

Maritime Hydraulics

The maritime hydraulics course is a specialized branch of hydraulic engineering that deals with the physical phenomena related to the interaction between the sea (or large bodies of water) and human-made structures, such as ports, dams, breakwaters, as well as natural coastal dynamics.



- More than 40% of the world's population lives within 100 km of the coast.
- Around 10 of the 15 largest cities in the world are coastal.

Waves remember the wind that generated them: Ocean swell can travel thousands of kilometers after the storm that generated it has disappeared.
Es. The waves arriving in California may have been generated near New Zealand days earlier.

The Hidden Energy in a Wave

Consider a moderate sea state:

- Significant wave height $H_s = 2 \text{ m}$ - Wave period $T = 8 \text{ s}$
- This carries approximately 30-40 kW per meter of wave crest.

→ That means: 100 meters of coastline can receive 3-4 MW of continuous power during a moderate storm.
In severe storms, wave power can exceed 200 kW per meter.

→ The Ocean as a Global Battery

Oceans cover 71% of Earth's surface.

- More energy-dense than wind
- More predictable than solar
- But technologically much more complex

But...in the 1970s, offshore platforms in the North Sea were designed using linear wave theory.

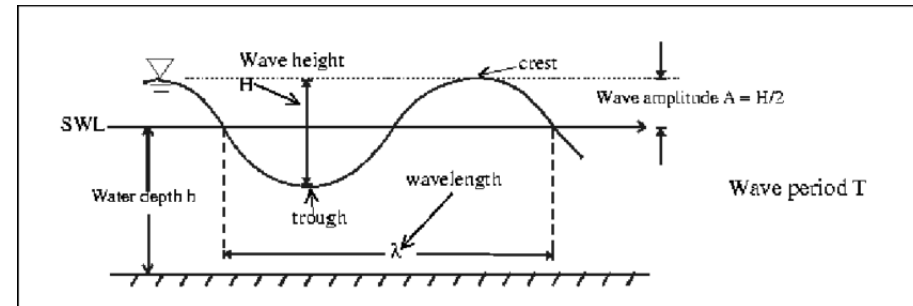
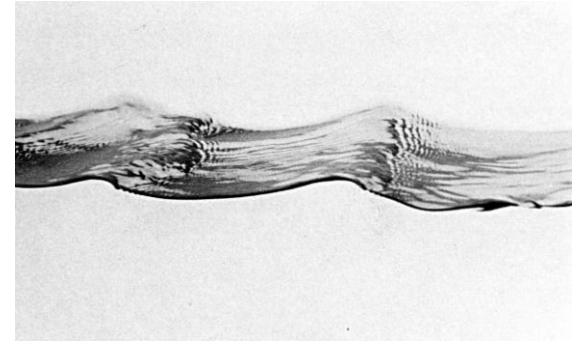
Then came the rogue waves:

- Heights up to 25-30 meters
- Much larger than statistical models predicted

..in 1995, the Draupner platform recorded a wave of 25.6 meters

..in 1953, a massive storm surge in the North Sea caused more than 1,800 deaths in the Netherlands, over 300 deaths in the UK

What is a wave?



What is a wave?

George Airy assumes waves to be:

- Small compared to the depth and wavelength (small amplitudes → linear waves),
- The fluid is incompressible and irrotational (no vortices),
- The bottom is horizontal and the depth is constant.

With these assumptions, the velocity potential $\phi(x,z,t)$ can be used to describe the fluid motion and Laplace's equation can be solved:

$$\nabla^2 \phi = 0$$



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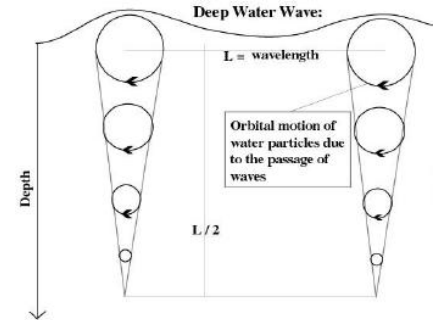
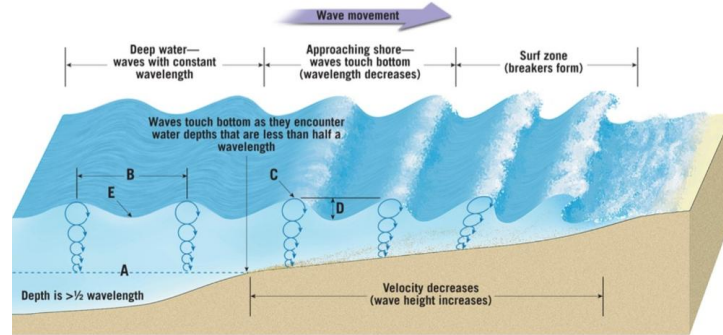
Then the boundary conditions are imposed

- Free surface (atmospheric pressure)
- Impermeable bottom (no normal flow)

Linear Theory

And the wave is shaped as a sinusoidal function

$$\eta(x, t) = a \cos(kx - \omega t)$$



What Airy's theory describes

1. Vertical decay of the wave effect (it diminishes with depth).
2. Elliptical orbits of water particles under the wave (circular in deep water).
3. Relationship between wavelength and period, the famous dispersion relation:

$$\omega^2 = gk \tanh(kh)$$


Linear Theory

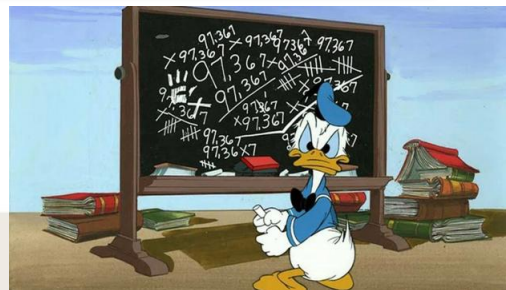
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Equations are derived for:

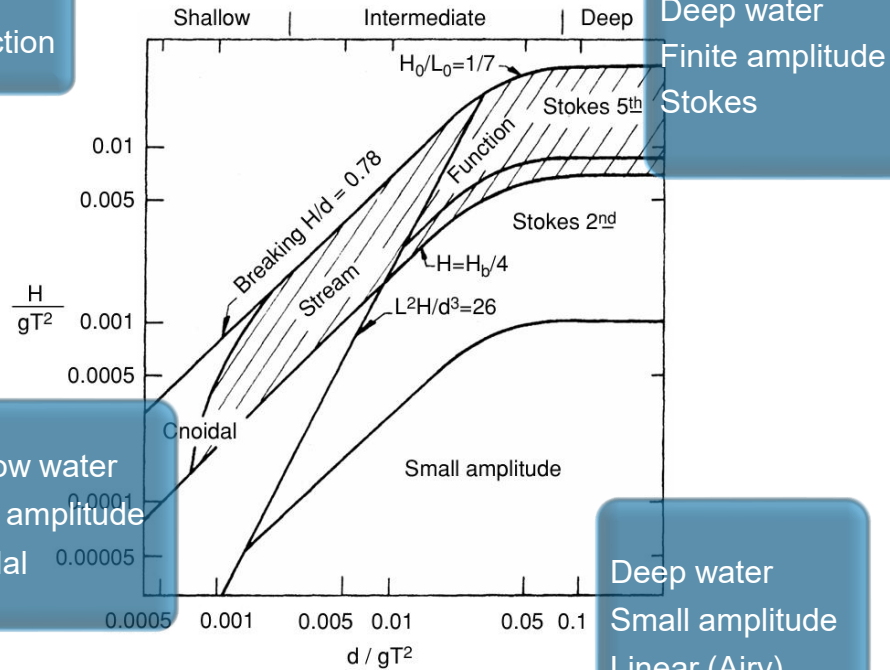
- Pressures under the wave
- Horizontal and vertical velocities
- Energy transported and forces on structures


$$p(x, z, t) = \rho g \eta(x, t) \cdot \frac{\cosh[k(z + h)]}{\cosh(kh)}$$



Beyond linear Theory

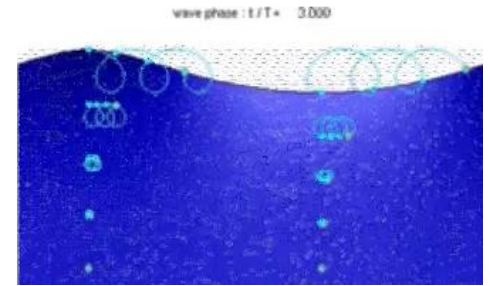
Strong general
nonlinearity
Stream function



