Lecture05-Surfzone_Circulation

September 30, 2025

1 Lecture05 - Wave-driven Surfzone Circulation

Learning Objectives: wave breaking, wave decay in surf zone, undertow in the surf zone, wave-induced sea-level set-up and set-down, wave run-up on the beach face, wave-induced longshore current, rip current, sediment transport due to longshore drift and longshore current

Before class:

- class survey!

After class:

- Watch video on why Cortes Banks have 77-foot waves!
- Explore website on rip current safety!

Reference:

- Textbook 5.3.1, 6.1-6.3, skip 6.3.2
- optional: BS 5.5.7

1.1 Class survey:

Feel free to share any thoughts or feedback throughout the semester using this Google Form (https://docs.google.com/forms/d/e/1FAIpQLSfaArgm-KJQl-Dj991iK-TPB4prWjb48T8KX1Ax6KkhAPF9HQ/viewform). The form is anonymous, but if you'd like to include your name, you're welcome to add it in your response.

1.2 1. Wave Reviews

Swells in open ocean - deep waver wave

Class Discussion 1: Waves arriving at a beach from a distant storm progressively decrease in wave period, from 10 to 5 sec, with the 5-sec waves arriving 10 hours later than the 10-sec waves. Assuming deep-water wave conditions for the entire travel distance, how far away was the storm?

Tsunami wave propagation - shallow water wave

Class Discussion 2: The wave length of a Tsunami wave is much larger than the water depth (e.g., L = 213 km, h=4000 m)! Estimate the propagation speed of a tsunami wave in the open ocean (approximately 4000 m deep) using the shallow water Airy wave theory. Is the speed of a tsunami more comparable to that of a jet plane (800 km/h) or a car (30–50 km/h)? How long does it take for a tsunami wave to travel across the Pacific Ocean? What happens when it enters shallow water near the coast?

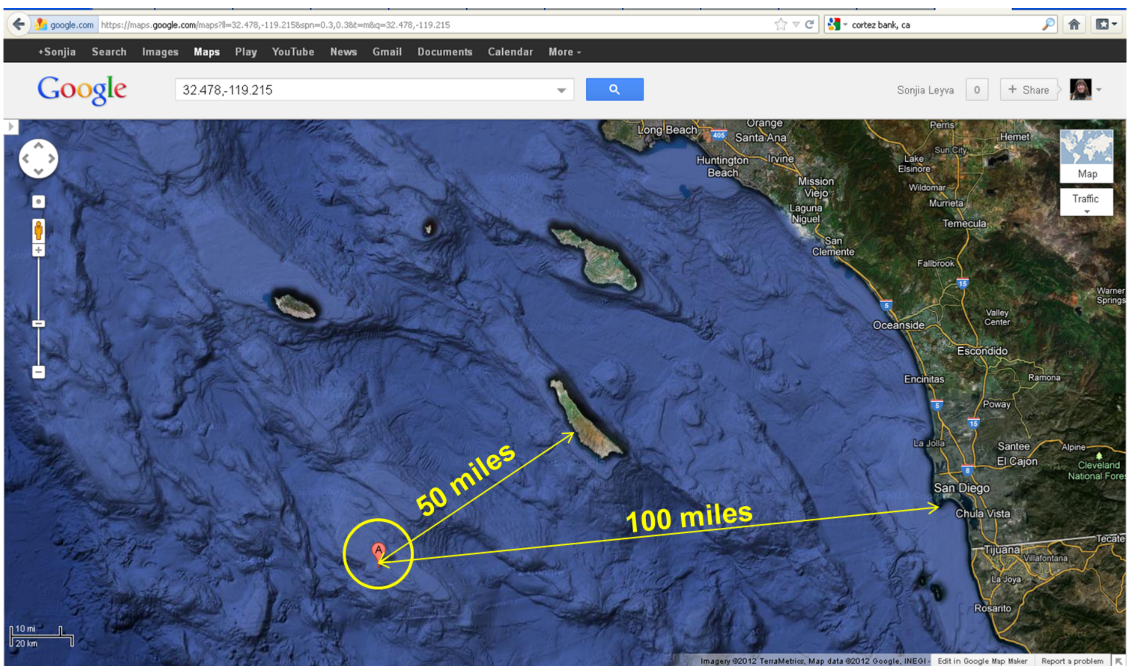
Wave breaking in deep vs shallow waters

Class Discussion 3: Consider a deep-water wave height $H_S = 1.5$ m and a wave period of $T = 5$ s. We find $L_\infty = \frac{g}{2\pi}T^2 = 39$ m, and $H_S/L_\infty = 0.04$. Under these conditions, even for the higher waves in the record, little white-capping is expected. However, when this wave enter shallow water ($\sim h = 10$ m), **depth-induced breaking** is expected since the maximum value of H_S/h for which the largest waves are breaking is therefore about 0.4~0.5.

