less extensive than the 1982/1983 storms, in terms of the quantity of destruction. But, the value of buildings and the investment in coastal living had grown so much that the costs for the 1997/98 El Niño were much higher financially.

Monitoring Options to Coastal Hazards

Coastal hazard monitoring options cover efforts to track weather patterns, waves, currents, changes in water level, tide gauges, landslide movement, water temperature and pollutants. This component of hazard prevention and response has two roles – providing better understanding of the hazards and providing an early warning system for various hazardous condition or locations or populations that may be at risk.

Hazard monitoring has changed dramatically over time. Even in the latter part of the 20th century, weather forecasts contained a large amount of uncertainty. At present, weather patterns are carefully tracked and most short-term weather forecasts are fairly accurate. Ocean/atmospheric monitoring could provide credible warning of storms and flooding. Monitoring has also increased public awareness of hazards. Along the Pacific coast in the early 1980s, few people had heard the term El Niño or recognized the connection between oceanic conditions and storms. By 1997/98, most people were familiar with El Niños and their possible climatic effects.

Major elements of monitoring are data, data analysis and distribution. The Internet had transformed the way information is used and distributed. Data that once were only compiled days or weeks following a hazard event and distributed in books or reports can now be compiled in almost real time and can be distributed to anyone using the internet. Currently, data users range from oceanographers, coastal engineers and scientists to surfers and vacation planners. Real-time information on currents can help track oils spills or storm water discharge for water quality clean-up efforts, or it can help trans-oceanic shippers optimize routes for energy saving. Data can be provided immediately on the Internet to vast numbers of users with existing distribution processes. The applications of data and options for hazard prevention and response can grow as more people learn of what is available.

Rescue Options to Coastal Hazards

The rescue component of coastal hazards includes many of the real-time hazard efforts such as beach patrols, fire, police, spill responders and lifeguards. Traditionally, rescuers react to hazardous events and try to contain or minimize risk. This effort has often been effective. For example, at guarded beaches nation-wide there is about one drowning per 18 million beach visitors. In 2003, there were over 50 million visitors to LA County beaches and only one drowning on the guarded beaches. Guards made over ten thousand rescues and provided medical assistance to over 20 thousand visitors (USLA, 2004).

In the future, the guard effort can be expanded to beach areas that are not now guarded. Guards can be added to match increases in beach attendance. Much of the work of lifeguards is to respond to unusual water conditions like rip currents and sneaker waves. In the future, guards can also be expected to respond to unusual water conditions such as tsunamis, resulting from earthquakes or landslides. In LA County, the office of Emergency Services has trained the lifeguards to recognize the signs of a near-field tsunami. Lifeguards are also being linked into the tsunami-warning network that provides alerts and warnings about far-field events. This is an adaptive approach to add preventative measures to traditional rescue efforts.

Multi-Hazard Prevention and Response

The early 1990s was one of the difficult periods for Santa Monica Bay. Several large coastal storms and large rain events occurred during the 1992/93 winter. Coastal properties had been pummeled by waves and inland properties were inundated by runoff and debris flows. The saturated soils triggered several landslides that destroyed buildings and roads. In the fall of 1993, a firestorm went through some of the same areas, adding to the previous damage or destroying some of the structures that had survived the waves, floods and debris. The winter clean up had occurred before the fall 1993 fires, but many individuals and communities were still dealing with the aftermath of those events when the fires happened. However, the responses to these individual events were never fully coordinated, and each type of damage was being covered slightly differently. In addition, property owners who wanted to combine their losses, vacate their property and use the insurance payouts to build in a safer, less hazard-prone area were not able to transfer the funds to another site. This coincidence of several hazards in such a short time period is not unique, however, the program responses were not able to address this version of a multi-hazard event in a comprehensive fashion. As a result, each component was addressed, and new structures have again been placed in areas with a potential for addition hazard events.

Both the 1982/3 El Niño and the 1997/98 El Niño caused extensive damage throughout the Santa Monica Bay area. The main damage resulted from wave impacts, creek and stream flooding, debris flows and landslides. The buildings that had been destroyed by the 1982/83 events have been rebuilt by 1997 – all as more resistant structures, and many as larger and more costly structures. In California, regulations allow reconstruction of buildings destroyed by natural disasters to be rebuilt in the same location and up to 10% larger. While planning efforts could identify less hazardous building sites, almost all buildings replaced following the 1982/83 El Niño were rebuilt in the same footprint. In 1997, the ocean monitoring systems had detected the development of a strong El Niño in the Pacific Ocean. In the fall of 1997, coastal residents were being advised that there could be frequent, intense storms, frequent rainstorms with large amounts of precipitation. Many agencies, including the California Coastal Commission were providing recommendations for El Niño preparedness. The level of preparation in advance of the 1997/98 storm season far exceeded that which had occurred in 1982/83; many buildings were protected by sand bags, gutters cleaned, detention basins emptied, and, streambeds cleared of vegetation. Monitoring, better engineering, planning and preparation had reduced the level of damage from what had happened in earlier events. Many of the locations that had been damaged in 1982/83 were damaged again in 1997/98; in most situations, the reoccupation of these sites will continue to expose new structures to hazardous conditions.

