Marine hydrodynamics

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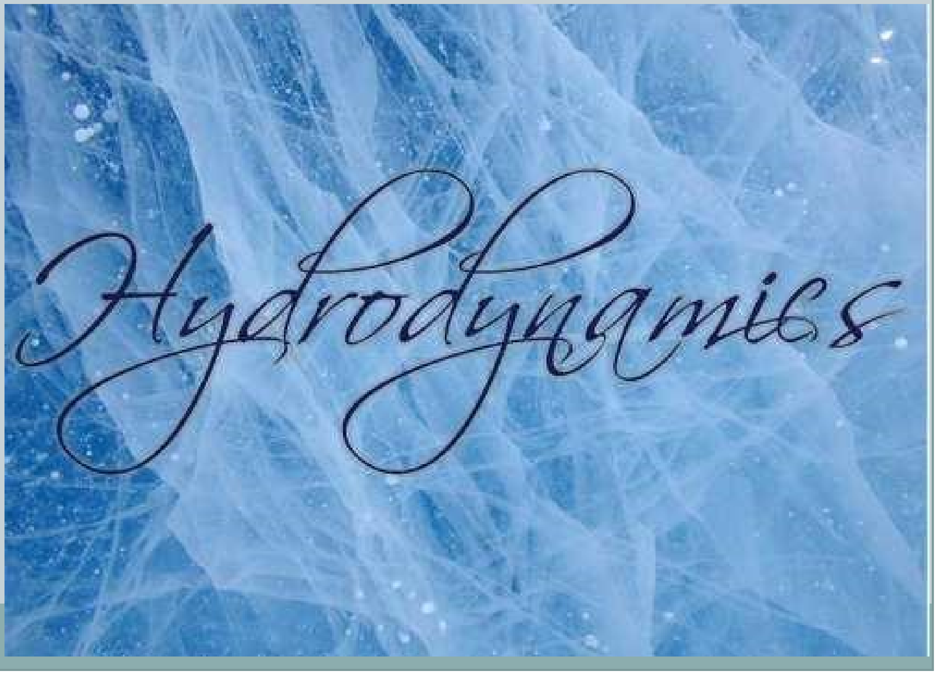
Overview

- Marine hydrodynamics
- Ocean waves and their anatomy
- Types of surface water waves
- Airy's theory of 2D waves
- Irrotational and potential flow



South Harbour, Aberdeen

‘World’s oldest intact shipwreck’

- Dated to 400BC
- Project surveyed 2,000km² seabed
- 60 shipwrecks discovered
- Video

2,000ft long floating boom

- Video

Rogue waves

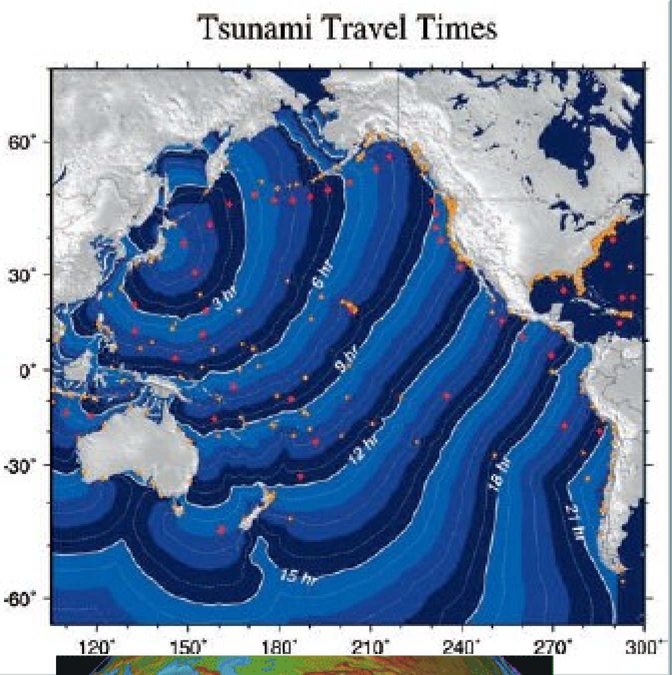
- MS München
- Lost in 1978
- 27 crew lost
- Weather caused an "*unusual event*"

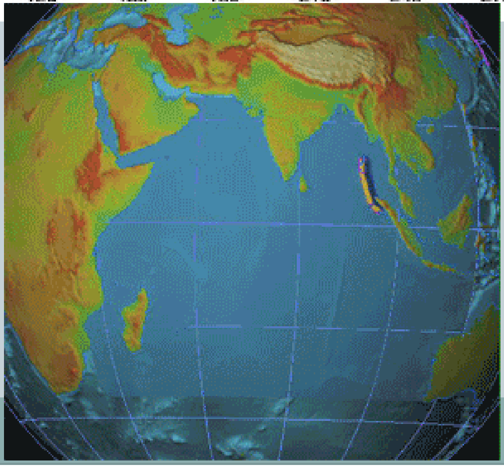
Garrison(2012)

Tsunamis

- Recall 2004 Indian ocean tsunami generated 30m waves; killed 230,000 people in 14 states
- 2011 Japan tsunami killed ~18,000 people; waves of about 40m high
- Tsunamis are known as seismic sea waves
- Generated from the displacement of large body of water after a quake or volcanic event
- Longer wavelength (λ) than ocean waves

Waves 2m high reached Chile 17,000km away from quake epicenter

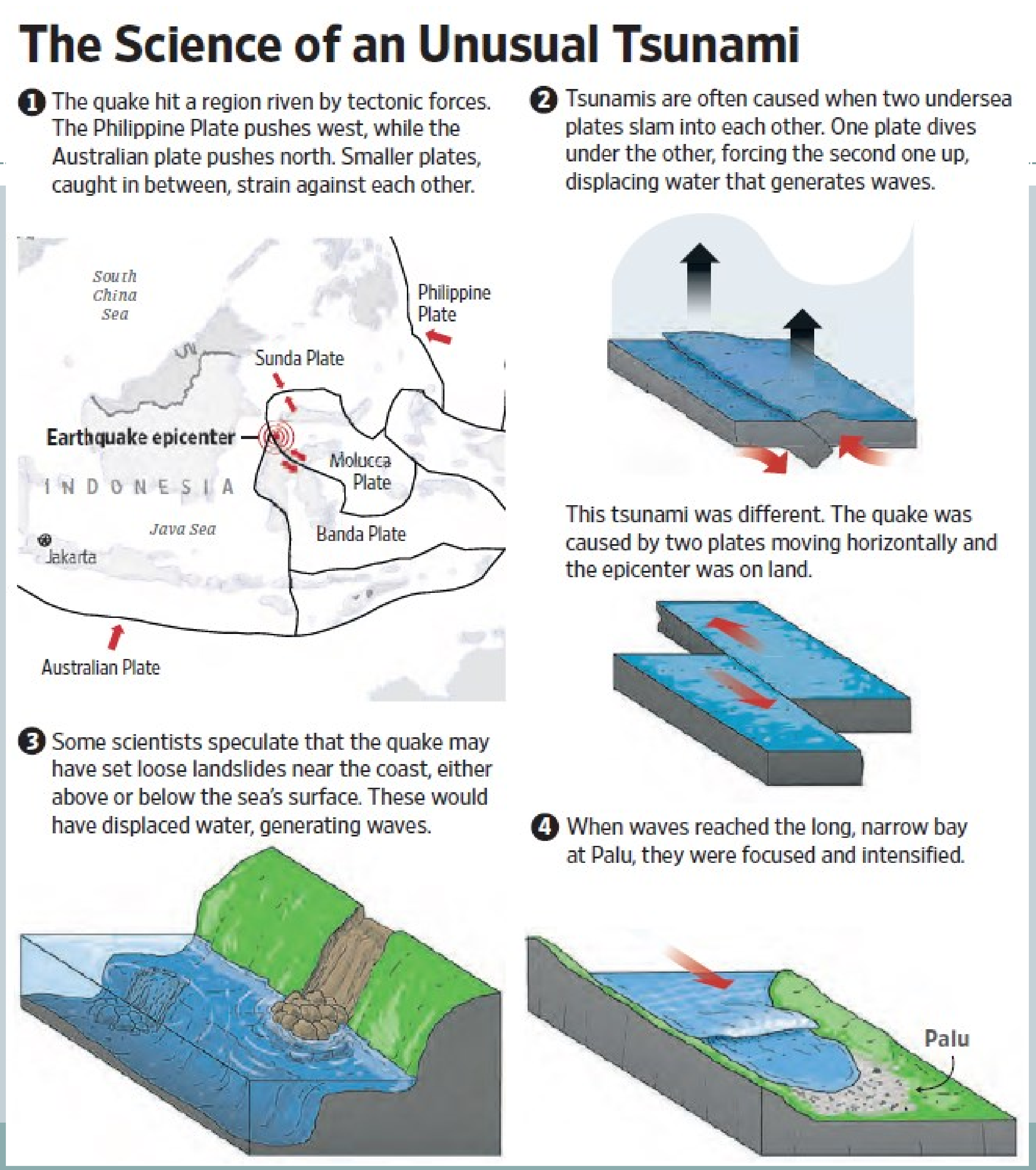




Sulawesi (Indonesia) tsunami

- Date: 01/10/2018
- Indonesian geophysics agency issues & withdraws alert
- Death toll: 800

- Megathrust quakes
- Strike-slip (transform) fault
- Submarine slide?

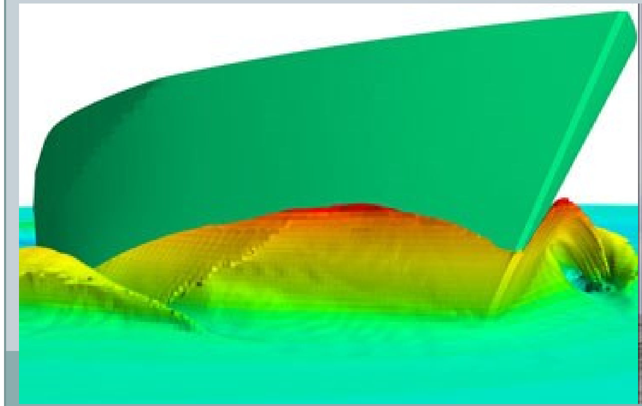


Fun waves

- Surfer M. Rothmans rides a 66ft (20m) wave in Maui in 2003
- He won a price of $66,000 or $1,000/ft!

Rationale for marine hydrodynamics

- Fixed or floating platforms & ship are affected by ocean waves
- Minimising motions from sea state is critical
- Waves affect ship and platform performance
- Wave shape is affected by a structure's geometry e.g., ship or column



Force 0: Wind Speed less than 1 knot
Sea: Sea like a mirror

Force 1: Wind Speed 1-3 knots
Sea: Wave height .1m (.25ft); Ripples with appearance of scales, no foam crests

Force 2: Wind Speed 4-6 knots
Sea: Wave height .2-.3m (.5-1 ft); Small wavelets, crests of glassy appearance, not breaking

Force 3: Wind Speed 7-10 knots
Sea: Wave height .6-1m (2-3 ft); Large-wavelets, crests begin to break, scattered whitecaps

Force 4: Wind Speed 11-16 knots
Sea: Wave height 1-1.5m (3.5-5 ft); Small waves becoming longer, numerous whitecaps

Force 5: Wind Speed 17-21 knots
Sea: Wave height 2-2.5m (6-8 ft); Moderate waves, taking longer form, many whitecaps, some spray

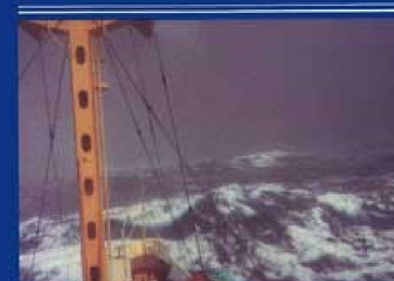
Force 6: Wind Speed 22-27 knots
Sea: Wave height 3-4m (9.5-13 ft); Larger waves forming, whitecaps everywhere, more spray

Force 7: Wind Speed 28-33 knots
Sea: Wave height 4-5.5m (13.5-19 ft); Sea heaps up, white foam from breaking waves begins to be blown in streaks along direction of wind

Force 8: Wind Speed 34-40 knots
Sea: Wave height 5.5-7.5m (18-25 ft); Moderately high waves of greater length, edges of crests begin to break into spindrift, foam is blown in well marked streaks

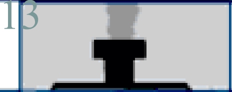
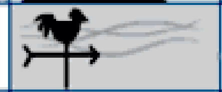
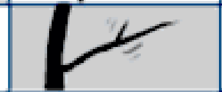
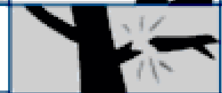
Force 9: Wind Speed 41-47 knots
Sea: Wave height 7-10m (23-32 ft); High waves, sea begins to roll, dense streaks of foam along wind direction, spray may reduce visibility