1.3 2. Wave Breaking

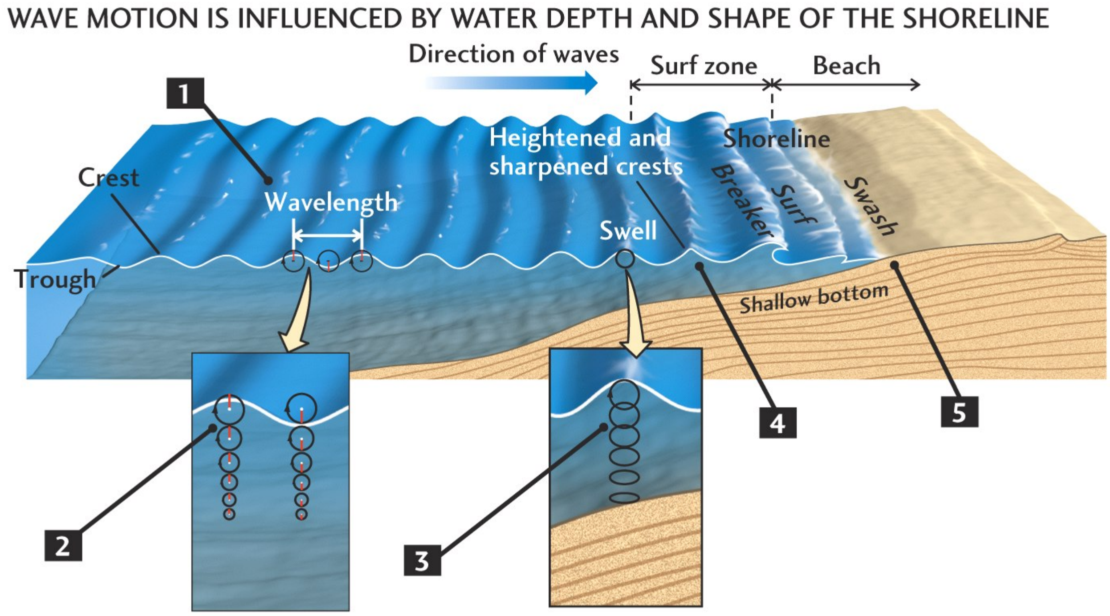
Recall the four types of wave breaking: **spilling, plunging, collapsing, and surging** and watch - Types of Waves - spilling and plunging in surfing - Surging Waves in North Spain - Mike Parsons surfing 77 foot wave at Cortes Bank. From the documentary "Billabong Odyssey"

Cortes Banks is located at 100+ miles off the coast! Why do big waves form?



Cortes Bank is a submerged ridge; were it any taller it would be an island. The water depth is pretty deep there, so the large waves formed by offshore storms can extend down deep. The seafloor shallows abruptly as the wave aproaches Cortes Bank. The wavebase starts to interact with the shallow seafloor, creating very high waves (**wave shoaling**).

1.3.1 1) surf zone



In the open ocean, the wave train begins to move towards the shore. So long as the wave is moving through water

(1) that is greater than 1/2 their wavelength the orbits will remain circular

(2). However, the circular motion of water molecules is interrupted and the wave slows as water becomes more shallow. Energy is no longer dissipated with depth, so the energy goes up and the wave becomes too high for its wavelength. The water at the top of the wave

(3) is now moving faster than that at the bottom of the wave. The orbits are still trying to form, and the wave breaks

(4) and forms the surf

(5) as it rushes on shore.

1.3.2 2) wave decay in surf zone

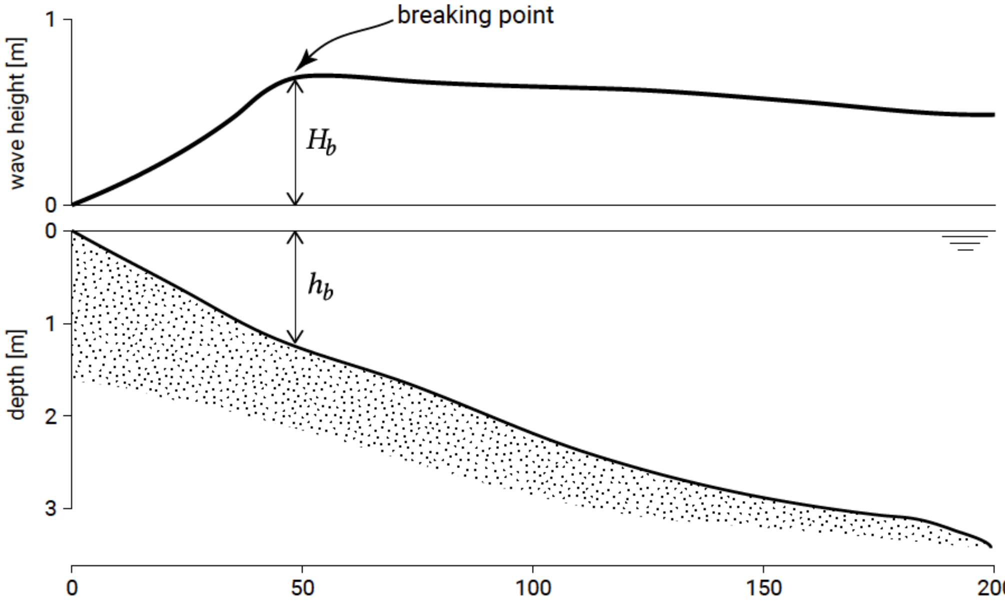


Figure 5.10: Wave-breaking parameters H_b and h_b.