Conclusions

Many individual hazard events are best addressed by multiple responses. An example is with far-field tsunamis where the monitoring network identifies the wave condition and lifeguards warn beach visitors that there may be a tsunami and that they should move to high ground. Many multi-hazard events can be anticipated, for example, storms that cause extensive mud and debris slides following a large fire, poor water quality following an intense rain. Multiple events normally are best addressed by multiple elements of prevention and response. However, it can be difficult to adjust from initial response efforts to those more appropriate for the subsequent hazard.

Planning has been shown to be an effective approach to multiple hazards, such as the concern for bluff stability and erosion, or beach erosion and flooding. However, planning is often most effective for hazard avoidance – before development is in place. Population pressures can be expected to increase; however, there will be fewer low hazard locations that can accommodate future demands for housing and business sites, transportation corridors and infrastructure routes. Planning techniques will be available, but opportunities for hazard avoidance may decrease as more people flock to coastal regions. Engineering will continue to provide stronger and more resilient buildings. But while engineering will strive to make stronger and stronger buildings, buildings will never be able to withstand every hazardous event. Monitoring and early warning efforts will be increasingly important to anticipate and prepare for potentially hazardous events. In combination, these three options seem to have helped reduce the number of coastal hazard fatalities; however, the losses in terms of societal disruption, as well as the direct costs of property damage continue to grow. And, hazards will never be completely avoided, and thus rescue components will remain part of the hazard response efforts.

Acknowledgments

The University of Southern California provided support for this effort. Neither the California Coastal Commission nor the USC Sea Grant Program has approved the material in this report.

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Laboratory Measurements of Rip Current Pulsations

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Abstract

Laboratory measurements of a rip current system were obtained from a series of experiments in a directional wave basin using both in situ instruments and optical based methods. The in situ measurements include both water level and velocity measurements at key locations in theflow domain and Lagrangian drifters were recorded with digital video. Rip current pulsations were investigated for both monochromatic and bi-chromatic wave conditions. Although the rip current system had a response at the forced group frequency, there was significant energy at additional un-forced frequencies. The temporal relationship between rip mechanisms was also investigated for bi-chromatic wave conditions. A considerable lag exists between the peak of the pressure gradient forcing and the peak of the resulting current.

Introduction

Rip currents are channels of water that flow offshore starting near the shore and extending beyond the breaker zone. They can have widths ranging from 10 – 30 meters and can easily exceed 1 m/s. These strong currents flowing offshore can be particularly disastrous if the victims are not educated on how to respond. The United States Lifesaving Association reported over 23,000 rip related rescues in 1999 along U.S. beaches. Also, the National Weather Service estimated that 100 people drown annually from rip currents. Rip current occurrences cannot be avoided, but a greater understanding by beachgoers can prevent potentially hazardous situations from becoming life-threatening.

There are many different generation mechanisms for rip currents. Jetties, piers, or other coastal structures can obstruct longshore currents and redirect them into offshore rip currents. Longshore variability in the wave forcing can create circulation cells with converging longshore currents which then turn offshore as rip currents. The focus of this paper is on rip currents generated on a barred beach with rip channels. The longshore currents that "feed" rip currents are driven by wave breaking variations along the beach (Bowen (1969); Dalrymple (1978)). Since breaking causes an increase in water level, non-uniform breaking creates non-uniform water levels. These hydraulic pressure gradients due to the water level differentials drive the longshore currents. A typical rip current bathymetry contains a sandbar with a channel opening in the middle creating two longshore feeder currents converging at the rip channel. The rip neck is the current extending from the feeder currents to outside the breaker zone. Beyond the breaker zone, the current can broaden into the rip head and turn in either longshore direction. Eventually, the incoming waves transport the water shoreward creating a closed circulation cell.

The flow in a rip current system is not always constant but can pulsate at a variety of time scales (Sonu (1972), Smith and Largier (1995) and MacMahan *et al.* (2002)). These pulsations are usually attributed to the groupiness of the incoming waves and infragravity motions but have also been linked to jet instability (Haller and Dalrymple (2001)). Simultaneous measurements of the pressure gradients, feeder currents, and rip currents provide a means for understanding the temporal variations of the mechanisms of a rip current system.

Experimental Setup

Currently this series of laboratory experiments contains the highest resolution rip current measurements, both temporally and spatially, to date. The laboratory experiments were performed in the directional wave basin located in the Ocean Engineering Laboratory at the University of Delaware. Design and construction details of the experimental setup are available in the Haller et al. (2000) paper.