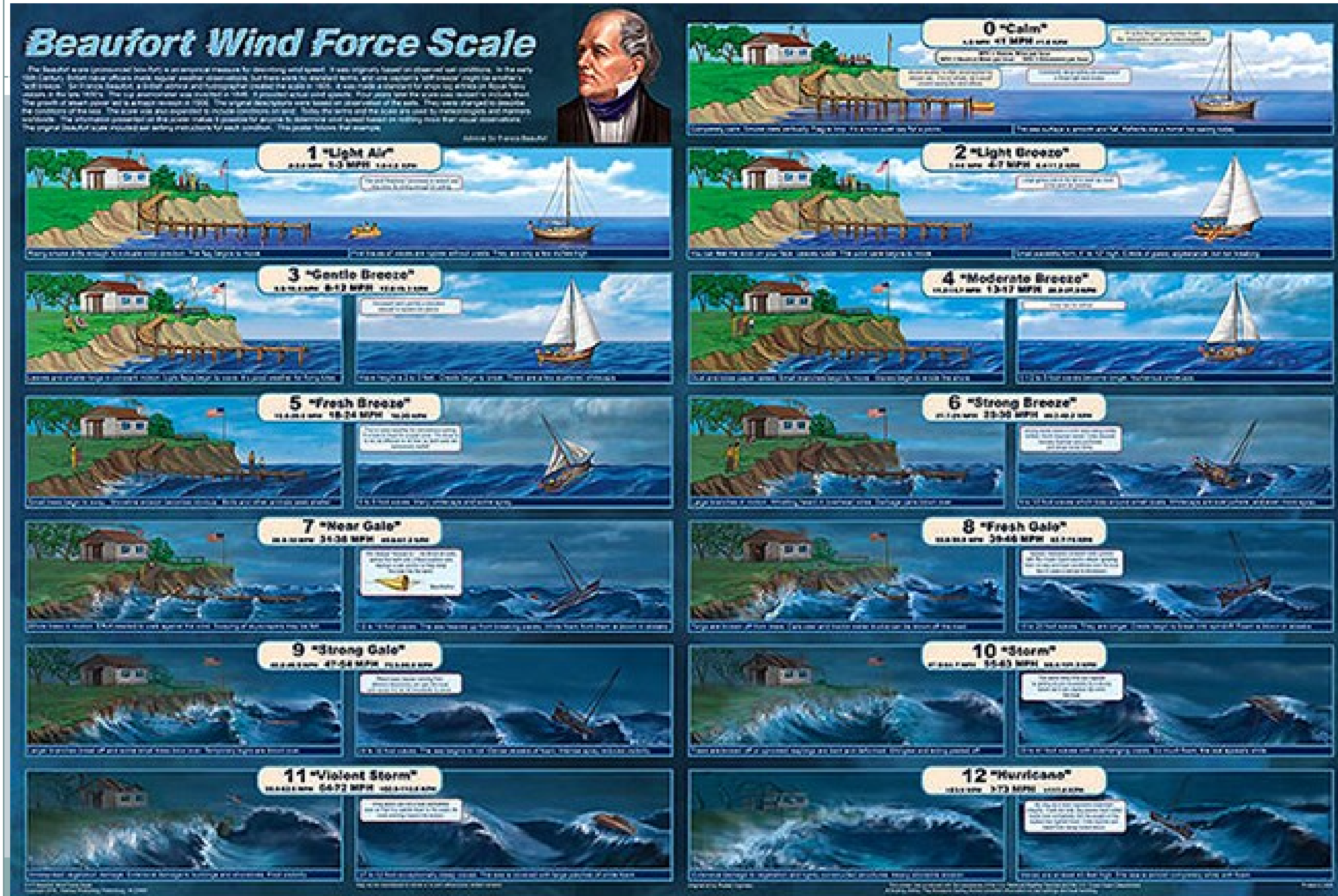
Force 10: Wind Speed 48-55 knots (storm)
Sea: Wave height 9-12.5m (29-41 ft); Very high waves with overhanging crests, sea takes white appearance as foam is blown in very dense streaks, rolling is heavy and shocklike, visibility is reduced.



Force 11: Wind Speed 56-63 knots
Sea: Wave height 11.5-16m (37-52 ft); Exceptionally high waves, sea covered with white foam patches, visibility still more reduced

Beaufort Scale

Beaufort number	Wind Speed (mph)	Seaman's term		Effects on Land
0	Under 1	Calm		Calm; smoke rises vertically.
1	1-3	Light Air		Smoke drift indicates wind direction; vanes do not move.
2	4-7	Light Breeze		Wind felt on face; leaves rustle; vanes begin to move.
3	8-12	Gentle Breeze		Leaves, small twigs in constant motion; light flags extended.
4	13-18	Moderate Breeze		Dust, leaves and loose paper raised up; small branches move.
5	19-24	Fresh Breeze		Small trees begin to sway.
6	25-31	Strong Breeze		Large branches of trees in motion; whistling heard in wires.
7	32-38	Moderate Gale		Whole trees in motion; resistance felt in walking against the wind.
8	39-46	Fresh Gale		Twigs and small branches broken off trees.
9	47-54	Strong Gale		Slight structural damage occurs; slate blown from roofs.
10	55-63	Whole Gale		Seldom experienced on land; trees broken; structural damage occurs.
11	64-72	Storm		Very rarely experienced on land; usually with widespread damage.
12	73 or higher	Hurricane Force		Violence and destruction.

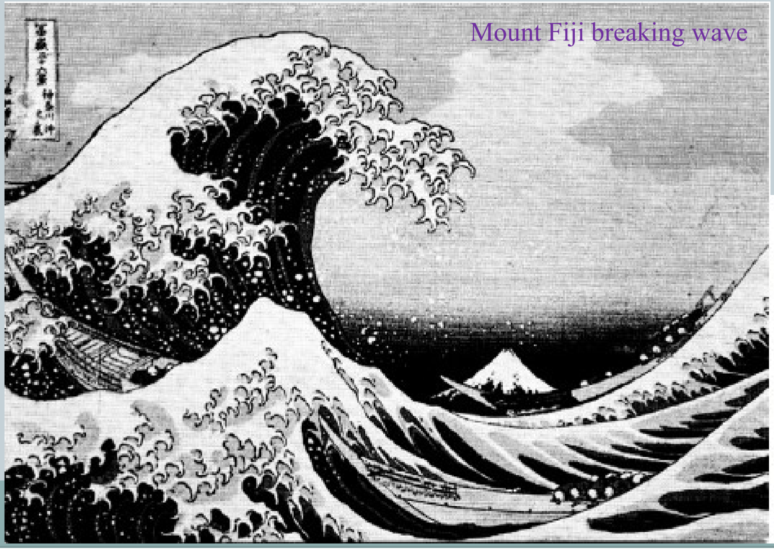

Beaufort Wind Force Scale
0 "Calm"
<1 MPH
1 "Light Air"
1-3 MPH
2 "Light Breeze"
4-7 MPH
3 "Gentle Breeze"
8-12 MPH
4 "Moderate Breeze"
13-17 MPH
5 "Fresh Breeze"
18-24 MPH
6 "Strong Breeze"
25-30 MPH
7 "Near Gale"
31-38 MPH
8 "Fresh Gale"
39-46 MPH
9 "Strong Gale"
47-54 MPH
10 "Storm"
55-63 MPH
11 "Violent Storm"
64-72 MPH
12 "Hurricane"
>73 MPH

Video

- Huge Ships in storm, 5:10

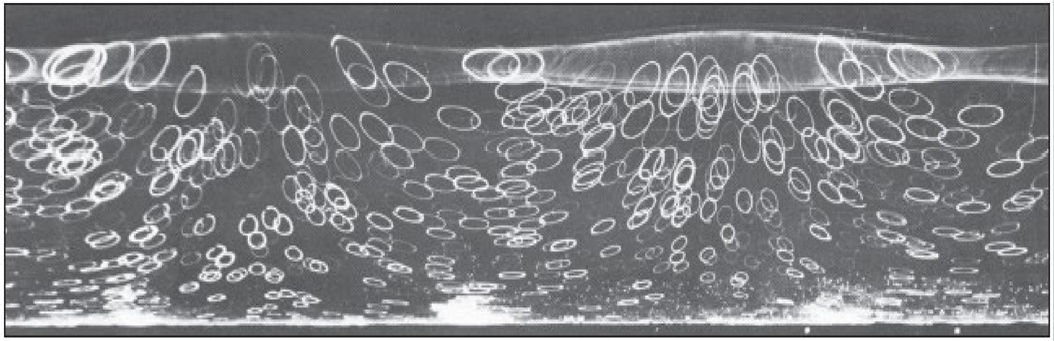
Ocean waves

- There is a limit to the energy contained by an ocean wave
- Once the threshold is surpassed a wave breaks
- Ocean waves are unique as they exhibit a dispersive nature
- Waves are generated by wind are called (surface) *gravity waves*



Mount Fiji breaking wave

White trace depicts wave particles. Image captured by time exposure photography.



Ocean waves (2)

- What is a wave?

A disturbance caused by the passage of energy through a medium i.e., solid, liquid or gas

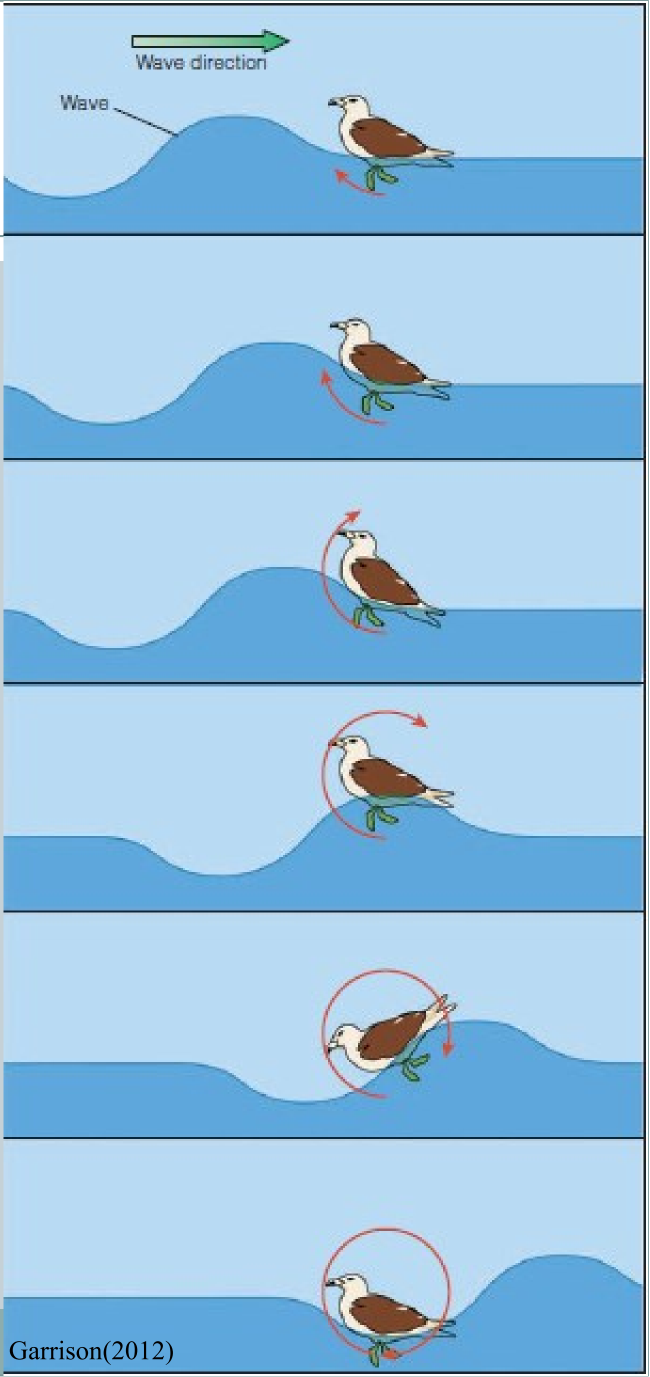
- In ocean waves, *energy* is moving @ speed of the wave but *water* is not

- Why a wave is an illusion?

Because water molecules do not travel (much) with the wave but are perturbed like the seagull

- Waves carry *energy* not *mass per se*!