Deep water
Finite amplitude
Stokes

Shallow water
Finite amplitude
Cnoidal

Deep water
Small amplitude
Linear (Airy)



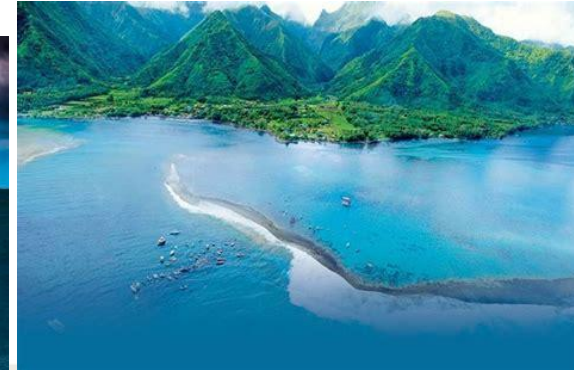
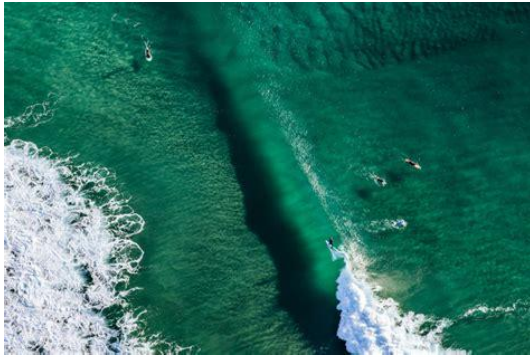
Wave transformation in shallow water

When waves approach the coast:

- Shoaling (change in height)
- Refraction (waves bend toward shallower depths)
- Diffraction (when they encounter obstacles like piers or islands)
- Breaking: a wave breaks if the height-to-depth ratio exceeds a certain value

Waves break where they find a shallow seabed, but not all of them do it in the same way.

Surfers study bathymetry (the shape of the seabed) to find spots where the wave breaks better and more consistently.



Coastal structures

Types of maritime structures and interaction with waves

Vertical structure

(e.g., piers, sluices, dams):

Waves strike the wall perpendicularly.

They can almost completely reflect, generating significant surges (impulsive impacts if the wave breaks).

In the presence of breaking, a maritime water hammer can occur (very high impact pressure, >200 kPa).

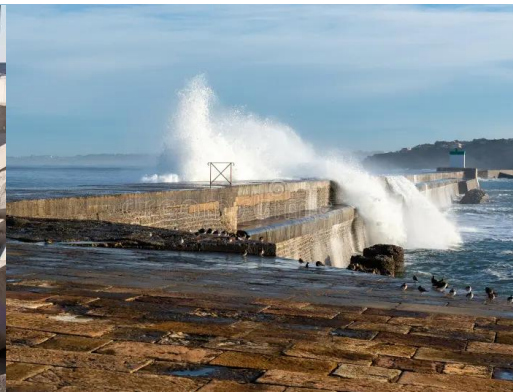
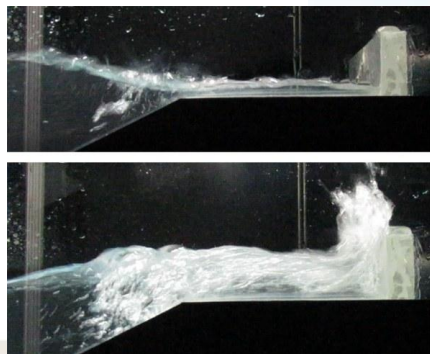
Inclined structure

(e.g., cliff, rubble mound breakwater):

It dissipates part of the energy through wave run-up and gradual breaking.

