Chapter 9

Coastal & Marine Environment

Basic Shore Processes

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Nearshore current patterns

- Nearshore current patterns are a combination of **alongshore currents**, **rip currents** and **undertow**.

(Svendsen•Lorenz, 1989)

Vertical distribution of coastal current
A rip current is strong narrow channel of water that flows from the surf-zone out to sea. It develops when breaking waves push onshore, then gravity pulls the water back out to sea. If the water converges into a narrow river like channel moving away from shore, a Rip Current forms.
Nearshore current patterns

Rip current generation

Flow from bar area towards channel

Nearshore current patterns

- Breaking waves
  - Wave setup
    - High MWL
- Unbroken waves
  - No Wave setup
    - Low MWL
- Breaking waves
  - Wave setup
    - High MWL

Incident waves
But water is being pumped onshore over the bar. This water has to go somewhere! Where can it go?
Nearshore current patterns

- For a large incident wave angle, alongshore momentum generated by the wave breaking process sets up strong alongshore currents (Fig. 12.1). Smaller incident wave angles generate weaker alongshore currents.

- Most of water flows from shore to deeper water in the form of undertow and rip currents as shown in Fig. 12.2.
Nearshore current patterns

The maximum value of the orbital motion near the breaker is

\[
\hat{u} = \frac{\pi H L}{T 2\pi d} = \frac{H}{2d} C = \frac{H}{2d} \sqrt{gd} 
\]

since

\[
\gamma_b = \frac{H_b}{d_b}
\]

so

\[
\hat{u}_b = \frac{\gamma}{2} \sqrt{gd_b} = \frac{I}{2} \sqrt{\gamma g H_b} \quad (12.5)
\]

The potential velocity of alongshore current, based on Longuet-Higgins (1970) is

\[
V_L = 20.7m \sqrt{gH_b} \sin 2\alpha_b \quad (12.6)
\]

where

- \( V_L \): Longshore current velocity
- \( m \): beach slope
Littoral materials vary in size from boulders to clay. They may be classified according to size, based on the median grain diameter $D_{50}$. Since sediment transport involves dynamics of particles under water, it is also common to use the settling velocity (fall velocity) of particles in still water to describe the sediment.

For natural grains

$$w_f = \left[ \left( \frac{\rho_s}{\rho} - 1 \right) g \right]^{0.7} \frac{D_{50}}{6\nu^{0.4}}$$

for $0.13 \cdot 10^{-3} \leq D_{50} \leq 1.6 \cdot 10^{-3} \text{ m}$

For larger material

$$w_f = 1.05 \left[ \left( \frac{\rho_s}{\rho} - 1 \right) g D_{50} \right]^{0.5}$$

for $1.6 \cdot 10^{-3} \leq D_{50} \leq 8 \cdot 10^{-3} \text{ m}$

where $\nu$ is the kinematic viscosity of water.
A beach is often characterized by its slope, which is related to grain size. Larger grain sizes generate steeper beaches.

Equation 12.14 may be explained as follows: Steep beach slopes result in a large energy dissipation rate (the breakers tend toward plunging and collapsing breakers). This results in more concentrated disturbing forces. Thus smaller grain sizes are readily removed from steeper beaches and the larger sizes remain.
According to Bruun (1954) and Dean (1977) the underwater portion of long-term average profiles may approximated by

\[ d = A_p x^{2/3} \]  \hspace{1cm} (12.15)

where
d: the depth of water and
x: the distance offshore of the still water line.
The profile coefficient \( A_p \) is mainly a function of grain size and Fig. 12.4 summarizes the relationship proposed by Moore (1982) and Dean (1983).

\[ A_p = (1.04 + 0.086 \ln D)^2 \quad \text{for} \quad 0.1 \times 10^{-3} \leq D \leq 1.0 \times 10^{-3} \text{ m} \] \hspace{1cm} (12.16)

Dean (1983) proposes \[ A_p = 0.50 w_f^{0.44} \] \hspace{1cm} (12.18)
Figure 12.4 Beach Parameter $A_p$ as a Function of Grain Size (after Dean, 1993)

$$A_p = (1.04 + 0.086 \ln D)^2$$

$$A_p = 0.50 w_f^{0.44}$$
Cross-shore sediment transport

• If the beach profile is close to its equilibrium with the existing environmental conditions, little cross-shore sediment motion will take place.