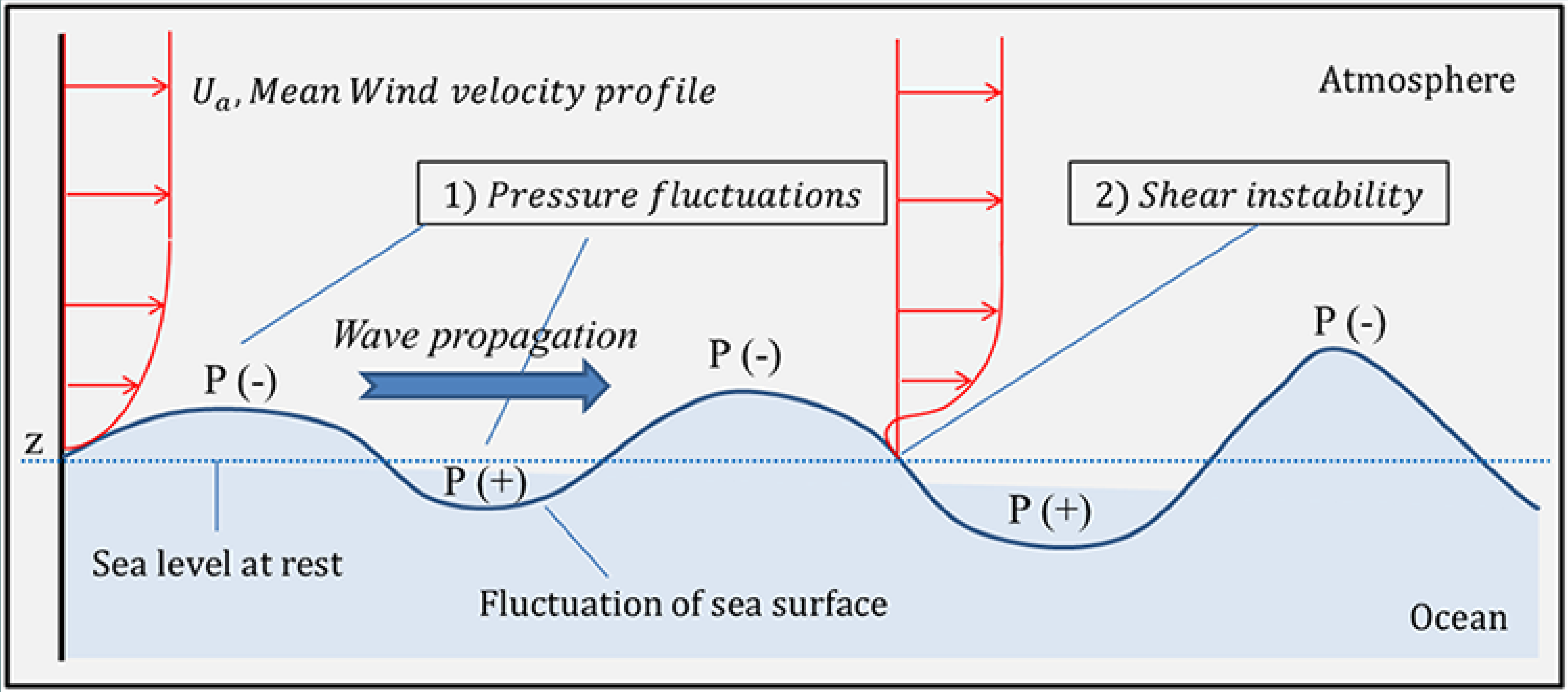
- *Water waves* occur at water-air boundary & are called *progressive waves*



Garrison(2012)

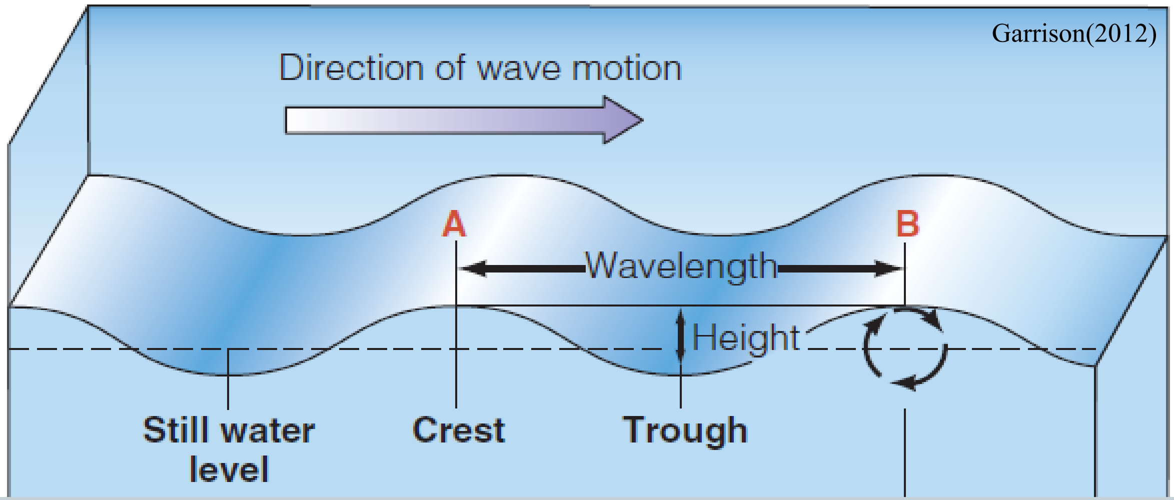
Generation of wind waves

- ρ_{sw}=1,026kg/m³ (@15°C) ρ_{air}=1.225kg/m³(15°C@sea-level) (836×)
- μ_{sw}=0.00123N·s/m² μ_{sw}=0.00001789N·s/m² (68×)



Anatomy of a water wave

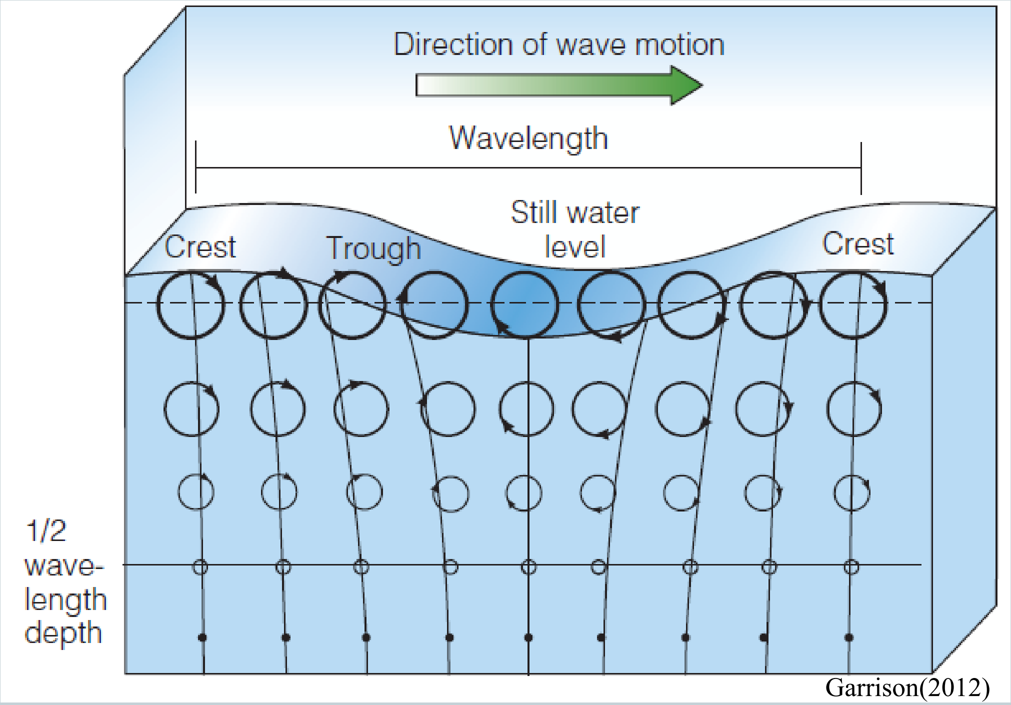
- Wave crest (peak)
- Wave trough (valley)
- Wave length (λ)



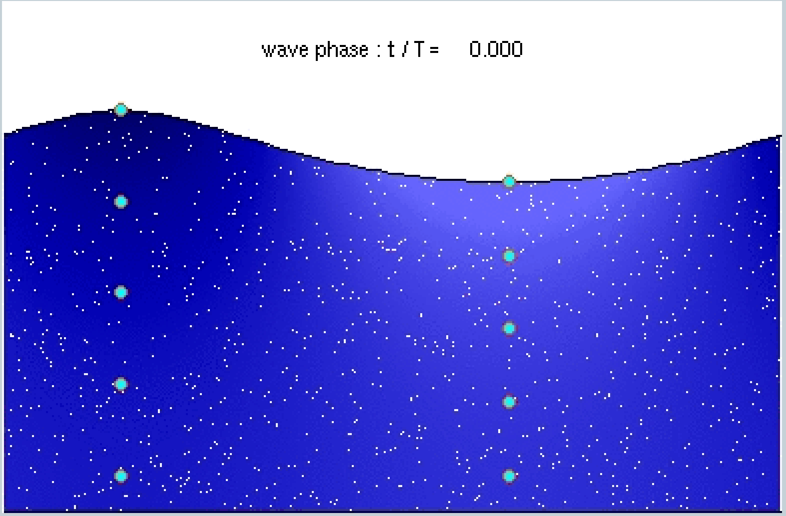
- Wave height = 2 × wave amplitude (A)
- Frequency (f): number of wave crests passing a point (e.g., A/s)
- Period (T): Time required for wave crest @ point A to reach point B

Orbital motions of water particles

- Observe that water molecules orbit in same rotational dn
- Circular motion of molecules diminishes rapidly with depth
- At 0.5λ, wave motion is negligible



Garrison(2012)