The forces are more distributed and generally lower.

It is designed to avoid reflection, but it occupies more space.

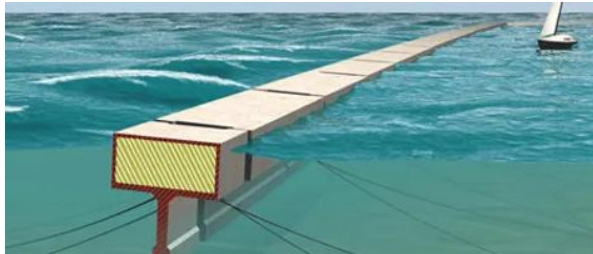


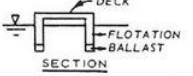
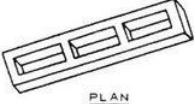
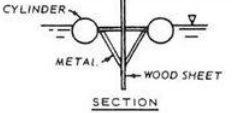

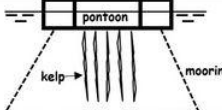
Coastal structures

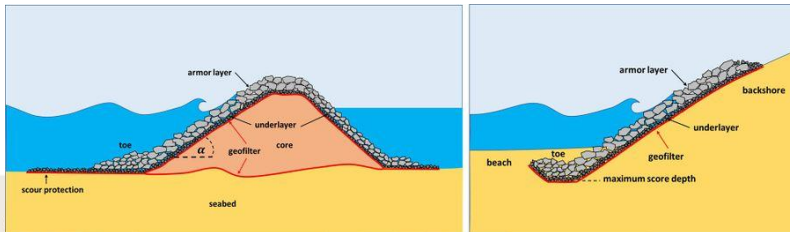
Types of maritime structures and interaction with waves

Floating structures

- Shore protection
- The waves hit them → part of the energy is reflected or dissipated.
- The rest passes underneath, but in a dampened way, reducing wave motion and turbulence behind.

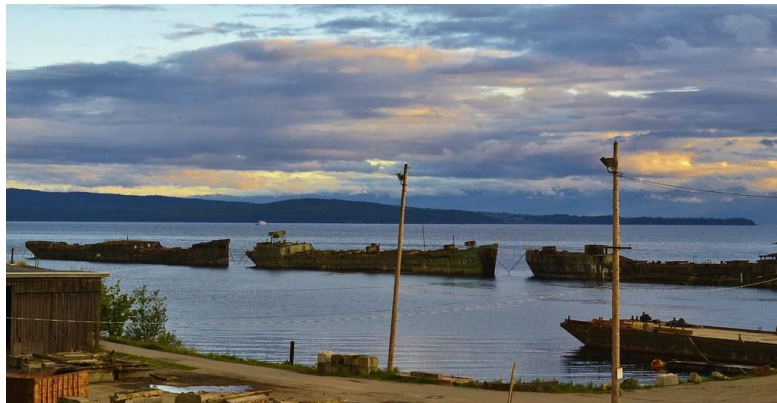


PONTOON Twin pontoon		Catamaran shape
Open compartment		Sometime called Alaska type
A frame		
Twin log		Deck is open wood frame
Pontoon with kelp wave attenuation		



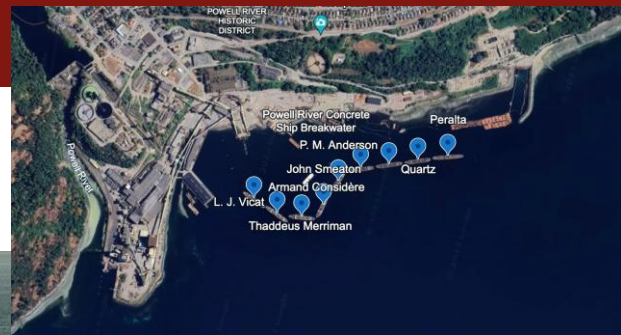
Coastal structures

Types of maritime structures and interaction with waves



Powell River Floating Breakwater (Canada)

Located in British Columbia, this floating breakwater is made up of reinforced concrete ships dating back to World War II. The ships, known as "The Hulks," were assembled to form a protective barrier for a pulp mill, creating a calm water area for lumber processing. It is considered one of the largest floating breakwaters in the world.



