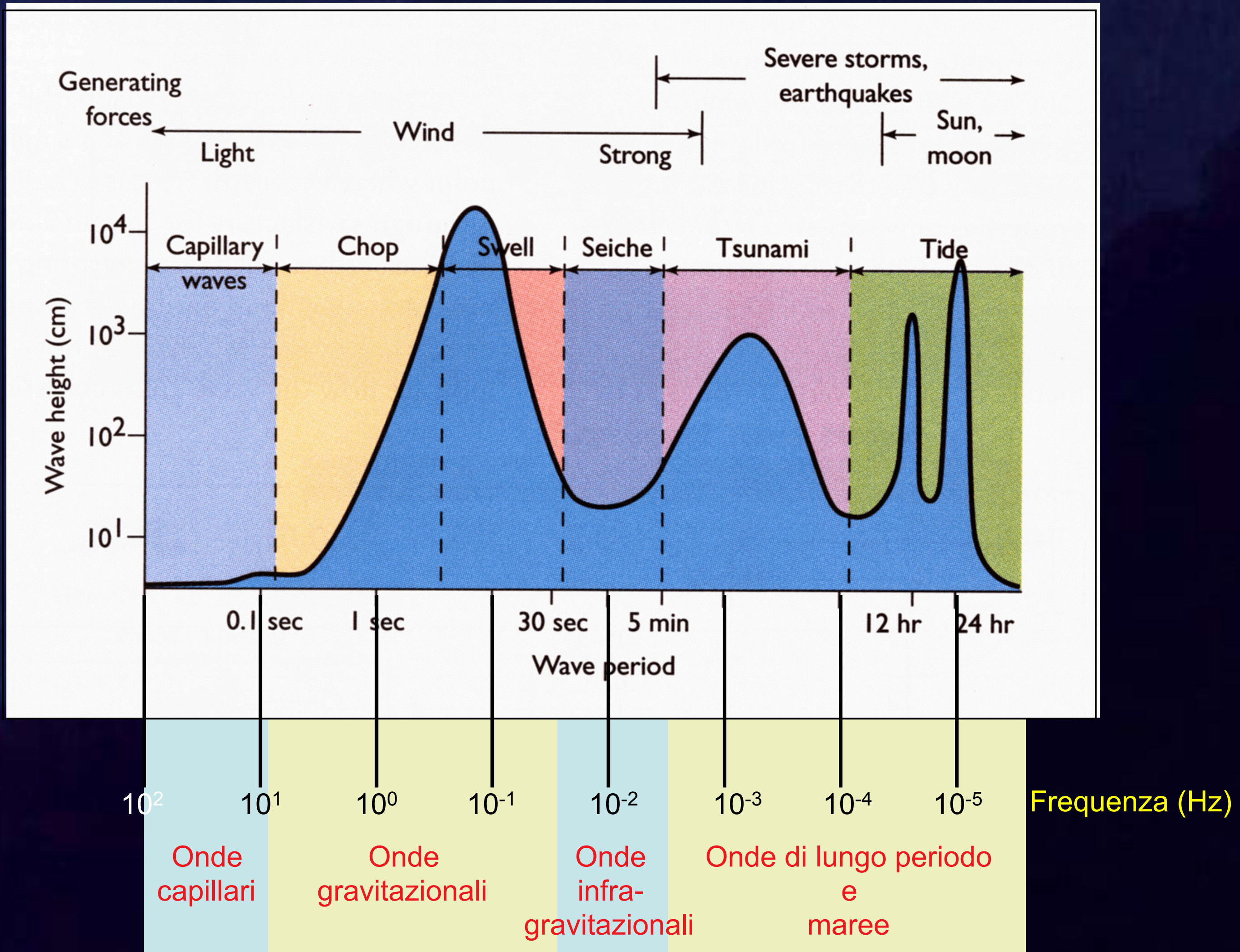
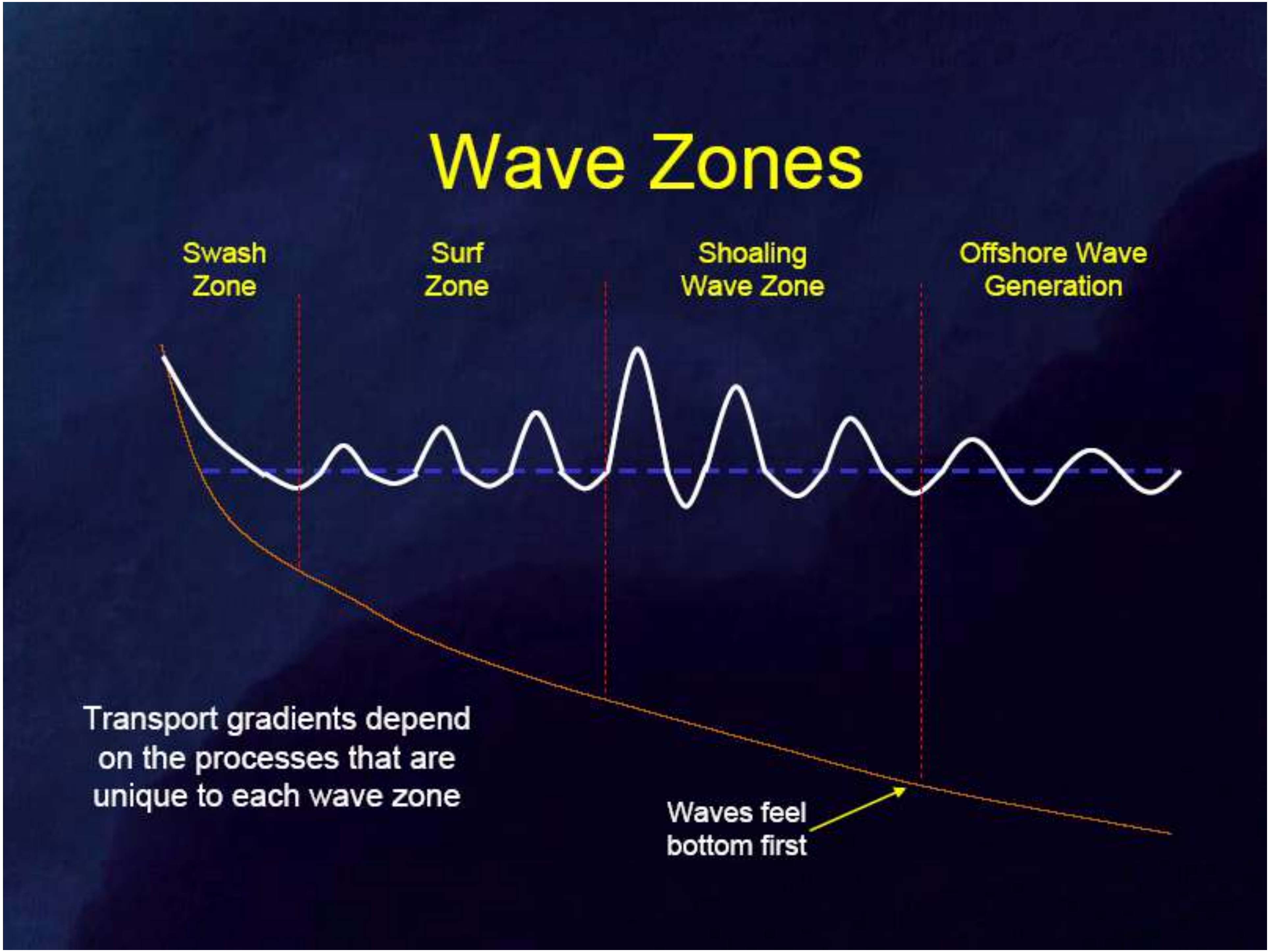
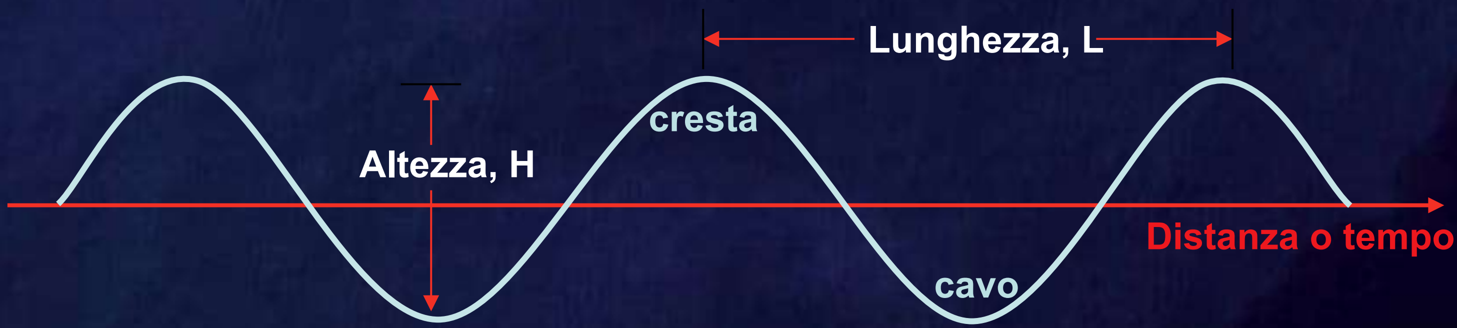

LE ONDE

Distribuzione dell' energia d' onda
In oceano in funzione del periodo (o frequenza) d' onda



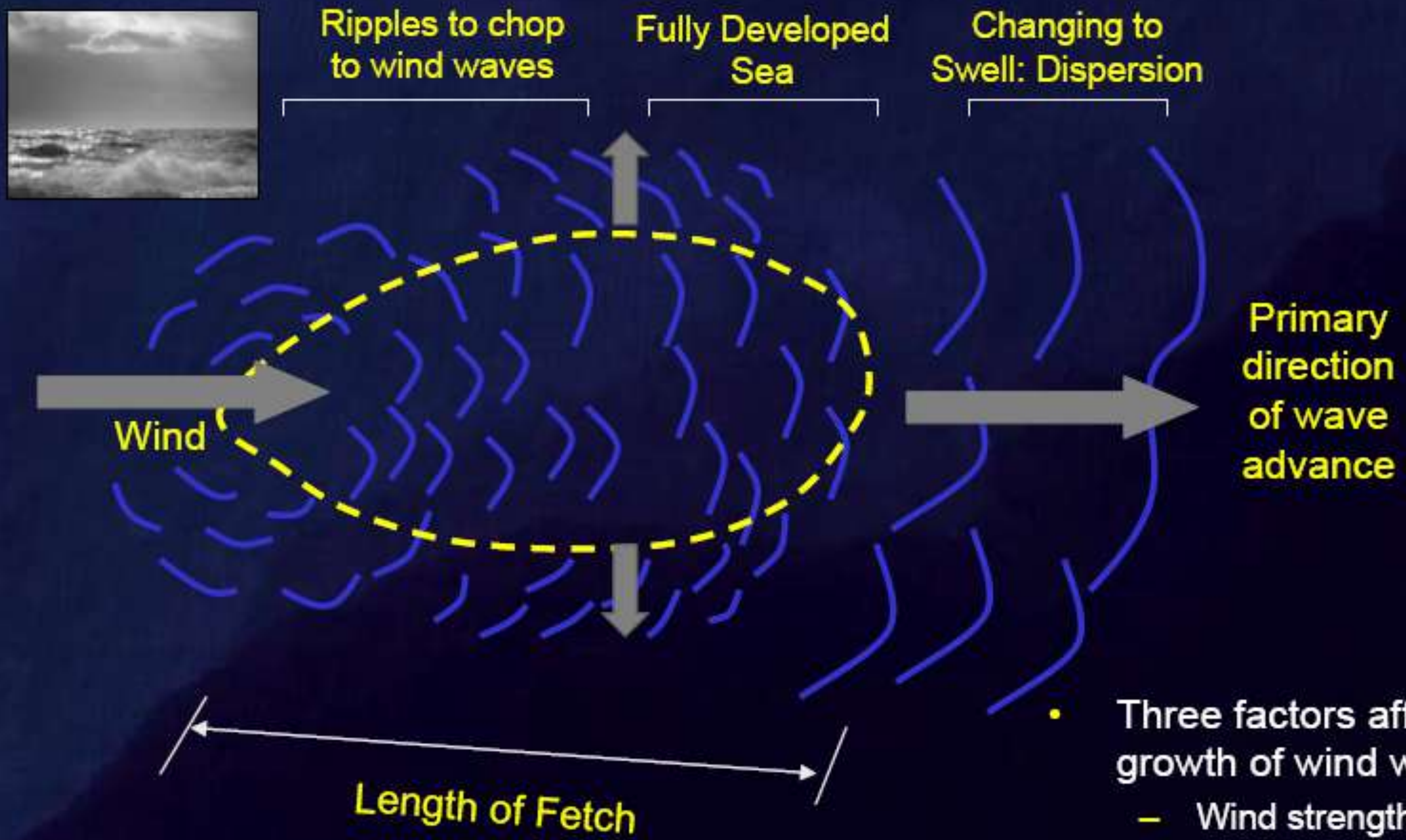

Wave Zones
Swash Zone
Surf Zone
Shoaling Wave Zone
Offshore Wave Generation
Transport gradients depend on the processes that are unique to each wave zone
Waves feel bottom first

Parametri d' onda



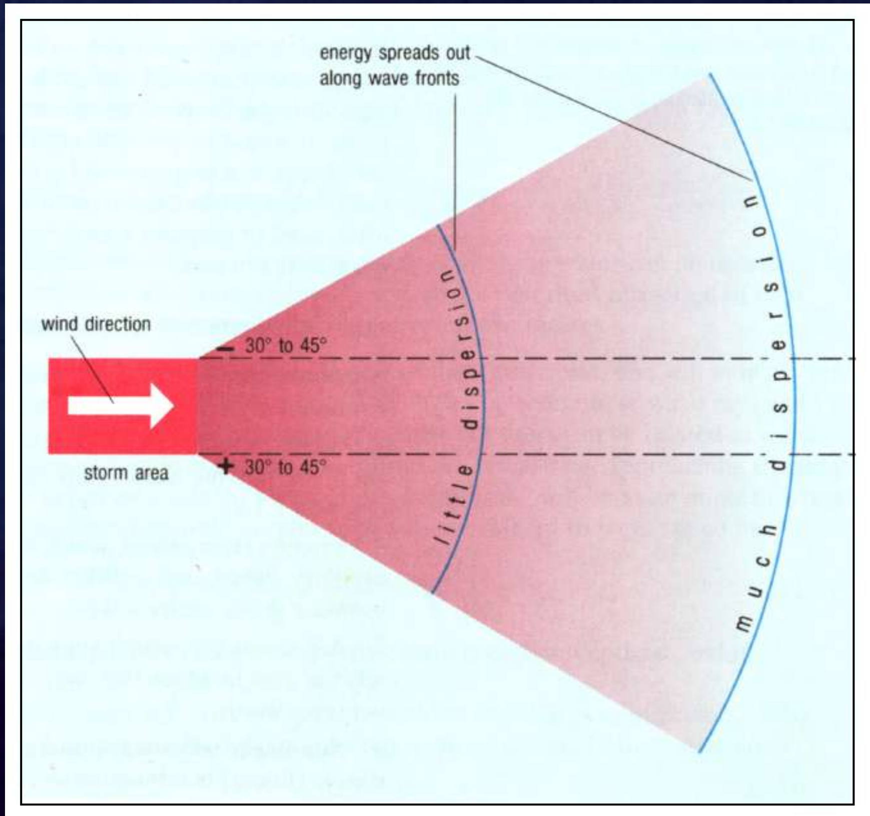
- Ampiezza (a)= Altezza/2
- Periodo (T)= Tempo impiegato da una cresta d' onda per percorrere la lunghezza d' onda L (unità: tempo)
- Frequenza (f)= Numero di creste per unità di tempo che passano in una posizione fissa (unità: 1/T o T^{-1})
- Velocità (C)= Distanza percorsa da una cresta per unità di tempo (unità: spazio/tempo = L/T)

Wave Growth



- Three factors affect the growth of wind waves:
  - Wind strength
  - Wind duration
  - Fetch length

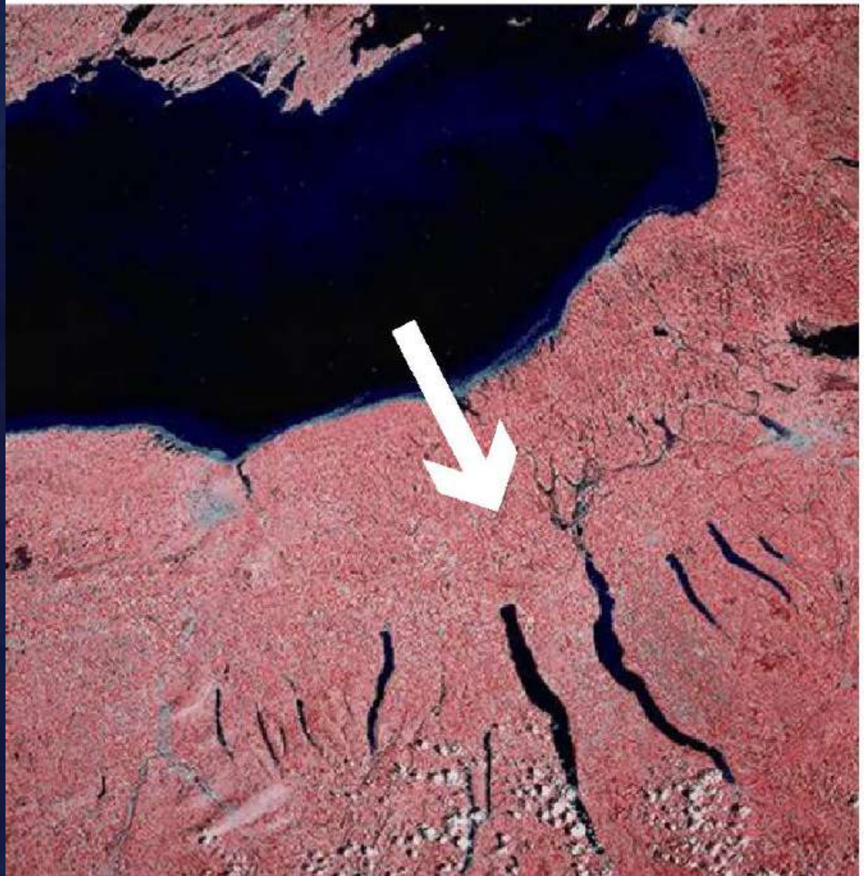
Lateral Spreading of Wave Energy from a Storm Source