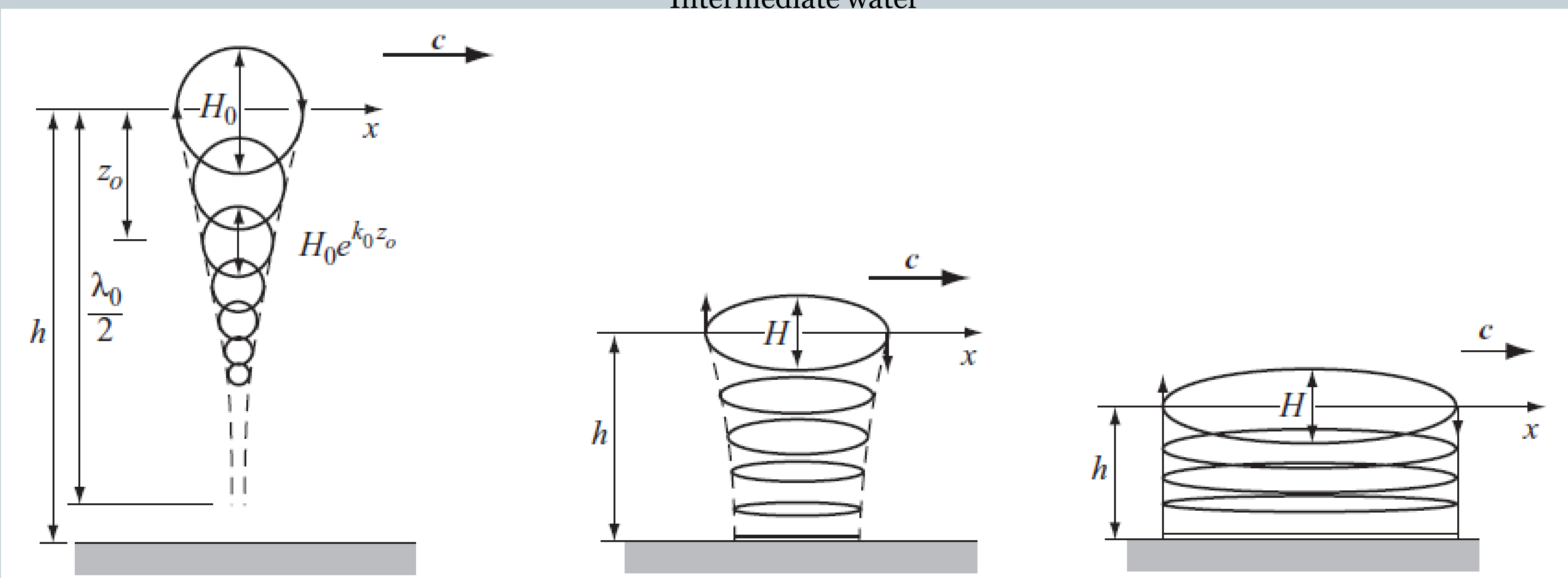


Water particle paths

Deepwater

Intermediate water

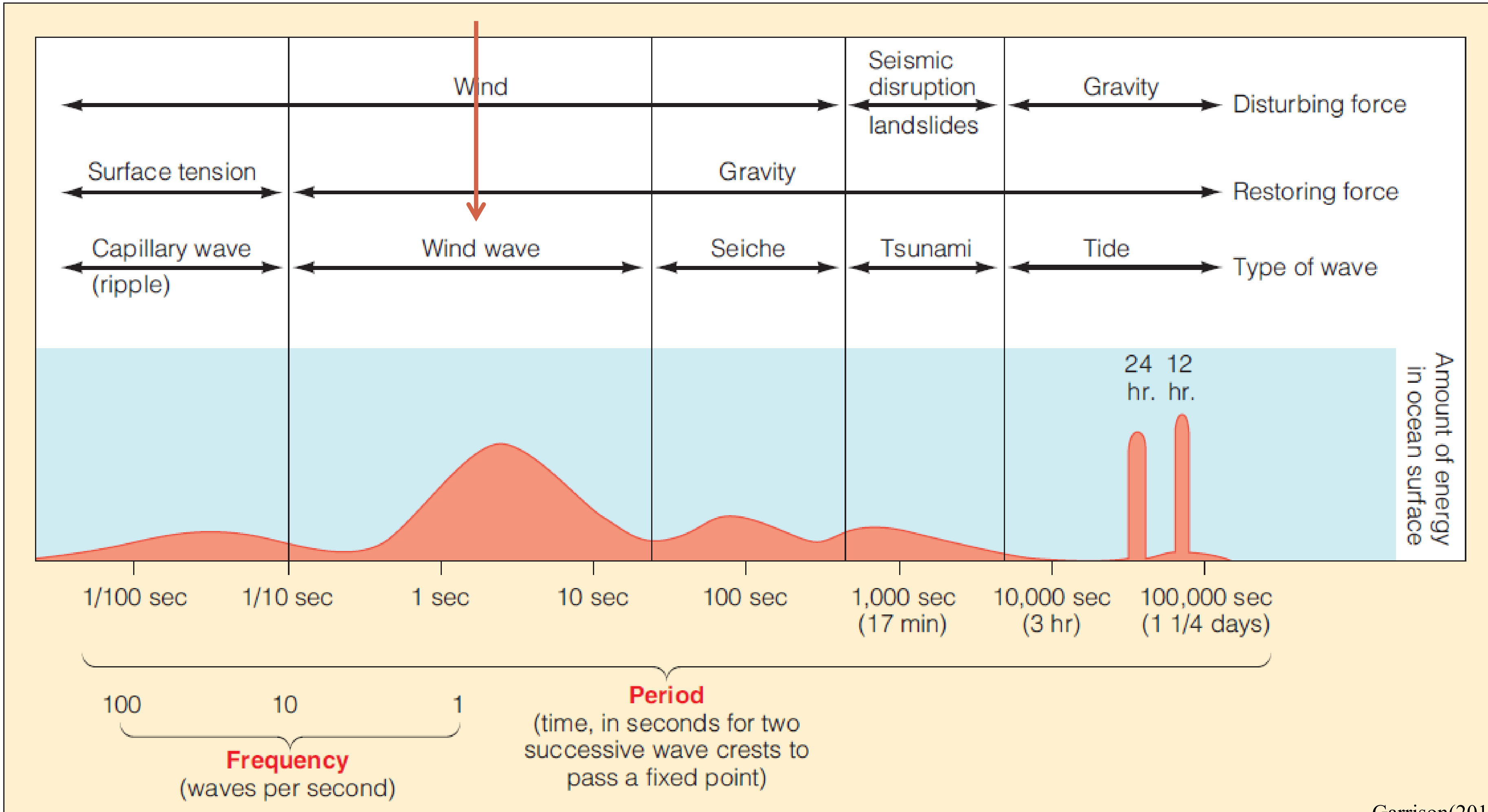
Swallow-water



Classification of ocean waves

- Waves are classified according to:
  - Disturbing force
  - Extent of disturbance
  - Damping/restoring force
  - Wavelength
- Waves are not classified by their height as it varies greatly on water depth, interference btw waves, etc.
- Disturbing forces arise from:
  - Winds
  - Storms
  - Seismic events
  - Atmospheric pressure
  - Landslides
  - Volcanic eruptions, geological faulting, …

Types of waves, wave energy & time scales



Garrison(2012)

Types of water waves

- Gravity waves with λ>1.73cm are dissipated by gravity

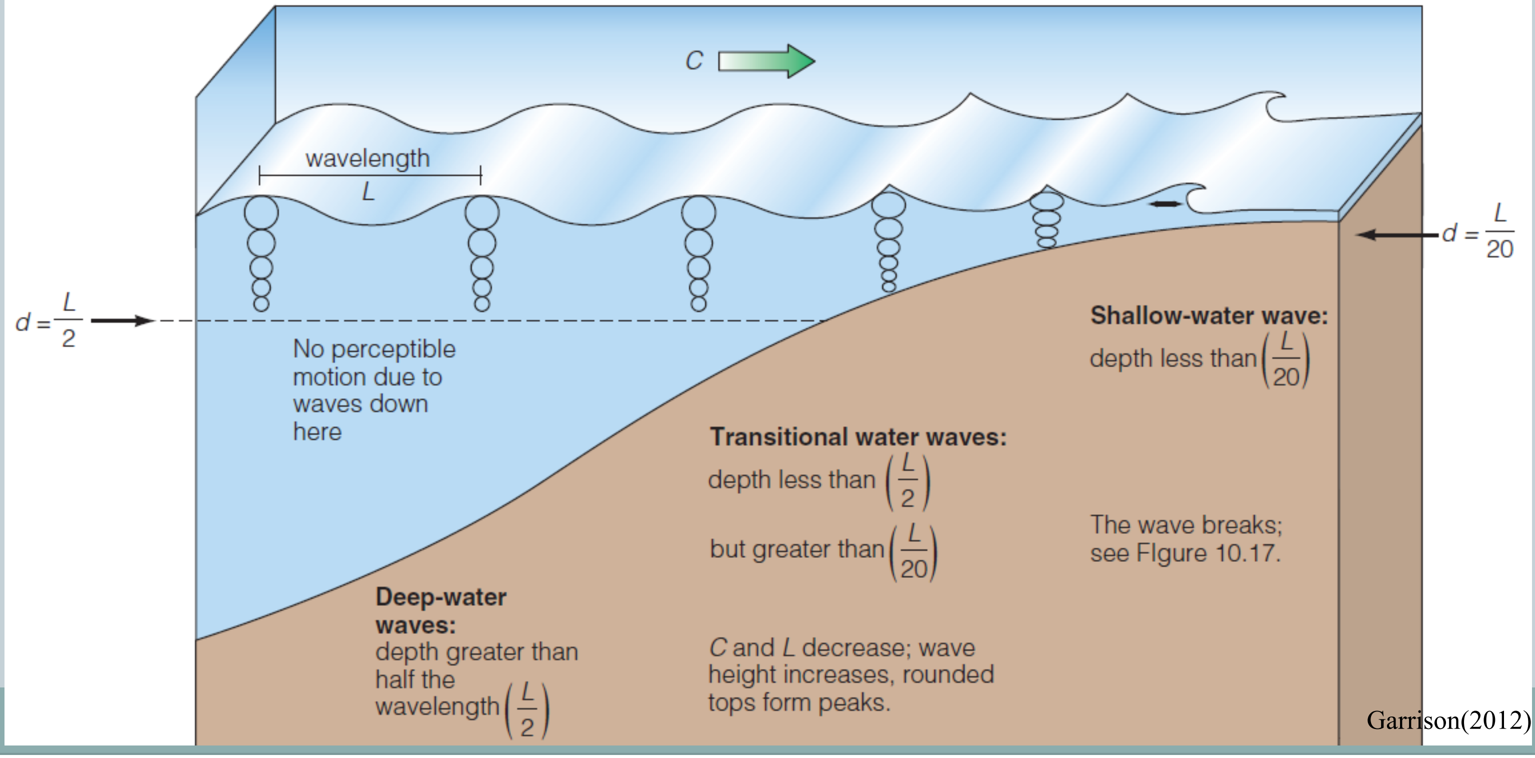
- Only exception are the capillary waves (ripples)

Wave Type	Disturbing Force	Restoring Force	Typical Wavelength
Capillary wave	Usually wind	Cohesion of water molecules	Up to 1.73 cm (0.68 in.)
Wind wave	Wind over ocean	Gravity	60–150 m (200–500 ft)
Seiche	Change in atmospheric pressure, storm surge, tsunami	Gravity	Large, variable; a function of ocean basin size
Seismic sea wave (tsunami)	Faulting of seafloor, vol-canic eruption, landslide	Gravity	200 km (125 mi)
Tide	Gravitational attraction, rotation of Earth	Gravity	Half Earth's circumference

Garrison(2012)

Influence of water depth

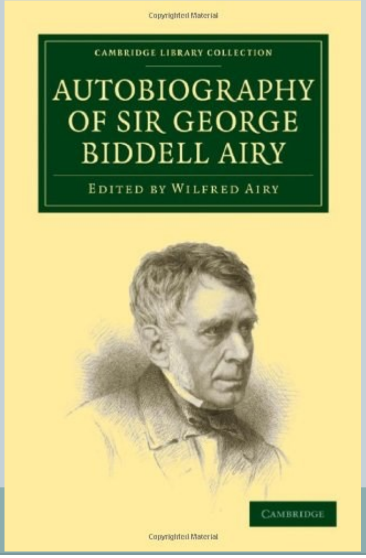
- *Wavelength* governs *size* of water molecule *orbits*
- *Water depth* determines *shape* of orbits eg, circular or elliptic
- Deep-water waves move thru water depth >0.5λ
- Shallow-water waves are in depths <(1/20)λ



Garrison(2012)

Airy's linear wave theory

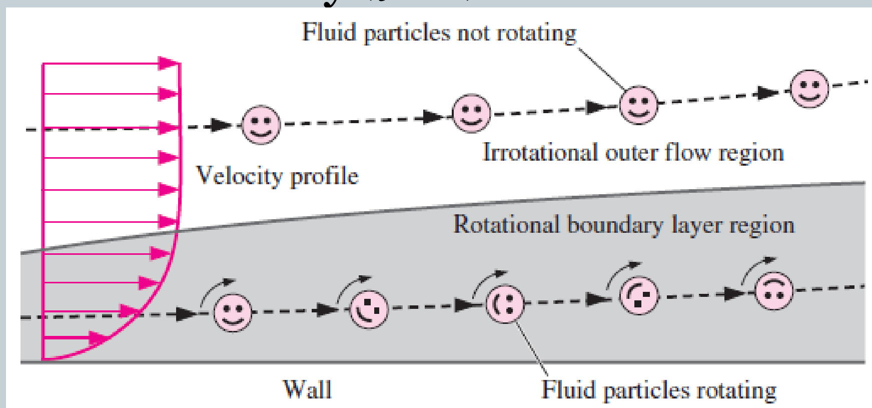
- George Airy proposed linear wave theory in 1845
- Airy's theorem applies to 2D small-amplitude water waves
- Theory defines most of kinematic & dynamic properties
- Predicts props within useful limits for most practical cases
- Freely propagating, periodic surface (gravity) waves



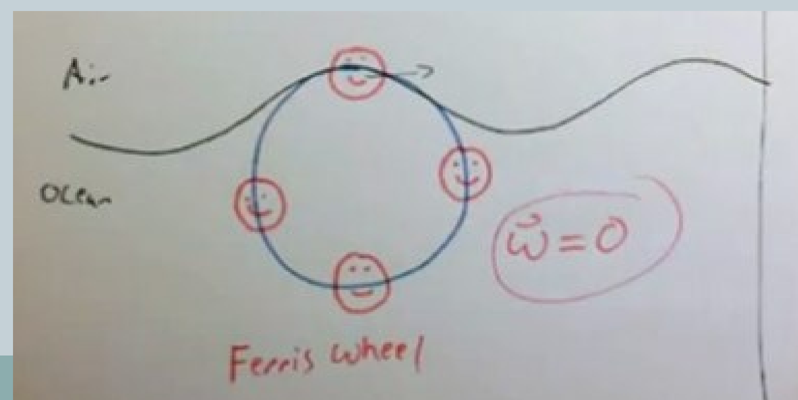
Breaking waves

Irrotational flow

- Consider boundary layer below. Fluid particles near surface will be rotational @ non-zero vorticity $(\vec{\zeta} \neq 0)$.



- Fluid particles outside the b.l. can be taken as irrotational ie, undergo no swirl, $(\vec{\zeta} = 2\vec{\omega} \ldots = 0)$. Examples: a) water particles at water-air interface or b) Ferris wheel:



Velocity potential (Φ)

- For an irrotational flow, the velocity potential Φ is defined as:

$$\vec{V} = -\nabla \varphi \qquad (1)$$

where Φ is the velocity potential function. Such a velocity field is termed as *potential* (or irrotational) *flow*.

The flow velocity u is the gradient of a scalar function Φ:

$$u = \nabla \phi = \frac{\partial \phi}{\partial x}\hat{i} + \frac{\partial \phi}{\partial y}\hat{j} + \frac{\partial \phi}{\partial z}\hat{k} \qquad (2)$$

Φ is the velocity potential of u.

- By definition of Φ, any continuous scalar function Φ(x,y,z,t) automatically satisfies the irrotational condition $(\nabla \times \vec{V} = 0)$ because of the fundamental identity:

$$\vec{\omega} = \nabla \times \vec{V} = -\nabla \times \nabla \phi = -curl\left(grad\,\phi\right) \equiv 0 \qquad (3)$$

–ve sign indicates that Φ decreases with in the flow dn.