a. decay in wave height

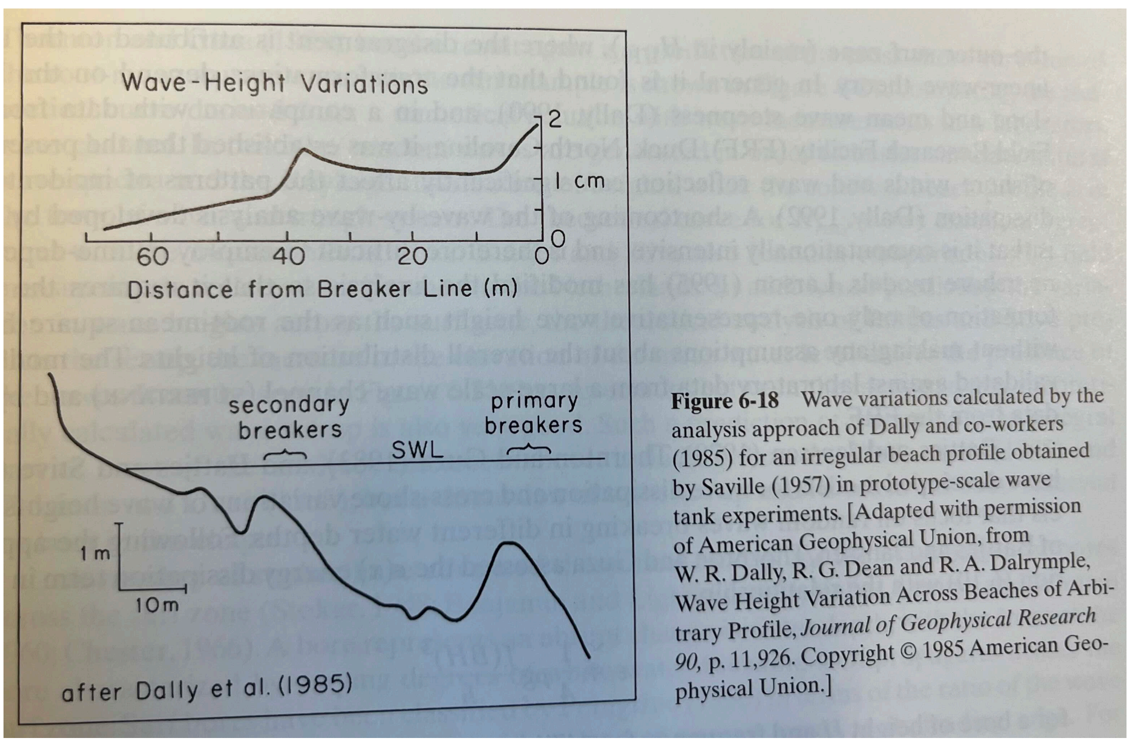


Figure 6-18 Wave variations calculated by the analysis approach of Dally and co-workers (1985) for an irregular beach profile obtained by Saville (1957) in prototype-scale wave tank experiments. [Adapted with permission of American Geophysical Union, from W. R. Dally, R. G. Dean and R. A. Dalrymple, Wave Height Variation Across Beaches of Arbitrary Profile, *Journal of Geophysical Research 90,* p. 11,926. Copyright © 1985 American Geophysical Union.]

The natural beach is characterized by the arrival of waves having a large range of heights, with the **largest waves breaking in deeper water** while the **smaller waves** approach more closely to shore before they **break in shallow water**. Thus, at any position within the surf, one observes some waves that have already broken and display the white-water foam of bores, while other waves are still undergoing their transformations leading to initial breaing. As one proceeds from deep to shallow water on a uniformly sloping beach, there is a progressive increase in the proportion of waves that are breaking versus those that still have not reached instability and broke.

b. energy dissipation Different from wave shoaling, when $\overline{E}c_g = \overline{E_0}c_{g0}$,
wave breaking and generation of turbulence causes **energy dissipation** to remove energy from the wave $\overline{E}c_g = \overline{E_0}c_{g0} - \int \epsilon(x)dx$, where ϵ is the loss in wave energy per unit area per unit time: J/(m^{2}s)

1.4 3. Wave set-up and set-down

1.4.1 1). undertow

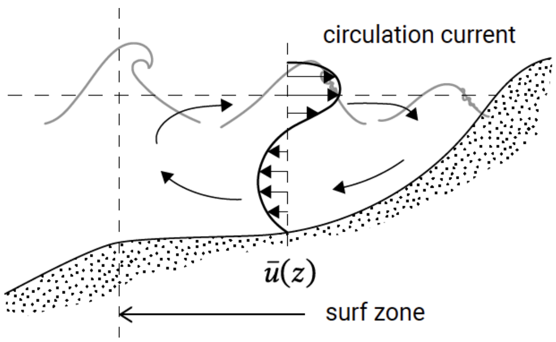


Figure 5.25: The undertow is a return current below the wave trough level to compensate for the onshore mass flux in the surf zone.

The undertow is important for seaward sediment transport, because of the relatively high offshore-directed velocity in the lower and middle part of the water column in a zone with relatively high sediment concentrations (due to wave-breaking). The undertow is thought to be responsible for the severe beach erosion during heavy storms (or the formation of "winter beaches").

1.4.2 2). wave set-up and set-down

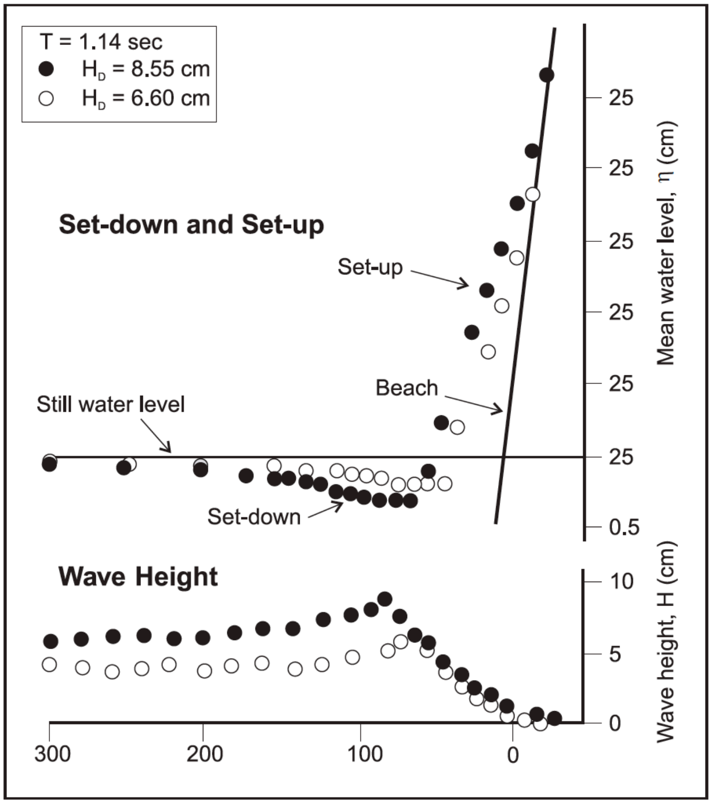


Figure 5.24 Wave set-down and set-up for waves of differing wave height in a laboratory wave tank (Bowen, 1969).