• The rate of cross-shore transport is normally assumed to be proportional to the difference between the existing beach profile and the equilibrium profile.

• Research to determine which wave conditions produce cross-shore sediment movement indicates that a fall velocity ratio

\[
\frac{H_o}{w_f T} \approx 1 \ \begin{cases} >1 & \text{sediment moves offshore} \\ <1 & \text{sediment moves onshore} \end{cases}
\]
Cross-shore sediment transport

\[ R = \frac{x_c \cdot h}{(d_d + d_c)} \]

- \( R \): the recession,
- \( h \): the water level rise,
- \( d_c \): the closure depth and
- \( d_d \): the dune height.

Figure 12.6 Beach Profile Recession from Water Level Rise
Cross-shore sediment transport

\[ Q_{\text{offshore}} = Q_{\text{in}} - Q_{\text{out}} - \Delta V \]
Cross-shore sediment transport

Cross-shore profile models

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Coastal & Marine Environment

Cross-shore transport

$D_c$

$R$

$y$

$z$

Storm
Alongshore sediment transport rate

Shoreline evolution models (one-line models)

oblique waves

littoral drift

$D_c$
Alongshore sediment transport rate

Example: Gaza, Palestine

\[ \Delta V \approx \Delta A \left( z_{\text{dune}} - z_{\text{toe active profile}} \right) \]

\[ S_{\text{alongshore}} \approx \frac{\Delta V}{\Delta t} \]
Alongshore transport is the most significant process for moving sediments in the coastal zone.

The alongshore sand transport rate is a measure of the rate at which littoral materials move alongshore in the surf zone from currents produced by obliquely breaking waves.

Information on prevailing alongshore sand transport rates is needed for the planning and design of all beach stabilization projects.
Net and gross transport rates

- Annual net transport rate: the net amount of sediment moving past a point on the beach in a year.
- Annual gross transport rate: the total amount of sediment moving past a point regardless of the direction in which it is moving.

\[
gross \text{ transport rate: } Q_g = Q_{(+)} + Q_{(-)}
\]

\[
net \text{ transport rate: } Q_n = Q_{(+)} - Q_{(-)}
\]
Chapter 9

Deriving alongshore sediment transport rate

**Energy flux method:** based on the assumption that the alongshore transport rate depends on the alongshore component of energy flux in the surf zone.
Alongshore sediment transport rate

Energy Flux Method

\[ Q = \frac{K}{(\rho_s - \rho) g a'} P_{ls} \]

- \( K \) = dimensionless empirical coefficient = 0.39
- \( \rho_s \) = sediment density
- \( \rho \) = water density
- \( g \) = acceleration of gravity
- \( a' \) = solid fraction of the in situ sediment deposit (1 - porosity)
- \( P_{ls} \) = alongshore component of energy flux in the surf zone (associated with significant wave)
Alongshore sediment transport rate

Energy Flux Method

\[ P_{ls} = \frac{\rho g H_{sb}^2}{16} C_{gb} \sin 2\alpha_b \]

- \( H_{sb} \): nearshore breaking height of the significant wave
- \( C_{gb} \): wave group speed at breaking
- \( \alpha_b \): angle between the breaking wave crest and the shoreline
CERC Formula

CERC: The Coastal Engineering Research Center formula (Shore Protection Manual, 1984)

The best known equation for bulk sediment transport rate is found in the CERC (1984).

\[ I_s = 0.39 P_{ash} \quad (12.30) \]

where \( I_s \) is the underwater weight of sediment transported.