Velocity potential (Φ)

- For inviscid fluids, irrotational flow may be a valid assumption. Example: Region outside bl of a wing section used to obtain lift

- Velocity given by the gradient of a scalar function & the continuity eqn $(\nabla \cdot V = 0)$ for an incompressible flow yields *Laplace's eqn*:

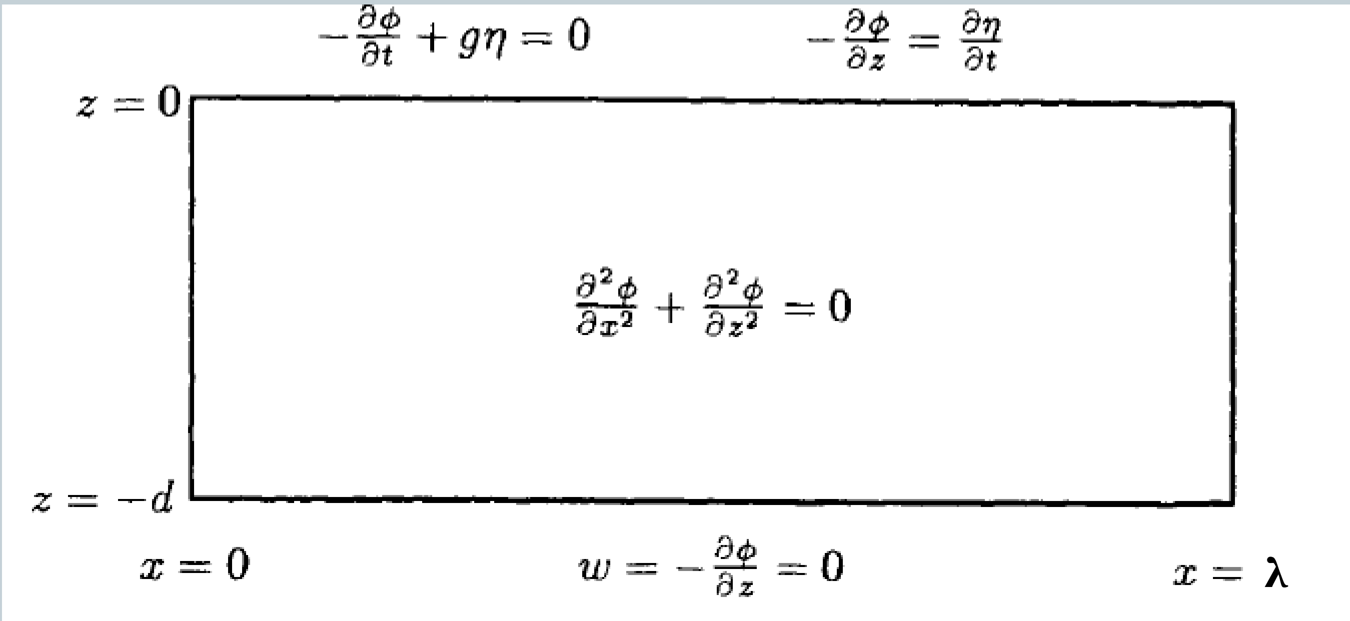
$$\nabla \cdot \nabla \phi = \nabla^2 \phi = 0 \qquad (4)$$

- For small amplitude water waves, velocity potential is *not valid* at the *free-surface* and *near the seabed*.

Airy's theory

- Theory

Boundary conditions

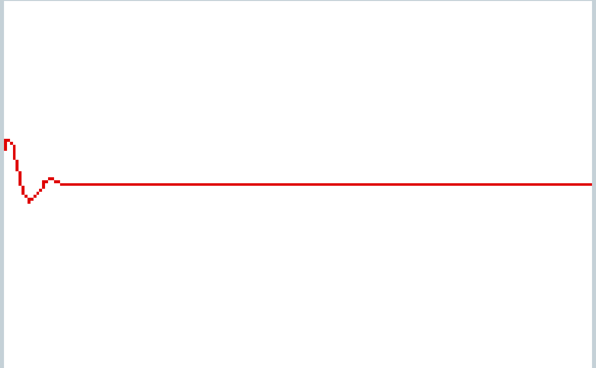


Dispersion relationship

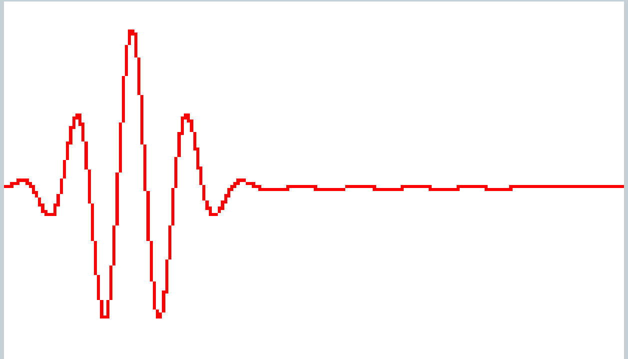
- Plane waves of different wavelengths (λ) have different velocities so that a *wave train* of mixed wavelengths tends to spread out in space

- *Wave train* (packet) is a short burst wave. It can be analysed/ synthesised from an infinite # of sinusoidal waves of different phases & amplitudes which interfere constructively

Wave packet with no dispersion



Wave packet with dispersion

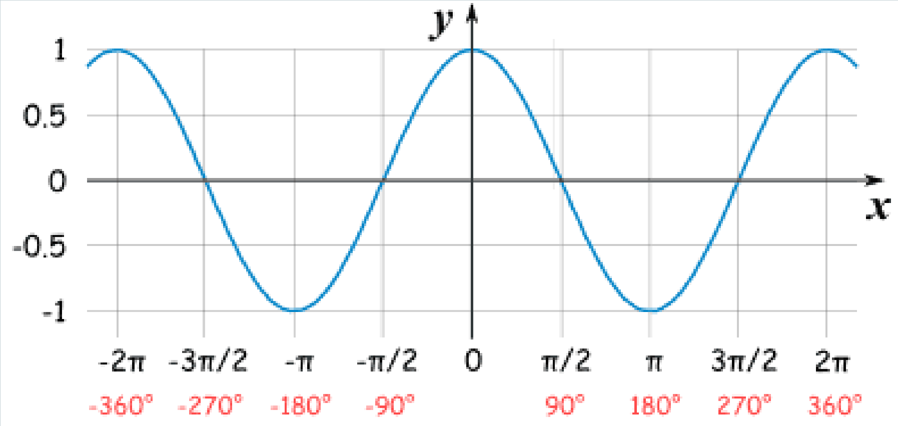


Travelling wave

- Expressed as:

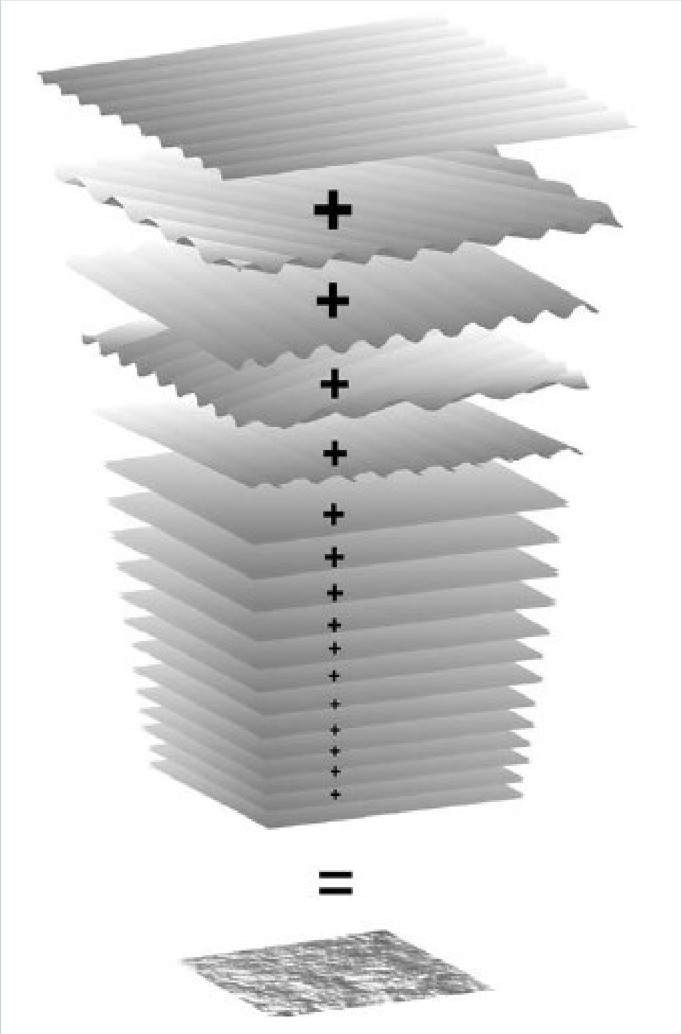
$$y(x,t)=A\cos(kx-\omega t)$$

where x is co-ordinate in space, t is time, k is the wave number ($k=2\pi/\lambda$), $\omega=2\pi f$ is the angular frequency, A is the wave amplitude



Making waves

- Random waves: sum large # of harmonic components possessing different T, a, phases (φ)



Pierson, W. J., G. et al. (1955) Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics, US Navy Hydrographic Office, Publication No. 603

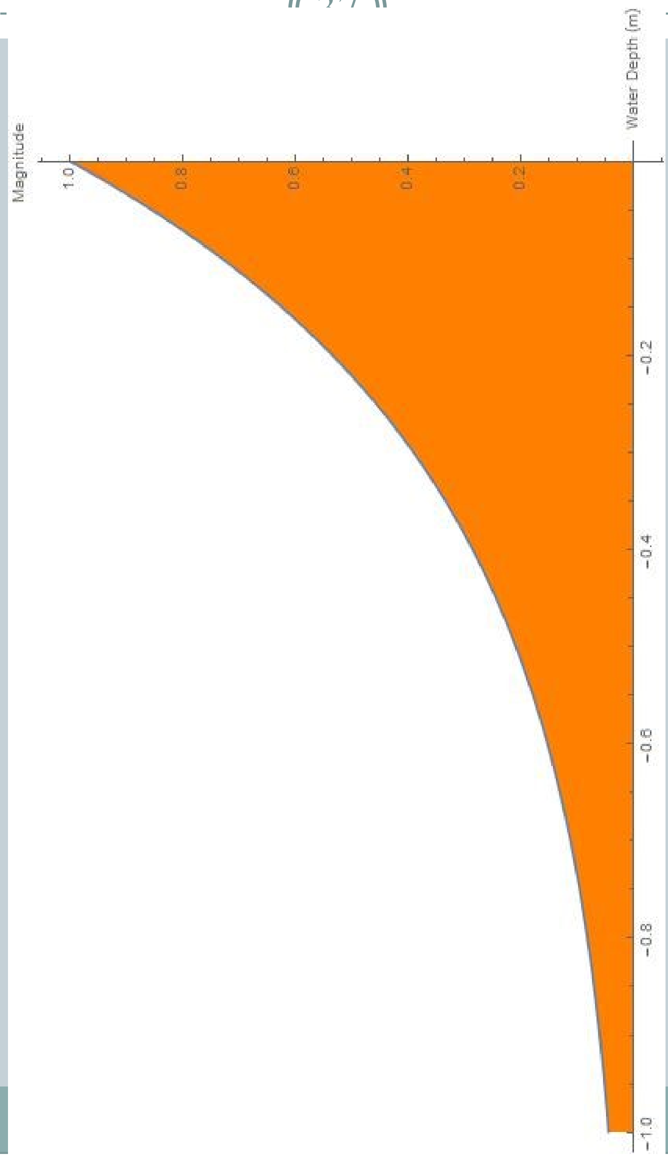
Depth classification of ocean waves on kd

RELATIVE DEPTH	SHALLOW WATER $kd < \pi/10$	TRANSITIONAL WATER $\pi/10 < kd < \pi$	DEEP WATER $kd > \pi$
Wave profile	Same as $\longrightarrow$	$\eta = a\sin(kx - \omega t)$	Same as $\longleftarrow$
Phase speed	$C = \sqrt{gd}$	$C = \frac{g}{\omega}\tanh(kd)$	$C = \frac{g}{\omega}$
Wave length	$L = T\sqrt{gd}$	$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$L = \frac{gT^2}{2\pi}$
Angular frequency	$\omega^2 = gk^2 d$	$\omega^2 = gk\tanh(kd)$	$\omega^2 = gk$
Group velocity	$C_g = \sqrt{gd}$	$C_g = \frac{1}{2}\left[1 + \frac{2kd}{\sinh(2kd)}\right]C$	$C_g = \frac{g}{2\omega}$
Velocity components	$u = a\sqrt{\frac{g}{d}}\sin\psi$	$u = \frac{agk}{\omega}\frac{\cosh[k(d+z)]}{\cosh(kd)}\sin\psi$	$u = a\omega e^{kz}\sin\psi$
	$w = a\omega\left(1 + \frac{z}{d}\right)\cos\psi$	$w = -\frac{agk}{\omega}\frac{\sinh[k(d+z)]}{\cosh(kd)}\cos\psi$	$w = -a\omega e^{kz}\cos\psi$
Particle displacements	$\xi = \frac{a}{\omega}\sqrt{\frac{g}{d}}\cos\psi$	$\xi = \frac{agk}{\omega^2}\frac{\cosh[k(d+z)]}{\cosh(kd)}\cos\psi$	$\xi = ae^{kz}\cos\psi$
	$\zeta = a\left(1 + \frac{z}{d}\right)\sin\psi$	$\zeta = -\frac{agk}{\omega^2}\frac{\sinh[k(d+z)]}{\cosh(kd)}\sin\psi$	$\zeta = -ae^{kz}\sin\psi$
Subsurface pressure	$\frac{p}{\rho_w g} = \eta - z$	$\frac{p}{\rho_w g} = \eta\frac{\cosh[k(d+z)]}{\cosh(kd)} - z$	$\frac{p}{\rho_w g} = \eta e^{kz} - z$

where: $\psi = (kx - \omega t)$

Decay of ocean wave energy wrt water depth

- F(*z*) = exp(2πζ/λ)
- λ=2m; ζ[0,−1].



