PROFESSIONAL DEVELOPMENT PROGRAMME:
COASTAL INFRASTRUCTURE DESIGN, CONSTRUCTION AND MAINTENANCE

A COURSE IN
COASTAL DEFENSE SYSTEMS I

CHAPTER 6

LONGSHORE SEDIMENT TRANSPORT PROCESSES

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Coastal Sediment Properties and Longshore Sediment Transport

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Coastal Planning Course
Lesson #8
Tuesday 8:00-9:00 am
CEM III-1, III-2
1. Coastal Sediment Properties (CEM III-1)

2. Longshore Sediment Transport (CEM III-2)
Coastal Sediment Properties

Reference: CEM Part III-1
Why Important?

**Dredging**: type of dredge

**Environmental**: transport of fines, contaminated material

**Beach Fill**: longevity, aesthetics

**Scour Protection**: resist movement, dissipate energy, relieve pressure

**Sediment Transport Studies**: tracer

*Coastal Sediment Properties (CEM III-1)*
How do we classify sediments?

**Size:** particle diameter

--> Mesh size just allowing grain to pass

**Fall Speed:** speed at which sediment falls in fluid

--> incorporates sediment density, shape, and fluid characteristics

“Sedimentation Diameter” = diameter of sphere having same density and fall speed

Coastal Sediment Properties (CEM III-1)
Virginia Beach (foreshore)

U.S. Standard Sieve Sizes

D_{90} \sim 2.0 \text{ mm}

D_{50} \sim 0.85 \text{ mm}

CEM Fig III-1-1, p.III-1-6
## Sediment Size Classifications

### Table III-1-2
Sediment Particle Sizes

<table>
<thead>
<tr>
<th>ASTM (Unified) Classification</th>
<th>U.S. Std. Sieve</th>
<th>Size in mm</th>
<th>Phi Size</th>
<th>Wentworth Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder</td>
<td>4096</td>
<td>-12.0</td>
<td>Boulder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1024</td>
<td>-10.0</td>
<td>Boulder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>256</td>
<td>-8.0</td>
<td>Large Cobble</td>
<td></td>
</tr>
<tr>
<td></td>
<td>128</td>
<td>-7.0</td>
<td>Large Cobble</td>
<td></td>
</tr>
<tr>
<td>Cobble</td>
<td>107.64</td>
<td>-6.75</td>
<td>Large Cobble</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90.51</td>
<td>-6.5</td>
<td>Large Cobble</td>
<td></td>
</tr>
<tr>
<td></td>
<td>76.11</td>
<td>-6.25</td>
<td>Small Cobble</td>
<td></td>
</tr>
<tr>
<td></td>
<td>64.00</td>
<td>-6.0</td>
<td>Small Cobble</td>
<td></td>
</tr>
</tbody>
</table>

12 in. (300 mm)

3 in. (75 mm)

CEM Table III-1-2, p.III-1-8
Units of Sediment Size

- U.S. Standard Sieve
- Millimeters
- Phi units

\[ \Phi = - \log_2 D \]
\[ D = 2^{-\Phi} \]
Bulk Properties of Sediments

Clays, silts, muds:
  foundation, dredged material, bluffs

Organically-bound sediment (peat):
  back bays and tidal wetlands
  very compressible

Sand and gravel:
  ocean beaches
  calcium carbonate sand
  oolites (elliptical in shape)
Experiment

- Settling characteristics of various sediments in water
- Samples A, B, & C

Coastal Sediment Properties (CEM III-1)
Fall Speed

$$W_f = f (D, \rho, \rho_s, C_D) \quad (Eq. 1-7)$$

- $D =$ grain diameter
- $\rho =$ density of water
- $\rho_s =$ density of sediment
- $C_D =$ drag coefficient

Coastal Sediment Properties
(CEM III-1)
Fall Speed

With all other parameters held constant....
As grain diameter increases, fall speed increases
\[ D \uparrow , \ W_f \uparrow \]
Which means that the coarsest sediment will fall the fastest...
and will tend to remain in the more energetic parts of the profile...
such as where waves plunge on the beach

Coastal Sediment Properties
(CEM III-1)
Longshore Sediment Transport (LST)

Reference: CEM Part III-2
What is LST?

“transport of sediments within the surf zone, directed parallel to the coast”

Shoreward Observer:

\[ Q_R = \text{transport to right} \]
\[ Q_L = \text{transport to left} \]

Longshore Sediment Transport
(CEM III-2)
Why is LST Important?