(95% of Energy Contained Within ±45^{o} of Storm Direction)

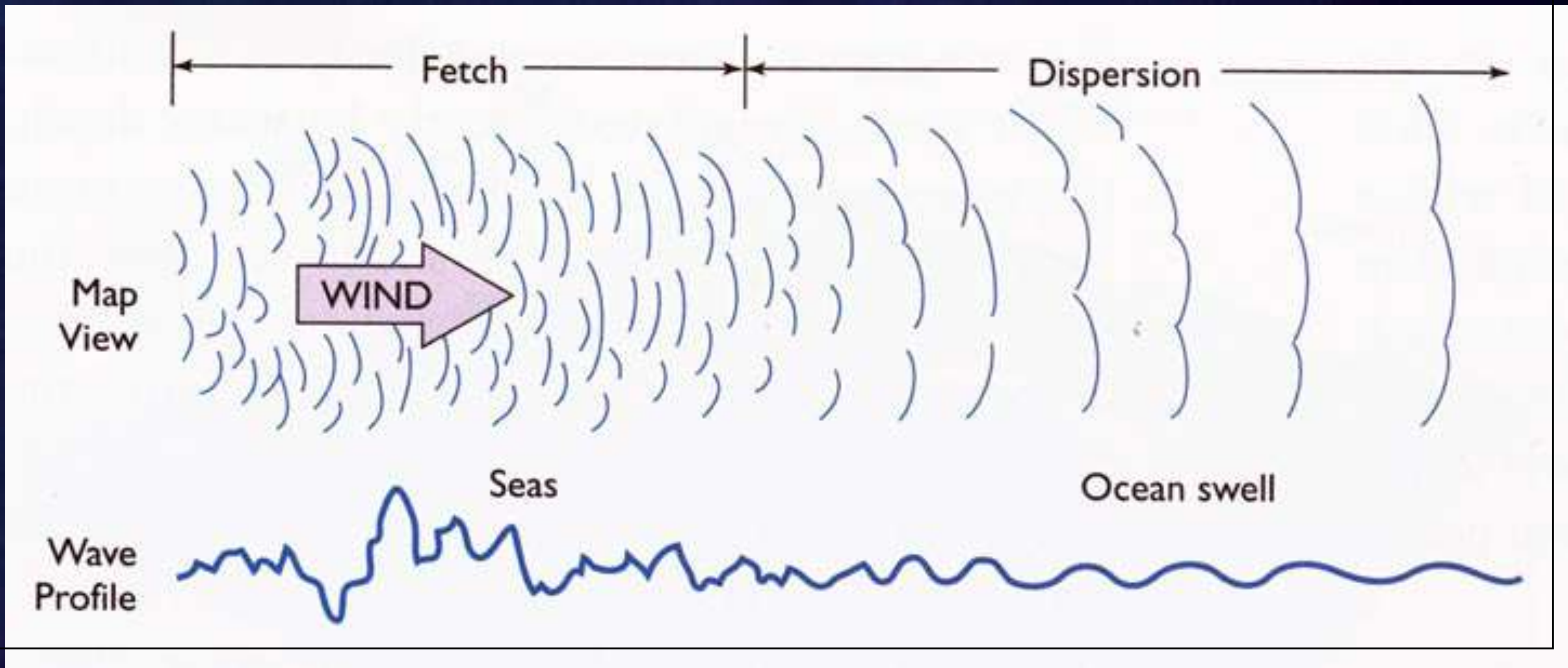
The Importance of Fetch

Northly Wind:
Long Fetch along Finger Lakes



Easterly Wind:
Short Fetch along Fingerl Lakes

Wave Dispersion: Self Sorting of *Deep-Water* Waves Leaving a Storm Region based on Wavelength. It Occurs Because Longer Wavelength Waves Travel Faster than Shorter Wavelength Waves *(for Deep Water)*.



Transformation at Sea

- Directional spreading
- Dispersion
  - Waves of different length travel at different speeds
- Friction with continental shelf
  - Energy of the largest waves dissipated through friction with bed
- Viscous dissipation
  - Energy within the waves is dissipated through viscosity
- Wave interference
  - additive and constructive interference creates wave groups

Question: why are waves along the Gulf Coast smaller than along the Atlantic Coast?

Dispersion

- Waves of different length travel at different speeds
- In deep water the wavelength (L) and wave celerity (C) are proportional to the wave period (T):

$$L = \frac{gT^2}{2\pi}$$

$$C = \frac{gT}{2\pi}$$

These equations are only valid for deep water

When should I go surfing: before or after a storm passes the coast?

Before: the large swell (surfing) waves hit the coastline first

Teoria dell' onda lineare (Airy)

Equazione di dispersione
(relazione tra L e T)

$$\omega^2 = g\,k\,\tanh(kd)$$

dove: $k = \frac{2\pi}{L} =$ numero d'onda

$\omega = \frac{2\pi}{T} =$ frequenza angolare

Trasformando:

$$\frac{(2\pi)^2}{T^2} = \frac{g \cdot 2\pi}{L}\tanh\left(\frac{2\pi d}{L}\right)$$

Teoria dell' onda lineare (Airy)

$$\frac{(2\pi)^2}{T^2} = \frac{g \cdot 2\pi}{L} \tanh\left(\frac{2\pi d}{L}\right)$$

Da questa possiamo derivare le relazioni tra k, L e c

$$L = \frac{g \cdot T^2}{2\pi} \tanh\left(\frac{2\pi d}{L}\right) \longrightarrow \frac{L}{T} = c = \frac{g \cdot T}{2\pi} \tanh\left(\frac{2\pi d}{L}\right)$$

$$\frac{L^2}{T^2} = c^2 = \frac{g \cdot L}{2\pi} \tanh\left(\frac{2\pi d}{L}\right)$$

Velocità di propagazione

$$c = \frac{\text{Lunghezza, (L)}}{\text{Periodo, (T)}}$$

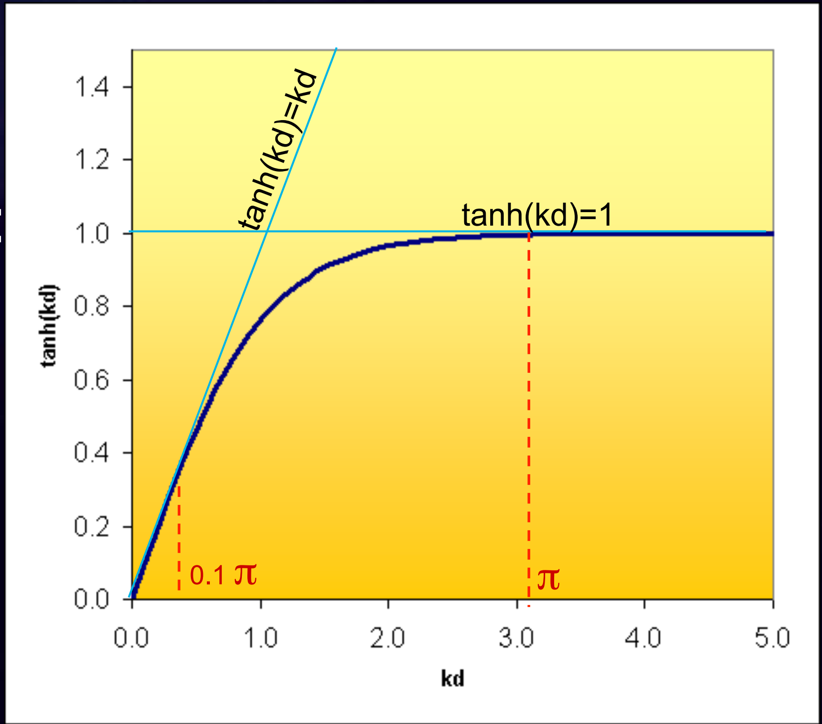
Matematicamente si esprime mediante:

$$c^2 = \frac{g \cdot L}{2\pi} \cdot \tanh \frac{2\pi d}{L}$$

g = acc. gravità, 9.81 ms^{-2}
d = profondità
tanh (x) = tangente iperbolica = $\frac{e^x - e^{-x}}{e^x + e^{-x}}$

Proprietà delle funzioni iperboliche:

Se x è piccolo → tanh (x) ~ x
Se x > π → tanh (x) ~ 1



Velocità di propagazione

$$c^2 = \frac{g \cdot L}{2\pi} \cdot \tanh \frac{2\pi d}{L}$$

Se x è piccolo → tanh (x) ~ x

Se x > π → tanh (x) ~ 1

Velocità d'onda in acque profonde

Se: $d > \frac{L}{2} \Rightarrow c^2 = \frac{g \cdot L}{2\pi} \cdot \tanh\left(> \frac{2\pi L}{2L}\right) \Rightarrow c^2 = \frac{g \cdot L}{2\pi} \cdot \tanh(> \pi)$

$$c^2 = \frac{g \cdot L}{2\pi}$$

La velocità dipende solo dalla lunghezza d'onda

Velocità d'onda in acque basse

Se: $d < \frac{L}{20} \Rightarrow c^2 = \frac{g \cdot L}{2\pi} \cdot \tanh\left(\frac{2\pi d}{L}\right) \Rightarrow c^2 = \frac{g \cdot L}{2\pi} \cdot \frac{2\pi d}{L} = gd$

$$c^2 = g \cdot d$$

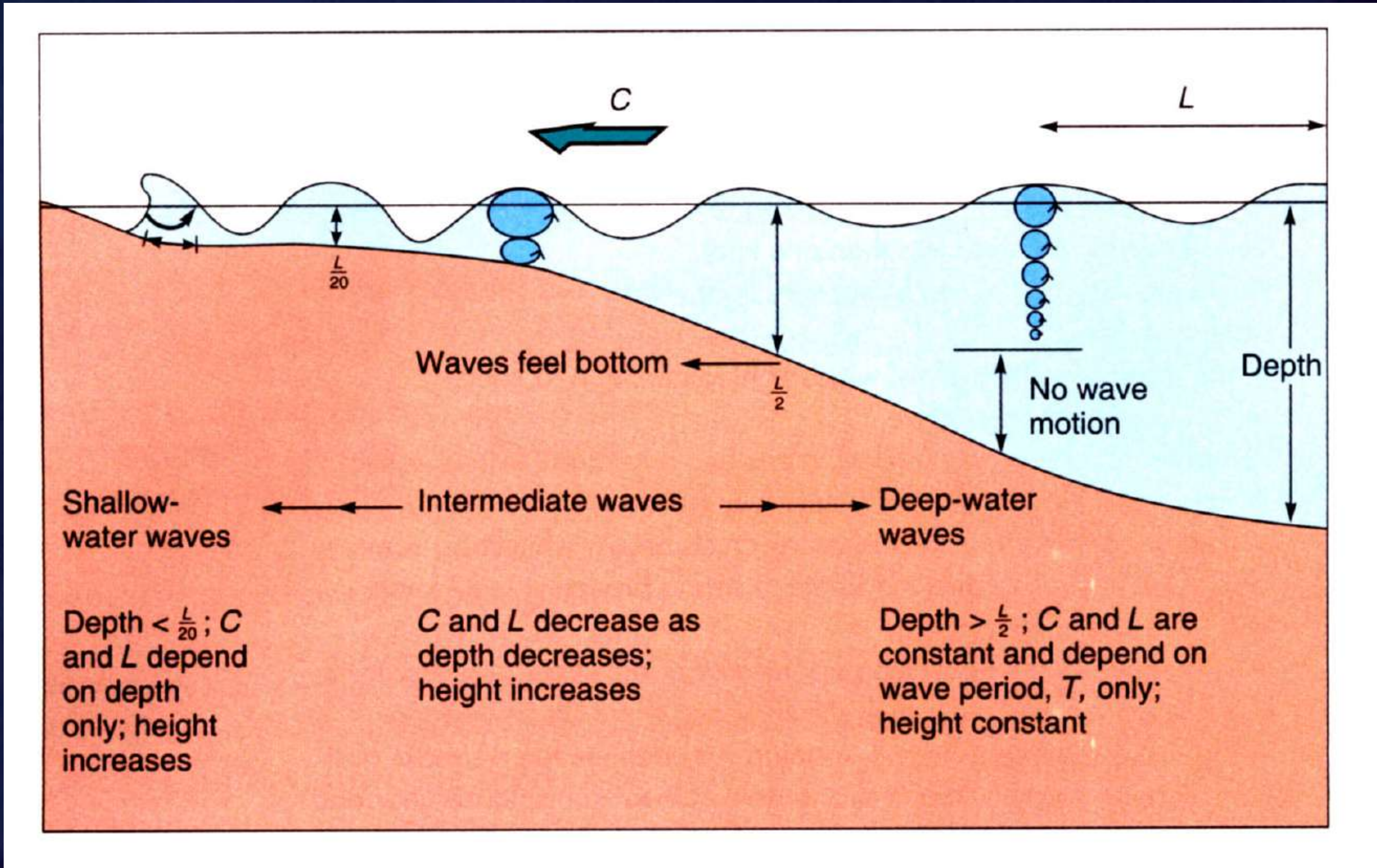
La velocità dipende solo dalla profondità

Onda di Airy

determinazione della lunghezza d'onda dal Periodo

$$c^2 = \frac{L^2}{T^2} = \frac{g \cdot L}{2\pi} \Rightarrow L = \frac{g \cdot T^2}{2\pi} \Rightarrow L_0 = 1.56 \cdot T_0{}^2$$

Le regioni d'onda: acque profonde ed acque basse



TSUNAMI

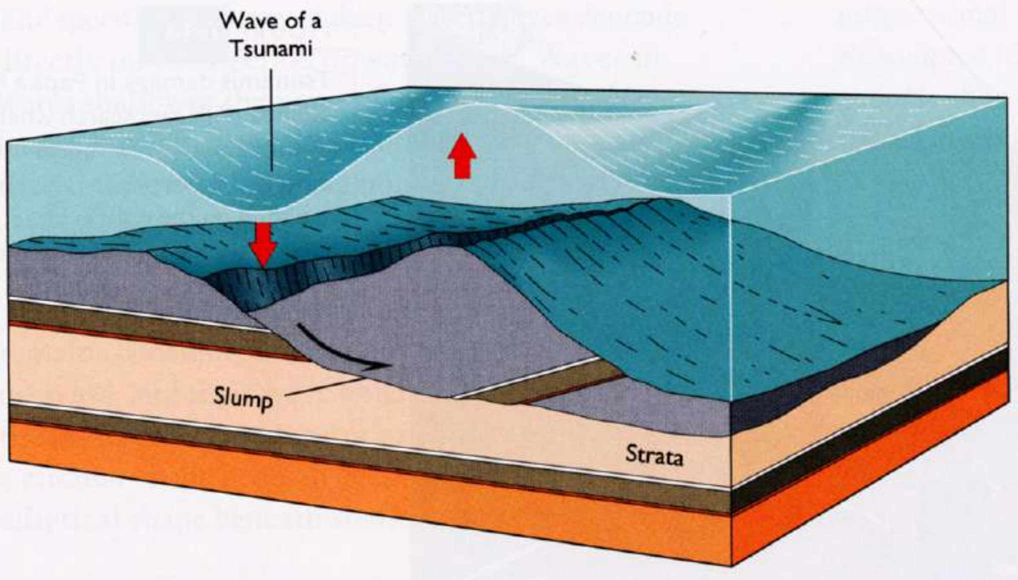
$$C = (g\ d)^{1/2}$$

Esempio:

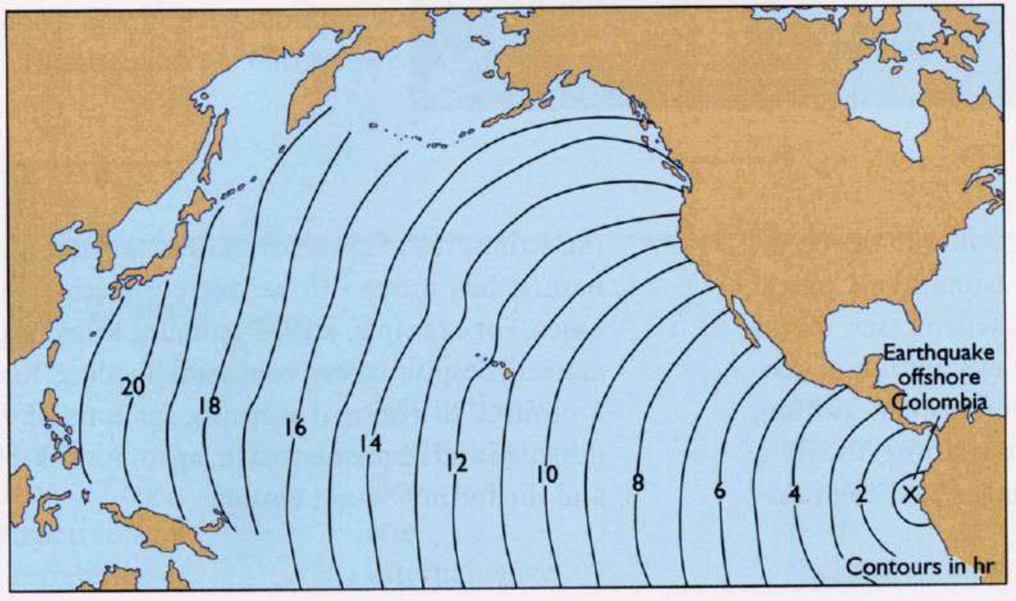
$$C = (9.81 \cdot 4000\ m)^{1/2}$$

$$C = 198\ m/s = 713\ km/h$$

Percorrenza giornaliera:
Circa 17.000 km

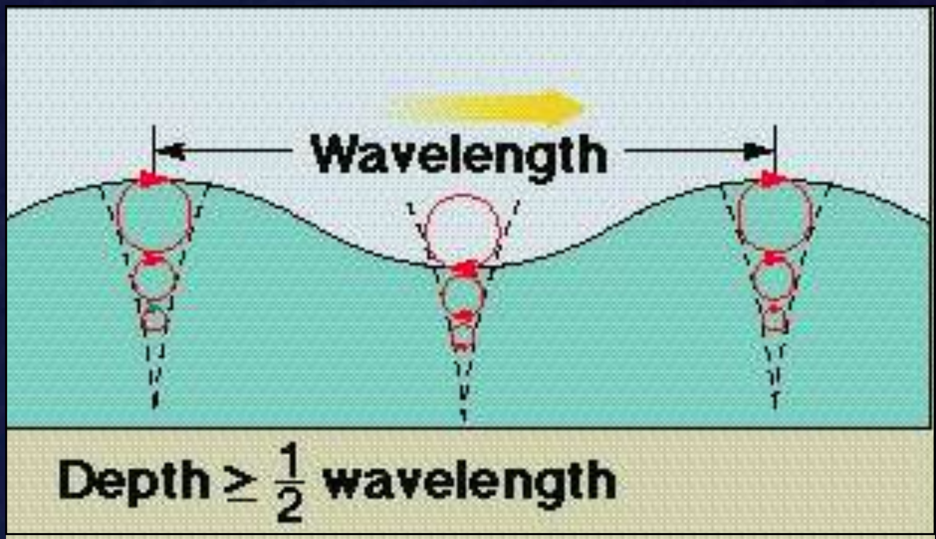


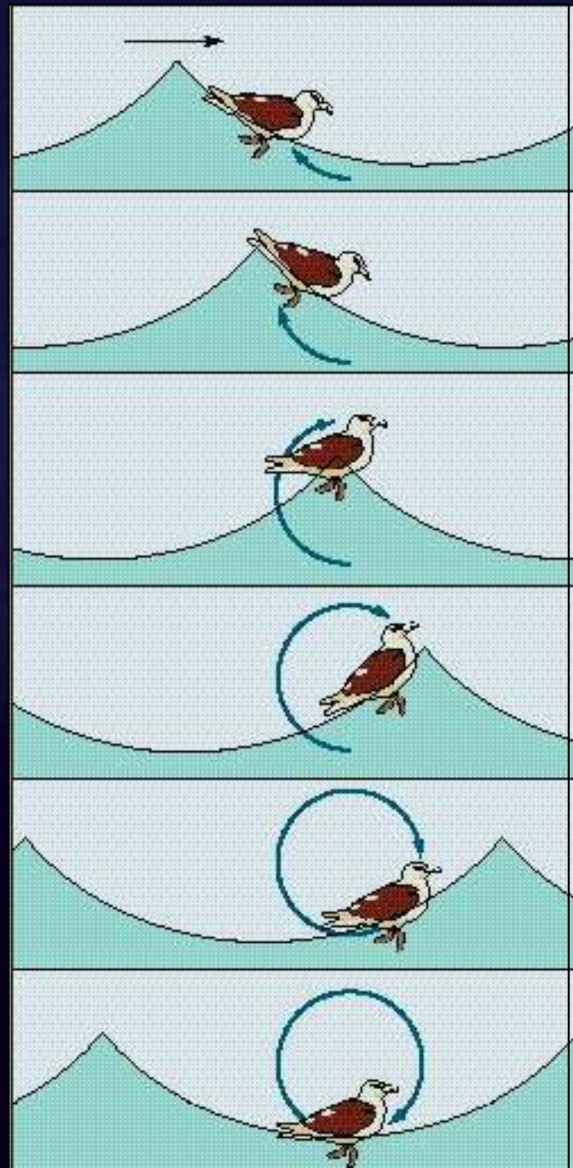
(a) GENERATION OF A TSUNAMI



(b) REFRACTION PATTERN OF 1979 TSUNAMI

Le onde ideali propagano energia e non massa

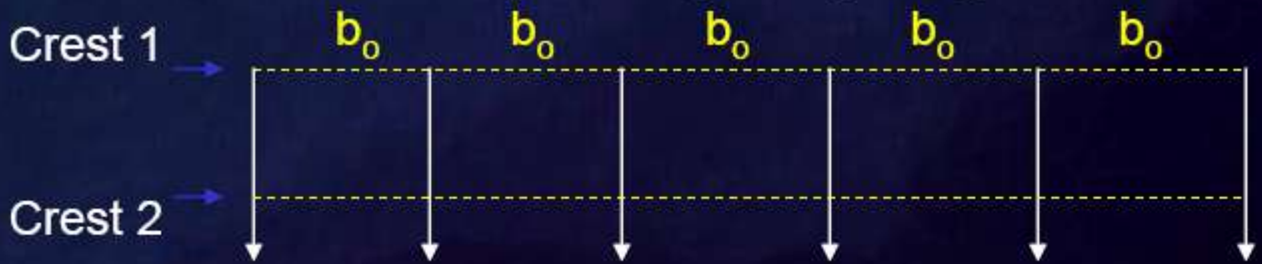




Energy Flux

- Assuming no diffraction in deep water, then:

Energy Flux= *f*(Energy Density, Phase velocity, Orthogonal spacing)



DEEP WATER:

$$P_o = \frac{1}{2} E_o C_o b_o$$

INTER. DEPTH:

$$P_h = E_h C_h b_h n$$

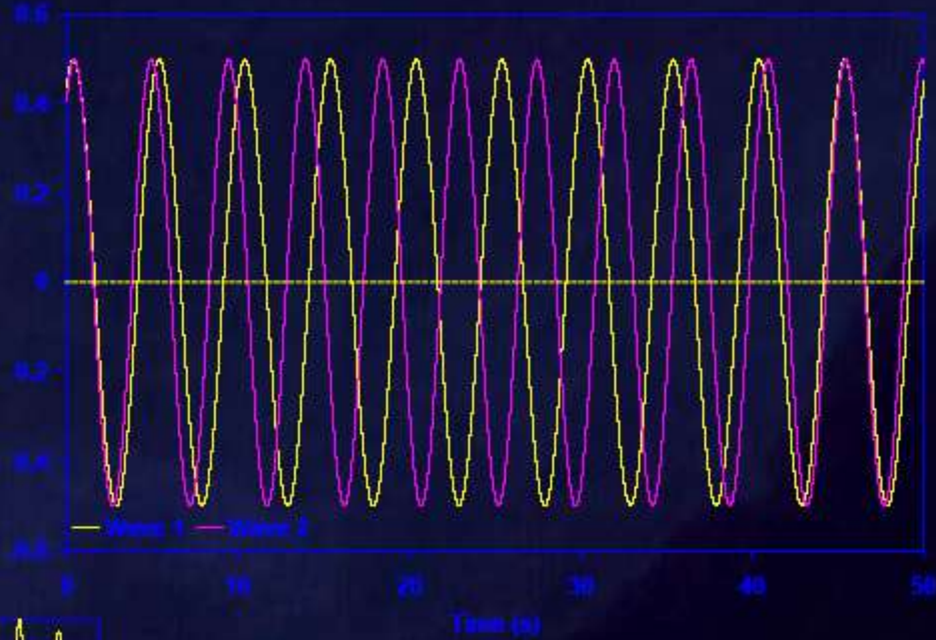
Orthogonal Spacing along wave crest

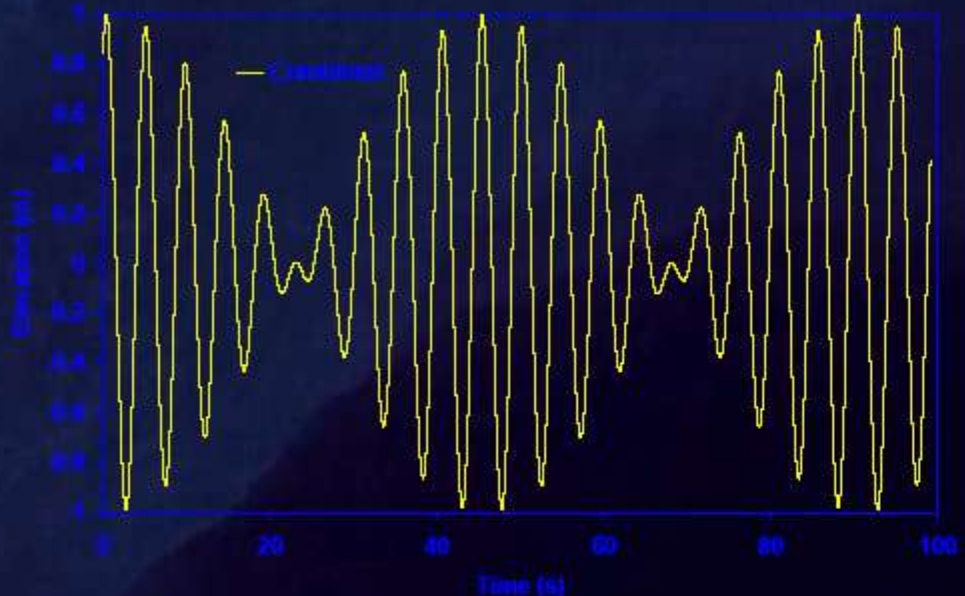
WAVE RAYS

Why is *n* here?

Wave Interference

- Two waves with different periods will move at different speeds





- Wave 1: 5 s
- Wave 2: 4.5 s

- Creates a WAVE GROUP with a period >20 s

http://www.coastal.udel.edu/faculty/rad/superplot.html

Shoreface Transformation

- Shoaling
  - Change in wave form in shallow water
- Refraction
  - changes in speed of propagation along crest causes a *bending* of crests
- Breaking
  - Wave collapses
- Reflection
  - Waves (particularly long waves) are reflected from any sloping surface (including gently sloping shoreface, but especially steeper beach face)
- Friction at bed and percolation into bed

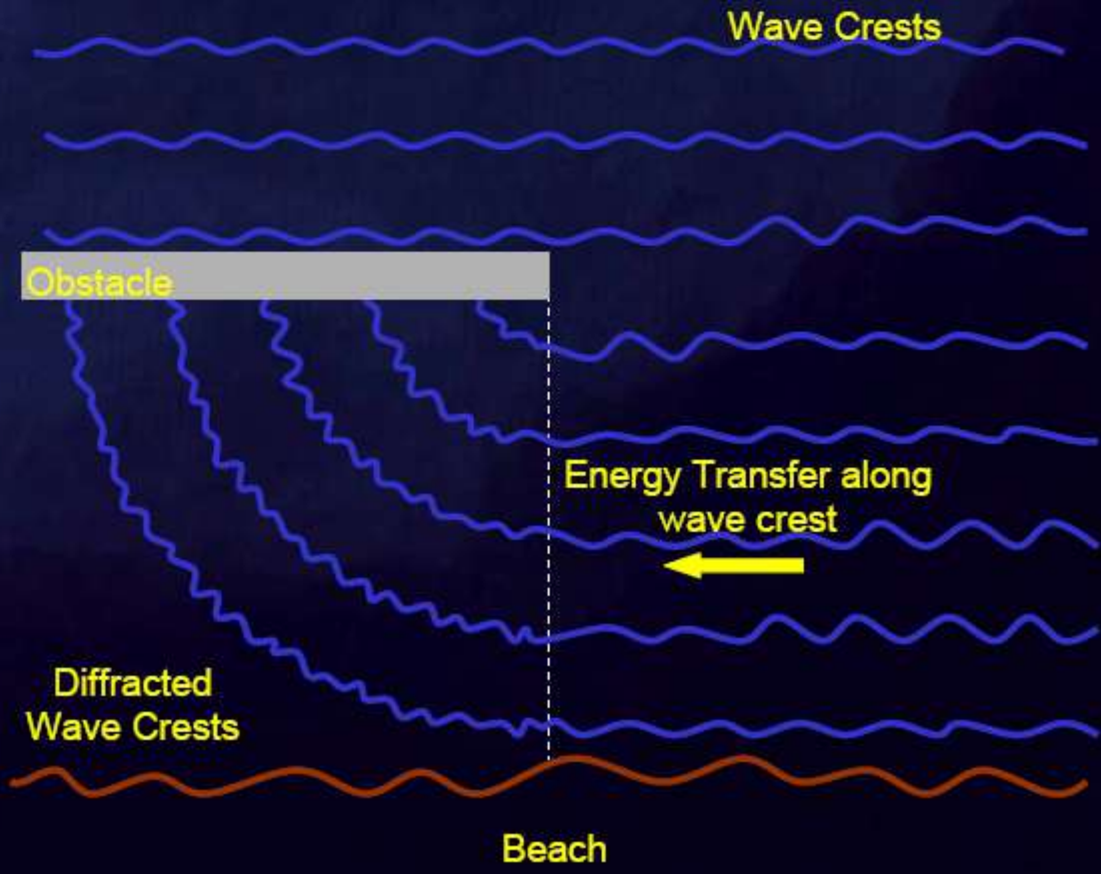
Reflect a feedback with the pre-existing morphology of the shoreface

How the waves change the beach may be more a reflection of the beach morphology than the magnitude of the storm

Diffraction

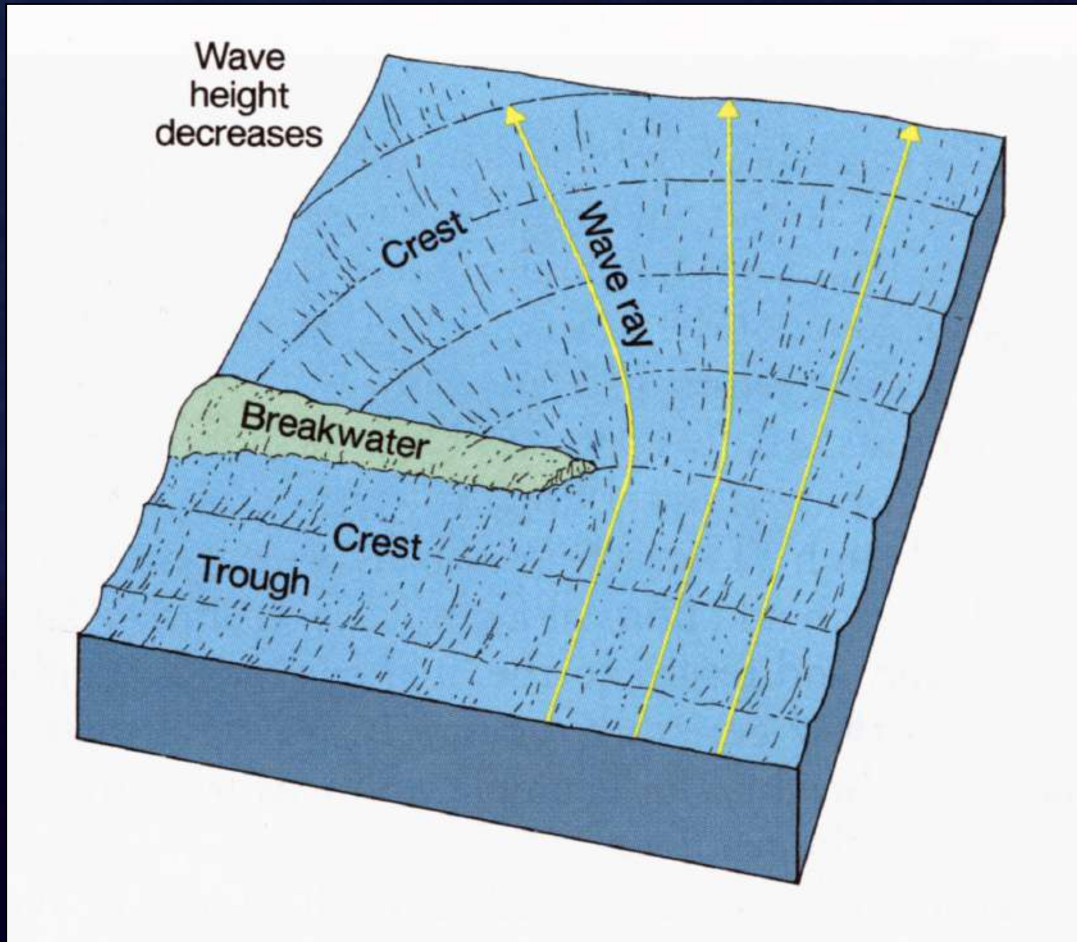
- Variation in crest and trough elevations perpendicular to the direction of propagation results in energy transfers along the crest/trough and thus change in wave height
- Energy can be transferred into sheltered areas

Possible Obstacles:
Breakwater
Island
Submerged Obstacle

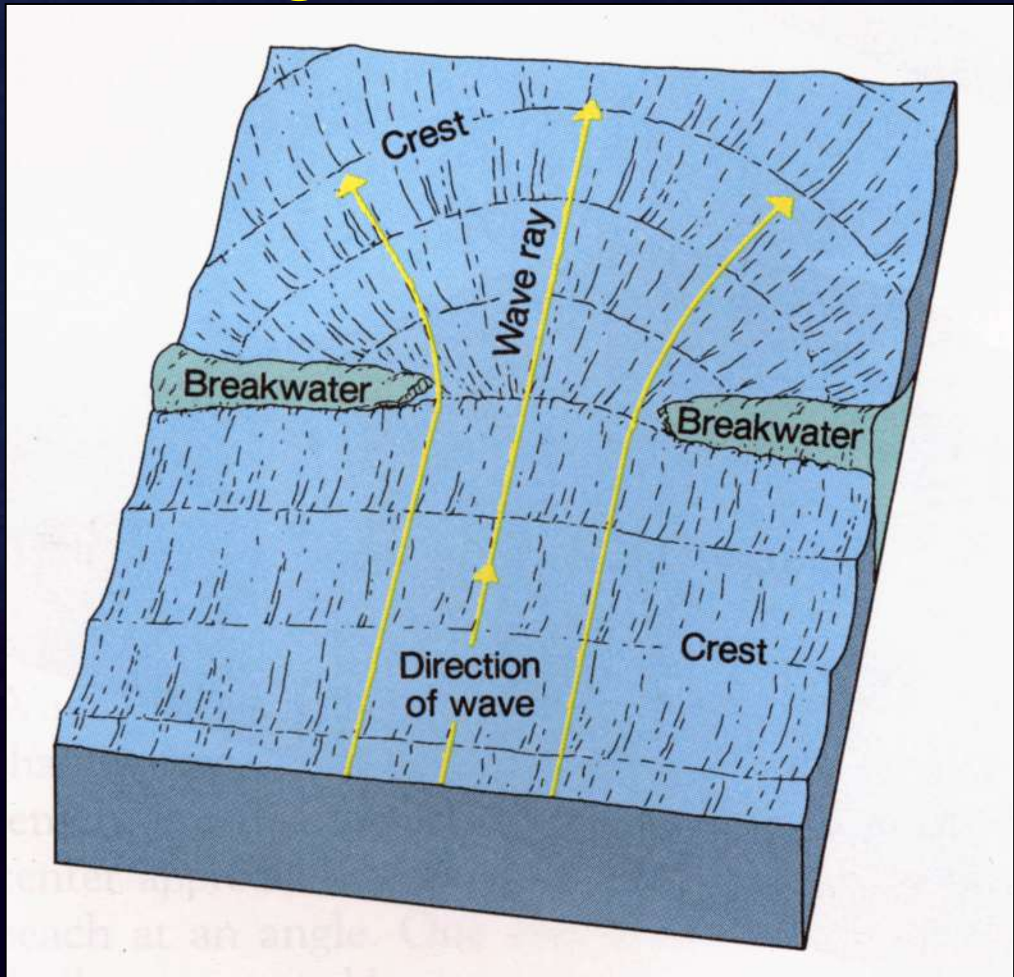


What is the consequence of wave diffraction for coastal processes?