Example 2

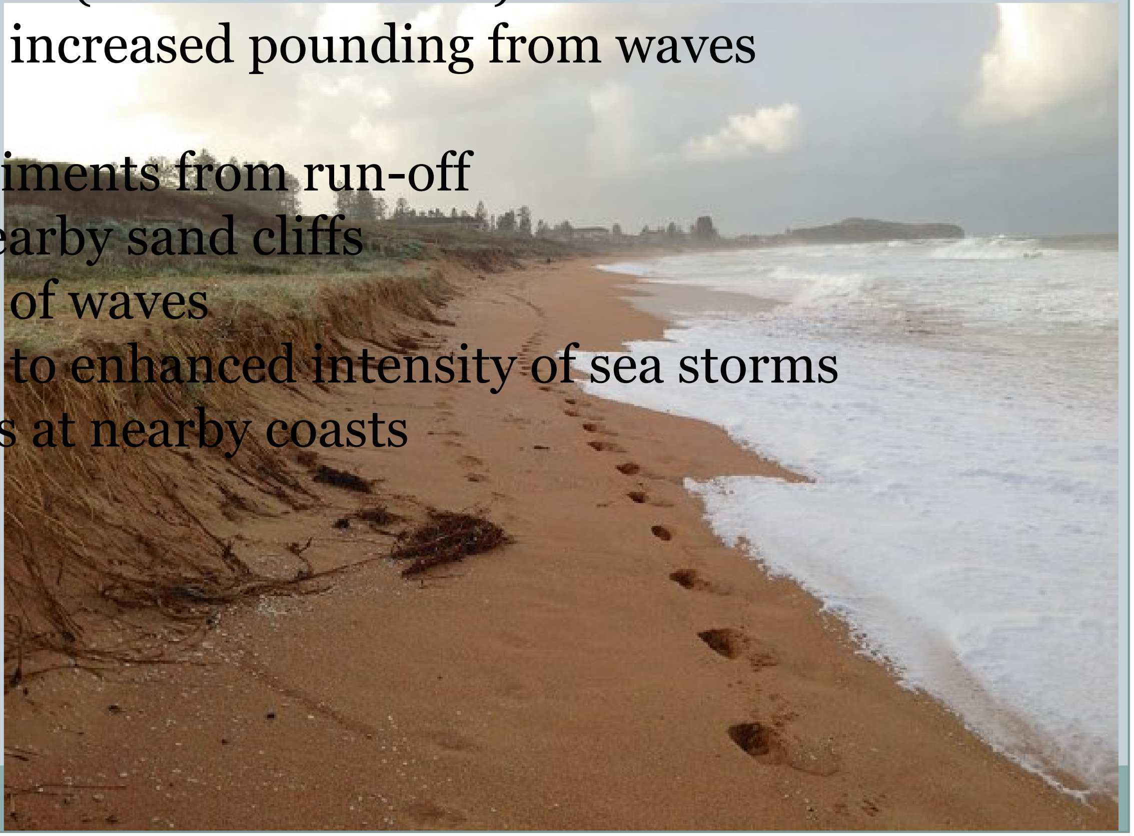
- Ex#2

Coastline erosion

Coastline erosion

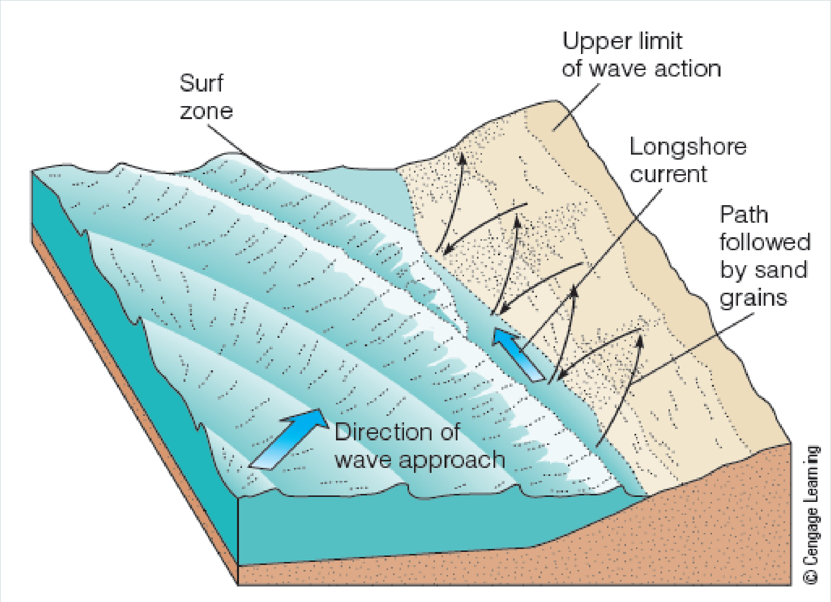
Main causes of coastline erosion

- Reduction in mass of sediments at seabed
- Drop in sediments from nearby cliffs
- Soft coastline soil
- Lower sediments from rivers (fluvial sediments) at seashore
- Submergence of coast and increased pounding from waves
- Rise in sea-level
- Transport of shoreline sediments from run-off
- Reduction in sand from nearby sand cliffs
- Change in incidence angle of waves
- Increase energy levels due to enhanced intensity of sea storms
- Displacement of sediments at nearby coasts
- Beach weathering



Longshore currents

- Waves approaching the shore at an angle
- Transport (introduction)/removal of sediments (sand) to coast
- The disturbance of currents helps with the deposition of sediments to the shore



Garisson (2016) NG Learning

Coastline erosion at Larnaka

Erosion of Fig tree bay (Ayia Napa)

- 30 April, 2018
- Ranked as 13 of 25 best beaches in the world (Traveller's Choice 2018)
- 4th best beach in Europe (Traveller's Choice 2018)

Fig tree (2)

Fig tree during day

Fig tree at night

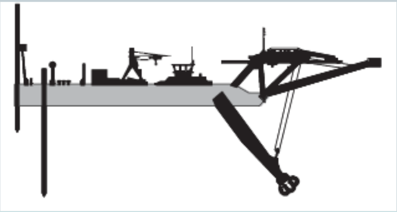
Beach sand

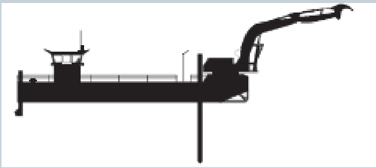
- Without sand there is no beach
- Causes of erosion comprise: air, seawaves, tides
- Renourishment with sand: rivers, currents, water runoff, water streams, dredging
- The transport of sand is/can be affected by:
  - Sea storms
  - Marine transport (ships) & pleasure craft
  - Piers/
  - Marinas
  - Ports
  - Subsea pipelines
  - Seagoers (people)
  - Wavebreakers
  - River barriers (dams)/water streams
  - Water diversion works
  - Marine buoys
  - Other obstacles

Anthropogenic causes

Coastline rehabilitation

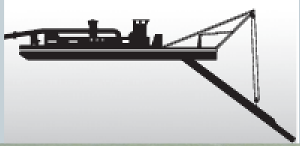
- Creation of groins
- Sand could be relocated from nearby beaches & seabed
- Dredging: a) excavation, b) seabed material suction





Cape May, New Jersey

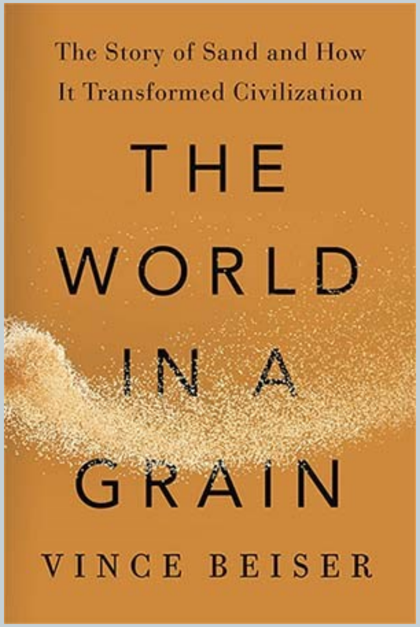
Jan van't Hoff *et al.* (2012)

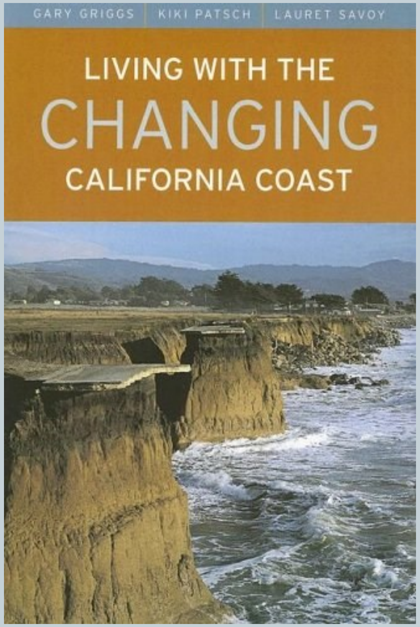


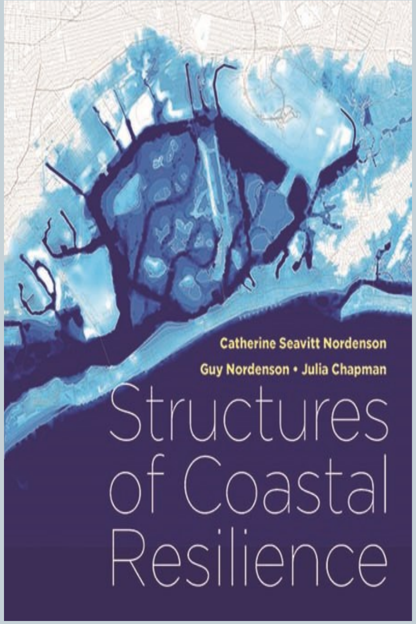
Video:

- Britain's disappearing cliffs

Various sources



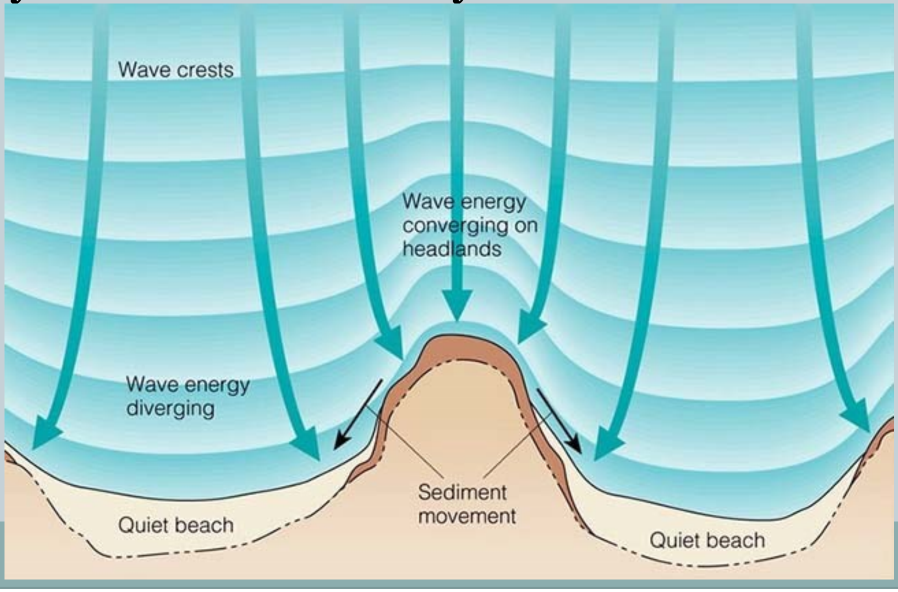




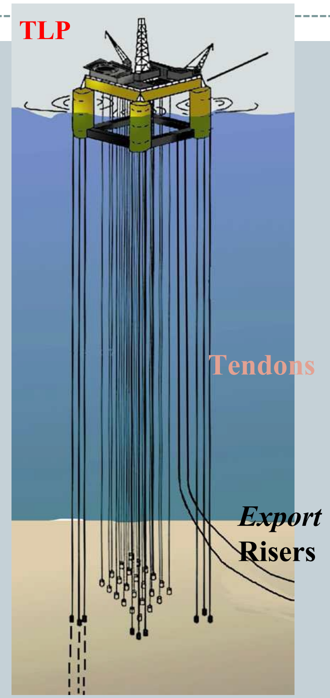
Wave refraction

Wave refraction

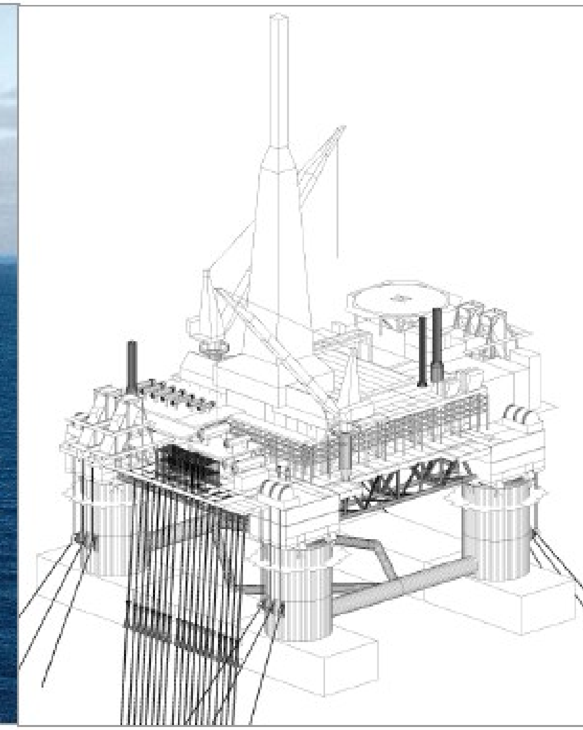
- "Bending" of waves at they propagate at different depths
- Refraction emanates from the interaction with seabed (topography)
- Refraction could affect wave celerity either +vely or –vely
- Refraction could assume 2 forms:
  - 1) Focusing (concave refraction) or
  - 2) Defocusing (convex refraction)
- Seawater/ocean swell triggered by distant weather systems instead of wind
- Swell λ could be 700m