**Dredging requirements**: deposition and shoaling in open-coast channels; placement of dredged material

**Beach condition**: understanding long- and short-term erosion & accretion trends

**Coastal projects**: designing structures & beach fill to mitigate for beach erosion; designing inlet structures to better operate and maintain channels

*Longshore Sediment Transport (CEM III-2)*
Definitions

(expressed as a negative value)

\[ Q_{\text{net}} = Q_{\text{right}} + Q_{\text{left}} \]

\[ Q_{\text{gross}} = |Q_{\text{right}}| + |Q_{\text{left}}| \]

Longshore Sediment Transport (CEM III-2)
**Definitions**

$Q_{\text{left}} = -100 \quad Q_{\text{right}} = 300$

$Q_{\text{net}} = Q_{\text{right}} + Q_{\text{left}} = 300 + (-100) = 200$

$Q_{\text{gross}} = |Q_{\text{right}}| + |Q_{\text{left}}| = 300 + 100 = 400$

*Units... thousands cubic yards per year or thousands cubic meters per year*

*Longshore Sediment Transport (CEM III-2)*
Importance of Left, Right, and Gross Transport

$$Q_{\text{gross}} = 400$$

$$Q_{\text{left}} = -100$$

$$Q_{\text{right}} = 300$$

Longshore Sediment Transport

(CEM III-2)
Estimating Net and Gross Transport Rates

1. Adopt a well-established rate from a nearby site
   - modify based on local conditions

2. Compute from historical data
   - shoreline position, bathymetric change, dredging volumes

3. Calculate using wave and beach data

4. Determine from experimental measurements

Longshore Sediment Transport
(CEM III-2)
1. Adopt a well-established rate from a nearby site (1 of 2)

(see also Table III-2-1)

**EAST AND GULF:**

<table>
<thead>
<tr>
<th>Location</th>
<th>Sediment Transport Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy Hook, NJ</td>
<td>380,000 m³/yr (net)</td>
</tr>
<tr>
<td>Cape May, NJ</td>
<td>900,000 m³/yr (gross)</td>
</tr>
<tr>
<td>Ocean City, MD</td>
<td>115,000 m³/yr (net)</td>
</tr>
<tr>
<td>Oregon Inlet, NC</td>
<td>1,600,000 m³/yr (gross)</td>
</tr>
<tr>
<td>Pinellas County, FL</td>
<td>40,000 m³/yr (net)</td>
</tr>
</tbody>
</table>
1. Adopt a well-established rate from a nearby site (2 of 2) (see also Table III-2-1)

PACIFIC AND GREAT LAKES:

Santa Barbara, CA  210,000 m³/yr (net)
Oceanside, CA     160,000 m³/yr (gross)

Columbia River WA/OR 1,500,000 m³/yr (gross)

Waukegan to Evanston, IL  40,000 m³/yr (net)

Longshore Sediment Transport (CEM III-2)
2. Compute from historical data (1 of 5)

a. Impoundment by Jetties and Breakwaters

b. Rate of Shoreline Change
   - long-term erosion/accretion
   - growth of spits

c. Rate of Bathymetric Change
   - deposition basin
   - rate of channel shoaling

d. Dredging volumes
   - indicator of gross?
a. Impoundment by Jetties and Breakwaters

Volume accreted $\sim Q_{\text{right}}$

Longshore Sediment Transport
(CEM III-2)
b. Rate of Shoreline Change

Volume growth $\sim Q_{\text{right}}$ or $Q_{\text{net}}$
c. Rate of Bathymetric Change

Volume accreted $\sim Q_{\text{right}}$

Longshore Sediment Transport
(CEM III-2)
d. Dredging volumes

\[ Q_{\text{right}} \quad \rightarrow \quad Q_{\text{shoaled}} \sim Q_{\text{gross}} \quad \leftarrow Q_{\text{left}} \]
3. Calculate using wave and beach data (1 of 5)
3. Calculate using wave and beach data (2 of 5)

\[ Q = f (H_b, \alpha_b, \rho_s, \rho, n, k) \] (Eq. 2-7b)

- \( H_b \) = breaking wave height
- \( \alpha_b \) = breaking wave angle relative to shoreline
- \( \rho_s \) = mass density of sediment
- \( \rho \) = mass density of water
- \( n \) = in-place sediment porosity \( \sim 0.4 \)
Note: $K$ can be calculated based on $D_{50}$

$$K = 1.4 \times e^{(-2.5 \times D_{50})}$$
Importance of $\alpha_b$

(breaking wave angle relative to the shoreline)

Waves

$Q_\perp = 0$  $Q_\perp$ increases  $Q_\perp$ greatest

Longshore Sediment Transport
(CEM III-2)
3. Calculate using wave and beach data (5 of 5)

\[ Q = f (H_b, W, V_l, C_f, V/V_o, \rho_s, \rho, n, k) \]  
(Eq. 2-11, 2-7a)

\( W = \) width of surf zone
\( V_l = \) measured longshore current
\( C_f = \) friction coefficient
\( V/V_o = \) dimensionless longshore current