Assuming a dense sand with \( \rho_s = 1800 \text{ kg/m}^3 \) and porosity, \( n = 0.32 \), Eq. 12.30 may be converted to m\(^3\)/yr as

\[ Q_C = 2.2 \times 10^6 \frac{H^{2.5}_{sb}}{\gamma^{0.5}_{sb}} \sin 2\alpha_b \quad (m^3 / yr) \]
Kamphuis Formula

Kamphuis: Queen's University in Ontario, Canada, 1991

\[ Q_{\text{Kamphuis}} = 5.85 \times 10^4 H_{sb}^2 T^{1.5} m_b^{0.75} D^{-0.25} \sin 0.6 \ 2\alpha_b \]

T: wave period in seconds
mb: beach slope at breaking zone
D: sediment size in meters
Example: Alongshore sediment transport rate

Equations 12.32 and 12.36 are compared in Table 12.1

$$ Q_c = 2.9 \cdot 10^6 \ H_{sb}^{5/2} \ sin \ 2\alpha_b \quad (m^3/yr) \quad (12.32) $$

$$ Q_{Kamphuis} = 5.85 \cdot 10^4 \ H_{sb}^2 \ T^{1.5} \ m_b^{0.75} \ D^{-0.25} \ sin^{0.6} \ 2\alpha_b \quad (12.36) $$
### Case Study: Gaza

<table>
<thead>
<tr>
<th>Wave Scenarios</th>
<th>Hs (m)</th>
<th>Ts (Sec)</th>
<th>αo (Deg)</th>
<th>Duration (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \leq 1.0m$</td>
<td>0.5</td>
<td>6.3</td>
<td>289</td>
<td>289</td>
</tr>
<tr>
<td>$1.0 &lt; H \leq 2.0$</td>
<td>1.3</td>
<td>7.1</td>
<td>300</td>
<td>63</td>
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<tr>
<td>$2.0 &lt; H \leq 3.0$</td>
<td>2.4</td>
<td>8.0</td>
<td>298</td>
<td>10</td>
</tr>
<tr>
<td>$3.0 &lt; H \leq 4.0$</td>
<td>3.4</td>
<td>8.8</td>
<td>297</td>
<td>2.7</td>
</tr>
<tr>
<td>$H &gt; 4.0m$</td>
<td>4.2</td>
<td>9.4</td>
<td>310</td>
<td>0.3</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>365</strong></td>
</tr>
</tbody>
</table>

26 = (360 – 45) – 289

Image © 2013 DigitalGlobe
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Data SID, NOAA, U.S. Navy, NGA, GEBCO
Sediment density \((R_S) = 1900 \text{ kg/m}^3\)
Water density \((R_W) = 1026 \text{ kg/m}^3\)
### Case Study: Gaza – alongshore sediment transport rate

<table>
<thead>
<tr>
<th>Wave Scenarios</th>
<th>Hs (m)</th>
<th>Ts (Sec)</th>
<th>αo (Deg)</th>
<th>Hb (m)</th>
<th>αb (Deg)</th>
<th>Duration (d)</th>
<th>Sediment m³/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>H ≤ 1.0m</td>
<td>0.5</td>
<td>6.3</td>
<td>26</td>
<td>0.62</td>
<td>8</td>
<td>289</td>
<td>60,746</td>
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<tr>
<td>1.0 &lt; H ≤ 2.0</td>
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<td>7.1</td>
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<td>8.8</td>
<td>18</td>
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<td>9</td>
<td>2.7</td>
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<td>4.2</td>
<td>9.4</td>
<td>5</td>
<td>4.32</td>
<td>3</td>
<td>0.3</td>
<td>3,078</td>
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</table>

Total 365 220,000

$$Q_{Kamphuis} = 5.85 \cdot 10^4 H_{sb}^2 T^{1.5} m_b^{0.75} D^{-0.25} \sin^{0.6} 2\alpha_b$$
Case Study: Gaza – alongshore sediment transport rate

<table>
<thead>
<tr>
<th>Wave Scenarios</th>
<th>Hs (m)</th>
<th>Ts (Sec)</th>
<th>α₀ (Deg)</th>
<th>Hb (m)</th>
<th>α₅ (Deg)</th>
<th>Duration (d)</th>
<th>Sediment m³/year</th>
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<td>5.9</td>
<td>-32</td>
<td>0.75</td>
<td>11</td>
<td>197</td>
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<td>6.5</td>
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<td>19</td>
<td>3</td>
<td>47,139</td>
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<tr>
<td>Total</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>365</td>
<td>160,000</td>
</tr>
</tbody>
</table>

\[ Q_{Kamphuis} = 5.85 \cdot 10^4 H_{sb}^2 T^{1.5} m_{b}^{0.75} D^{-0.25} \sin^{0.6} 2\alpha_b \]
Next Lecture
Shore Protection