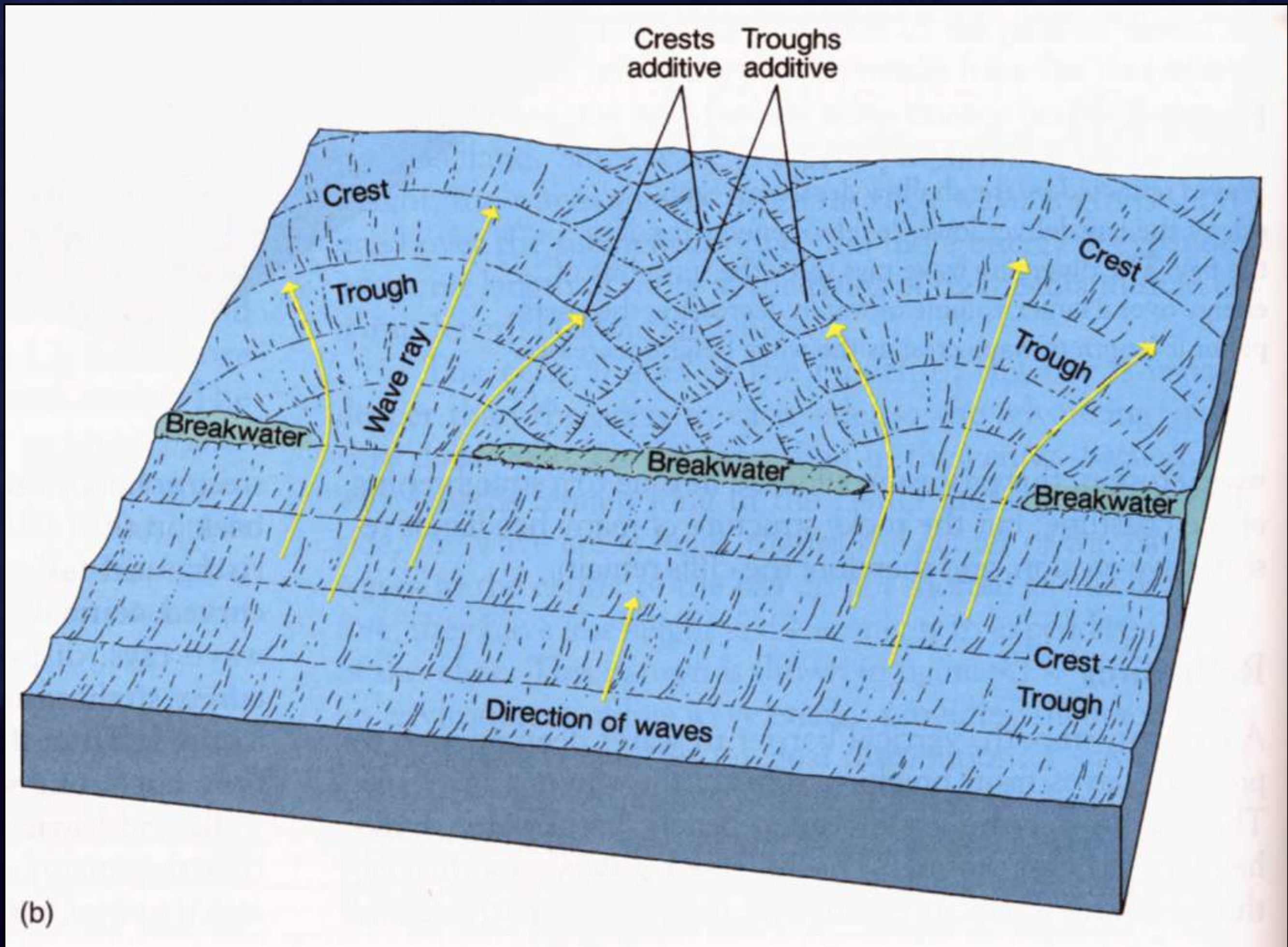
DIFFRAZIONE
(sorgente puntiforme)



DIFFRAZIONE
(sorgente lineare)



DIFFRAZIONE
(sorgente lineare multipla)

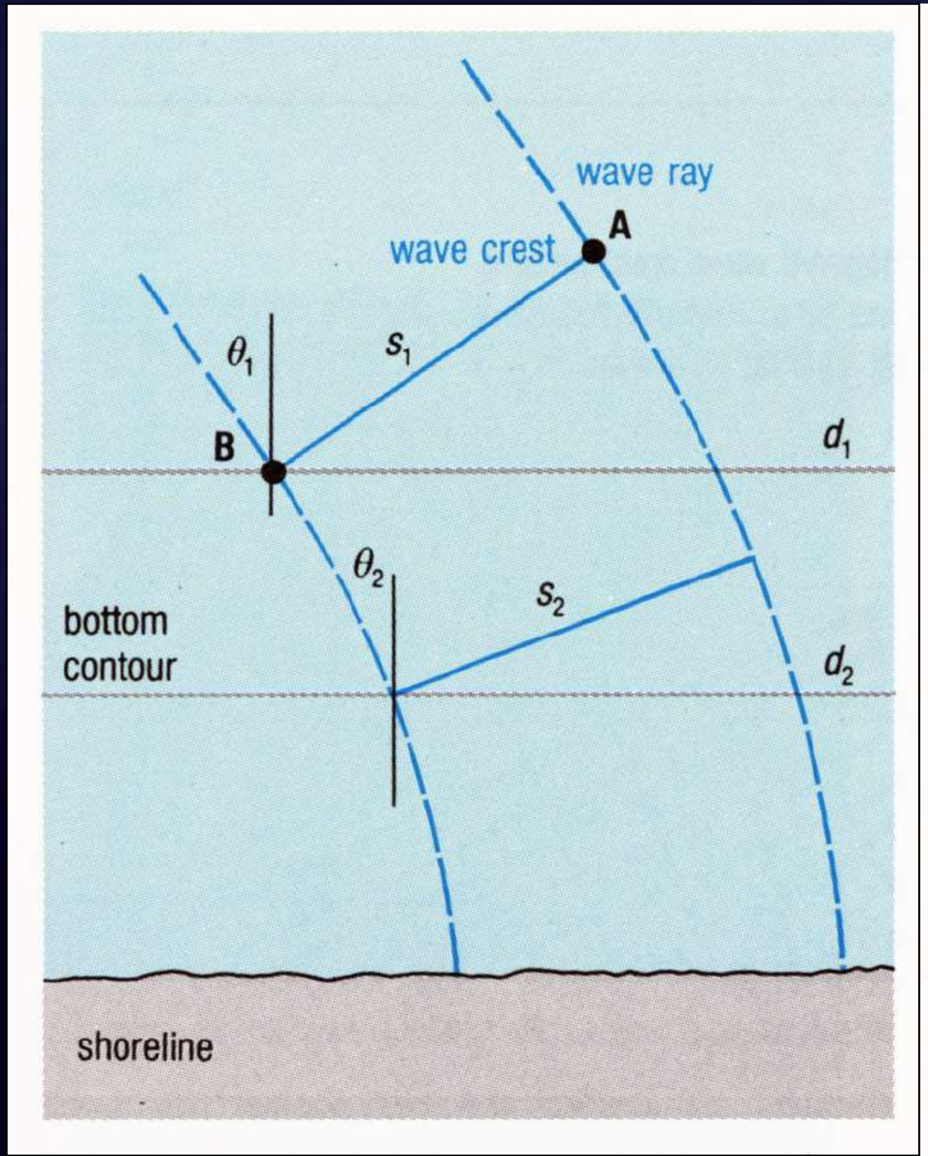


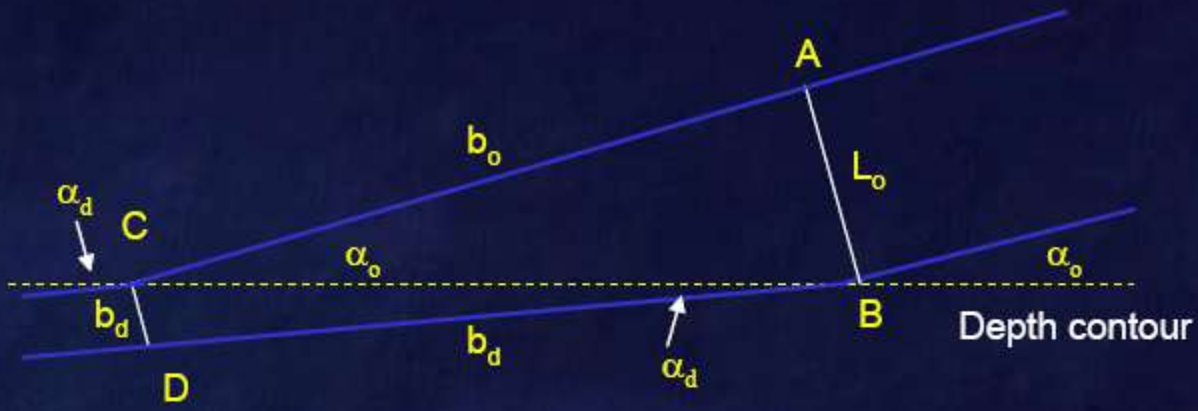
Refraction

- In a time interval T (e.g. a single wave period) a wave crest in deep water travels exactly 1 wavelength (L_o)
- In shoaling depths, where celerity is reduced, the distance of travel will be less as it is inversely proportional to the depth (L_h)
- Wave crest travels different distances depending on the water depth

Rifrazione delle onde:

La curvatura dei fronti d'onda in acque basse è dovuta ai cambiamenti di profondità.
La parte verso terra del fronte d'onda (in **B**) entra in acque più basse e rallenta, mentre il resto del fronte (in **A**) continua a muoversi più velocemente.
Il risultato è una rotazione dei fronti d'onda che tendono a raggiungere una configurazione parallela all'andamento batimetrico.





- From trigonometric relationship for the two similar triangles ABC and BCD

$$\sin \alpha_h = \frac{L_h}{CB}$$

$$\sin \alpha_o = \frac{L_o}{CB}$$

$$\frac{\sin \alpha_h}{\sin \alpha_o} = \frac{L_h}{L_o} = \frac{C_h}{C_o}$$

Legge di Snell

$$\sin \alpha_h = \frac{C_h}{C_o} \sin \alpha_o$$

Consequence of Wave Refraction

Focusing and Defocusing of Wave Energy on Headlands and Bays, Respectively

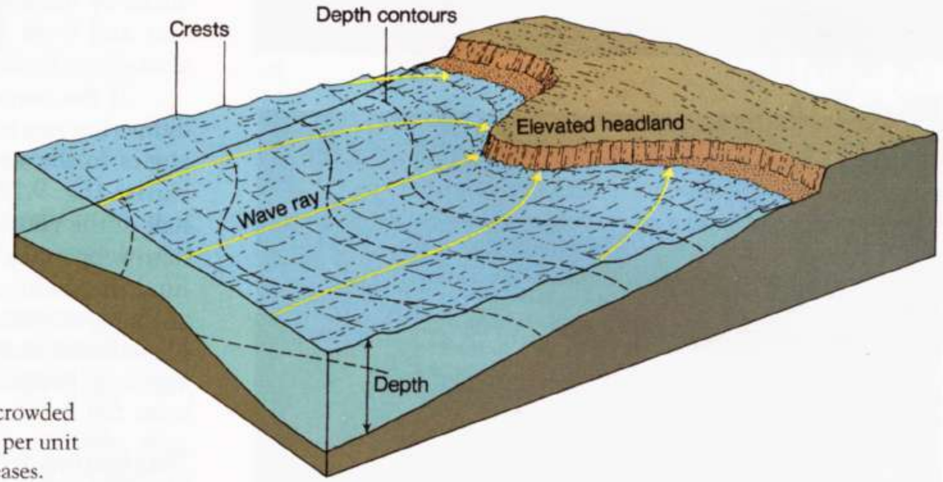


Figure 9.14

The energy of waves refracted over a shallow submerged ridge is focused on the headland. The converging wave rays show the wave energy being crowded into a small volume of water, increasing the energy per unit length of wave crest as the height of the wave increases.

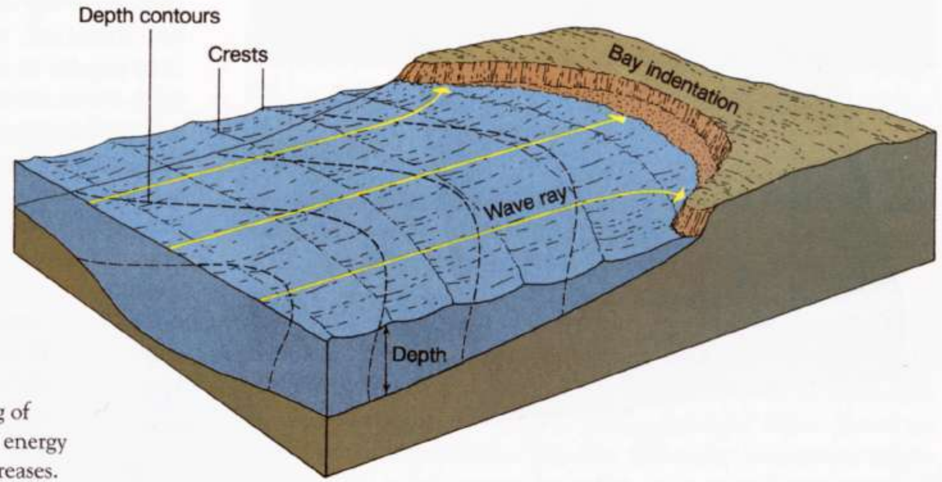
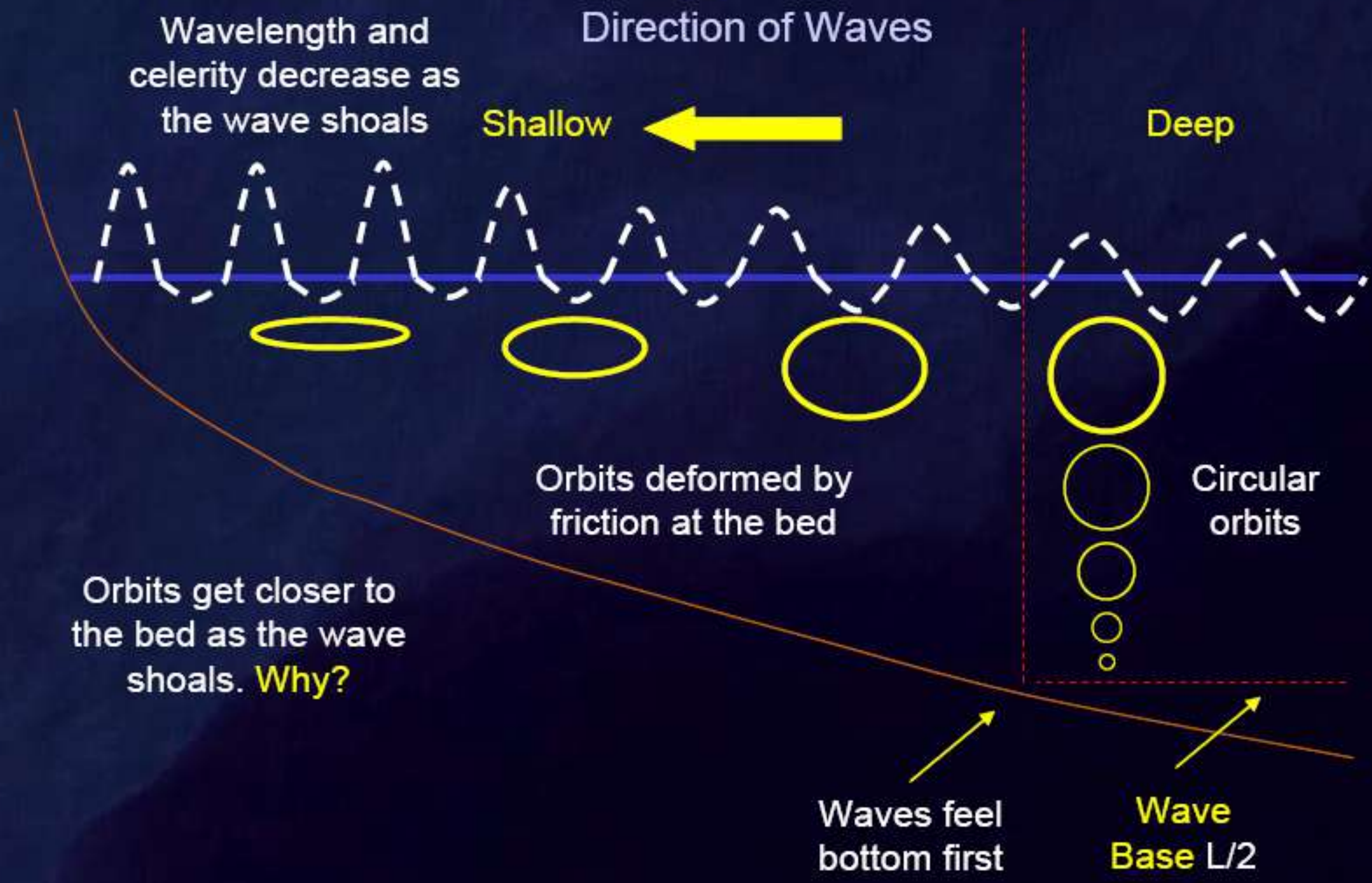


Figure 9.15

Waves refracted by the shallow depths on each side of the bay deliver lower levels of energy inside the bay. The diverging wave rays show the spreading of energy over a larger volume of water, decreasing the energy per unit length of wave crest as the wave height decreases.