When waves break on a beach, they produce a **set-up**, a rise in the mean water level above the still-water elevation of the sea. The set-up is confined to the surf zone shoreward of the point of initial wave breaking and consists of an upward slope of the water in the landward direction. The slope of the set-up water surface is less than the slope of the beach face, so the water intersects the beach at an effective shoreline elevation that is above the still-water shoreline. There is also a zone of **set-down**, a depression in the mean water surface below the still-water level that occurs in the offshore prior to wave breaking, the zone where waves are undergoing rapid transformations in their heights and energy as they shoal.

Guza and Thornton (1981) measured wave set-up on beaches in southern California. They found that the maximum set-up at the shoreline above the still-water level is $> \bar{\eta}_{max} = 0.17H_\infty$

where H_∞\$ is the significant height of the incident waves in deep water.

1.5 4. Wave run-up on the beach face

As waves crash and rush onto the shore, it not only move water but also a little bit of sediment onto the beach. This is called the **swash**. Then the water pulls back away from the shore, moving water and a little bit of sediment off the beach. This is called the **backwash**.

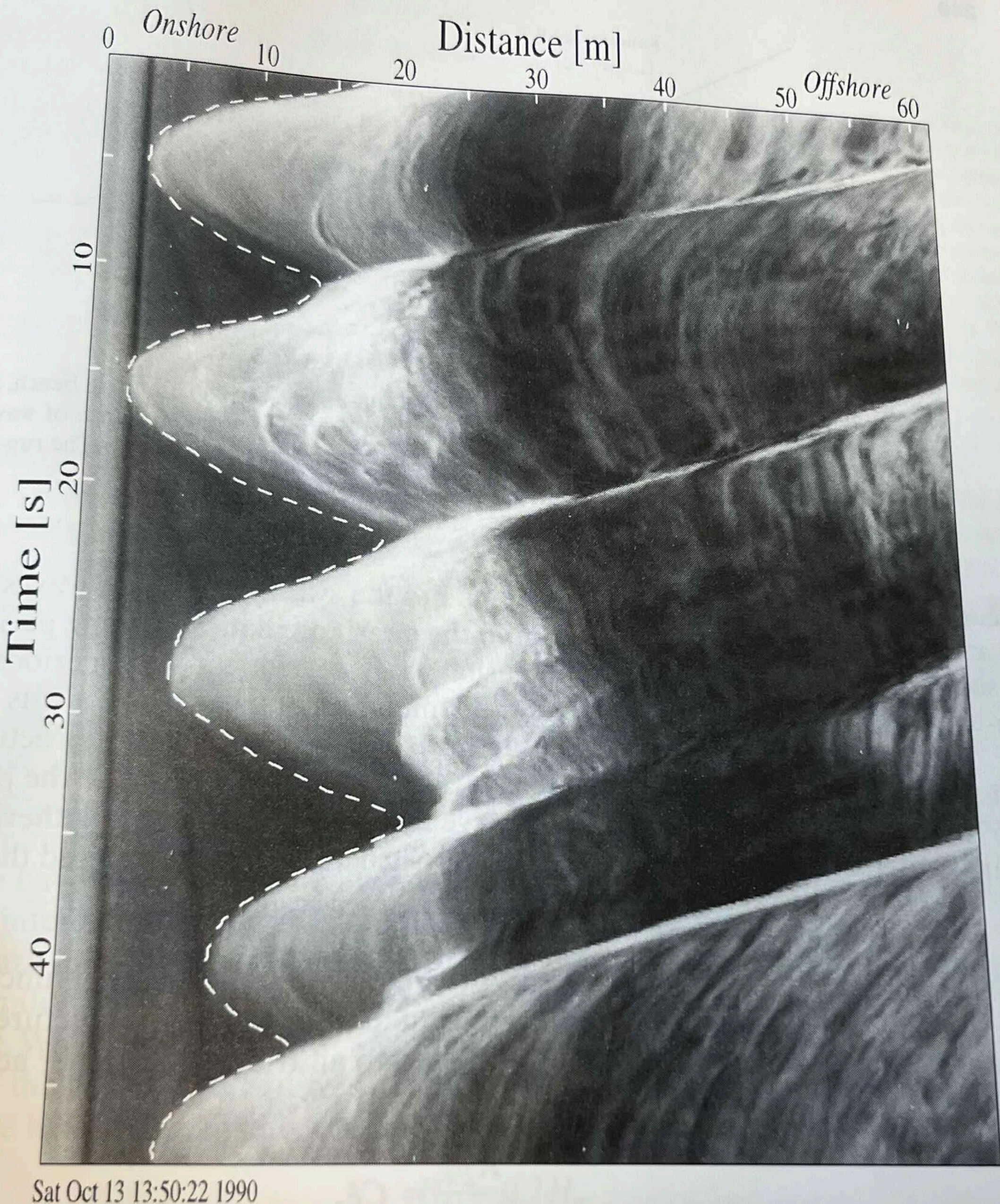


Figure 6-29 Time stacking video documentation of the time variations in the wave run-up along a fixed cross-shore profile. The slanted traces downward and to the left represent bores approaching the shore, while the dashed line is the maximum run-up position. The shades of white versus dark reveal the movement of foam on clear water. [Used with permission of American Geophysical Union, from K. T. Holland and R. A. Holman, The Statistical Distribution of Swash Maxima on Natural Beaches, *Journal of Geophysical Research 98,* p. 10,273. Copyright © 1993 American Geophysical Union.]

