Coastal Dynamics

Surface Gravity Waves, Estuaries & Types of Tide Gauges for the Coastal Ocean

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with some slides courtesy of
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I. Surface Gravity Waves
Properties of Waves

Wave Height (H)
Amplitude (A)
Wavelength (L)
Wave Steepness
Wave Period (T)
Wave Phase Speed $c = \frac{L}{T}$
Some Wave Field Characterization Terms

The ocean surface has waves of many different periods and wavelengths traveling in different directions. Some ways to characterize this wave field are:

• Significant Wave Height: $H_{1/3}$
  • Older: Average of the highest 1/3 of waves – similar results to what a trained observer estimates as the wave heights
  • Newer: $=4*\text{standard deviation of surface displacement}$
• Dominant Wave Period: Wave period with most energy
Wave Generation by Winds

Conceptual Description of Wind Wave Development
1. Wind begins blowing over calm water
2. Instabilities cause air pressure fluctuation
3. Air pressure fluctuations create small waves
4. Surface waves on ocean further perturb wind field, which leads to more wave development on the ocean surface
5. Wave-wave interactions lead to lower frequency waves
Wind Generation of Surface Gravity Waves
Wavewatch III- Surface Wave Wave Forecast

- SO storms very energetic
- swell versus wind waves
- swell- long waves arrive first

http://polar.ncep.noaa.gov/waves/
Surface Gravity Waves

Deep Water Waves

Shallow Water Waves
Surface Gravity Waves— Wave Speed \((c=L/T)\)

\[
c = \sqrt{\frac{gL}{2\pi}} \tanh \left( \frac{2\pi d}{L} \right)
\]

\(c\) is the wave speed, \(g\) is the gravitational acceleration, \(L\) is the wavelength, and \(d\) is the water depth.

Shallow Water Waves: \(\frac{d}{L} \ll 1\)

\[
\tanh \left( \frac{2\pi d}{L} \right) \rightarrow \frac{2\pi d}{L}; c = \sqrt{\frac{gL \times 2\pi d}{2\pi L}} = \sqrt{gd}
\]

Deep Water Waves: \(\frac{d}{L} \gg 1\)

\[
\tanh \left( \frac{2\pi d}{L} \right) \rightarrow 1; c = \sqrt{\frac{gL}{2\pi}} = \frac{gT}{2\pi}
\]
Dispersion: Deep Water Waves \[ c = \sqrt{\frac{gL}{2\pi}} = \frac{gT}{2\pi} \]

Swell Period & Mean Direction

Sea Period & Mean Direction
Shallow Water Wave Example

Tsunami

Animation: http://nctr.pmel.noaa.gov/sumatra20100406/

\[ c = \sqrt{gd} \]

Animation: http://nctr.pmel.noaa.gov/sumatra20100406/
Wave Shoaling

\[ c = \sqrt{\frac{gL}{2\pi}} \]

Waves become steep and can break which can cause long-shore and rip currents.

\[ c = \frac{L}{T} = \sqrt{gd} \]

Since energy density conserved, \( H \)

Since \( c = \sqrt{gd} \) crests move faster than trough and waves steepen.

Deep water (depth > \( L/2 \))

Transition zone \( L/2 \leq \text{depth} > L/20 \)

Shallow zone depth \( \leq L/20 \)

\( d \downarrow \) then \( c \downarrow \)
Breaking surface waves break when the wave height is greater than 0.78 times the water depth

\[ H > 0.78h \]
Spilling Breakers

- foam, turbulence at crest
- gently sloping beach
- starts some distance from shore
Plunging Breakers

- dissipated over short distance
- variable slopes
- shallower slopes/distant swell
- wind—collapsing breaker

Figure 17.4 Steep, plunging breakers are the archetypical breaker. The edge of such breakers are ideal for surfing. From photo by Jeff Devine.

Plunging Breaker

Breaking depth < 5/3 * H
Surging Breakers

- unbroken
- steep slopes
- waves run-up beach
What happens if a wave is incident at an angle to the shore (or the shore bends)?

\[ c = \sqrt{gd} \]
What happens if a wave is incident at an angle to the shore (or the shore bends)?

\[ c = \sqrt{gd} \]
Refraction

Figure 17.2 sub-sea features, such as submarine canyons and ridges, offshore of coasts can greatly influence the height of breakers inshore of the features. After Thurman (1985: 229).
Rip Currents

The Nearshore Environment

Shoaling zone → Breaker zone → Surf zone → Swash zone

waves steepen → begins to break → rolling bores
What happen to wave speed and height as waves shoal?
Variability in Breaking Zone will result in variability of the alongshore pressure gradient.
Rip Currents

manmade & natural structures, topography, character of incident wave field, slope of the beach
(steep=small surf zone= weak longshore currents)
Some Examples of Surface Gravity Wave Measurement Techniques

- Observers
- Pressure gauges in shallow water
- Buoys with accelerometers
- GNSS Buoys
- Acoustic Doppler Current Profilers
- Satellite Altimeters
- Satellite Scatterometers

August 2005
II. Estuaries

Akwidaa Estuary, Western Region, Ghana
Definitions...