Shore currents and solid transport

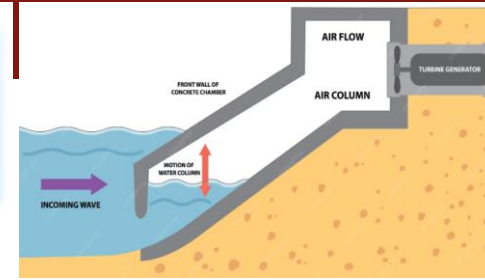
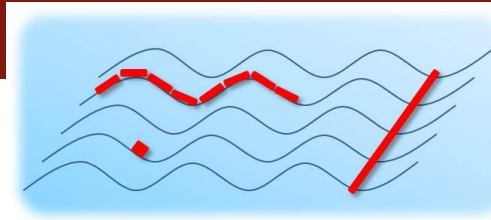
Waves carry not only energy but also sediments: sand, silt, gravel.

This is known as longshore drift, the alongshore transport caused by the oblique incidence of waves.

Coastal morphological changes are modeled, essential for understanding the retreat or advance of the shoreline.



Wave Energy

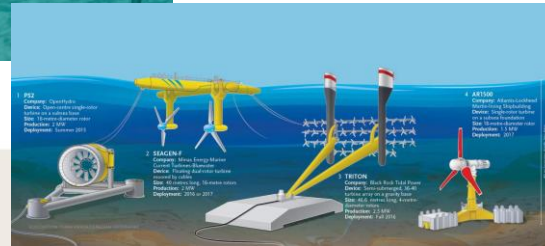
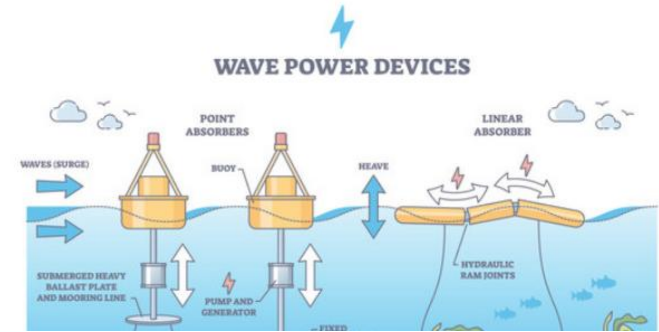
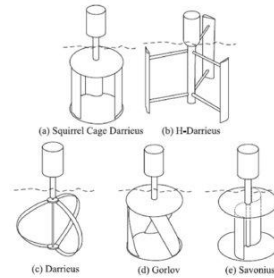


Classification of Wave Energy Converters (WECs) :

- Point absorbers: small relative to wavelength, extract energy from vertical motion
- Oscillating water columns (OWC): air turbine driven by wave-induced water column oscillation
- Attenuators: long devices parallel to wave direction, flex and bend
- Overtopping devices: reservoir-based systems capturing water above sea level

Tidal Stream Turbines (TSTs) types

- Tidal energy vs. wave energy
- Horizontal-axis tidal turbines (HATTs)
- Vertical-axis tidal turbines (VATTs)
- Venturi effect devices
- Oscillating hydrofoils



Course Outline

Introduction to the course

1. Two-Dimensional Wave Equations and Wave Characteristics

- Surface Gravity Waves
- Small-Amplitude Wave Theory
- Wave Classification
- Wave Kinematics and Pressure
- Energy, Power, and Group Celerity
- Radiation Stress and Wave Setup
- Standing Waves, Wave Reflection
- Wave Profile Asymmetry and Breaking
- Wave Runup

2. Finite-Amplitude Waves

- Finite-Amplitude Wave Theory Formulation
- Stokes Waves
- Cnoidal Waves
- Solitary Waves
- Stream Function Numerical Waves
- Wave Theory Application