It is the maximum shoreward extent of the wave run-up that has particular significance to the erosion of properties backing the beach and in the overtopping of jetties. It has been found that the total run-up consists of three primary components (Fig. 6-30): (1) the set-up, which determines the mean shoreline position above which the swash of individual waves occurs; (2) fluctuations about that mean, due to the swash of incident waves producing run-up and run-down; and (3) a component in the swash oscillations having periods in excess of 20 sec, infragravity periods beyond the usual range of incident-wave periods. The maximum run-up height achieved by the water is the summation of these components (Fig. 6-30).

Guza and Thornton (1982) found that the excursion distance of the swash fluctuations about the mean set-up level was directly dependent on the incident wave height. When expressed as a "significant" run-up height, R_S, the average of the highest one-third of the run-up levels, it was found that the swash was related to the deep-water significant wave height, H_∞, by the relationship $> R_S = 0.7H_\infty$

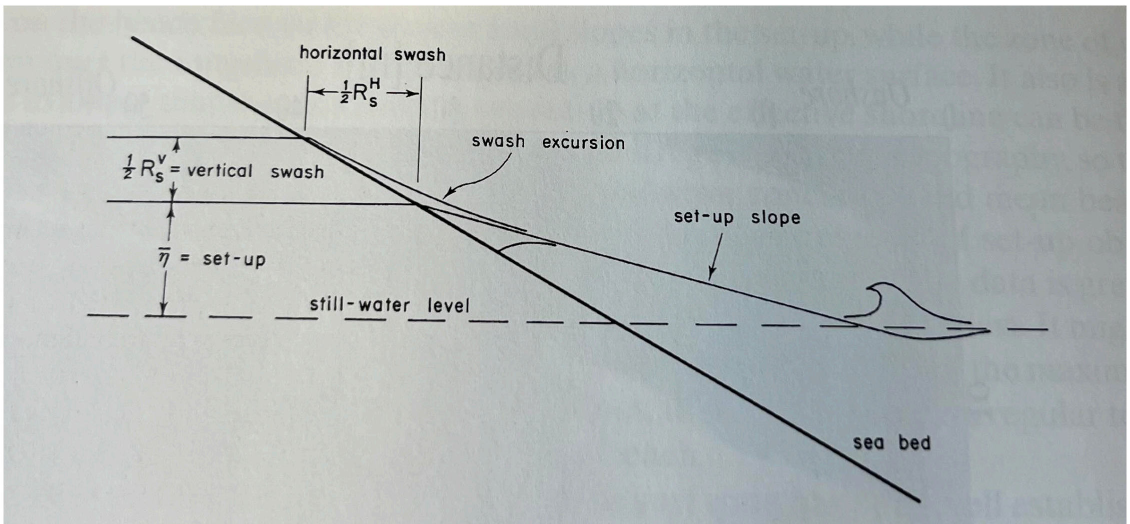
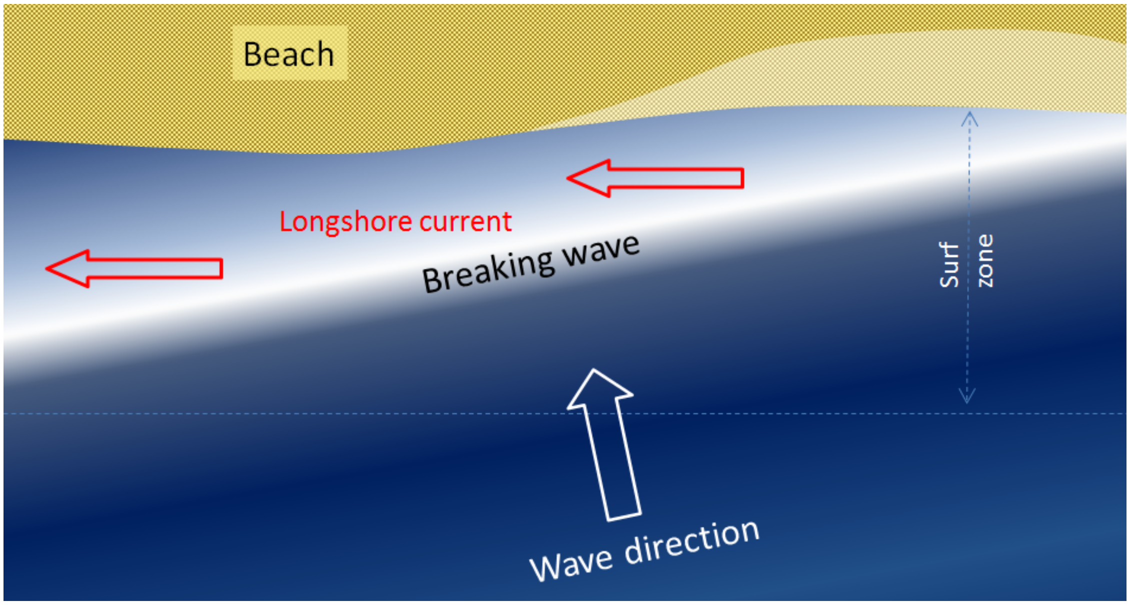


