1 **CHAPTER 8**
Waves and Water Dynamics

2 **A little wave haiku:**

- Gulf of Alaska
- miles and miles of storm wind fetch
- at Black's Beach, surf's up!

3 **Chapter Overview**

- Most waves are wind-driven.
- Most waves are generated by storms.
- Waves transmit energy across the ocean surface.
- Deep water and surf zone waves have different characteristics.
- Tsunami are special fast, long waves generated by seismic events.

4 **Wave Generation**

- Disturbing force causes waves to form.
- Wind blowing across ocean surface
- Interface of fluids with different densities
  - Air – ocean interface
    - Ocean waves
  - Air – air interface
    - Atmospheric waves
  - Water – water interface
    - Internal waves

5 **Types of Waves**

6 **Internal Waves**

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

7 **Wave Movement**

- Waves transmit energy
- Cyclic motion of particles in ocean
  - Particles may move
    - Up and down
    - Back and forth
    - Around and around

8 **Types of ocean waves**

9 **Progressive Waves**

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

10 **Longitudinal Waves**

- Also called push-pull waves
- Compress and decompress as they travel, like a coiled spring

11 **Transverse Waves**

- Also called side-to-side waves
- Energy travels at right angles to direction of moving particles.
- Generally only transmit through solids, not liquids

12 **Orbital Waves**

- Also called interface waves
- Waves on ocean surface

13 **Wave Terminology**
- Crest
- Trough
- Still water level
  - Zero energy level
- Wave height (H)

14 **Orbital Wave Characteristics**
- Wave steepness = H/L
  - If wave steepness > $^1/_7$, wave breaks
- Wave period (T) = time for one wavelength to pass fixed point
- Wave frequency = inverse of period or 1/T
-

15 **Orbital Wave Characteristics**
- Diameter of orbital motion decreases with depth of water.
- Wave base = ½ L
- Hardly any motion below wave base due to wave activity

16 **Circular Orbital Motion**
- Wave particles move in a circle.
- Waveform travels forward.
- Wave energy advances.

17 **Deep Water Waves**
- Wave base – depth where orbital movement of water particles stops
- If water depth is greater than wave base ($\geq$½L), wave is a deep water wave.
- Lack of orbital motion at depth useful for floating runways and other structures

18 **Deep Water Waves**
- Case in point:
- FLIP
  - (FLoating Instrument Package)

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21 **Deep Water Waves**
- Case in point:
- FLIP
  - (Flipped!)

22 **Deep Water Waves**
- All wind-generated waves in open ocean
- Wave speed = wavelength (L)/period (T)
- Speed called celerity (C)

23 **Speed of Deep Water Waves**

24 **Shallow-Water Waves**

- Water depth (d) is less than 1/20 L
  - Water "feels" seafloor
- C (meters/sec) = 3.13 √ d(meters) or
- C (feet/sec) = 5.67 √d (feet)

25 **Transitional Waves**
- Characteristics of both deep- and shallow-water waves
- Celerity depends on both water depth and wavelength

26 **Wave Motion and Refraction**

27 **Wind-Generated Wave Development**
- Capillary waves
  - Wind generates stress on sea surface
- Gravity waves

– Increasing wave energy
–

28 **Wind Generated Wave Development**
- Capillary Waves
  - Ripples
  - Wind generates initial stress on sea surface
- Gravity Waves
  - More energy transferred to ocean
  - Trochoidal waveform as crests become pointed

29 **Sea**
- Sea
  - Where wind-driven waves are generated
  - Also called sea area

30 **Factors Affecting Wave Energy**
- Wind speed
- Wind duration
- Fetch – distance over which wind blows

31 **Wave Height**
- Directly related to wave energy
- Wave heights usually less than 2 meters (6.6 feet)
- Breakers called whitecaps form when wave reaches critical steepness.
- Beaufort Wind Scale describes appearance of sea surface.

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33 **Global Wave Heights**

34 **Beaufort Wind Scale**

35 **Maximum Wave Height**
- *USS Ramapo* (1933): 152-meters (500 feet) long ship caught in Pacific typhoon
- Waves 34 meters (112 feet) high
- Previously thought waves could not exceed 60 feet

36 **Wave Damage**
- *USS Ramapo* undamaged
- Other craft not as lucky
- Ships damaged or disappear annually due to high storm waves

37 **Wave Energy**
- Fully developed sea
  - Equilibrium condition

- Waves can grow no further
- Swell
  - Uniform, symmetrical waves that travel outward from storm area
  - Long crests
  - Transport energy long distances

38 **Fully Developed Sea**

39 **Swells**

40 **Wave Train Movement**

41 **Wave Interference Patterns**

42 **Wave Interference Patterns**

43 **Rogue Waves**

44 **Rogue Waves**

45 **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 ½ their wavelength, they become transitional waves.