Figure 1 shows the geometry of the wave basin used in the experiments. The waves are created by a multi-paddle wave maker located at the toe of a steep 1:5 slope preceding a milder 1:30 slope. A longshore bar of height 6 cm with two channels is centered about 11.8 m from the offshore wall and the two channels are approximately 1.8 m wide.

This set of experiments contains tests of various shore normal wave conditions for both monochromatic and bi-chromatic waves. For the monochromatic cases, the amplitude and period were the only variable parameters. The bi-chromatic cases, however, introduced two other variables: the group period and amplitude ratio . The amplitude ratio is the ratio of the two amplitudes superimposed to create the wave group. The wave periods used were 1.33, 1.5, and 2 seconds, while the amplitudes were 2.5, 3, 4, and 5 cm. Group periods of 16, 32, and 64 seconds were chosen for the bi-chromatic waves with amplitude ratios of 1 and 2.

For the in situ measurements, 3 Sontek Acoustic Doppler Velocimeters (ADV's) and 5 Nortek Acoustic Doppler Velocimeters (NDV's) all with side looking probes were used to measure the currents. The sampling frequency was set to 20 Hz for both the ADV's and the NDV's. The locations of the velocimeters, shown in Figure 2, were chosen to capture the feeder currents and the rip current.

The water level is measured using ten capacitance gages recording at a frequency of 10 Hz. The wave heights as well as the mean water level (MWL) are extracted from the time series produced by these gages. The water level gages were located in the trough and the rip channel (Figure 2) in order to resolve the longshore hydraulic gradients in the feeders and the cross-shore gradient in the rip.

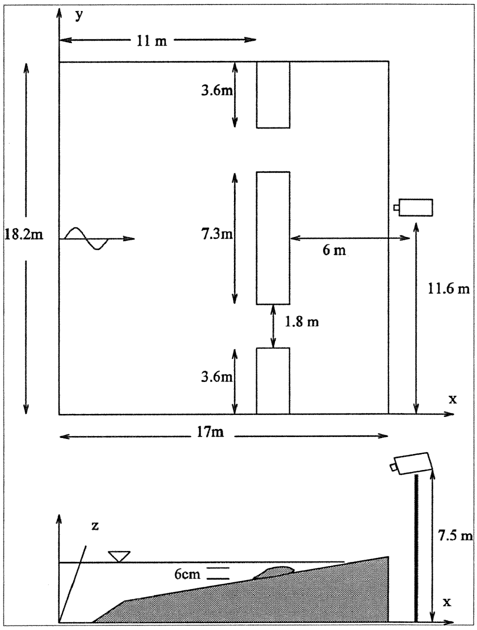

Figure 1: Wave basin geometry with camera position

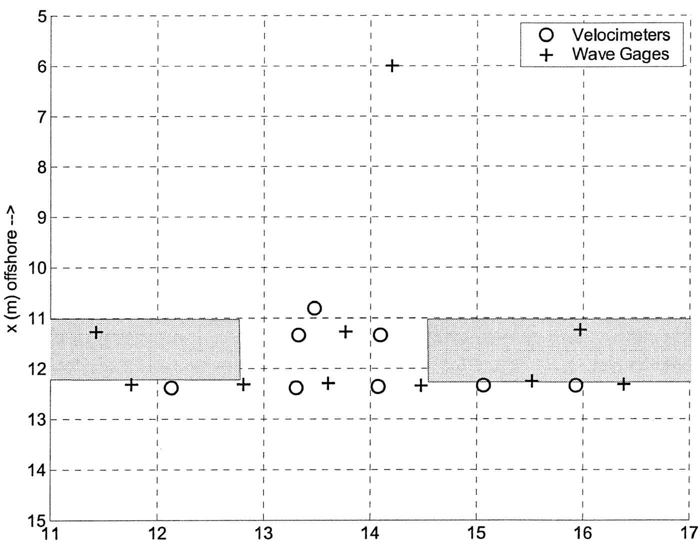

Figure 2: Instrument locations

Each experiment was approximately 27.3 minutes in duration corresponding to 16,384 points for the water level time series and 32,768 points in the velocity time series.

The video experiments involved capturing digital video of surface drifters moving in the flow field. The drifters were weakly-buoyant disks of 5.65 cm radius. For each experiment, approximately 20 minutes of video was captured repeating the wave conditions used for the instrument data experiments. At any given time, approximately 30 – 50 drifters were in thecamera view. The drifters that d rifted out of the camera view (i.e. on the beach or offshore) were collected and tossed back into the flow field to ensure consistent spatial coverage.