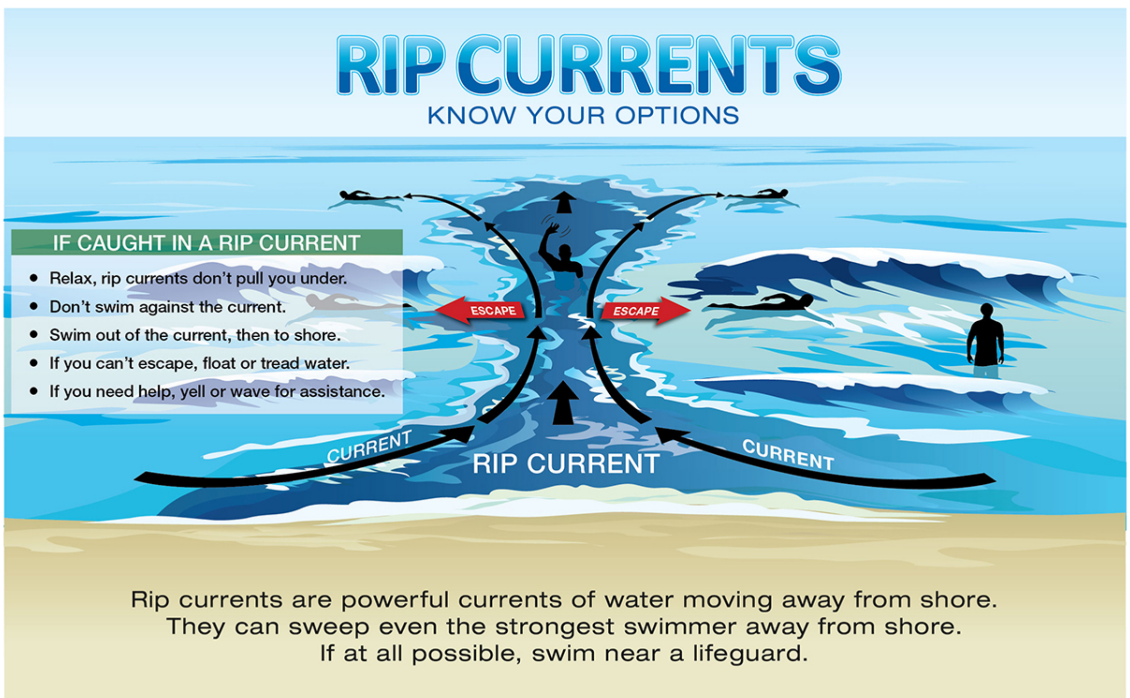
Figure 6-30 The factors that affect the total run-up of swash on a sloping beach, including the set-up that determines the effective shoreline in the presence of waves and the run-up of individual swash beyond that mean shoreline position. The run-up can be analyzed in terms of its vertical or horizontal components.

1.6 5. Longshore currents due to obliquely breaking waves

Waves do not typically reach the beach perfectly parallel to the shoreline. Rather, they arrive at a slight angle, called the "angle of wave approach." When a wave reaches a beach or coastline, it releases a burst of energy that generates a current, which runs parallel to the shoreline. This type of current is called a "longshore current." Longshore currents can move up to 4 km/hr, strong enough to carry people with them, as everyone knows who has been swimming in the ocean only to look up and see that they have been carried far down the beach from their towel!

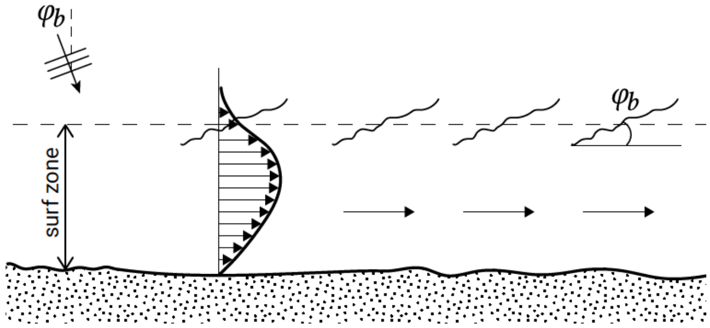


1.7 6. Rip currents and cell circulation

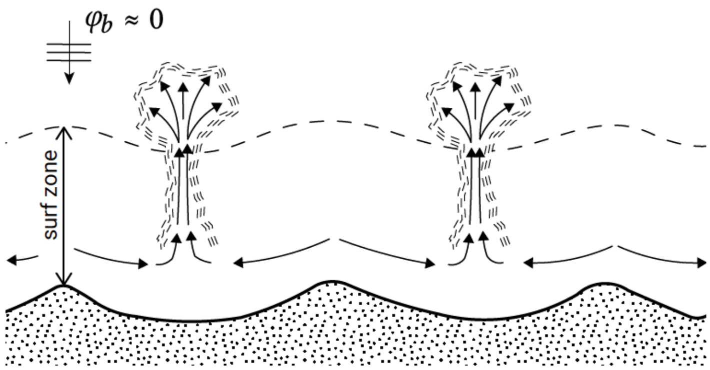


1.7.1 1) due to shape of coastline

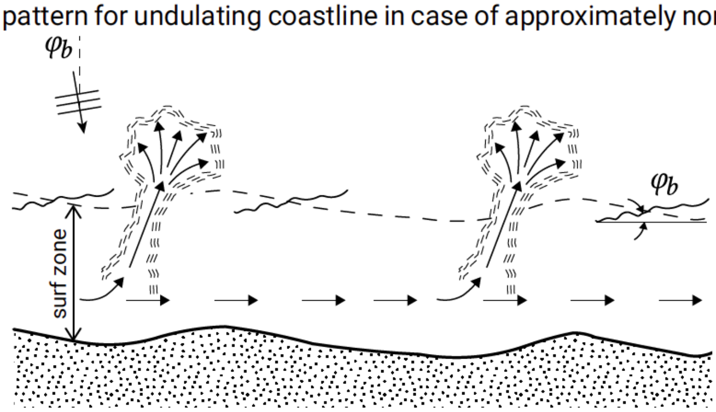
Rip currents are strong, narrow currents that flow seaward from the surf zone. They are fed by longshore-directed surf zone currents that turn seaward to form a rip current. The longshore currents are generated by set-up differences and run from the position of the highest set-up towards the position of the lowest set-up. The alongshore variation in wave set-up can be generated by convergence and divergence of wave energy due to depth refraction or sheltering effects due to for instance headlands. An undulating coastline gives concentration of wave energy towards the undulations due to depth refraction.