Longshore Sediment Transport  
(CEM III-2)
4. Experimental Measurements

Sand tracer

Instruments (Optical Backscatter Sensors, Pumping samplers)

Traps (suspended and bedload)

Temporary structure (e.g., groin)
Characteristics of LST: Conceptual Yearly Cycle
(see Figs III-2-7 and III-2-9)

Longshore Sediment Transport
(CEM III-2)
Characteristics of LST: Yearly Variation
(see Fig III-2-8)

Longshore Sediment Transport
(CEM III-2)
Characteristics of LST: Cross-shore Distribution
(see Fig III-2-21)
Sediment Budgets

\[ \Delta V \text{ (beach erosion/accretion),} \]
\[ P \text{ (beach fill, dredged placement),} \]
\[ R \text{ (dredging, mining)} \]

\[ Q_{\text{source (LST)}} \]
\[ Q_{\text{sink (LST)}} \]

\[ Q_{\text{sink (e.g., sea level, submarine canyon)}} \]
\[ Q_{\text{source (e.g., bluffs, river influx)}} \]
\[ Q_{\text{sink (e.g., wind-blown transport)}} \]
Sediment Budgets

\[ \sum Q_{\text{source}} - \sum Q_{\text{sink}} - \Delta V + P - R = \text{Residual} \]

For a balanced cell, \( \text{Residual} = 0 \)
\[ \Delta V = ?, \ P = 0 \]
\[ R = 0 \]

\[ \Sigma Q_{\text{source}} - \Sigma Q_{\text{sink}} - \Delta V + P - R = 0 \]

\[ 100 + 0 - (200 + 0) - (\text{?}) + 0 - 0 = 0 \]

\[ \Delta V = -100 \]
\[ \Sigma Q_{\text{source}} - \Sigma Q_{\text{sink}} - \Delta V + P - R = 0 \]

\[ 100 + 20 - (20 + Q_{1\_\text{left}}) - (-20) + 50 - 0 = 0 \]

\[ Q_{1\_\text{left}} = 170 \]
Numerical LST Shoreline Change Model -- GENESIS

- predict future, with-project shoreline positions
- essentially a sediment budget for each grid cell
- driven by waves, site characteristics
- can incorporate structures, beach fill

Coastal Sediment Properties (CEM III-1)
HYDRODYNAMICS OF COASTAL REGIONS

RADIATION STRESS PRINCIPLES

- the time-averaged excess horizontal momentum flux due to presence of water waves.

\[ S_{xx} = \int_{-d}^{0} (p + \rho u^2) \, dz - \int_{-d}^{0} \rho g \, dz \]

Coordinate Transformation

\[ S_{xx}, S_{yy}, S_{xy} \]
Idealized environment for longshore current theory

Wave Field

• Simple, monochromatic gravity wave trains
• Steady-state, incident wave field
• Two-dimensional, horizontally propagating
• Linearized theory and radiation stresses
• Oblique angle of incidence, long wave crests
• Spilling-type breakers
• Constant breaker ratio in surf zone
Idealized environment for longshore current theory

**Beach**
- Infinite length, straight and parallel contours
- Plane bottom slope
- Gentle slope
- Impermeable bottom

**Fluid**
- Incompressible
- Homogeneous (no air entrainment)

**Current**
- Depth-integrated, parallel to coastline
- Time-average (one wave period)
Idealized environment for longshore current theory

Neglected Stresses and Accelerations

• No surface wind stress
• No atmospheric pressure gradient
• No Coriolis acceleration
• No tides
• No local (time-average acceleration, i.e., steady flow)
• No wave-turbulence interaction stresses
• No bed shear stress outside of surf zone
• No rip currents present
• No wave-current interaction stresses
THEORY (Longuet-Higgins, 1970, 1972)

Velocity $V$

Distance from Shoreline $X$

Momentum Balance

$$\frac{dS_{xy}}{dx} - \bar{T}_B + \frac{dT_L}{dx} = 0$$

$$P = \frac{N \pi \tan \beta}{C_f \gamma}$$
\[ H_b = 100 \text{ cm} \]
\[ \alpha_b = 10^\circ \]
\[ S = 0.100 \]

Maximum velocity: 70.3 cm/sec

\[ \bar{v}_l = 2.7 u_m \sin \alpha_b \cos \alpha_b \]

Max. 64.4 cm/sec

\[ P = 0.4 (c_f = 0.01333) \]

\[ P = 0.1 (c_f = 0.01754) \]

Breaker zone
THEORY (Kraus and Sasaki, 1979)
EXPERIMENTS (Mizuguchi, et al. 1978)

