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The impacts of hardened coastal structures on the formation of rip currents

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Introduction

Coastal structures, whether natural or anthropogenic, have direct impacts on coastline dynamics and can increase the risk of rip currents in surrounding areas. For this reason it is important to analyze man-made coastal structures and ensure that dangerous environmental effects do not outweigh intended benefits. Rip currents are prominent near hardened structures such as groins, breakwaters, and jetties, and the risks of one developing can be exacerbated if these structures are built in close proximity to other features known to induce rip currents such as deep channels. They present a serious threat to swimmers due to their "invisible" nature; the untrained eye would not recognize the presence of a rip current until being caught in its path. This review will discuss the physical processes that create rip currents, the correlation between coastal structures and rip current formation, the interactions between coastal structures and other coastal features, and safe development practices to reduce risks to human safety.

Causes of Rip Currents

Rip currents are streamlined jets of water moving rapidly away from shore. They can occur at any beach with breaking waves, and extend from the shoreline past the wave breaking area (*Rip Currents,* n.d.). The water follows a circular path consisting of four phases (Castelle et al., 2016):

(1) Water is transported to shore through the force of waves.
(2) When the water approaches the shoreline, it funnels into a feeder current moving in the alongshore direction.
(3) The feeder currents converge, forming a rip neck moving in the shore-normal direction out to sea.
(4) The rip current dissipates, allowing the water to move in the shoreward direction again.

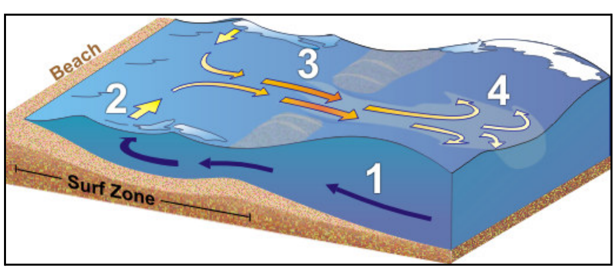

Figure 1. Stages of Rip Current Formation (Source: *Rip Currents,* n.d.)

Rip currents can be categorized as hydrodynamically-controlled, bathymetrically-controlled, and boundary-controlled. Different types of rip currents can exist on the same beach at the same time, even combining at times to form mixed types, though their driving forces are what separate them. Hydrodynamically-controlled rip currents are found on alongshore-uniform sections of coastline. These rip currents are categorized as flash rips, brought on unpredictably and suddenly, or shear instability rips, caused by instability of longshore currents due to shearing in the cross-shore direction (Castelle et al., 2016).

Bathymetrically-controlled rip currents are formed due to alongshore variations in submarine conditions. For these currents, subtypes include channel rips and focused rips. Channel rips occur in deep water between sandbars in the surf zone. Wave energy is not dissipated evenly due to this alongshore variability in water depth, causing a rip current to form. Focused rips are caused by anomalies in the outer surf zone or inner shelf creating variable heights and angles of breaking waves. The variations in heights and angles create opposing currents in the alongshore direction causing deflecting rip currents (Castelle et al., 2016).

Boundary-controlled rip currents are caused by coastal rigid features such as groins and jetties. Such physical boundaries affect the lateral bathymetry of the coastline. The resulting rip currents can be categorized as shadow rips, occurring down-wave of the boundary, or deflection rips, occurring up-wave of the boundary. Shadow rips are caused by rigid features dissipating wave energy and creating variable alongshore wave heights and energy. Deflection rips are driven by the deflection of alongshore waves in the seaward direction due to rigid features (Castelle et al., 2016).

Each type of rip-current, whether formed due to hydrodynamic processes, bathymetric abnormalities, or anthropogenic structures, is characterized by a narrow jet of water flowing away from the shore. Water naturally follows its path of least resistance and will thus create a strong current if localized areas deflect the water away from shore (as is the case for man-made features) or present an easy path of return compared to neighboring areas (such as a deep channel).

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Impacts of Beach Development on Coastline Dynamics

Figure 2. Navigational Jetties (Source: U.S. Army Corps of Engineers, n.d.)

Jetties are used on either side of a navigational channel to limit sediment intrusion, shelter the channel and harbor from waves and currents, and prevent inlet migration. They are often constructed using large slabs of concrete or stone. A jetty may be permeable or impermeable depending on the goals of the developer, though sediment and debris may get trapped and render a permeable jetty impermeable. Assuming that the wave direction is not perfectly parallel to the direction of the jetties, these structures will deflect waves in the up-wave direction and dissipate wave energy in the down-wave direction. These processes are likely to cause deflection rips and shadow rips, respectively. The effects of these rip currents could be exacerbated by channel rips forming in the navigational waterway (U.S. Army Corps of Engineers, n.d.).

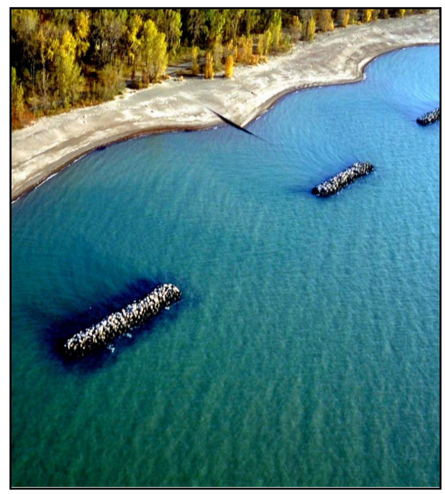

Figure 3. Nearshore Breakwaters (Source: U.S. Army Corps of Engineers, n.d.)