(a) typical longshore current distribution in case of obliquely incident waves



(b) rip current pattern for undulating coastline in case of approximately normal incidence



(c) combination of previous two cases for slightly oblique waves

Figure 5.47: Nearshore circulation patterns for different angles of wave incidence φ_b.

1.7.2 2) due to bathymetry (sand bar or submerged breakwater)

The interruption of wave-breaking can generate rip currents along a stretch of coast. Non-homogeneous wave-breaking can occur in the case of a nonhomogeneous alongshore bar system or a (series of) submerged breakwater(s) on which waves break, see Fig. 5.49. (Partial) wave-breaking on the bar induces a set-up over the bar as well as an onshore flow. Water level gradients and continuity force the flow to deflect to the sides and return seaward in between the breakwaters or bars in a concentrated rip current.

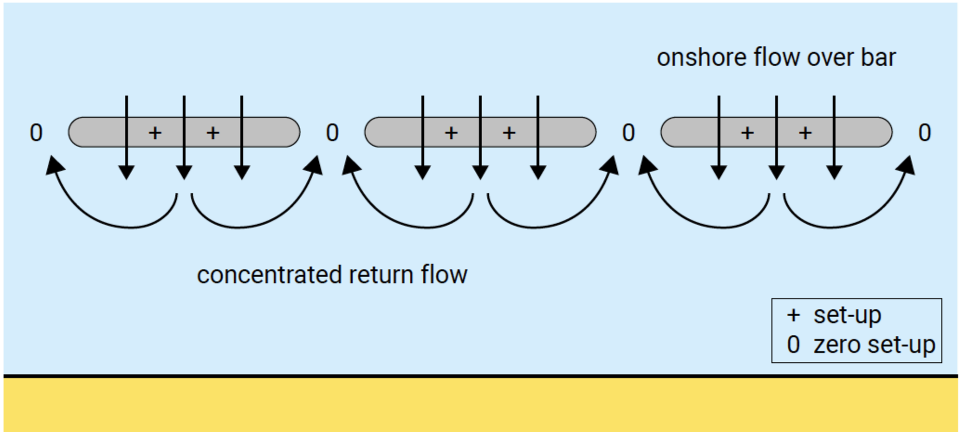


Figure 5.49: Rip currents in case of submerged breakwaters (or an interrupted bar system).

1.7.3 3) identify & survive a rip current

Before you go to a beach, make sure to check out the National Weather Service Surf Zone Forecast

Look for any of these clues to identify rip current:

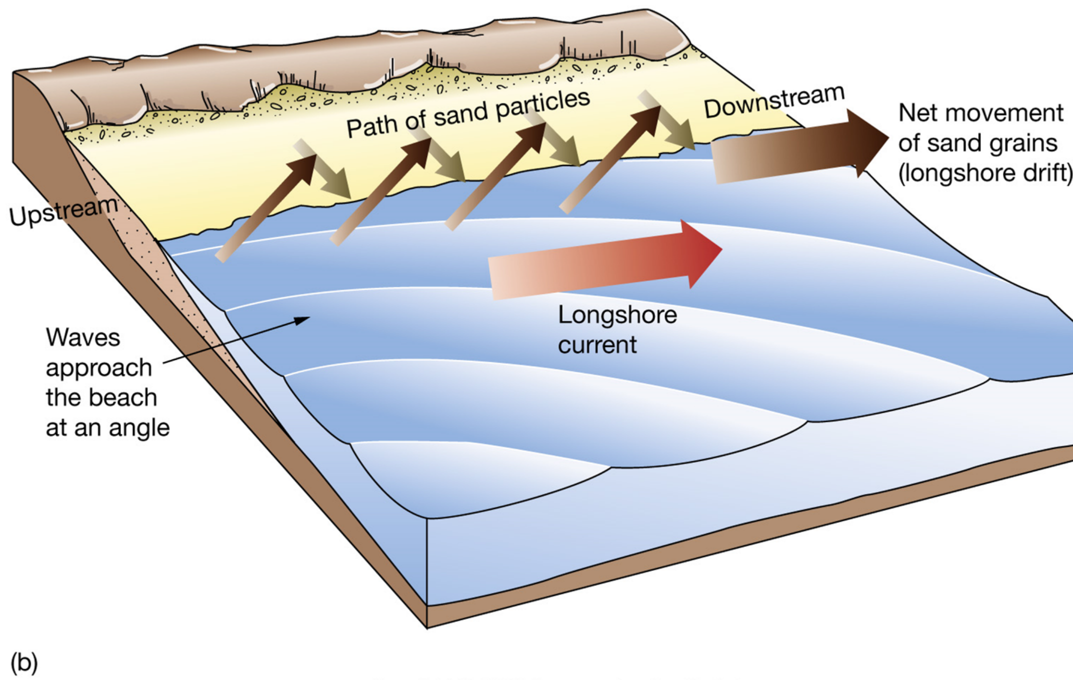
- a channel of churning, choppy water
- an area having a notable difference in water color
- a line of foam, seaweed, or debris moving steadily seaward
- a break in the incoming wave pattern

How to Survive a Rip Current:

- Relax. Rip currents don't pull you under.
- A rip current is a natural treadmill that travels an average speed of 1-2 feet per second, but has been measured as fast as 8 feet per second – faster than an Olympic swimmer. Trying to swim against a rip current will only use up your energy; energy you need to survive and escape the rip current.
- Do NOT try to swim directly into to shore. Swim along the shoreline until you escape the current's pull. When free from the pull of the current, swim at an angle away from the current toward shore.
- If you feel you can't reach shore, relax, face the shore, and call or wave for help. Remember: If in doubt, don't go out!
- If at all possible, only swim at beaches with lifeguards.
- If you choose to swim on beaches without a lifeguard, never swim alone. Take a friend and have that person take a cell phone so that person can call 911 for help.