Shoaling Changes



Shoaling

- In shallow water the wavelength (L) and wave celerity (C) are proportional to the water depth (h)

$$L = T\sqrt{gh}$$

$$C = \sqrt{gh}$$

- Wave period does not change

Deep Water | Wave Shoaling

- Wavelength and celerity decrease as the wave shoals

- In order to conserve energy what happens to the wave height?

The shape of a wave

- The waves shown to this point have been sinusoidal
  - This is only valid for deep water waves

- There are two general classes of models:

DEEP WATER
Linear

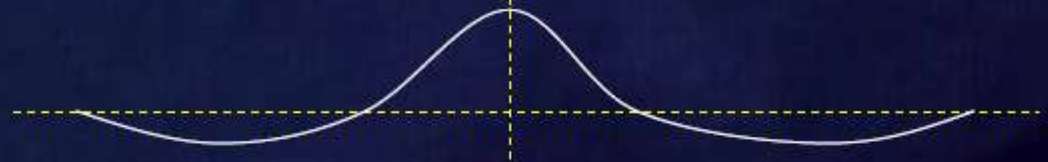
SHALLOW WATER
Non-linear

- All models vary in their level of approximation to real wave forms

- Linear
  - AIRY: deep water $H L^{-1} \Rightarrow 0$

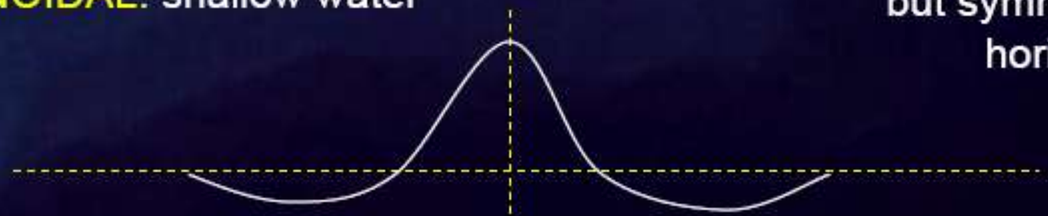
Symmetric in the horizontal and the vertical

- Non-Linear
  - STOKES: deep water $H L^{-1}$ large

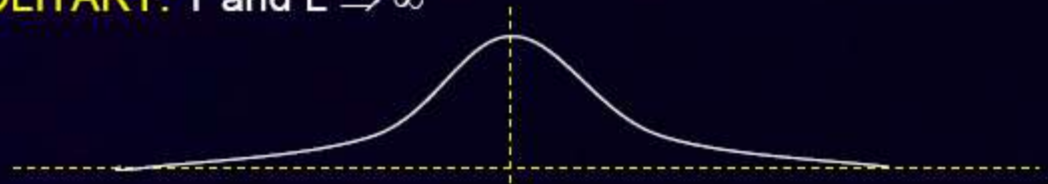


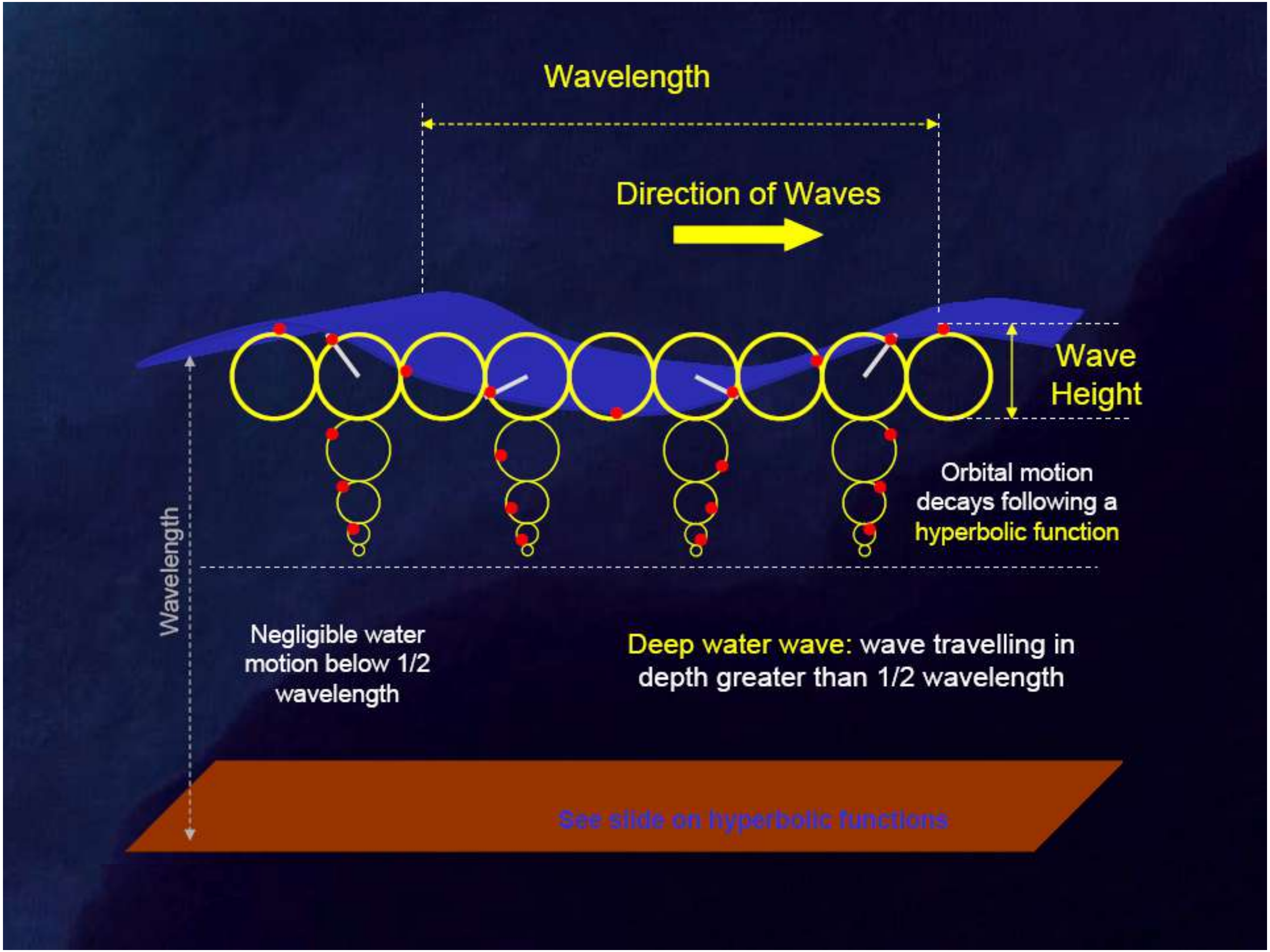
  - CNOIDAL: shallow water

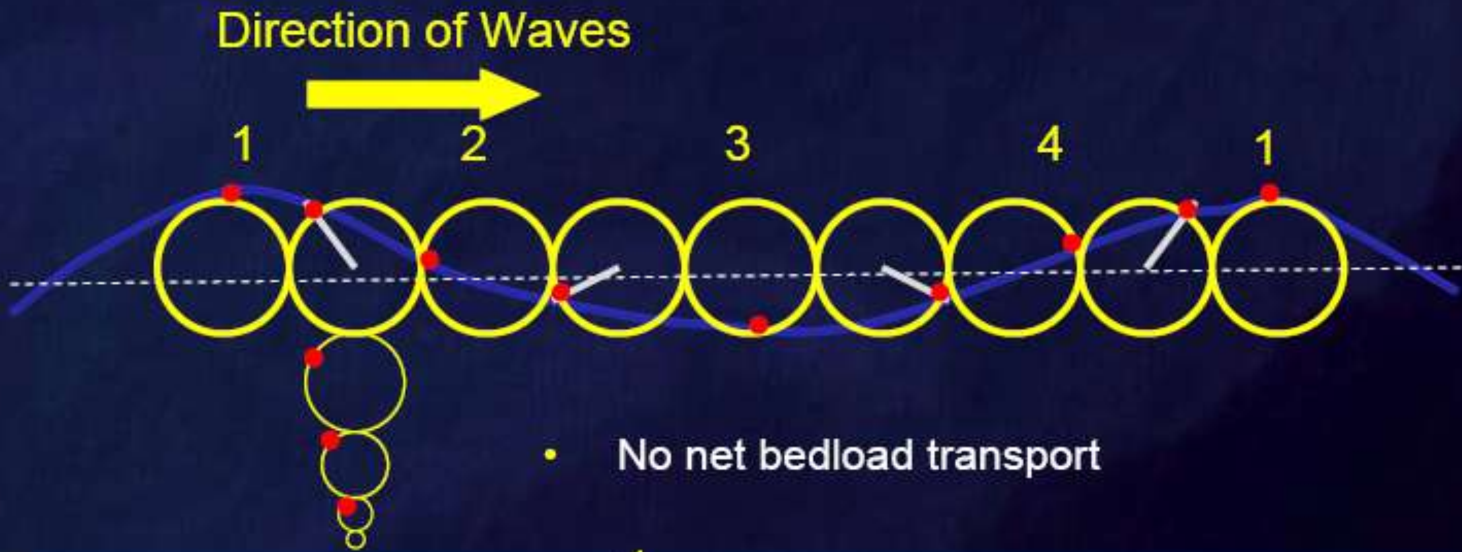
Asymmetric in the Vertical but symmetric in the horizontal



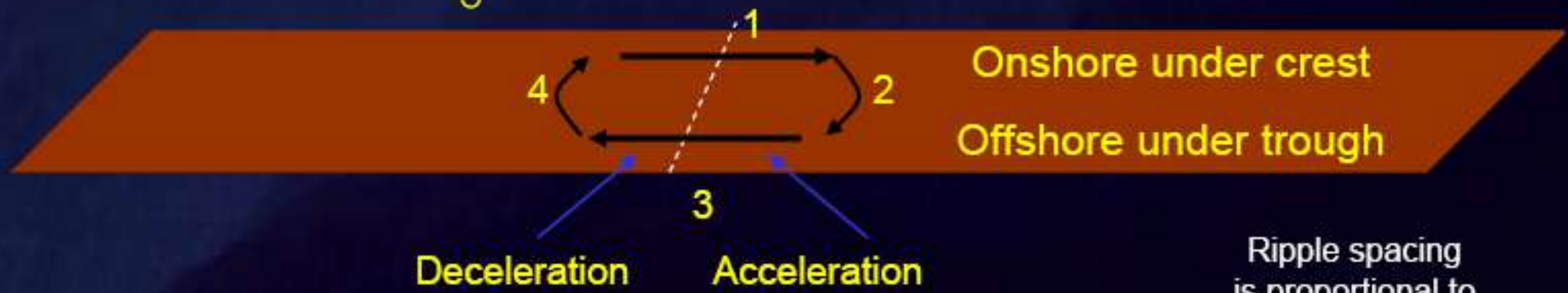
  - SOLITARY: T and $L \Rightarrow \infty$

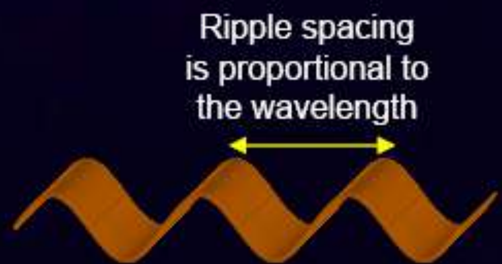



Wavelength
Direction of Waves
Wave
Height
Orbital motion
decays following a
hyperbolic function
Wavelength
Negligible water
motion below 1/2
wavelength
Deep water wave: wave travelling in
depth greater than 1/2 wavelength
See slide on hyperbolic functions