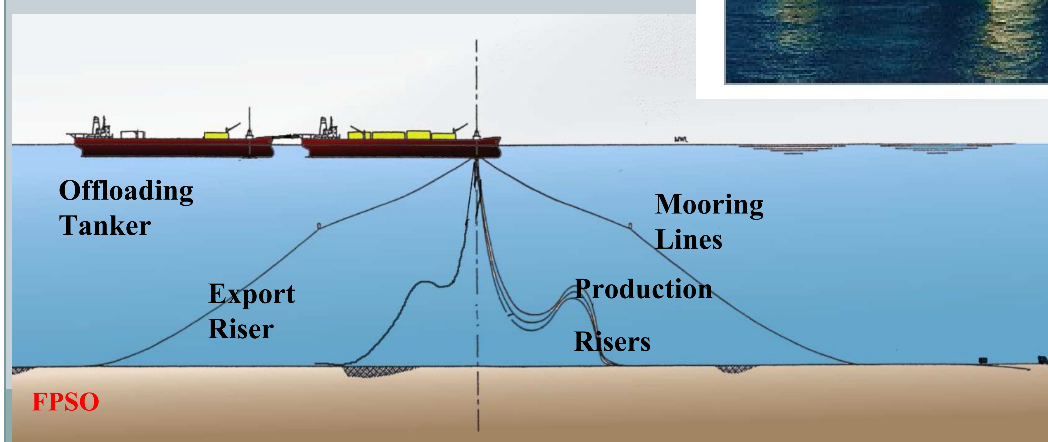


Wave induced forces



Njord Semi-sub, offshore Norway, Statoil





Theory

- Continuation

Example 3

- Ex#3

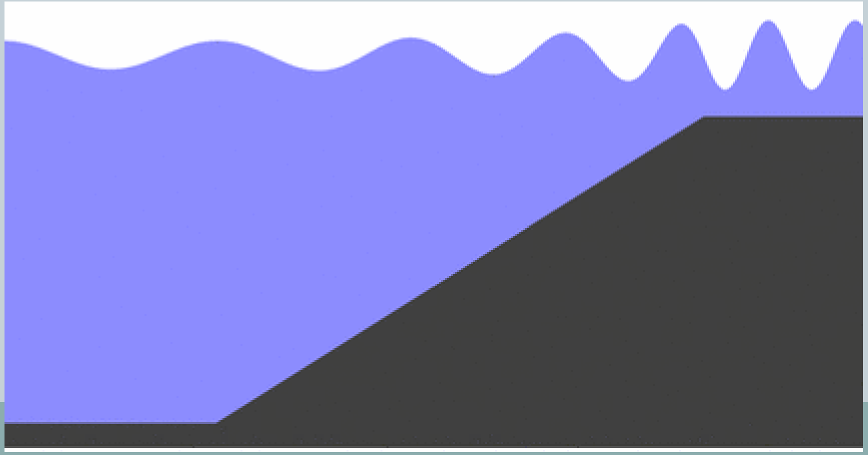
Wave shoaling

- Why does water wave height increases as waves approach the shore?
- In order to maintain a constant energy flux a decrease in transport speed is offset by an increase in energy density.

Hence, tsunamis are generated!

- When does a wave break?

If $H:\lambda > 1:7$



Ex#4

- $d/\lambda_o=0.06405$
- $d/\lambda\approx0.1082$

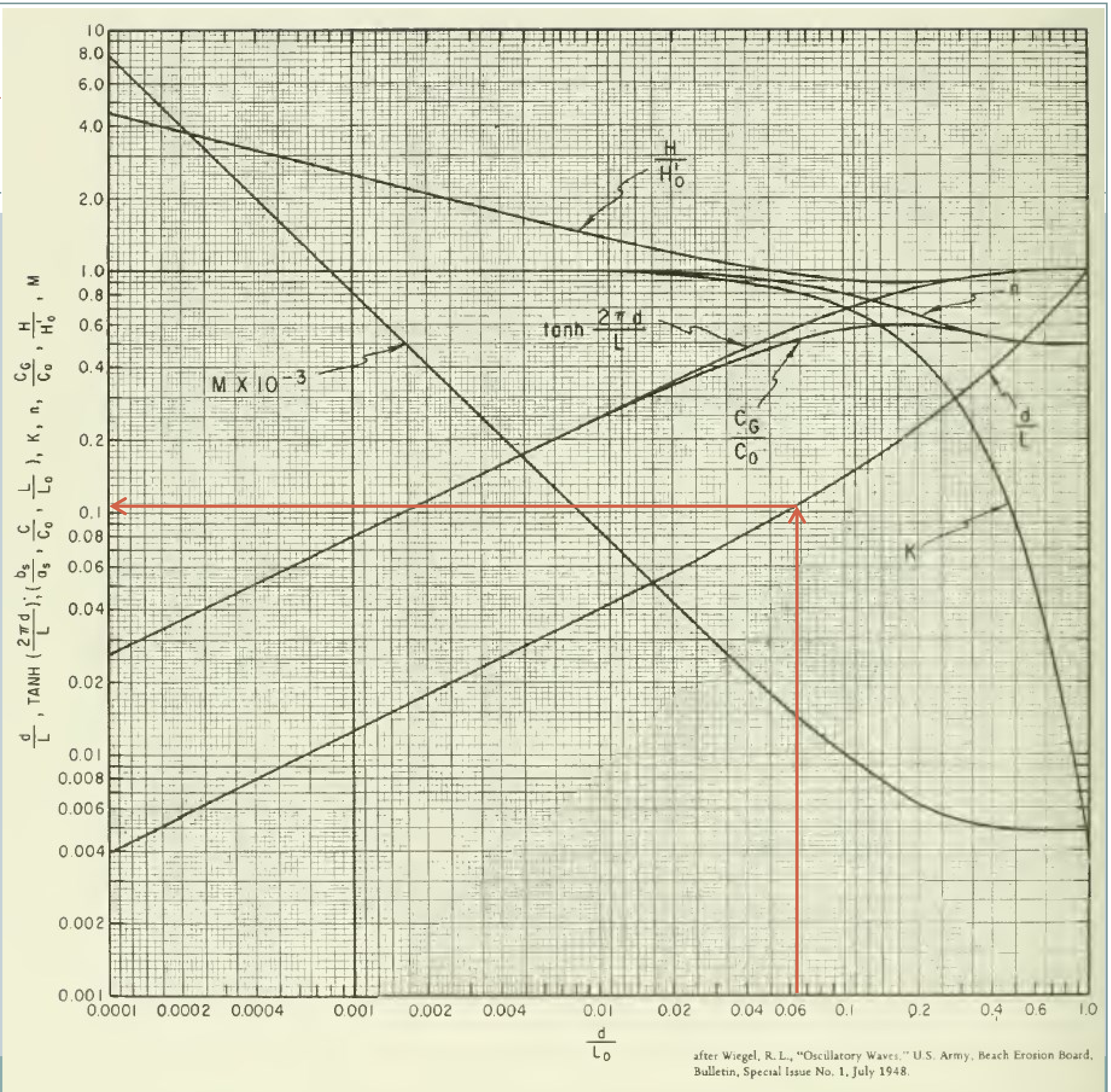
Shore protection manual: VII, Table C-1, p.590

Table C-1. Continued.

d/L_o	d/L	$2\pi d/L$	TANH $2\pi d/L$	SINH $2\pi d/L$	COSH $2\pi d/L$	H/H_o'	K	$4\pi d/L$	SINH $4\pi d/L$	COSH $4\pi d/L$	n	C_G/C_o	M
.03000	.07135	.4483	.4205	.4634	1.1021	1.125	.9073	.8966	1.022	1.430	.9388	.3947	27.9
.03100	.07260	.4562	.4269	.4721	1.1059	1.118	.9042	.9124	1.044	1.446	.9369	.4000	27.1
.03200	.07385	.4640	.4333	.4808	1.1096	1.111	.9012	.9280	1.067	1.462	.9349	.4051	26.3
.03300	.07507	.4717	.4395	.4894	1.1133	1.104	.8982	.9434	1.090	1.479	.9329	.4100	25.6
.03400	.07630	.4794	.4457	.4980	1.1171	1.098	.8952	.9588	1.113	1.496	.9309	.4149	24.8
.03500	.07748	.4868	.4517	.5064	1.1209	1.092	.8921	.9737	1.135	1.513	.9289	.4196	24.19
.03600	.07867	.4943	.4577	.5147	1.1247	1.086	.8891	.9886	1.158	1.530	.9270	.4242	23.56
.03700	.07984	.5017	.4635	.5230	1.1285	1.080	.8861	1.003	1.180	1.547	.9250	.4287	22.97
.03800	.08100	.5090	.4691	.5312	1.1324	1.075	.8831	1.018	1.203	1.564	.9230	.4330	22.42
.03900	.08215	.5162	.4747	.5394	1.1362	1.069	.8801	1.032	1.226	1.582	.9211	.4372	21.90
.04000	.08329	.5233	.4802	.5475	1.1401	1.064	.8771	1.047	1.248	1.600	.9192	.4414	21.40
.04100	.08442	.5304	.4857	.5556	1.1440	1.059	.8741	1.061	1.271	1.617	.9172	.4455	20.92
.04200	.08553	.5374	.4911	.5637	1.1479	1.055	.8711	1.075	1.294	1.636	.9153	.4495	20.46
.04300	.08664	.5444	.4964	.5717	1.1518	1.050	.8688	1.089	1.317	1.654	.9133	.4534	20.03
.04400	.08774	.5513	.5015	.5796	1.1558	1.046	.8652	1.103	1.340	1.672	.9114	.4571	19.62
.04500	.08883	.5581	.5066	.5876	1.1599	1.042	.8621	1.116	1.363	1.691	.9095	.4607	19.23
.04600	.08991	.5649	.5116	.5954	1.1639	1.038	.8592	1.130	1.386	1.709	.9076	.4643	18.85
.04700	.09098	.5717	.5166	.6033	1.1679	1.034	.8562	1.143	1.409	1.728	.9057	.4679	18.49
.04800	.09205	.5784	.5215	.6111	1.1720	1.030	.8532	1.157	1.433	1.747	.9037	.4713	18.15
.04900	.09311	.5850	.5263	.6189	1.1760	1.026	.8503	1.170	1.456	1.766	.9018	.4746	17.82
.05000	.09416	.5916	.5310	.6267	1.1802	1.023	.8473	1.183	1.479	1.786	.8999	.4779	17.50
.05100	.09520	.5981	.5357	.6344	1.1843	1.019	.8444	1.196	1.503	1.805	.8980	.4811	17.19
.05200	.09623	.6046	.5403	.6421	1.1884	1.016	.8415	1.209	1.526	1.825	.8961	.4842	16.90
.05300	.09726	.6111	.5449	.6499	1.1926	1.013	.8385	1.222	1.550	1.845	.8943	.4873	16.62
.05400	.09829	.6176	.5494	.6575	1.1968	1.010	.8356	1.235	1.574	1.865	.8924	.4903	16.35
.05500	.09930	.6239	.5538	.6652	1.2011	1.007	.8326	1.248	1.598	1.885	.8905	.4932	16.09
.05600	.1003	.6303	.5582	.6729	1.2053	1.004	.8297	1.261	1.622	1.906	.8886	.4960	15.84
.05700	.1013	.6366	.5626	.6805	1.2096	1.001	.8267	1.273	1.646	1.926	.8867	.4988	15.60
.05800	.1023	.6428	.5668	.6880	1.2138	.9985	.8239	1.286	1.670	1.947	.8849	.5015	15.36
.05900	.1033	.6491	.5711	.6956	1.2181	.9958	.8209	1.298	1.695	1.968	.8830	.5042	15.13
.06000	.1043	.6553	.5753	.7033	1.2225	.9932	.8180	1.311	1.719	1.989	.8811	.5068	14.91
.06100	.1053	.6616	.5794	.7110	1.2270	.9907	.8150	1.323	1.744	2.011	.8792	.5094	14.70
.06200	.1063	.6678	.5834	.7187	1.2315	.9883	.8121	1.336	1.770	2.033	.8773	.5119	14.50
.06300	.1073	.6739	.5874	.7256	1.2355	.9860	.8093	1.348	1.795	2.055	.8755	.5143	14.30
.06400	.1082	.6799	.5914	.7335	1.2402	.9837	.8063	1.360	1.819	2.076	.8737	.5167	14.11
.06500	.1092	.6860	.5954	.7411	1.2447	.9815	.8035	1.372	1.845	2.098	.8719	.5191	13.92
.06600	.1101	.6920	.5993	.7486	1.2492	.9793	.8005	1.384	1.870	2.121	.8700	.5214	13.74
.06700	.1111	.6981	.6031	.7561	1.2537	.9772	.7977	1.396	1.896	2.144	.8682	.5236	13.57
.06800	.1120	.7037	.6069	.7633	1.2580	.9752	.7948	1.408	1.921	2.166	.8664	.5258	13.40
.06900	.1130	.7099	.6106	.7711	1.2628	.9732	.7919	1.420	1.948	2.189	.8646	.5279	13.24