1.8 6. Sediment Transport

There are two processes that work together to move sediment along a coastline: Longshore Drift and the Longshore Current. Combined, they are called **longshore transport**, or **littoral drift**.



1.8.1 1) longshore drift

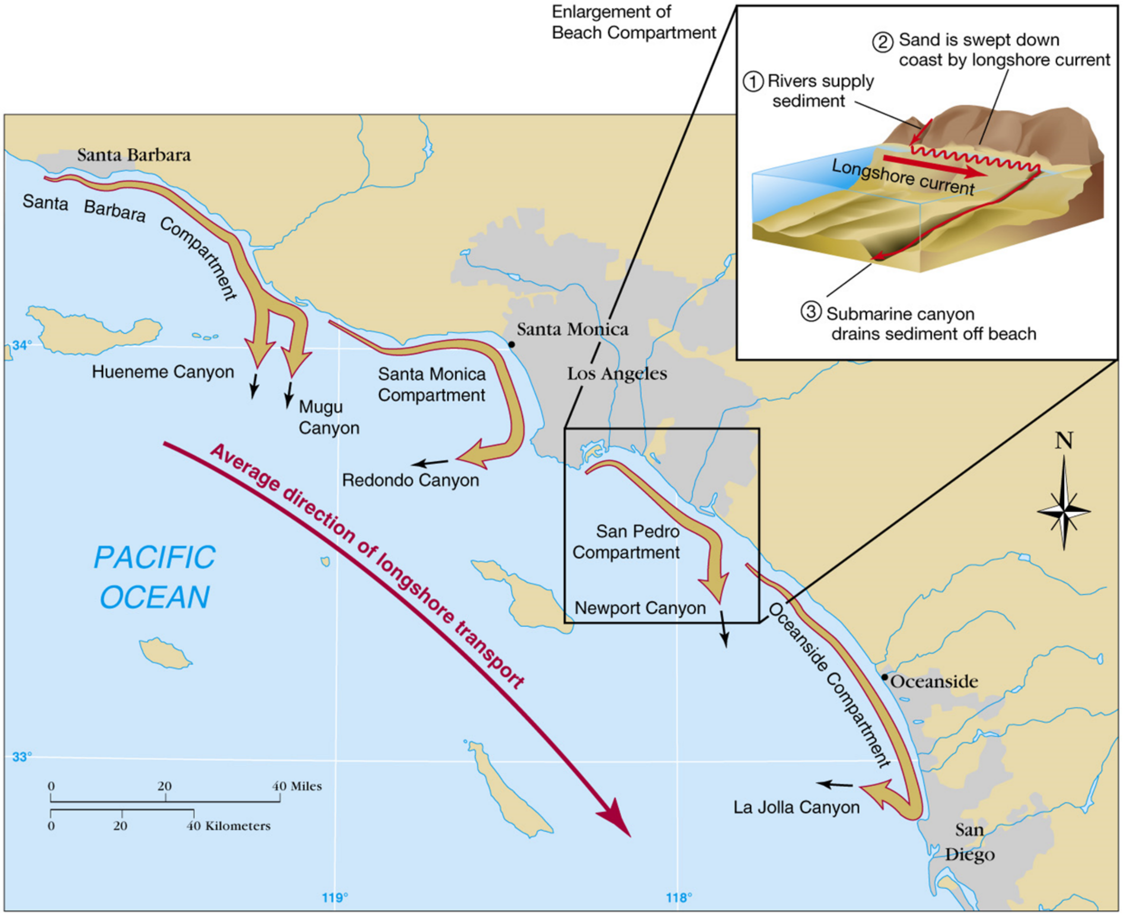
The zig-zag motion of sediment via the swash/backwash is called Longshore (or beach) Drift. Longshore drift is often interrupted by jetties, groins and breakwaters. This causes an undesirable build up of sand in areas where there shouldn't be.

1.8.2 2) longshore current

The Longshore Current moves down beach and is caused by waves hitting beach at angle. This current flows parallel to the shore and transports sediments down the coast. The longshore current moves substantially more sediment than does the longshore drift. How much? Around 150,000 to 300,000 m^3/yr on the Atlantic seaboard and 750,000 m^3/yr offshore Oxnard, California.

1.8.3 3) loss of sediment into submarine canyons & through rip currents

Together, the longshore drift and current transport sediment along a coastline until it reaches a submarine canyon. All of the sediment gets funneled down the canyons and onto the deep sea floor. Then the process starts up again just down shore from the canyon. Sections of coast in which sand input and sand output are balanced are referred to as coastal cells. Different canyons remove sediments at different rate, but the amount of sediment being removed by La Jolla canyon just north of San Diego is enormous: 150,000 m^3/yr.



Another way for a beach to loose sand is through rip currents. Rip currents or other strong currents carry sand offshore into deep water.

1.9 References:

Guza, R. T., and E. B. Thornton (1981), Wave set-up on a natural beach, J. Geophys. Res., 86(C5), 4133–4137, doi:10.1029/JC086iC05p04133.

Guza, R. T., and E. B. Thornton (1982), Swash oscillations on a natural beach, J. Geophys. Res., 87(C1), 483–491, doi:10.1029/JC087iC01p00483.

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