**Velocity**

<table>
<thead>
<tr>
<th>CASE 1</th>
<th>CASE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_B = 45^\circ$, $P = 0.067$</td>
<td>$\alpha_B = 48^\circ$, $P = 0.058$</td>
</tr>
<tr>
<td>$V/V_m$ vs. Distance</td>
<td>$V/V_m$ vs. Distance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CASE 3</th>
<th>CASE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_B = 15^\circ$, $P = 0.170$</td>
<td>$\alpha_B = 11.4^\circ$, $P = 0.077$</td>
</tr>
<tr>
<td>$V/V_m$ vs. Distance</td>
<td>$V/V_m$ vs. Distance</td>
</tr>
</tbody>
</table>

- **CASE 1**
  - Observed ($P = 0.99$)
  - $\alpha_B = 45^\circ$ ($P = 0.067$)
  - L-H ($P = 0.049$)

- **CASE 2**
  - Observed ($P = 1.12$)
  - $\alpha_B = 48^\circ$ ($P = 0.058$)
  - L-H ($P = 0.043$)

- **CASE 3**
  - Observed ($P = 1.15$)
  - $\alpha_B = 45^\circ$ ($P = 0.067$)
  - L-H ($P = 0.049$)

- **CASE 4**
  - Observed ($P = 1.28$)
  - $\alpha_B = 11.4^\circ$ ($P = 0.077$)
  - L-H ($P = 0.055$)
NMLONG LONGSHORE CURRENT

(after Kraus and Larson, 1991)
data of Visser (1991)

DISTANCE OFFSHORE (meters)

LONGSHORE CURRENT (m/sec)

WAVE HEIGHT (meters)

wave height model and data

current data

longshore current model
KOMAR AND INMAN (1970)

Field Data:
- Putnam, Munk and Traylor (1949)
- Galvin and Savage (1966)
- Komar and Inman (1970)

Laboratory Data:
- Putnam, Munk and Traylor (1949)
- Saville (1950)
- Brebner and Kamphuis (1963)

\[ \bar{V}_x = 1.17 \left( gH_b \right)^{1/2} \sin \alpha \cos \alpha_b, \text{ cm/sec} \]
SURF ZONE WAVE

OUTER REGION
Rapid transitions of wave shape.

INNER REGION
Rather slow change in wave shape
Front part resembles (periodic) bore

RUN-UP REGION
No "surface roller."

Point of breaking

MWS

SWL
A UNDERTOW

B MEASURED VELOCITIES

theory of Stive and Wind (1986)

data of Buhr-Hansen and Svendsen (1984)
Wave motion & longshore current of "equal influence"

Strong longshore current

Fig. 2. The mean motion of bottom sediments in the surf zone (from Ingle, 1966).

Dominant and secondary paths of tracer grains on the foreshore slope

Path of tracer grains within and immediately shoreward of the breaker (plunge) zone

Path of tracer grains seaward of the breaker zone

Weak longshore current
Fig. 1. Three-dimensional resultant mean velocities in the surf zone.
18 November 1948
Wave period 7.6 sec
Waves from WNW

- 0 - ½ kn
- ½ - 1 kn
- 1 - 1½ kn
- > 1 kn

- Observed current (not measured)
- Starting position of surface float

Hb = Breaker height

Float recovery area

No. 1 - Beach club
No. 20 - Shelf
No. 30 - Scripps Institution
No. 40 - Scripps Canyon

La Jolla Canyon

N

ft

0 500 1000 m

0 100 200 300 m
EXPERIMENT

$T = 1.14 \text{ sec}$

$\bullet \ H_b = 8.55 \text{ cm}$

$\circ \ H_b = 6.60 \text{ cm}$

SET-DOWN AND SET-UP

MEAN WATER LEVEL, $\bar{h}$, cm

WAVE HEIGHT

WAVE HEIGHT, $H$, cm

still water level

beach

set-down

set-up
low waves  low set-up

low waves  low set-up

high waves  high set-up

high waves  high set-up

rip current

longshore current

rip current
$H_b = 100 \text{ cm}$

$\alpha_b = 20^\circ$

$\tan \beta = 0.100$

$X_b = 1250 \text{ cm}$

$N = 0.005$

$c_f = 0.010$

$\frac{\partial \eta}{\partial y} = -0.0005$

$\frac{\partial \eta}{\partial y} = 0.0025$

Longshore Current, $\bar{V}_l$, cm/sec

$x / X_b$

$\bar{V}_l$
PHASE-AVERAGED MODELS

Energy Density $e(f, \theta)\newline$

Direction $rown$

Model Calculates - Steady State

$e(f, \theta, x, y)\newline$

$H_{in}(x, y, \theta)\newline$

$T_{p}(x, y, \theta)\newline$

$\Theta_{m}(x, y)\newline$

PHASE-RESOLVING MODELS

Water Surface $\eta(t)\newline$

Model Calculates - Time Marching

$\eta(x, y, t)\newline$

$U(x, y, t)\newline$

$V(x, y, t)\newline$