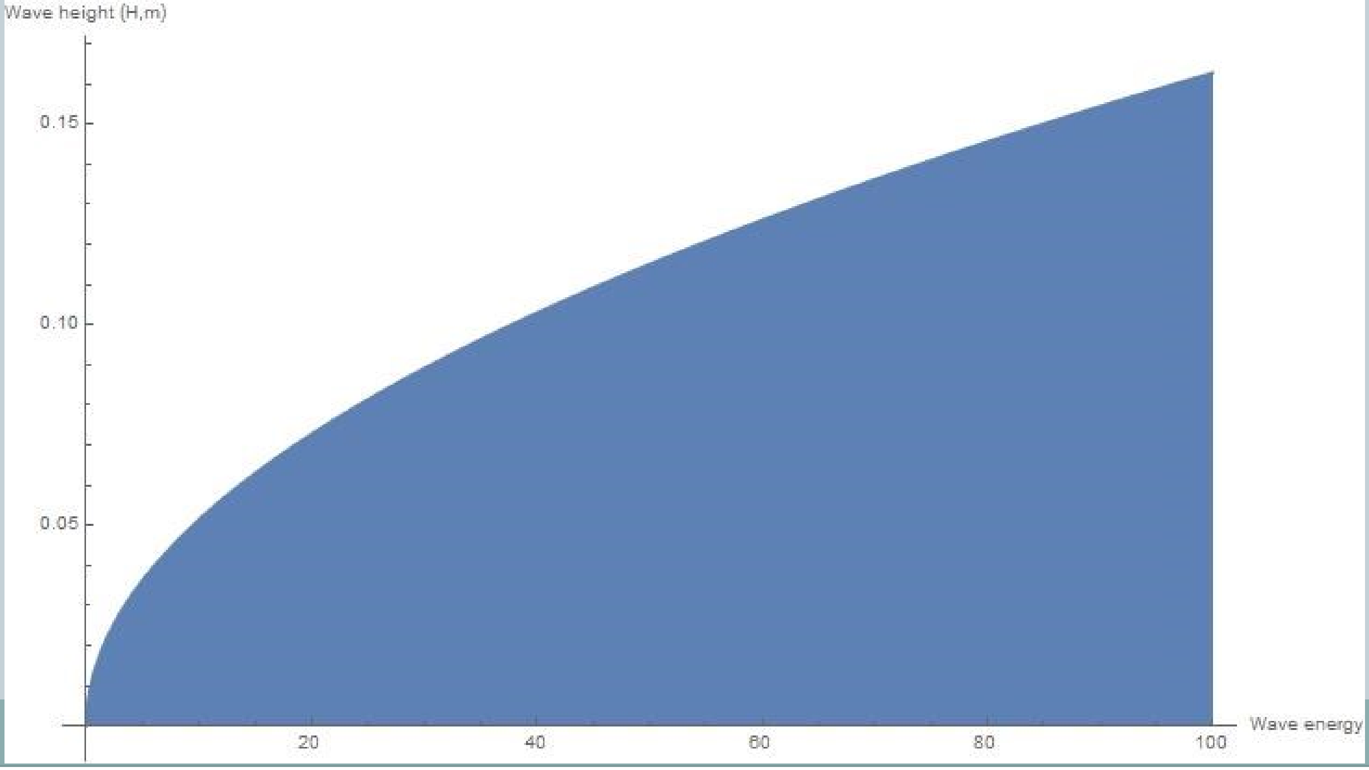
Graphical form

- $d/\lambda_0 = 0.06405$
- $d/\lambda \approx 0.11$



Wave energy vs wave height

- E_t=100; H=0.163m
- E_t=50; H=0.115m
- λ=3m;
- $H=\text{sqrt}(E_t*8/\rho g\lambda)$

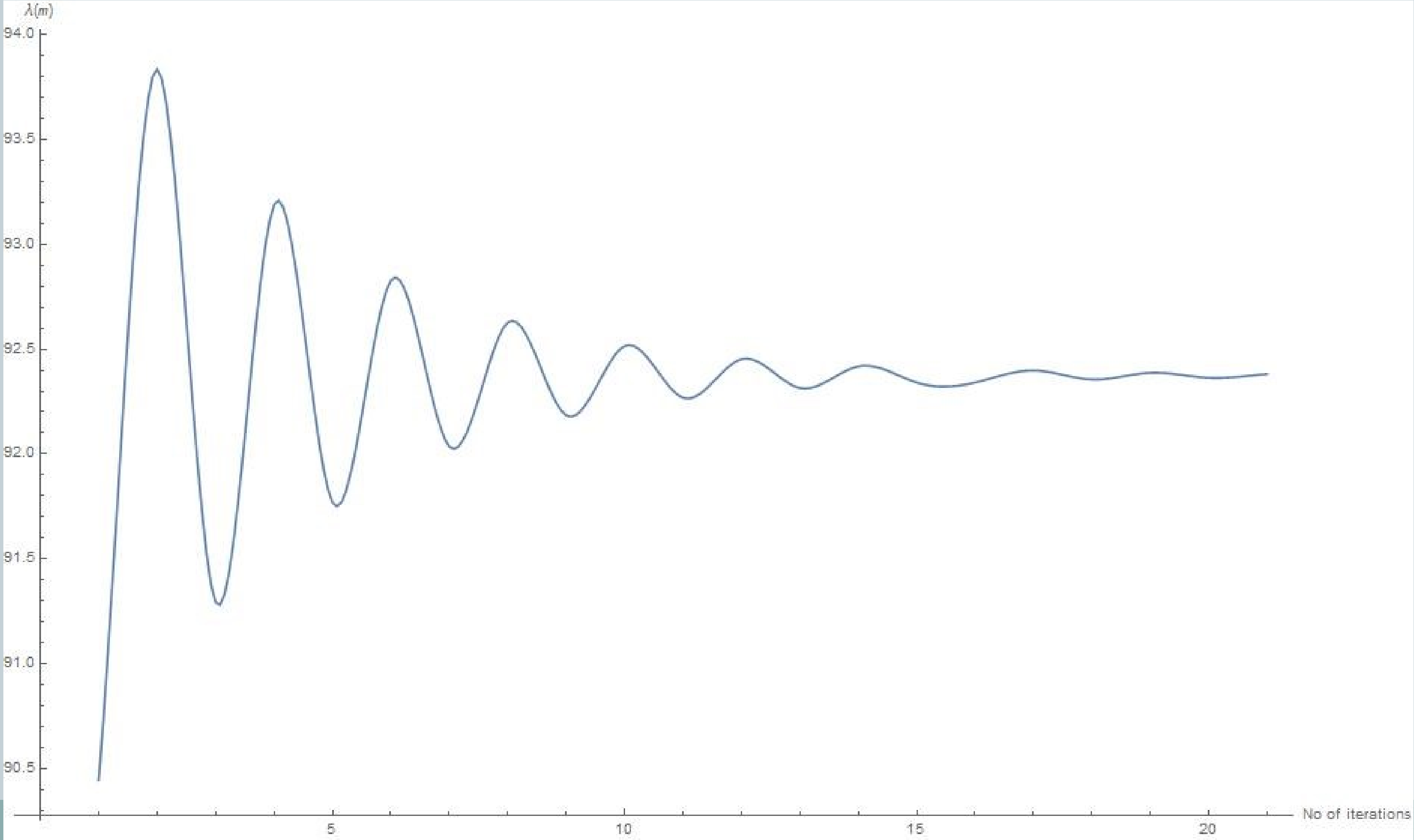


Video

- Wave refraction

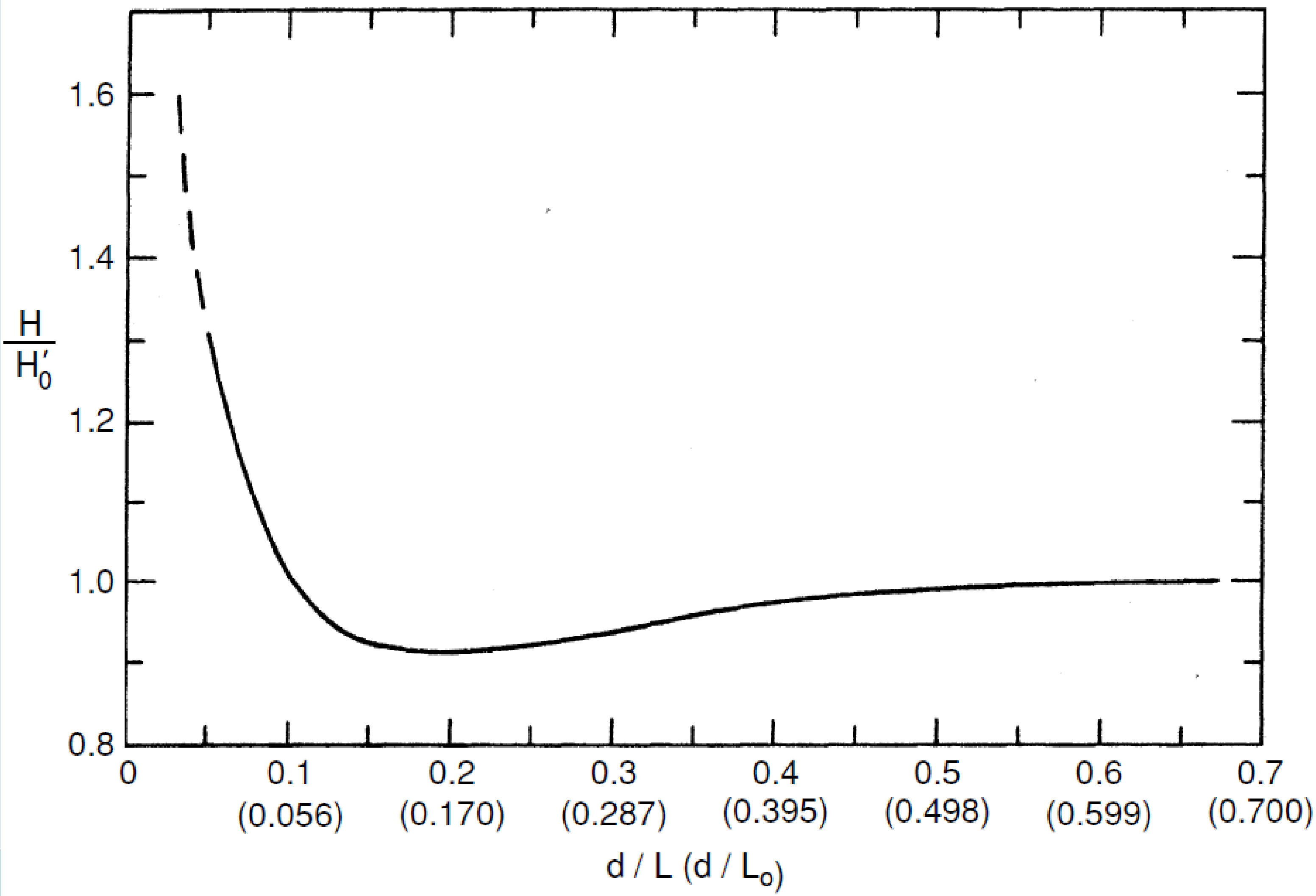
Example 5

- Ex#5



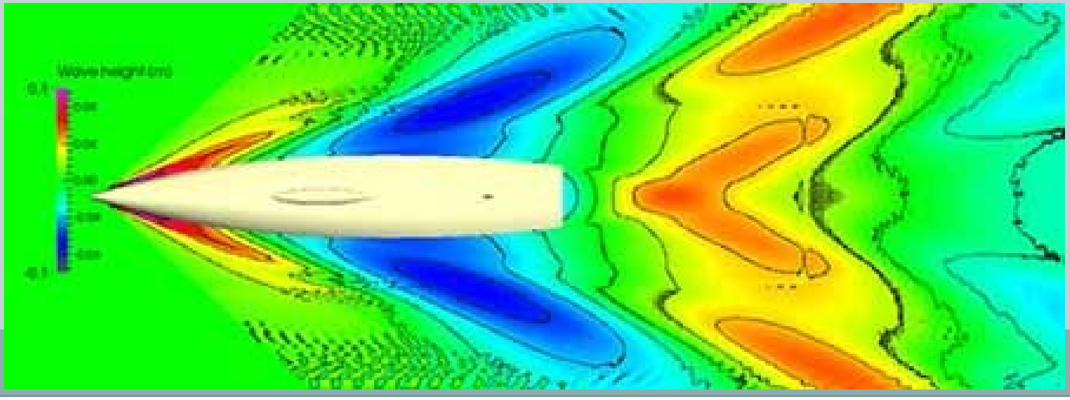
Exercise 5

- Ex#5



Summary

- Mechanics of ocean waves
- 2D linear wave theory
- Orbital motions eg, velocities & accelerations
- Deepwater, transitional & shallow water waves
- Calculations e.g., c, λ, p, H, u, …



Thanks for your attention!