Nearshore breakwaters lay parallel to the shoreline to reduce and reflect wave energy to prevent beach erosion. These structures cause protruding sections of sand called salients to form. Some salients eventually attach to the nearshore breakwater, creating a sand structure called a tombolo. Breakwaters strongly impact the surrounding bathymetry such that rip currents are a much greater risk. Because water can only funnel out in between the breakwaters, the outflow can carve out channels in these areas creating channel rips. Boundary-induced rips are also likely to occur due to the uneven dissipation of wave energy (Nearshore Breakwaters, 2003).

Groins are hard coastal structures intended to prevent beach erosion by impeding longshore sediment flow. The structures trap sediment on the upcurrent side, usually leading to increased erosion on the downcurrent side due to a lack of natural sediment replenishment. Groins are the most common structure used for beach stabilization by engineers, though “probably the most misused and improperly designed of all coastal structures” according to the Army Corps of Engineers (Institute for Water Resources, n.d.). Groins are capable of reflecting waves into the offshore direction, creating boundary-controlled rip currents. Similar to jetties, groins can cause deflection currents in the up-wave direction and shadow currents in the down-wave direction due to energy dissipation.

A terminal groin is placed at the end of a littoral cell to retain the beach directly updrift of the inlet area. This differs from a jetty in that it is not used for navigation purposes (Fitzgerald et al., 2010), but the risks associated with these structures mimic those of jetties and standard groins. Much like navigational jetties, placement of a groin at the end of a littoral cell increases the likelihood of rip current formation in the area due to the potential for channel currents.

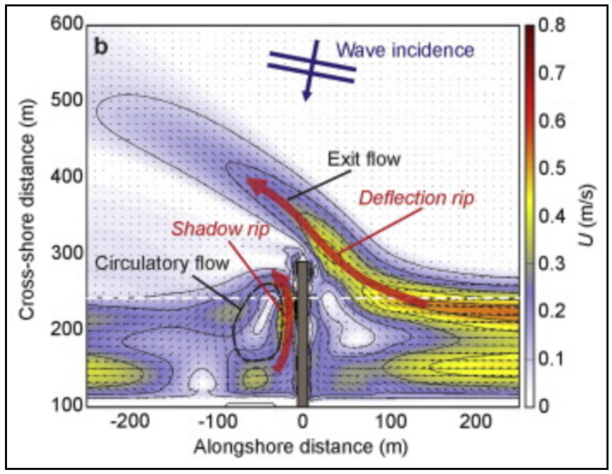

Figure 4. Deflection and Shadow Rip Current Formation at Groins (Source: Castelle et al., 2016)

Safe Coastline Development Practices

Research has indicated that hardened coastal structures are catalysts for rip current formation, but certain structures are more conducive to these hazards than others. If structures are built near each other such that the width of the enclosed embayment is narrow compared to the width of the surf zone, the rigid boundary will be the dominant force controlling the circulation of water. This creates a cellular rip current caused by deflection, shadowing, and channelization (Castelle et al., 2016). To prevent cellular rip currents from forming, adjacent coastal structures protruding perpendicular to the coastline should be limited in length and proximity to each other.

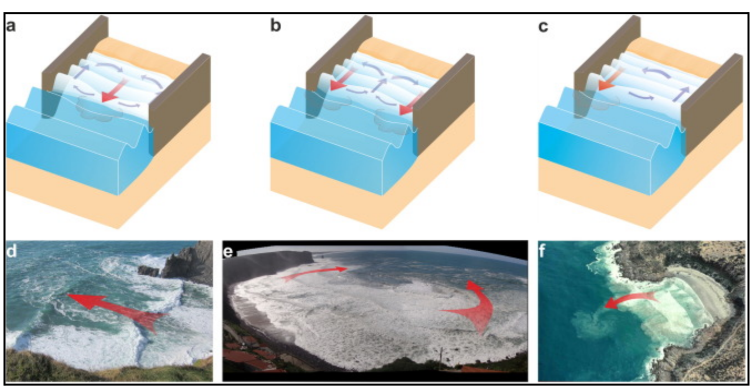

Figure 5. Cellular Rip Current Formation (Source: Castelle et al., 2016)

Coastal structures can directly cause boundary-induced rip currents, but they may also indirectly cause rip currents by changing the local bathymetry of the coastline. For this reason, it may be beneficial to either 1) incorporate beach nourishment practices into the local area of shoreline or 2) avoid building in

areas highly prone to erosion or other morphological changes. Most rigid structures will affect the morphology and hydrodynamics of the coast in some way, thus it is important to know how any adverse effects on the natural coastline can be safely and responsibly mitigated before moving forward with a design plan.

Conclusion

While rip currents can occur on any beach regardless of bathymetry and presence of coastal structures, there is overwhelming evidence to suggest that hardened structures play a role in the formation of rip currents. Such structures can directly cause boundary-controlled rip currents due to deflection and dissipation of wave energy, but they may also be indirectly responsible for rip currents caused by changes in coastal bathymetry and hydrodynamics. This should be taken into account when considering building a coastal structure in or around an area with high concentrations of swimmers and/or existing features that could exacerbate risks of rip current formation.

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