- No net bedload transport

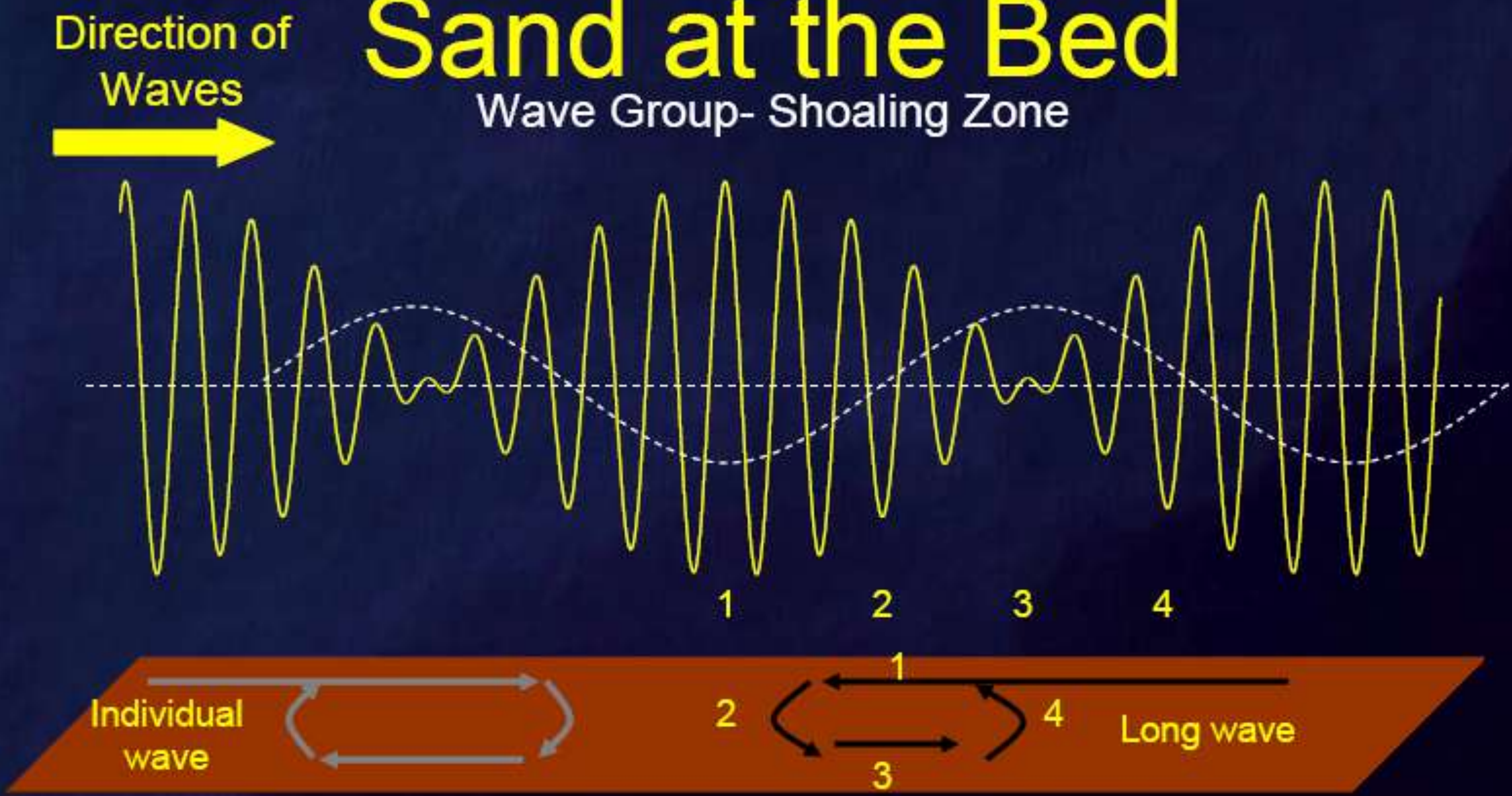




- Forms symmetrical **orbital ripples**

Sand at the Bed

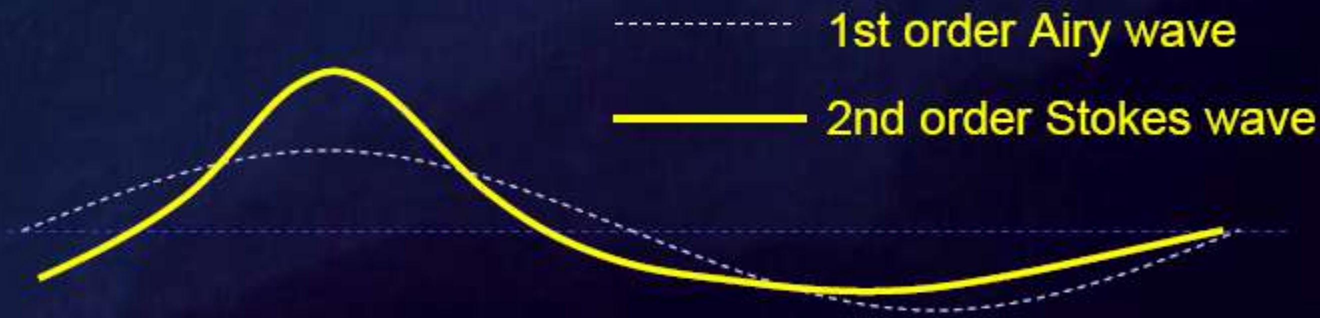
Wave Group- Shoaling Zone



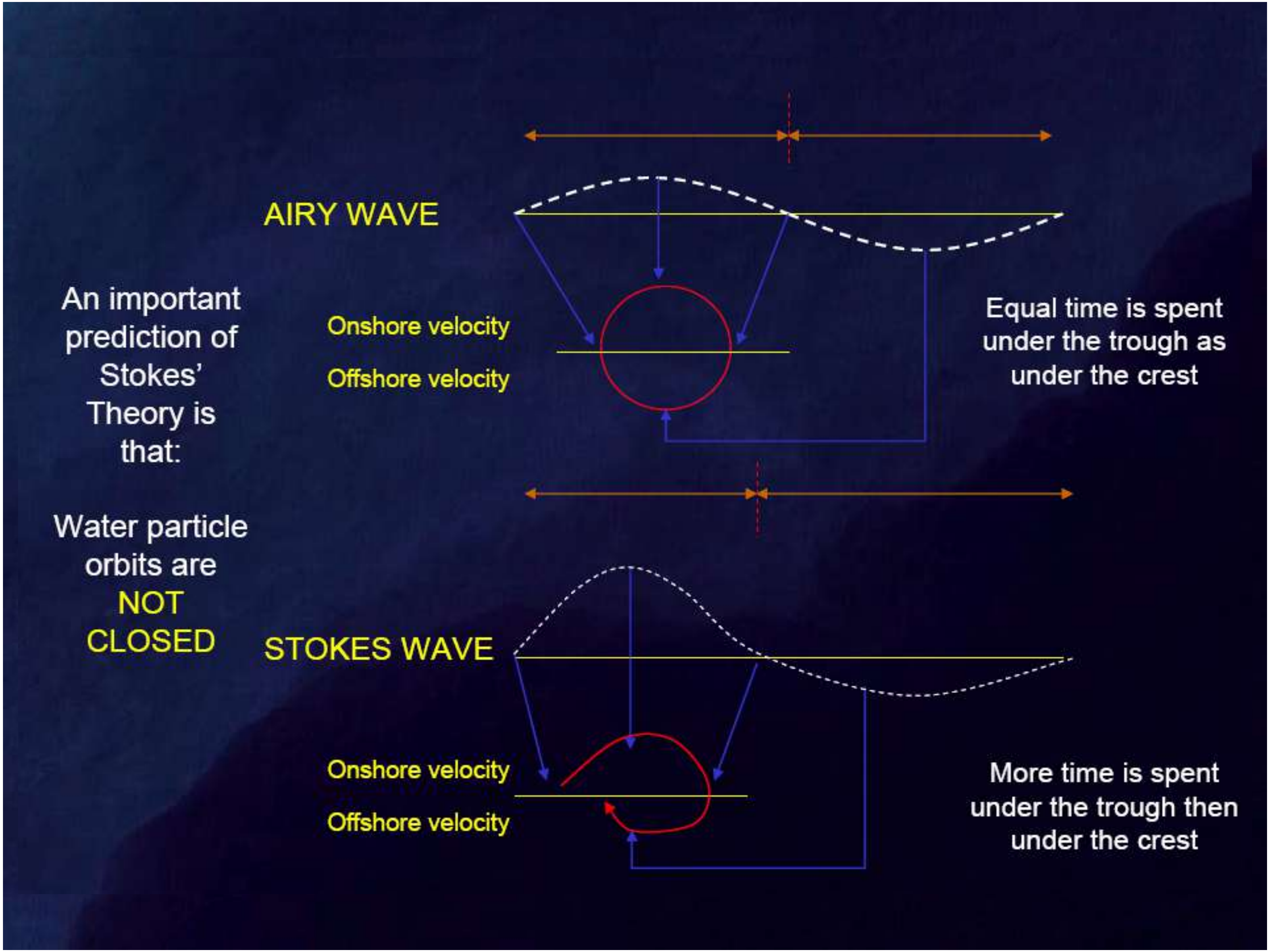
- Individual gravity waves move sediment landward (Stokes Drift)
  - Sediment suspended under long wave trough moves offshore
  - Bigger waves under the long wave trough- more sediment suspended-> offshore transport

Stokes Wave

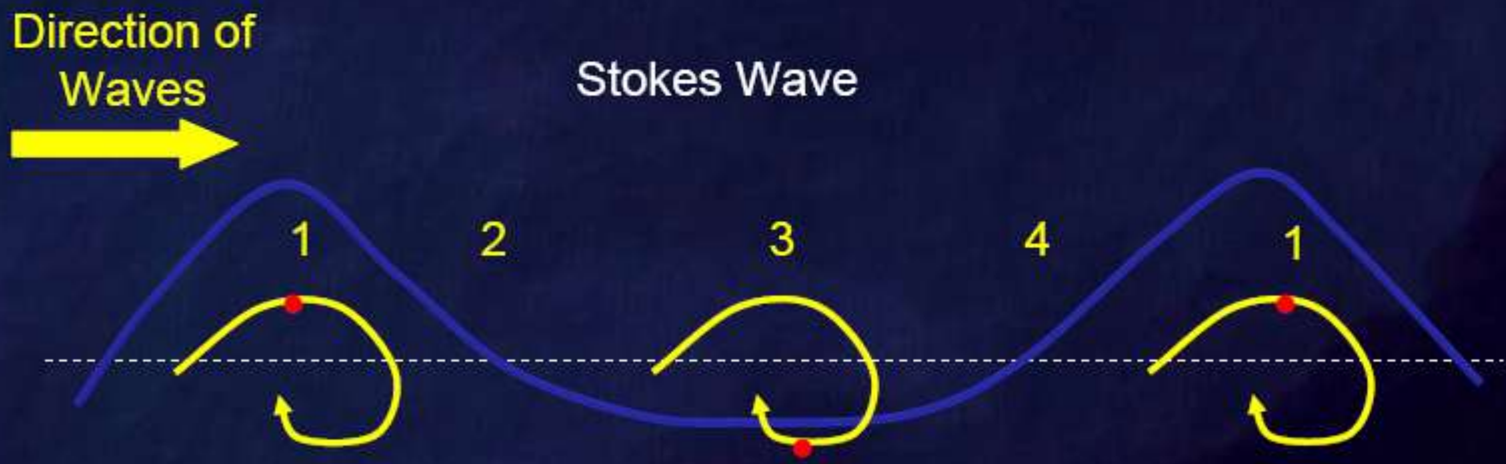
- Non-linear approach results in several predictions which more closely fit the behavior of real waves:
  - allows for the possibility of *increases in crest amplitude and decreases in trough amplitude* which is observed as waves shoal



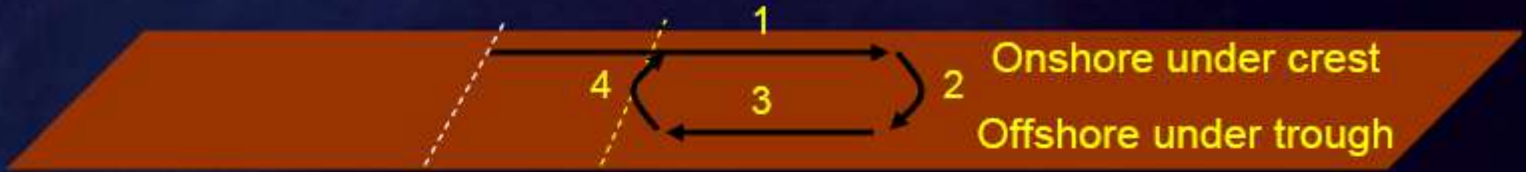
  - Still symmetrical relative to planes through the crest and trough
  - Difference (between crest and trough) increases with H/L


AIRY WAVE
An important prediction of Stokes' Theory is that:
Onshore velocity
Offshore velocity
Equal time is spent under the trough as under the crest
Water particle orbits are NOT CLOSED
STOKES WAVE
Onshore velocity
Offshore velocity
More time is spent under the trough then under the crest

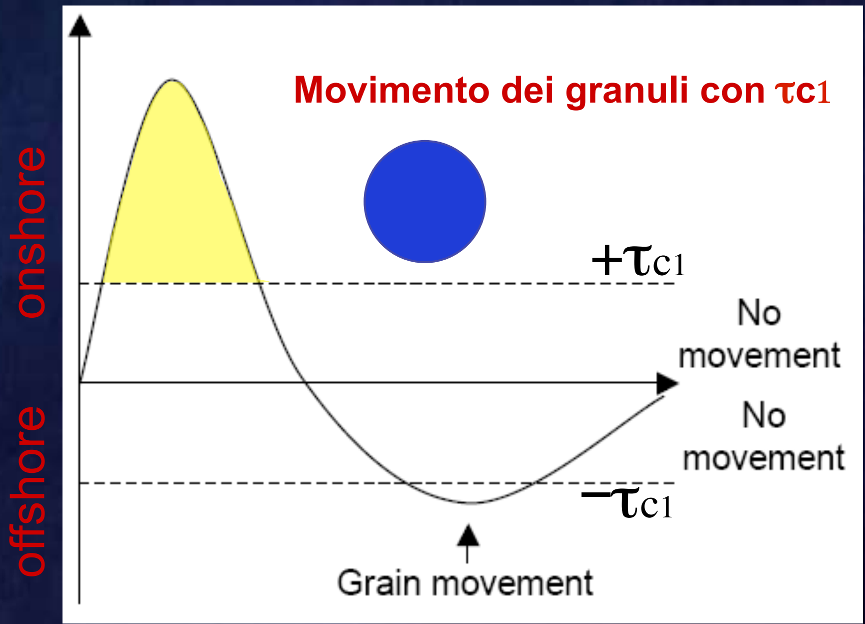
Sand at the Bed

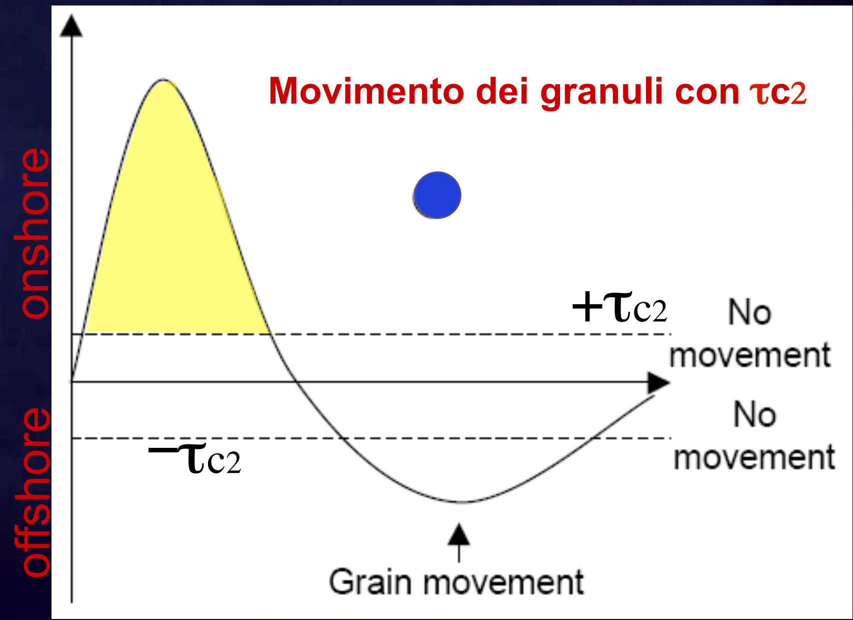


- Net onshore bedload transport



- Transport varies nonlinearly with the instantaneous oscillatory velocity
  - More sediment is transported by the larger onshore-directed velocities under the sharply peaked crests of skewed waves than by the longer-duration, but smaller offshore directed velocities under their broad, flat troughs



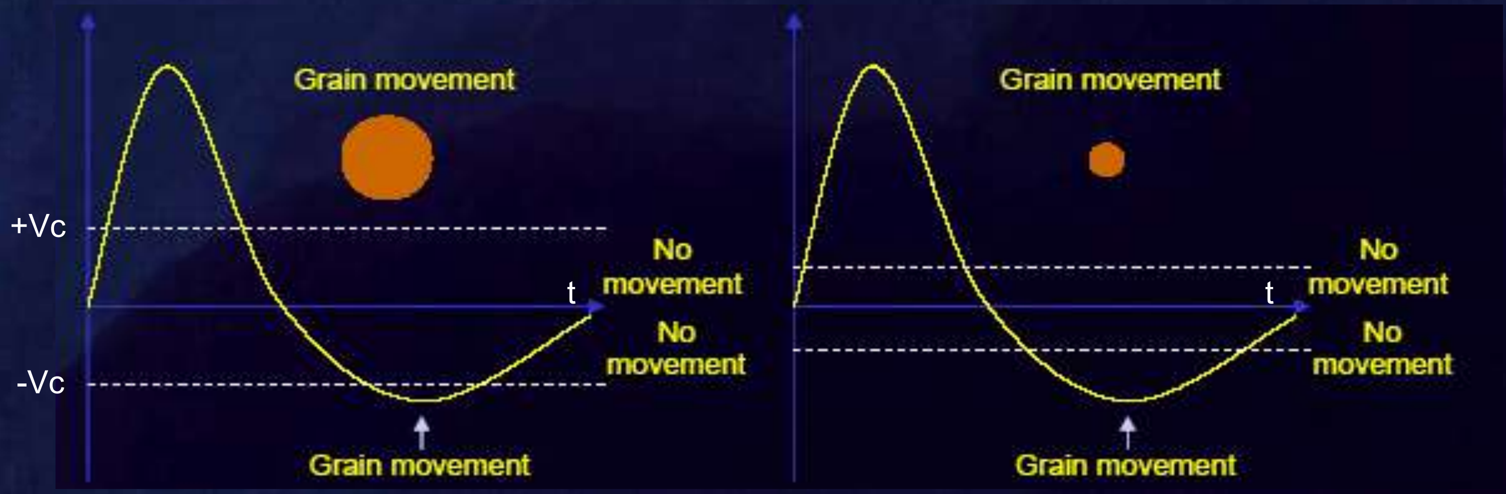


Il trasporto al fondo e la selezione dei materiali

Il risultato è un movimento verso riva più efficace nel trasportare il materiale grossolano:

- il materiale a granulometria maggiore non riesce ad essere preso in carico dalla corrente offshore

- il materiale fine si muoverà sia sotto la cresta che sotto il cavo d'onda, con deriva netta verso il largo



CASO A: Granulometria grossolana

- La velocità critica di erosione è superata sotto il passaggio della cresta e molto poco sotto il cavo
- componente netta di deriva: ONSHORE

CASO B: Granulometria fine

- La velocità critica di erosione è superata sia sotto il passaggio della cresta che sotto il cavo
- maggior durata della velocità al cavo
- componente netta di deriva: OFFSHORE

Breaking

- The wave motion at some stage becomes UNSTABLE

WAVE FORM relative to the OSCILLATORY MOTION

- At some point the ORBITAL VELOCITY = PHASE VELOCITY and the wave becomes unstable and BREAKS

- Wave breaks give rise to:
  - Large increase in TURBULENCE
  - AIR ENTRAINMENT
  - Complex FLUID DYNAMICS

  - Secondary CURRENTS
  - INFRAGRAVITY (EDGE) WAVES

→ Can oppose onshore transport by orbital skewness

- Stokes solution also predict an UPPER LIMIT to WAVE HEIGHT for a given depth of water and wave period

A WAVE BREAKING CRITERION

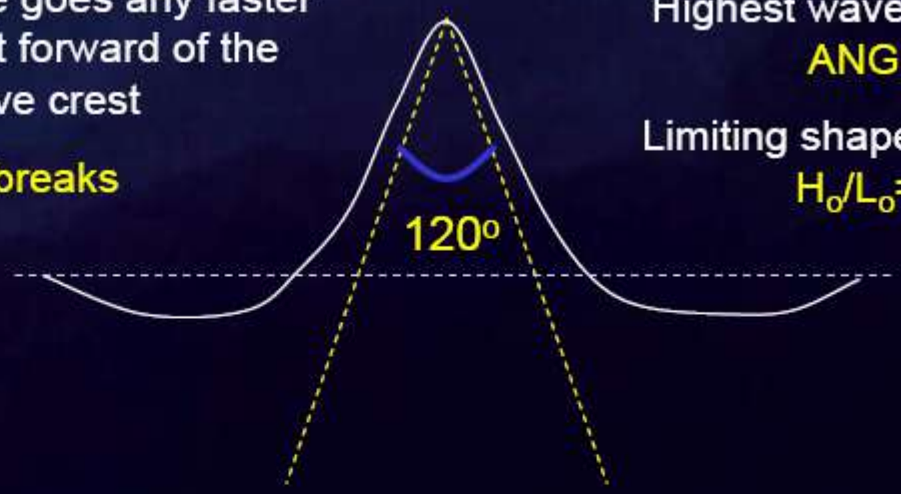
WATER PARTICLE VELOCITY AT CREST

=

WAVE CELERITY

If the particle goes any faster it will shoot forward of the wave crest

it breaks



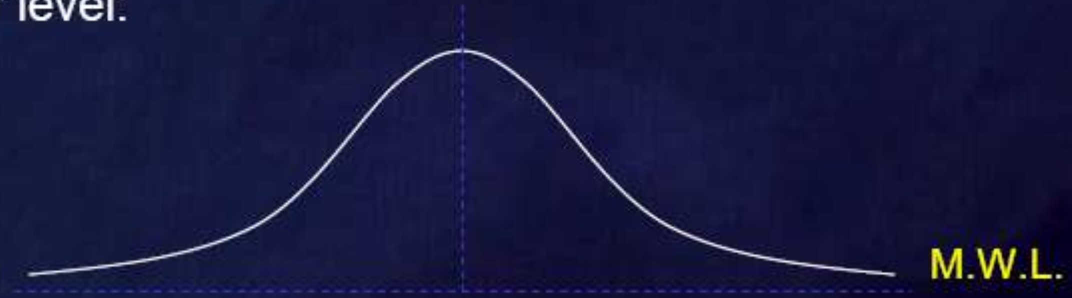
Highest wave was distinctly ANGULAR

Limiting shape occurs when: $H_o/L_o = 0.142$

INTERNAL ANGLE AT WAVE CREST=120°

Solitary Wave

- Russell (1938) noted the existence of a wave form lying entirely above the mean water level:

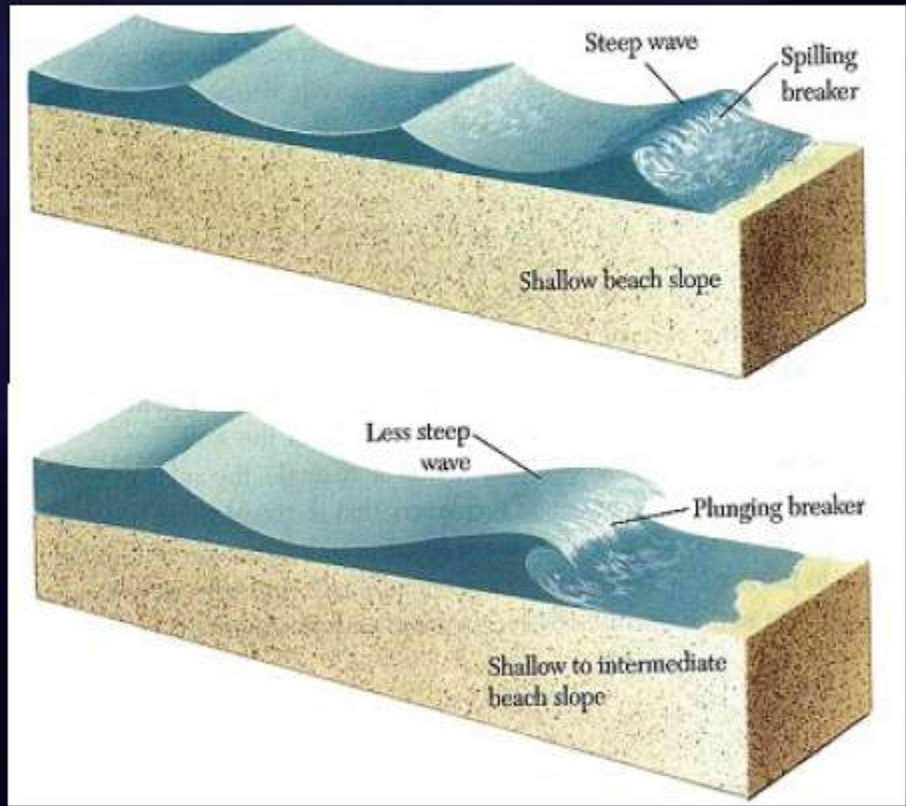


- Consists of a SINGLE CREST
- Troughs are very long and flat
  - basic oscillatory nature is lost
- Gives a CRITICAL CONDITION for WAVE BREAKING:

$$\frac{H_b}{h} = 0.78$$

Breaker Forms

- Galvin (1968) defined 4 wave types:



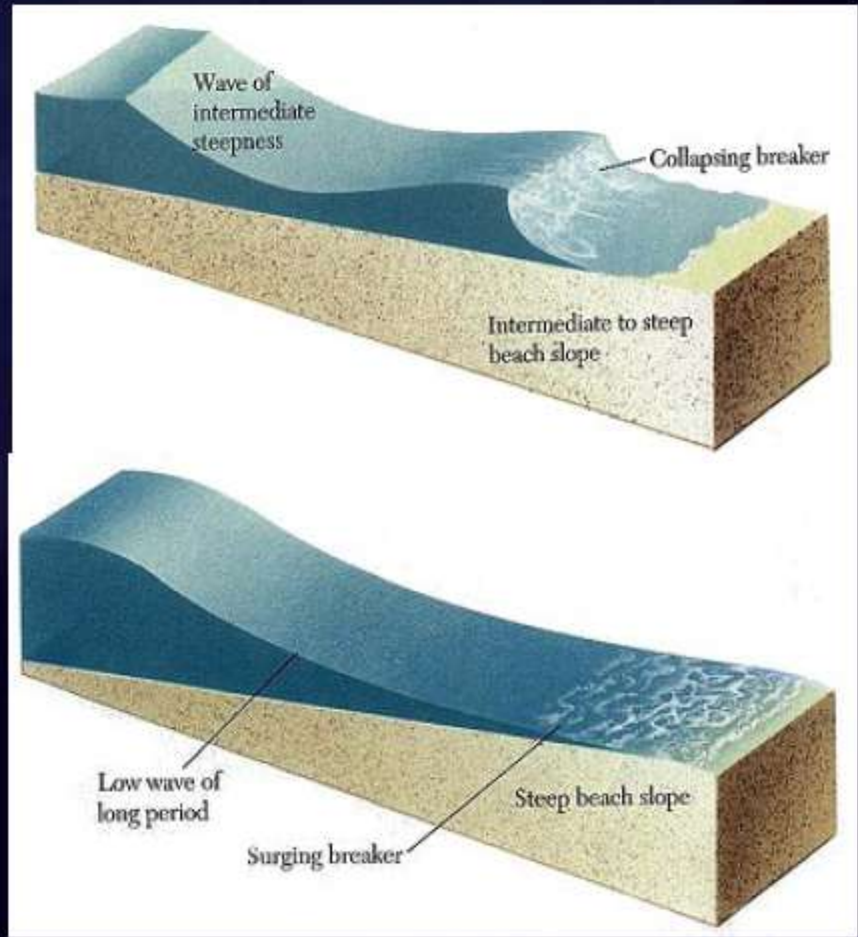
- Spilling
  - Remains oscillatory
  - Little mass transport
  - No reverse flow on face

- Plunging
  - Creates a roller vortex
  - Reversed slopes

Breaker Forms

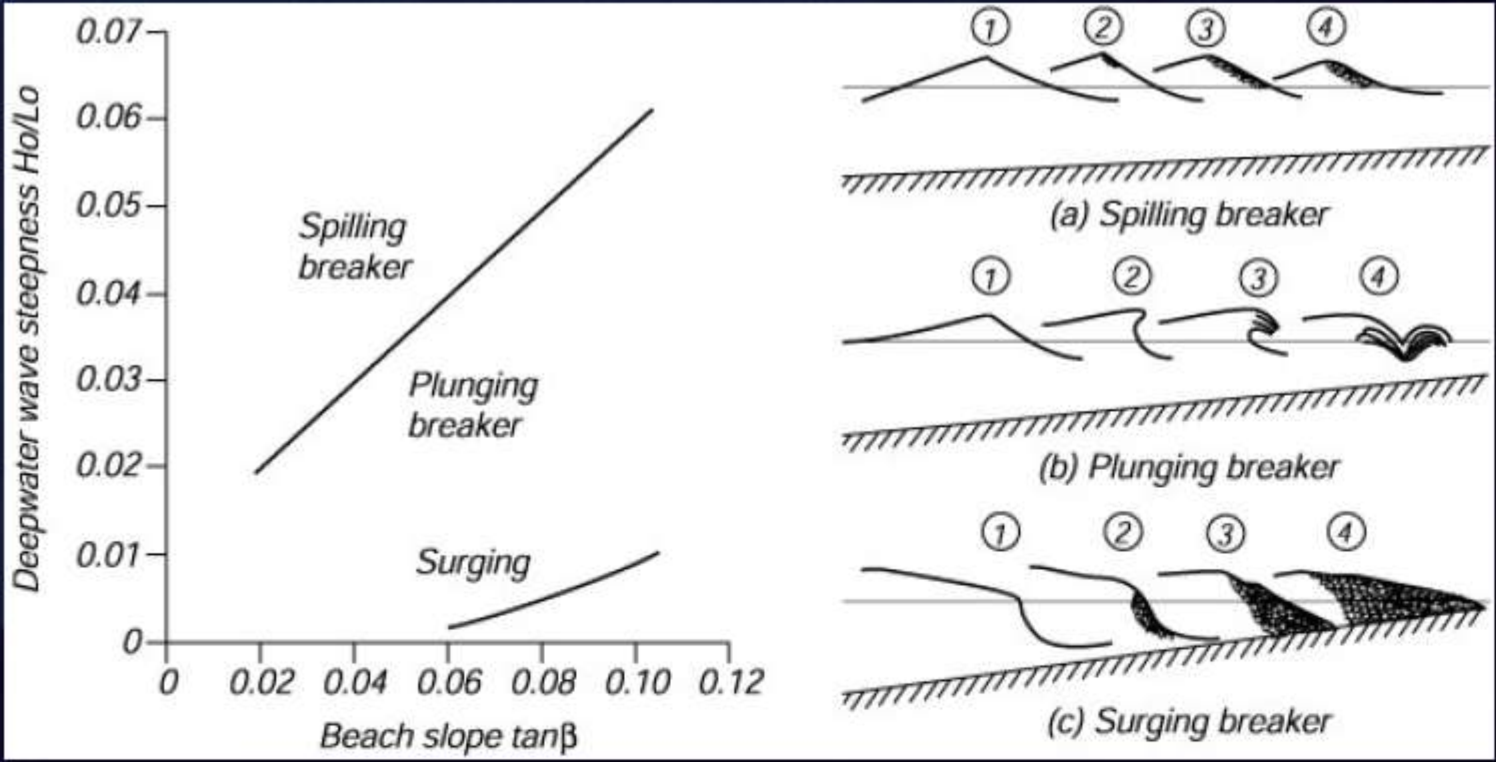
- Collapsing
  - Tend to be associated with reflection
  - Cusps and synchronous edge waves
  - transition between plunging and surging

- Surging
  - Landward and seaward motion controlled by oscillatory
  - Tends to be low frequency
  - Short distance of energy dissipation



- BREAKER FORM varies and depends on:
  - Wave height
  - Wave period (wavelength)
  - Beach slope

Breaker Type



Similarity

- More recent research on beaches has emphasized:

MODE & DEGREE of ENERGY DISSIPATION

- There has been an effort to compare beaches in this regard
  - Concept of SIMILARITY

- BATTJES SURF SIMILARITY PARAMETER
  - Derived from the analysis of important DIMENSIONS in the system
  - DIMENSIONLESS NUMBER describing the fundamental properties of the hydrodynamic system:

$$\xi_b = \frac{\tan \beta}{\sqrt{\frac{H_b}{L_o}}}$$

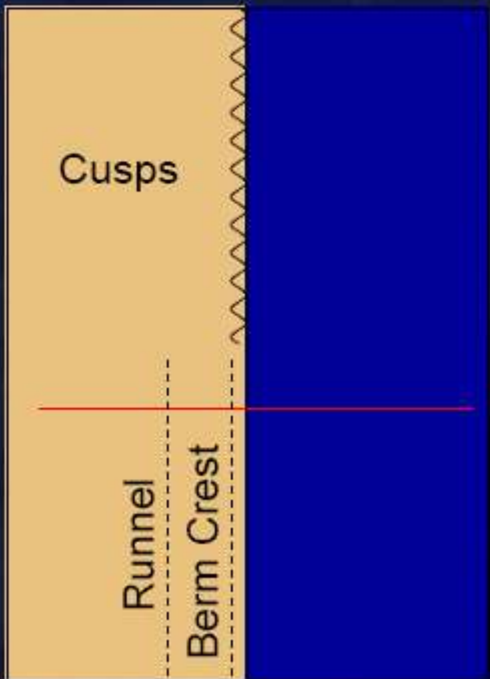
$\tan\beta$= slope

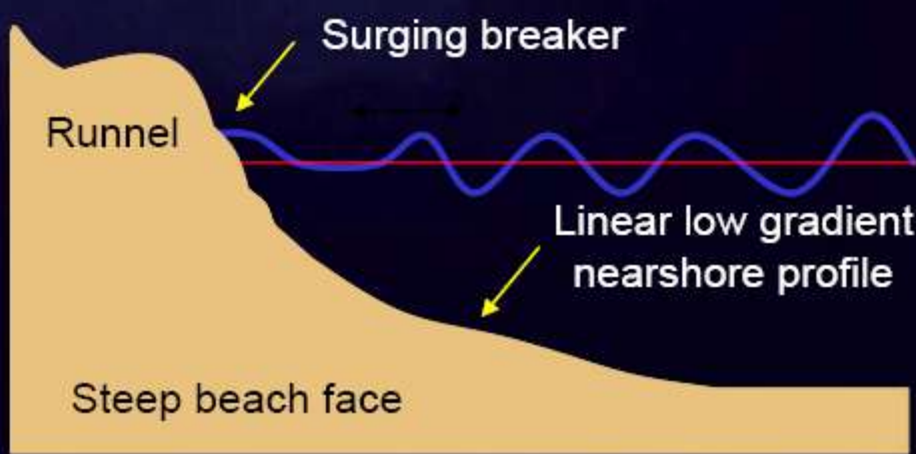
REFLECTIVE→ ξ_b>2.0

Surging/Collapsing Breakers

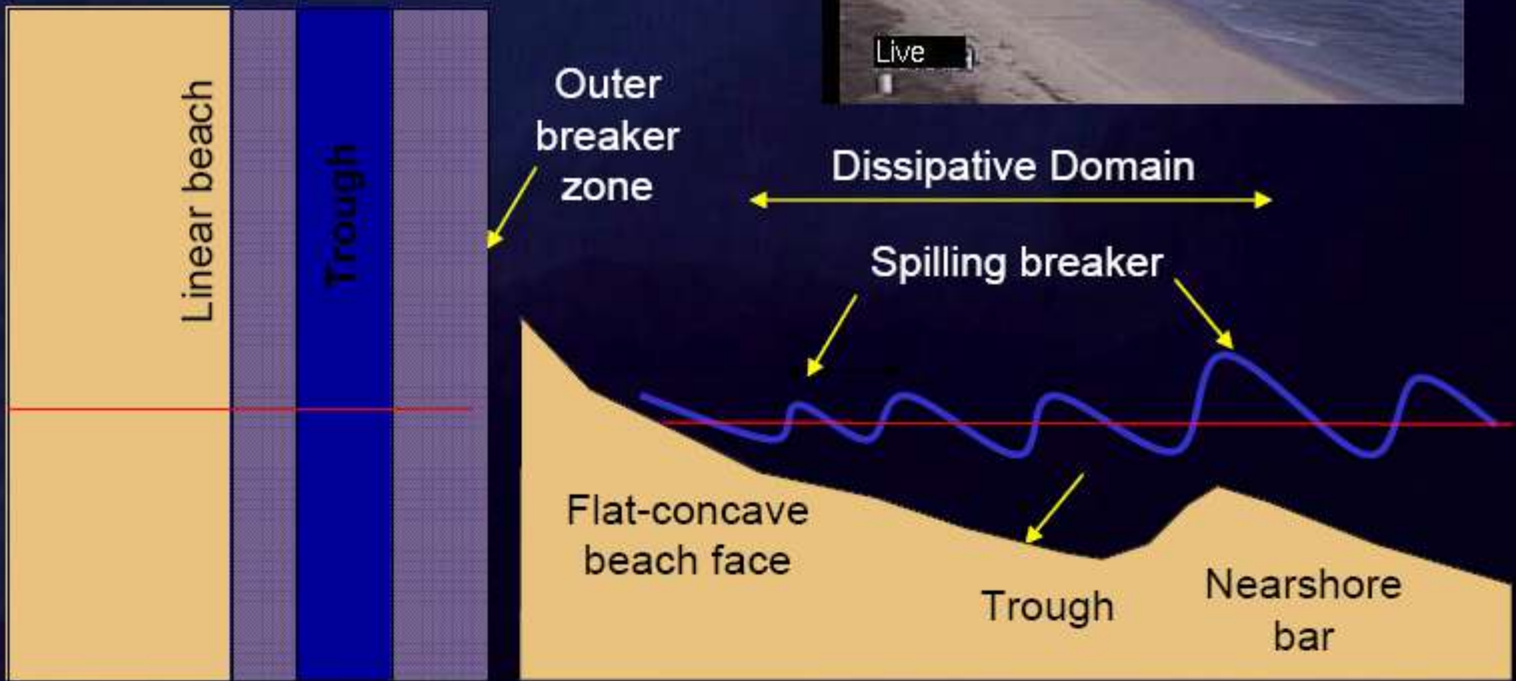
Reflective Domain

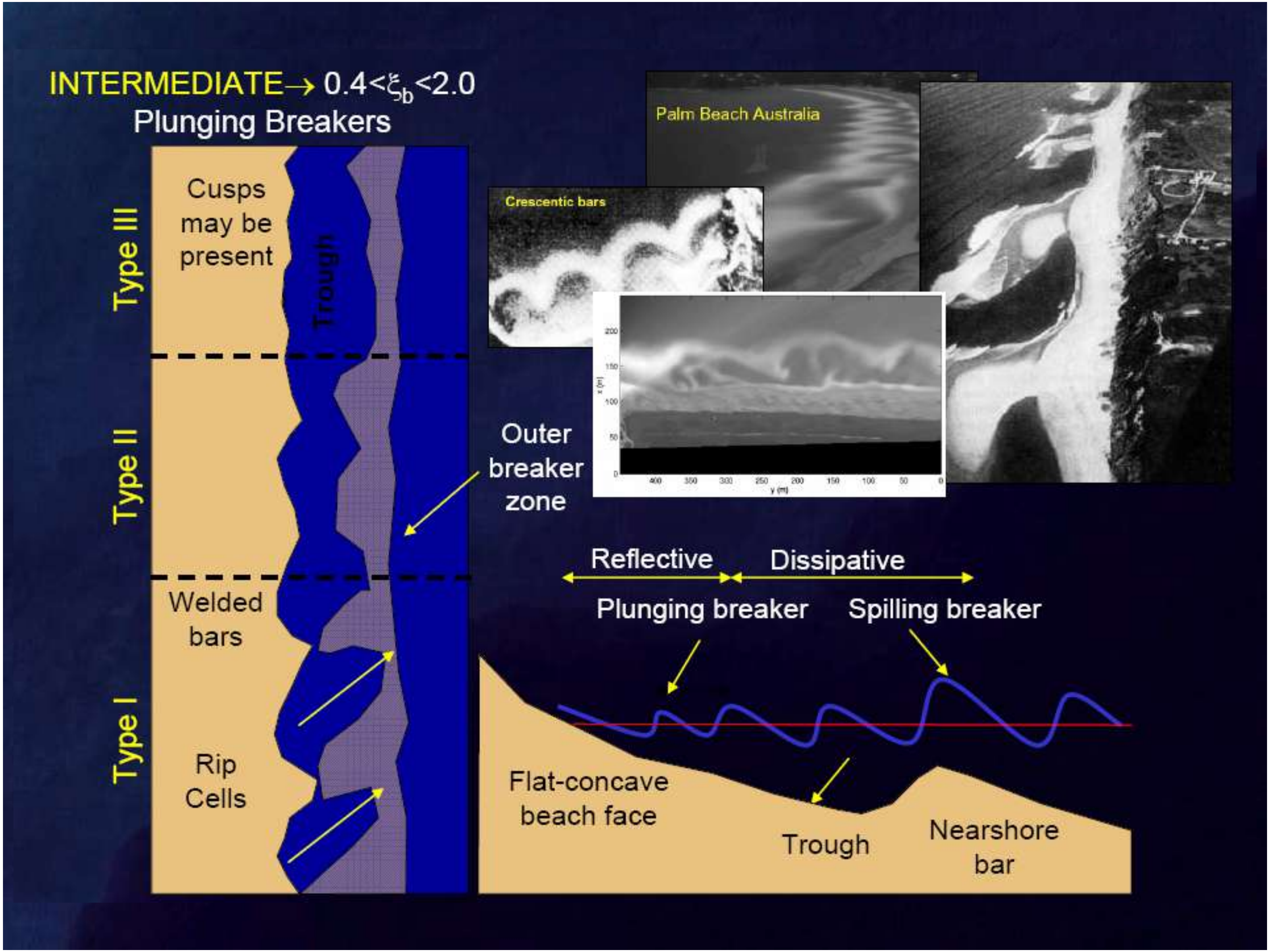
Small ξ_b





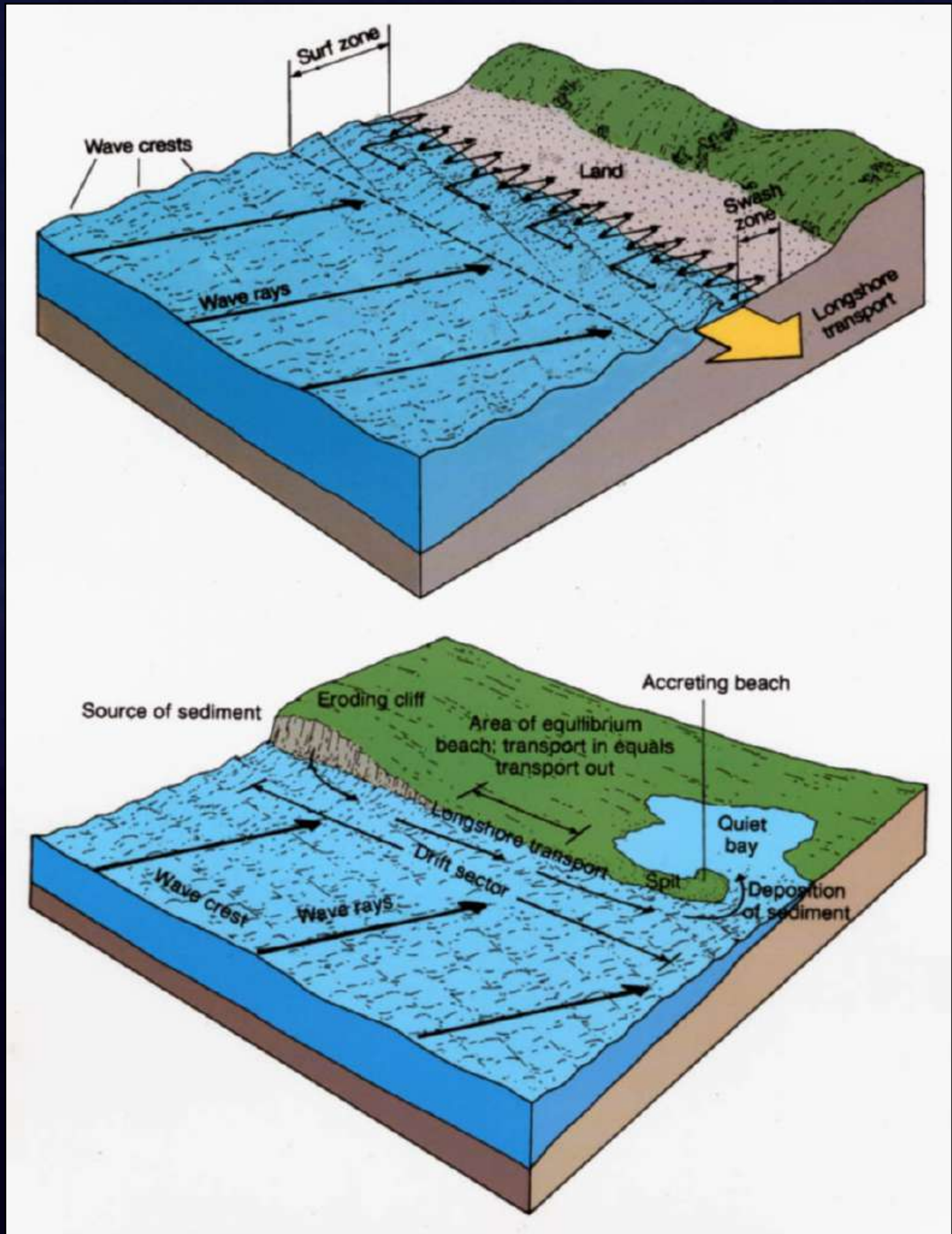
DISSIPATIVE → $\xi_b < 0.4$
Spilling Breakers

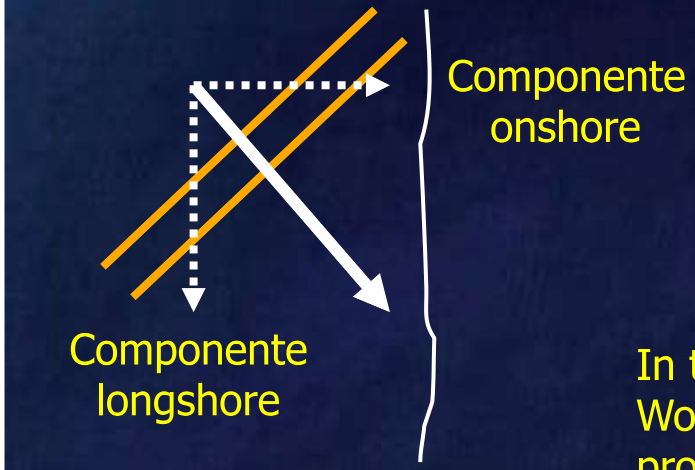




INTERMEDIATE→ 0.4<ξb<2.0
Plunging Breakers
Type III
Cusps may be present
Trough
Type II
Type I
Welded bars
Rip Cells
Outer breaker zone
Palm Beach Australia
Crescentic bars
Reflective
Dissipative
Plunging breaker
Spilling breaker
Flat-concave beach face
Trough
Nearshore bar

Il trasporto lungo riva

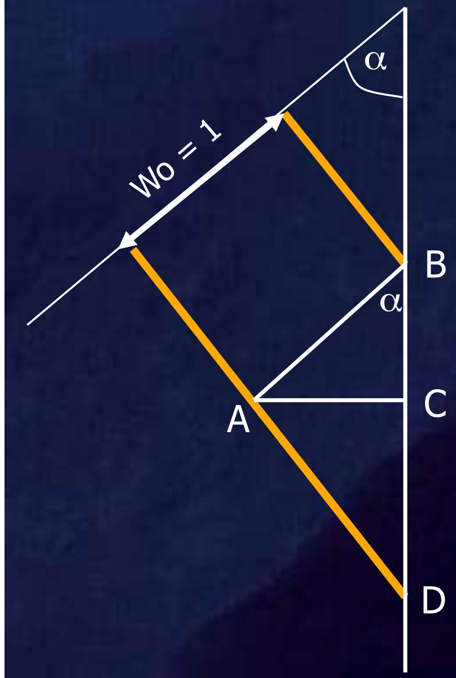




Flusso di energia $P_L = E\ C\ n$

$$E = \frac{1}{8}\rho \cdot g \cdot H^2$$

In termini unitari (per unità di larghezza di cresta d'onda AB = Wo = 1m), la componente longshore del flusso di energia si propaga per una larghezza pari ad AC, entro un tratto unitario di linea di riva pari a BD.



Poiché AC = AB sin $\alpha = 1$ sin α e BD = $1/\cos\alpha$

$$P_L = \frac{(ECn)_b \sin\alpha_b}{\dfrac{1}{\cos\alpha_b}}$$

ovvero:

$$P_L = (ECn)_b \sin\alpha_b \cos\alpha_b$$

Componente longshore del flusso di energia

IL TRASPORTO LONGSHORE

Il trasporto lungo riva può essere espresso sia in forma volumetrica Q_L che in forma di peso immerso I_L tramite la seguente relazione:

$$I_L = (\rho_s - \rho) \cdot g a' Q_L$$

Dove a' rappresenta il fattore di porosità per convertire volume in peso; per le sabbie possiamo assumere tale valore pari a circa 0.6 (=porosità del 40%).
Il vantaggio dell'utilizzo di I_L è che tiene conto della densità dei granuli e che dimensionalmente viene espresso nella stessa forma di P_L (Newton/s o Watt/m).

La proporzionalità tra I_L e P_L è stata dimostrata sperimentalmente e di conseguenza:

$$I_L = kP_L = k(ECn)_b \sin\alpha_b \cos\alpha_b$$

Poiché il fattore di proporzionalità k si deriva sperimentalmente, il valore cambia molto a seconda dei casi (da 0.4 a più di 1). In generale assume il valore di 0.77 (Komar & Inman, 1970) ma in pratica può essere considerato il valore di 0.7.

Il coefficiente k

Autore	Note	k
Swart	Dipende dalla granulometria	$K = A \log_{10} (0.00146/D_{50})$ A sperimentale
C.E.R.C. (Komar)	Statistica generale	0.77
Kamphuis & Readshow	Dipende dal numero di Iribarren, ζ $\zeta_b = \frac{\tan\beta}{\left(\frac{H_b}{L_0}\right)^{1/2}}$	0.28 per $\zeta_b < 0.4$ (spiagge dissipative)
		$0.7\ \zeta_b$ per $0.4 \leq \zeta_b \leq 1.0$ (spiagge interm.-dissip.)
		1.0 per $\zeta_b > 1.0$ (spiagge interm.-riflettent)

Per k = 0.7 :

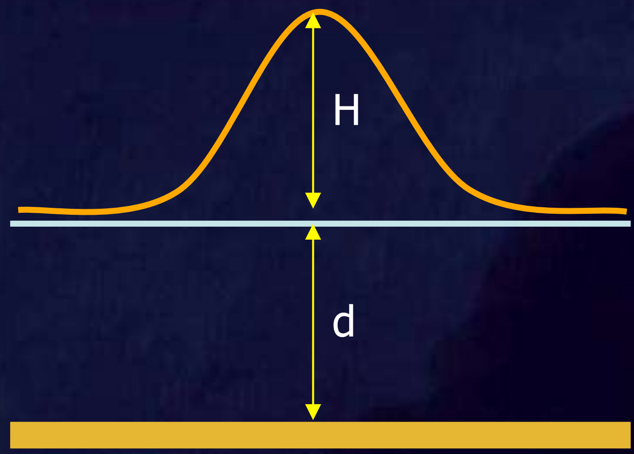
$$I_L = 0.7 \cdot P_L = 0.7(ECn)_b \sin\alpha_b \cos\alpha_b$$

$$I_L = 0.7(\frac{1}{8}\rho \cdot gH^2Cn)_b \sin\alpha_b \cos\alpha_b$$

In acque basse può essere assunto n =1 e usare la teoria dell'onda solitaria per computare C = (g d)$^{1/2}$, semplicemente aumentando il battente d'acqua del valore corrispondente all'altezza dell'onda

Semplificando il criterio di frangenza con γ = d/H = 1 invece che 0.78

Onda solitaria



$$C = \sqrt{g \cdot (d + H)}$$

In frangenza (semplificazione):
d/H = 1 → d = H

$$C = \sqrt{g \cdot (2H_b)}$$

$$I_L = 0.7(\frac{1}{8}\rho \cdot gH_b^{\,2}) \cdot (2g \cdot H_b)^{\frac{1}{2}} \sin\alpha_b \cos\alpha_b$$

$$I_L = 0.12\rho \cdot g^{3/2} H_b^{5/2} \sin\alpha_b \cos\alpha_b$$

$$I_L = 0.12\rho \cdot g^{3/2} H_b^{5/2} \sin\alpha_b \cos\alpha_b$$

Poiché:

$$I_L = (\rho_s - \rho) \cdot g a' Q_L$$

Assumendo una densità ρ_s = 2650 kg/m^3 (quarzo) e una densità dell'acqua ρ = 1020 kg/m^3 si ottengono le seguenti relazioni:

$$Q_L = 6.2 \cdot P_L$$

$$Q_L = 1.1 \cdot \rho \cdot g^{3/2} H_b^{5/2} \sin\alpha_b \cos\alpha_b$$

Espresse in m^3/giorno
g = 9.81 m/s^2
ρ= kg/m^3
P_L= watt/m

$$Q_L = 34474 \cdot H_b^{5/2} \sin\alpha_b \cos\alpha_b$$

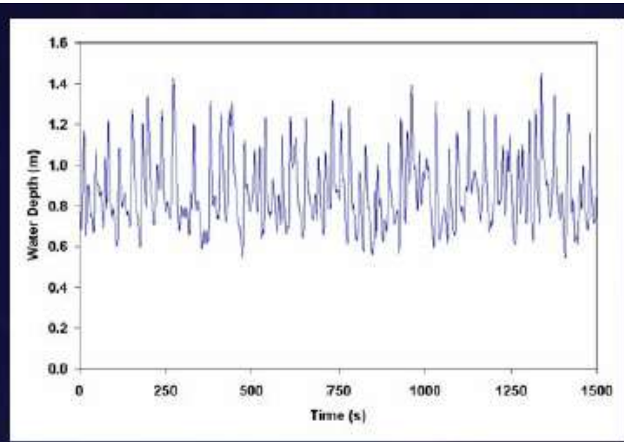
E poiché →

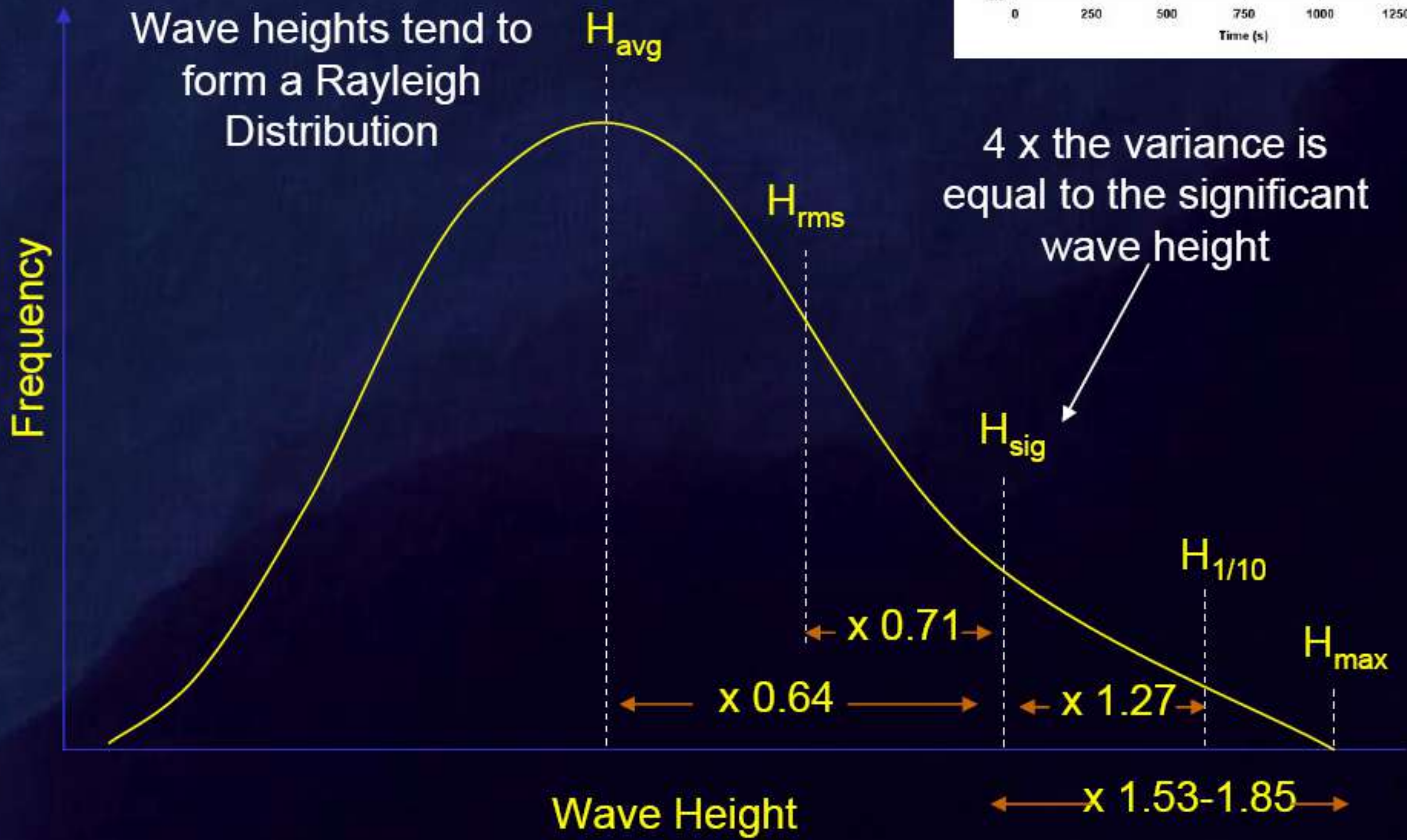
$$\sin\alpha_b \cos\alpha_b = \frac{1}{2} \sin 2\alpha$$

$$Q_L = 17237 \cdot H_b^{5/2} \sin 2\alpha_b$$

Le relazioni espresse finora considerano H in frangenza come valore dato dalla radice dell'altezza quadratica media, che è più corretta per definire E

Altezze d'onda





Se vogliamo usare l’altezza dell’onda significativa in frangenza:

$H_s = 1.41\ H_{rms}$

Conseguentemente l’energia varierà di un fattore $(1.41)^2 \sim 2.0$
Mentre la velocità C varierà di un fattore $(1.41)^{0.5} \sim 1.2$

$$I_L = 0.30 \cdot P_L = 0.053 \rho \cdot g^{3/2} H_b^{5/2} \sin\alpha_b \cos\alpha_b$$

$$Q_L = 0.46 \cdot \rho \cdot g^{3/2} H_b^{5/2} \sin\alpha_b \cos\alpha_b$$

$$Q_L = 0.23 \cdot \rho \cdot g^{3/2} H_b^{5/2} \sin 2\alpha_b$$

sempre in m^3/giorno