An **estuary** is a semi-enclosed region influenced by both **fresh** water from the land and **salty** water from the sea.

Estuaries are thus regions of **property exchange** between the continent and the ocean.

The **unique dynamics** of estuaries control property exchange and transport and thus are critical to pollutant dispersal.

Estuaries provide many important **ecosystem services**, including habitat/nurseries for commercially valuable species, improve coastal water quality, support tourist actives, form the basis of many major shipping lanes.
Motivations…

Container ship in a US estuary

Many of the largest coastal cities are located where rivers meet the sea. Estuaries are major routes of transport and are often heavily influenced by human activities.
Estuaries often receive intentional and unintentional discharge of effluent (sewage), industrial waste, storm water, and other pollutants.

“After Blaze, Sewage Floods City Rivers” – New York Times
07/22/2011
Many commercially valuable fish, shrimp, crab species, etc. live or breed in estuaries. Also home to many birds and marine mammals. Human activities include fishing and tourism.
The river water is fresh and the sea water is salty. What happens when the river water encounters the sea water?

The unique dynamics of estuaries control property exchange and transport and thus are critical to pollutant dispersal.

Estuaries are thus regions of property exchange between the continent and the ocean.
Akwidaa Estuary, Western Region, Ghana
Estuary Classification: Geological

• Coastal plain estuaries were formed at the end of the last ice age. As the ice melted and the waters warmed, sea level rose. The rising seas invaded low-lying coastal river valleys. These valleys are usually shallow with gentle sloping bottoms. Their depth increases toward the river's mouth.

• Bar-built Bar-built estuaries are formed when sandbars build up along the coastline. These sand bars partially cut off the waters behind them from the sea. Bar-built estuaries are usually shallow, with reduced tidal action. Wind is frequently the most important mixing tool for the fresh and salt water.
Estuary Classification: Geological

• **Tectonic:** Tectonic estuaries are created when the sea fills in the "hole" or basin that was formed by the sinking land. San Francisco Bay is a good example of this type of estuary.

• **Fjords:** Fjords are valleys that have been deepened by moving glaciers. They have a shallow barrier at their mouth that limits exchange between the waters of the fjord and the sea. They are narrow with steep sides and usually straight and long.
Estuary Classification: Geological

- Delta: Delta estuaries are formed when rivers flow out into the ocean and the sediment load falls out as the velocity of the water decreases.
River inflow volume $R$ to Tidal inflow volume $V$: $R/V$

- $R/V \geq 1$
- $R/V \sim 0.1 - 1.0$
- $R/V \sim 0.005 - 0.1$
- $R/V < 0.005 - 0.1$
Schematic estuaries: Vertically homogenous

Fresh (0 g/kg) — Salty (35 g/kg)

LAND — Region of exchange — SEA

“Well-mixed estuary”

$S_1 < S_2 < S_3 < S_4 < S_5 < S_6$

The Hudson River Estuary, New York City, USA
Schematic estuaries: Vertically stratified

“Salt wedge estuary”

The Rio de la Plata, Argentina

\[ S_1 < S_2 < S_3 < S_4 \]
Idealized, tidally averaged, partially mixed estuary

Salinity profile (c) and Velocity profile (d) with respective depth layers $z = 0$ and $z = -H$. 

