CHAPTER 8
Waves and Water Dynamics
Wave Generation

- Disturbing force
- Interface of fluids with different densities
  - Air – ocean interface
  - Air – air interface
  - Water – water interface
Types of Waves

- Surface waves
- Low-density water
- Internal waves
- High-density water
Internal Waves

- Associated with pycnocline
- Larger than surface waves
- Caused by tides, turbidity currents, winds, ships
- Possible hazard for submarines
Other Types of Waves

- **Splash wave**
  - Coastal landslides, calving icebergs
- **Seismic sea wave or tsunami**
  - Sea floor movement
- **Tides**
  - Gravitational attraction among Moon, Sun, and Earth
- **Wake**
  - Ships
Energy in Ocean Waves

- **Wave period**:
  - 0.1 sec
  - 1.0 sec
  - 30 sec
  - 1 hr
  - 12 hr
  - 24 hr

- **Wave energy**

- **Wave type**:
  - Wind-generated waves
  - Wind
  - Tsunami
  - Tides
  - Earthquakes, volcanoes, landslides, storms
  - Moon and Sun

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Progressive Waves

- **Progressive waves** oscillate uniformly and progress without breaking
  - Longitudinal
  - Transverse
  - Orbital

1. **LONGITUDINAL WAVE**
   Particles (color) move back and forth in direction of energy transmission. These waves transmit energy through all states of matter.

2. **TRANSVERSE WAVE**
   Particles (color) move back and forth at right angles to direction of energy transmission. These waves transmit energy only through solids.

3. **ORBITAL WAVE**
   Particles (color) move in orbital path. These waves transmit energy along interface between two fluids of different density (liquids and/or gases).
Orbital Waves

(a) Wave characteristics

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Orbital Wave Characteristics

• Wave steepness \( = \frac{H}{L} \)
  
  – If wave steepness \( > \frac{1}{7} \), wave breaks

• Wave period \( (T) \) = time for one wavelength to pass fixed point

• Wave frequency = inverse of period or \( \frac{1}{T} \)
Orbital Wave Characteristics

- Diameter of orbital motion decreases with depth of water
- Wave base = \( \frac{1}{2} L \)
Circular Orbital Motion
Deep-Water Waves

- Water depth is greater than wave base ($\geq \frac{1}{2}L$)
- Wave speed = celerity ($C$)
- $C = \frac{L}{T}$
- $C = 1.25\sqrt{L}$
- $C = 1.56T$
Speed of Deep Water Waves

The graph shows the relationship between speed (in feet per second) and wavelength (in meters) for deep water waves. The speed is plotted on the y-axis in both feet per second and meters per second, with a period in seconds marked on the x-axis. The graph includes a line with data points indicating how speed changes with wavelength, with specific values noted at various points.
Transitional Waves

- Characteristics of both deep- and shallow-water waves
- Celerity depends on both water depth and wavelength

(b) Transitional wave: $\frac{1}{20}$ wavelength $\leq$ depth $\leq \frac{1}{2}$ wavelength
Shallow-Water Waves

- Water depth is $\leq \frac{1}{20} L$
- $C \text{ (meters/sec)} = 3.13 \sqrt{d \text{ (meters)}}$
- Where $d$ is water depth
Wind-Generated Wave Development

• Capillary waves
  – Wind generates stress on sea surface

• Gravity waves
  – Increasing wave energy

• Trochoidal waveforms
  – Increased energy, pointed crests
Global Wave Heights
Maximum Wave Height

Wave movement

To horizon

Eye height of observer on bridge

Crow's nest

Bridge

USS Ramapo

34 meters (112 feet)

152 meters (500 feet)

Stern of ship in trough

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Sea and Swell

- **Sea or sea area** – where wind-driven waves are generated
- **Swell** – uniform, symmetrical waves originating from sea area
Wave Energy

• Fully developed sea
  – Maximum wave height, wavelength for particular fetch, speed, and duration of winds at equilibrium conditions