46 **Waves Approaching Shore**

- As a deep-water wave becomes a shallow-water wave:
  - Wave speed decreases
  - Wavelength decreases
  - Wave height increases
  - Wave steepness (height/wavelength) increases
  - When steepness $\geq {}^{1}/_{7}$, wave breaks

47 **Waves Approaching Shore**

48 **Breakers in Surf Zone**

- Surf as swell from distant storms
  - Waves break close to shore
  - Uniform breakers
- Surf generated by local winds
  - Choppy, high energy, unstable water
- Shallow water waves

49 **Three Types of Breakers**

- Spilling
- Plunging
- Surging

50 **Spilling Breakers**

- Gently sloping sea floor
- Wave energy expended over longer distance
- Water slides down front slope of wave

51 **Plunging Breakers**

- Moderately steep sea floor
- Wave energy expended over shorter distance
- Best for board surfers
- Curling wave crest

52 **Surging Breakers**

- Steepest sea floor
- Energy spread over shortest distance
- Best for body surfing
- Waves break on the shore

53 **Surfing**

- Like riding a gravity-operated water sled

- Balance of gravity and buoyancy
- Skilled surfers position board on wave front
  - Can achieve speeds up to 40 km/hour (25 miles/hour)

54 **Wave Refraction**
- Waves rarely approach shore at a perfect 90-degree angle.
- As waves approach shore, they bend so wave crests are nearly parallel to shore.
- Wave speed is proportional to the depth of water (shallow-water wave).
- Different segments of the wave crest travel at different speeds.

55 **Wave Refraction**

56 **Wave Refraction**
- Wave energy unevenly distributed on shore
- Orthogonal lines or wave rays – drawn perpendicular to wave crests
  - More energy released on headlands
  - Energy more dissipated in bays

57 **Wave Motion and Refraction**

58 **Wave Refraction**
- Gradually erodes headlands
- Sediment accumulates in bays

59 **Wave Reflection**
- Waves and wave energy bounced back from barrier
- Reflected wave can interfere with next incoming wave.
- With constructive interference, can create dangerous plunging breakers

60 **Wave reflection**

61 **Standing Waves**
- Two waves with same wavelength moving in opposite directions
- Water particles move vertically and horizontally.
- Water sloshes back and forth.

62 **Standing Waves**
- Nodes have no vertical movement
- Antinodes are alternating crests and troughs.

63 **Tsunami**
- Seismic sea waves
- Originate from sudden sea floor topography changes
  - Earthquakes – *most common cause*
  - Underwater landslides
  - Underwater volcano collapse
  - Underwater volcanic eruption
  - Meteorite impact – splash waves

64 **Tsunami Characteristics**
- Long wavelengths (> 200 km or 125 miles)
- Behaves as a shallow-water wave
  - Encompasses entire water column, regardless of ocean depth
  - Can pass undetected under boats in open ocean
- Speed proportional to water depth
  - Very fast in open ocean

65 **Tsunami**

66 **Tsunami Destruction**
- Sea level can rise up to 40 meters (131 feet) when a tsunami reaches shore.

67 **Tsunami**
- Most occur in Pacific Ocean
  - More earthquakes and volcanic eruptions

- Damaging to coastal areas
- Loss of human lives

68 **Historical Tsunami**
- Krakatau – 1883
  - Indonesian volcanic eruption
- Scotch Cap, Alaska/Hilo, Hawaii – 1946
  - Magnitude 7.3 earthquake in Aleutian Trench
- Papua New Guinea – 1998
  - Pacific Ring of Fire magnitude 7.1 earthquake

69 **Historical Large Tsunami**

70 **Historical Large Tsunami**

71 **Indian Ocean Tsunami**
- December 26, 2004
  - Magnitude 9.2 earthquake off coast of Sumatra
  - 1200 km seafloor displaced between two tectonic plates
  - Deadliest tsunami in history
  - Coastal villages completely wiped out

72 **Indian Ocean Tsunami**
- Detected by Jason-1 satellite
- Traveled more than 5000 km (3000 mi)
- Wavelength about 500 km (300 mi)
- 230,000–300,000 people in 11 countries killed
- Lack of warning system in Indian Ocean

73 **Japan Tsunami**
- March 11, 2011 – Tohoku Earthquake
  - Magnitude 9.0 earthquake in Japan Trench
  - Felt throughout Pacific basin
  - Most expensive tsunami in history
- Initial surge 15 meters (49 ft)
  - Topped harbor-protecting tsunami walls
  - Amplified by local topography
  -

74 **Japan Tsunami**
- Killed 19,508 people
- Disrupted power at Fukushima Daiichi nuclear power plant
  - Reactors exploded
  - Radioactivity problem initiated

75 **Tsunami Warning System**
- Pacific Tsunami Warning Center (PTWC) – Honolulu, HI
  - Uses seismic wave recordings to forecast tsunami
- Deep Ocean Assessment and Reporting of Tsunami (DART)
  - System of buoys
  - Detects pulse of tsunami passing

76 **Tsunami Watches and Warnings**
- Tsunami Watch – issued when potential for tsunami exists
- Tsunami Warning – unusual wave activity verified
  - Evacuate people
  - Move ships from harbors

77 **Waves as Source of Energy**
- Lots of energy associated with waves
- Mostly with large storm waves
  - How to protect power plants

  - How to produce power consistently
- Environmental issues
  - Building power plants close to shore
  - Interfering with life and sediment movement

78 **Wave Power Plant**

79 **Wave Power Plants**

- First commercial wave power plant began operating in 2000.
- LIMPET 500 – Land Installed Marine Powered Energy Transformer
  - Coast of Scotland
  - 500 kilowatts of power under peak operating capacity

80 **Wave Farms**

- Portugal – 2008
  - Ocean Power Delivery
  - First wave farm
- About 50 wave power development projects globally

81 **Global Wave Energy Resources**

82 **End of CHAPTER 8**

Waves and Water Dynamics