The video setup utilized a Sony TRV-900 digital video camera with three 1-megapixel CCD chips and a Raynox0.66x wide angle lens. The camera was located approximately 6 m shoreward of the bars, 11.6 m from the sidewall and 7.5 m high. The camera was connected with a FireWire cableto a PC allowing for the full resolution video (720x480) to be captured in real time. The digital video was sampled at 30 Hz.

The video data was post-processed to obtain Lagrangian tracks of each drifter in the flow field throughout the video segment. The tracking resolution was set at 15 Hz, half of the sampling rate of the digital video.

Flow Properties

Before discussing the rip current pulsations, the mean current flow field is described. This can be estimated rather easily from the Lagrangian tracks by using a low-pass filter to remove all orbital motion as well as all high frequency noise contained in the tracks. The Lagrangian velocity is then computed and sorted into spatial bins based on the location of the drifter in any given frame.

The mean current patterns can have significant variation for different wave conditions. Under certain wave conditions, the resulting rip current is strongly biased in a particular direction. In Figure 3, the rip is strongly left-biased for the 2-second monochromatic case. For a similar wave condition except for being a bi-chromatic wave, the mean flow pattern appears very symmetrical as shown in Figure 4.

The reason the mean flow field looks symmetric for the bi-chromatic case and not the monochromatic case can be explained by examining the pulsations of the rip current. For the monochromatic case, the rip remains relatively stable and continuously flows towards the left hand side, whereas for the bi-chromatic wave casethe ri p is highly unstable and oscillates back and forth. Figure 5 shows one minute time averaged snapshots of the rip current velocity field which demonstrates some of the variability of the flow field. The rip flops back and forth between the left and right sidesfairly evenly such that the mean flow field ends up being quitesymmetric.

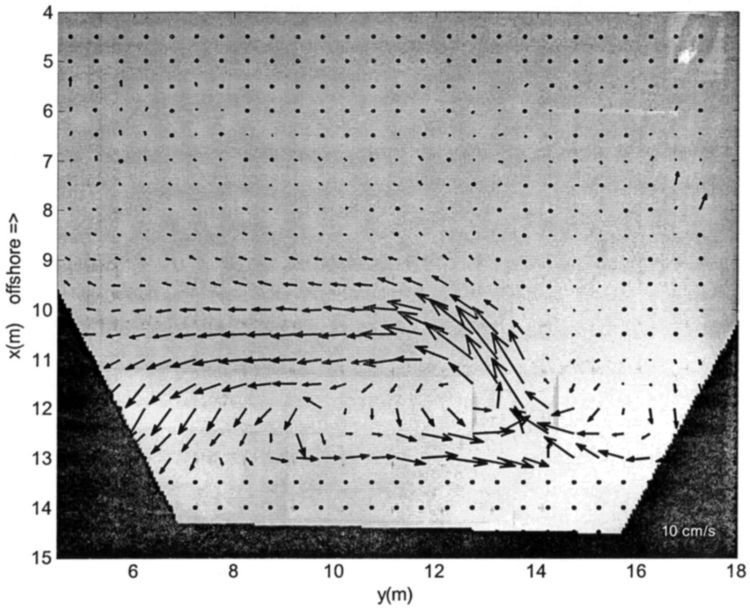

Figure 3: Mean velocity field (T = 2 s; Monochromatic)

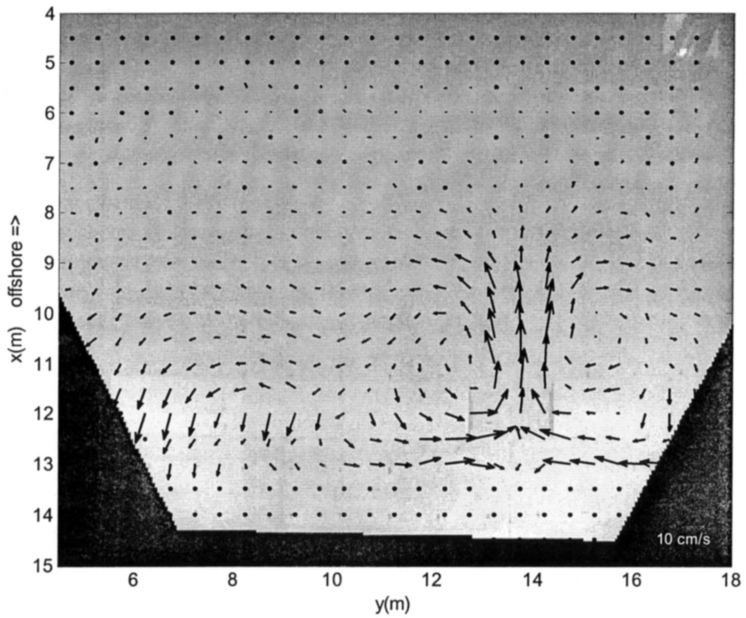

Figure 4: Mean velocity field (T = 2 s; T_g = 32 s)