• Swell
  – Uniform, symmetrical waves that travel outward from storm area
  – Long crests
  – Transport energy long distances
Wave Train Movement

Wave 4  Wave 3  Wave 2  Wave 1

Wave train

Wave 5  Wave 4  Wave 3  Wave 2  (Wave 1 dies out)

Wave train

Wave 6  Wave 5  Wave 4  Wave 3  (Wave 2 dies out)

Wave train

(Waves 2 and 1 have disappeared)

Wave 7  Wave 6  Wave 5  Wave 4  (Wave 3 dies out)

Wave train
Wave Interference Patterns
Waves in Surf Zone

- Surf zone – zone of breaking waves near shore
- Shoaling water – water becoming gradually more shallow
- When deep water waves encounter shoaling water less than \( \frac{1}{2} \) their wavelength, they become transitional waves.
Waves Approaching Shore

- Waves with constant wavelength
- Waves touch bottom (wavelength shortens)
- Surf zone (breakers form)
- Wave base
- Depth = 1/2 wavelength
- Velocity decreases (wave height increases)

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Three Types of Breakers

a) Spilling
b) Plunging
c) Surging
Wave Refraction

1. Waves travel at original speed in deep water.
2. Waves "feel bottom" and slow down in surf zone.
3. Result: Waves more directly face the shore, causing wave crests to bend.

Land

Surf zone

Ocean

Wave crest
Wave Refraction

- Wave energy unevenly distributed on shore
- Orthogonal lines or wave rays – drawn perpendicular to wave crests
Wave Reflection

1. Wave crest approaches shore
2. Wave reflects off of jetty
3. Reflected wave overlaps with original wave, producing The Wedge

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Standing Waves

(a) Motionless

(b) 0.25T
   Maximum water flow

(c) 0.50T
   Motionless

(d) 0.75T
   Maximum water flow

(e) 1.0T
   Motionless

Begins again at (b)

Seiche in Lake Geneva (Switzerland)

One wavelength equals twice the length of the lake.
Tsunami Characteristics

• Long wavelengths

• Behaves as a shallow-water wave

• Speed proportional to water depth
Tsunami
Tsunami Destruction

• Sea level can rise up to 40 meters (131 feet) when a tsunami reaches shore.
Tsunami

- Most occur in Pacific Ocean
  - More earthquakes and volcanic eruptions
- Damaging to coastal areas
- Loss of human lives
Historical Large Tsunami

- July 12, 1999, Okushiri, Japan: MAXIMUM WAVE: 3.1 m, FATALITIES: 1
- January 1, 1996, Sulawesi Island: MAXIMUM WAVE: 3.4 m, FATALITIES: 9
- June 2, 1994, East Java: MAXIMUM WAVE: 14 m, FATALITIES: 238
- July 17, 1998, Papua New Guinea: MAXIMUM WAVE: 15 m, FATALITIES: 161
- July 17, 2006, Central Java: MAXIMUM WAVE: 2 m, FATALITIES: 339
- December 12, 1992, Flores Island: MAXIMUM WAVE: 26 m, FATALITIES: >1,000
- April 1, 2007, Solomon Islands: MAXIMUM WAVE: 5 m, FATALITIES: 52
- September 26, 2003, Tokachi, Japan: MAXIMUM WAVE: 1.3 m, FATALITIES: 1
- October 9, 1995, Jalisco, Mexico: MAXIMUM WAVE: 11 m, FATALITIES: 1
- September 2, 1992, Nicaragua: MAXIMUM WAVE: 10 m, FATALITIES: 170
- September 29, 2009, Samoan Islands: MAXIMUM WAVE: 14 m, FATALITIES: 189
- December 29, 2004, Sumatra, Indonesia: MAXIMUM WAVE: 35 m, FATALITIES: 309,000 (throughout Indian Ocean)
Tsunami Warning System

• Pacific Tsunami Warning Center (PTWC) – Honolulu, HI

• Deep Ocean Assessment and Reporting of Tsunami (DART)
End of CHAPTER 8
Waves and Water Dynamics