Steady state: $Q_R + Q_2 = Q_1$
Idealized, tidally averaged, partially mixed estuary

\[
\frac{\partial \rho}{\partial z}, \quad z = 0
\]

\[
\frac{\partial u}{\partial z}, \quad z = -H
\]

Steady state: \( Q_R + Q_2 = Q_1 \)
Idealized, tidally averaged, partially mixed estuary

Richardson Number (Ri) = \[ \frac{N^2}{S^2} \]

Steady state: \( Q_R + Q_2 = Q_1 \)
III. Tide Gauges for Coastal Tidal Measurements

• Visual Sensors (tide poles and staffs)
• Mechanical Sensors (float buoyancy)
• Pressure sensors (diaphragm, bubble, piezoelectric, vibration, strain gauge)
• Acoustic sensors (air acoustic and water acoustic)
• Electromagnetic
  • Capacitive and resistive staffs,
  • Altimeter
  • RF sensors
  • GNSS receiver on buoys
  • ...
Tide Poles and Staffs

Fig. 49. Staff gauge installations (a) on wharf piling, (b) on submerged platform and (c) on long sloping beach.
# InSitu Level Troll 700 Pressure Sensor

## General

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Level TROLL 500</th>
</tr>
</thead>
</table>
| **Temperature ranges**     | Operational: -20–80°C (-4–176°F)  
Storage: -40–80°C (-40–176°F)  
Calibrated: -5–50°C (23–122°F) |
| **Diameter**               | 1.83 cm (0.72 in.)                                                             |
| **Length**                 | 21.6 cm (8.5 in.)                                                              |
| **Weight**                 | 197 g (0.43 lb)                                                                |
| **Materials**              | Titanium body; Delrin nose cone                                                 |
| **Output options**         | Modbus/RS485, SDI-12, 4–20 mA                                                 |
| **Battery type & life**    | 3.6V lithium; 10 years or 2M readings                                           |
| **External power**         | 8–36 VDC                                                                       |
| **Memory**                 | 2.0 MB                                                                          |
| Data records               | 130,000 logs                                                                   |
| Data logs                  | 50 logs                                                                        |
| **Fastest logging rate**   | 2 per second                                                                   |
| **Fastest output rate**    | Modbus: 2 per second SDI-12 & 4–20 mA: 1 per second                           |
| **Log types**              | Linear, Fast Linear, and Event                                                 |

## Sensor Type/Material

<table>
<thead>
<tr>
<th>Sensor Type/Material</th>
<th>Piezoresistive; titanium</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td>Gauged (vented)</td>
</tr>
<tr>
<td></td>
<td>5 psig: 3.5 m (11.5 ft)</td>
</tr>
<tr>
<td></td>
<td>15 psig: 11 m (35 ft)</td>
</tr>
<tr>
<td></td>
<td>30 psig: 21 m (69 ft)</td>
</tr>
<tr>
<td></td>
<td>100 psig: 70 m (231 ft)</td>
</tr>
<tr>
<td></td>
<td>300 psig: 210 m (692 ft)</td>
</tr>
<tr>
<td></td>
<td>500 psig: 351 m (1153 ft)</td>
</tr>
</tbody>
</table>

| **Accuracy**          | ±0.05% FS at 15°C          |
|                      | ±0.1% FS at 0 to 50°C      |

| **Resolution**        | ±0.005% FS or better       |

| **Units of measure**  | Pressure: psi, kPa, bar, mbar, mmHg, inHg, cmH2O, inH2O |
|                      | Level: in., ft, mm, cm, m |

## Temperature Sensor

<table>
<thead>
<tr>
<th>Sensor Type/Material</th>
<th>Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>±0.1°C</td>
</tr>
</tbody>
</table>

| **Resolution**       | 0.01°C or better |

| **Units of measure** | Celsius or Fahrenheit |
Float Gauge

Fig. 50. Electric sight gauge, with metal stilling well.
Bubbler Pressure Gauge

Data Logger

Accubar Barometer

Bubbler Pump
Ultrasonic 2 way travel time measurement:
Downward looking air acoustic measurement

- Protective pipe
- Sutron ultrasonic sensor
- Aquatrak Ultrasonic
Electromagnetic Sensors

Microwave radar measures 2-way travel time between sensor and sea surface. High frequency waves filtered through software. Accuracy ~ +/- 1 cm.
GPS or GNSS Buoy

![Graph showing tide gauge, Filtered RTK, and Difference measurements with error bars]

- **Tide gauge**
- **Filtered RTK**
- **Difference**

- $1\sigma = 2.0$ cm
- $95\% = 3.7$ cm

**Buoy Dimensions**
- 12 feet waterline to antenna top
- 5 feet draft from waterline
- 1200 lb total weight

**Electronics and Battery Rack**
- 60 Watt solar panels (4 @ 20° angle)
- 4 Sealed Pressure Regulated Secondary Batteries

**Telemetry Radio & Solar Power Controller**
- Pentium CPU, 20GB HDD
- EtherNet, RS-232 Ports, Digital Ports, PC-104 interface for A/D

**GPS L1/L2 Receiver**
- Antenna
- RTK & data telemetry