3. Wave Refraction, Diffraction and Reflection

- Three-Dimensional Wave Transformation
- Wave Refraction
- Manual Construction of Refraction Diagrams
- Refraction by Currents
- Wave Diffraction
- Combined Refraction and Diffraction
- Wave Reflection
- Vessel-Generated Waves

Course Outline

4. Coastal Water Level Fluctuations

- Long Wave Equations
- Astronomical Tide Generation and Characteristics
- Tide Datums and Tide Prediction
- Tsunamis
- Basin Oscillations
- Resonant Motion in Two- and Three-Dimensional Basins
- Storm Surge and Design Storms
- Simplified Analysis of Storm Surge
- Long-Term Sea Level Change

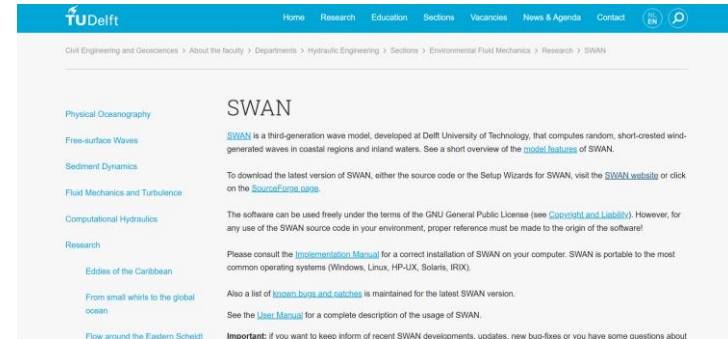
5. Wind-Generated Waves

- Waves at Sea
- Wind-Wave Generation and Decay
- Wave Record Analysis for Height and Period
- Wave Spectral Characteristics
- Wave Spectral Models
- Wave Prediction-Early Methods
- Wave Prediction-Spectral Models
- Extreme Wave Analysis

6. Wave Energy Conversion

- Fundamentals of wave energy conversion theory
- Classification of wave energy converters WECs
- Types of tidal stream turbines (TSTs)

→ Use of SWAN model



The screenshot shows the TU Delft website page for the SWAN model. The page title is "SWAN" and it is part of the "Physical Oceanography" section. The content includes a brief description of SWAN as a third-generation wave model, information on how to download the latest version, and details about the GNU General Public License. There are also links to the implementation manual, a list of known bugs and catches, and a user manual. The page is well-organized with a clear navigation menu and a sidebar with various links.

Course Outline

Ch. 5 → Generation.

Wind creates irregular waves (spectra).

Ch. 1 e 2 → Wave structure.

Understanding the shape and dynamics, for small amplitude waves and when the amplitude increases.

Ch. 3 → Coastal transformation.

How waves change as they approach the coast.

Ch. 4 → Long waves

Processes on a different scale: tides and tsunamis.

Let's start with some clips

[How do Ocean Waves Work?](#)

[How do waves work?](#)

Vorticity is a fancy word for the chaotic twist and turn that happen in turbulent flow

The speed of a wave and the speed of wind can be equal at certain heights in the wind shear layer (Miles) - longer and stronger the wind acts, bigger are the waves.

Speed of waves depends on wavelength, longer waves move faster! When a storm occurs and waves are created, longer wavelength waves move away from the storm faster than the shorter ones + and they have so much momentum and water has so little internal friction, they are able to travel huge distances: named swells or ground swells. **This is why you can surf in a sunny day, exploiting the waves created in a storm region.**

The trajectories are not circle indeed, since forward velocity at shallower depth is slightly greater than its return velocity: **Stokes' drift** (1847) isn't that fast, a few centimeters per seconds. But it transports things all over the ocean.

Total energy conserved: kinetic (water moving in its orbits) + gravity potential. As the wave enter to shallow water and the seafloor forces its height to grow, potential energy grows, so kinetic energy decreases. This means that wave slow down, and so - for the dispersion effects, the wavelength must decrease: **Shoaling effect.**

Let's start with some clips

Experiment (small tank) impact to coastline: [Wave tank demonstration showing the impact of coastal defences on flood risk](#)

Experiment (huge tank) [Inside The Navy's Indoor Ocean - YouTube](#)