The University of the West Indies

Organization of American States

PROFESSIONAL DEVELOPMENT PROGRAMME: COASTAL INFRASTRUCTURE DESIGN, CONSTRUCTION AND MAINTENANCE

A COURSE IN

COASTAL DEFENSE SYSTEMS I

CHAPTER 6

LONGSHORE SEDIMENT TRANSPORT PROCESSES

By DAVE BASCO, PhD

Professor, Department of Civil and Environmental Engineering
And Director, the Coastal Engineering Centre,
Old Dominion University
Norfolk, VA

Organized by Department of Civil Engineering, The University of the West Indies, in conjunction with Old Dominion University, Norfolk, VA, USA and Coastal Engineering Research Centre, US Army, Corps of Engineers, Vicksburg, MS, USA.

St. Lucia, West Indies, July 18-21, 2001

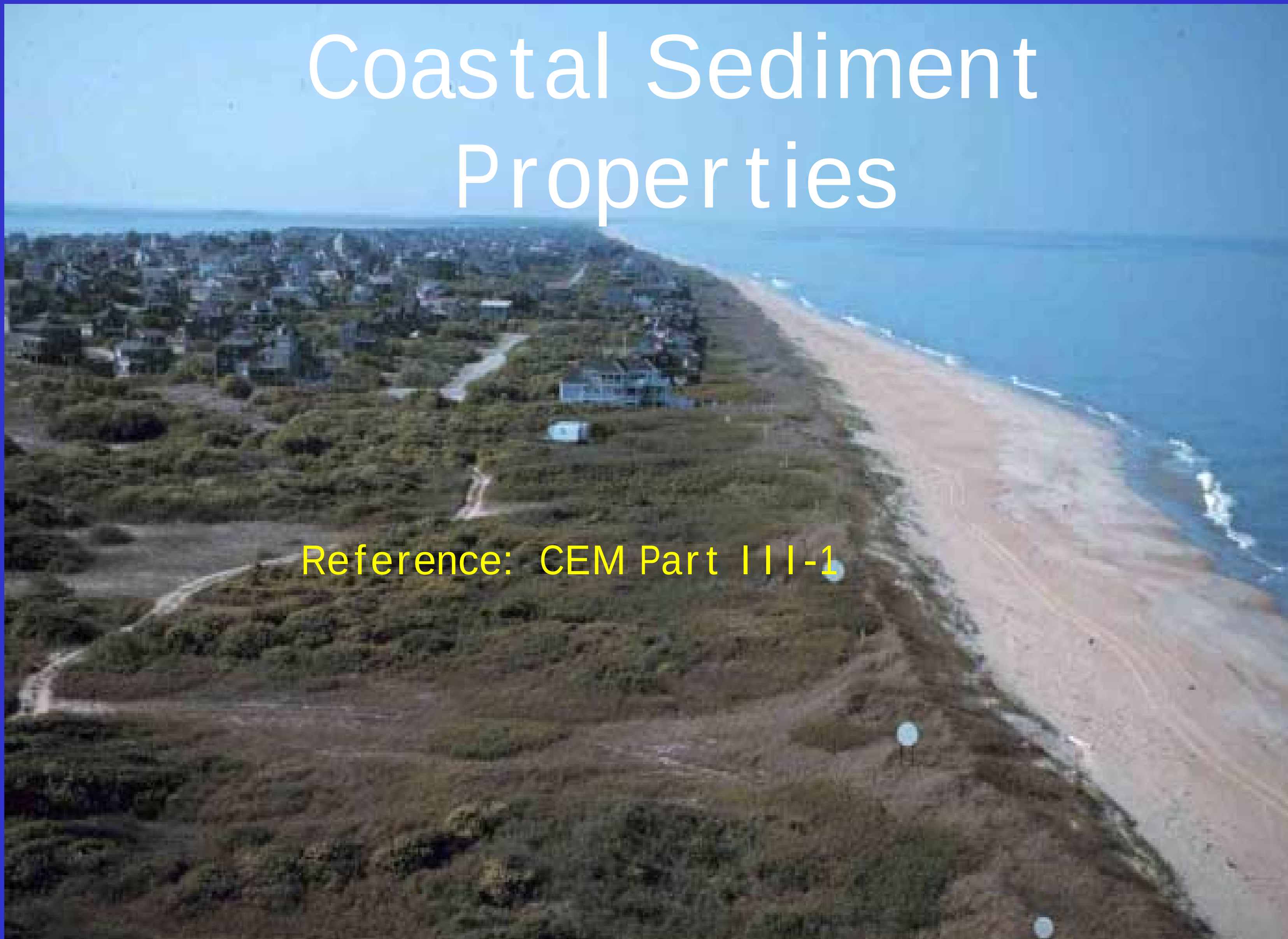
Coastal Sediment Properties and Longshore Sediment Transport

Julie Rosati
Julie.D.Rosati@erdc.usace.army.mil
601-634-3005

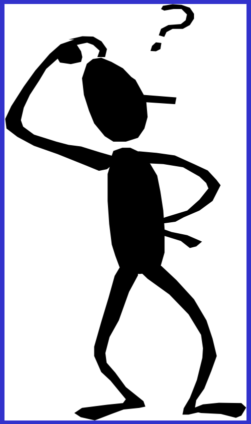
Coastal Planning Course
Lesson #8
Tuesday 8:00-9:00 am
CEM III-1, III-2


2. Longshore Sediment Transport
(CEM III-2)
1. Coastal Sediment
Properties
(CEM III-1)

Coastal Sediment Properties



Reference: CEM Part III-1



Why Important?

Dredging: type of dredge

Environmental: transport of fines, contaminated material

Beach Fill: longevity, aesthetics

Scour Protection: resist movement, dissipate energy, relieve pressure

Sediment Transport Studies: tracer

How do we classify sediments?

Size: particle diameter

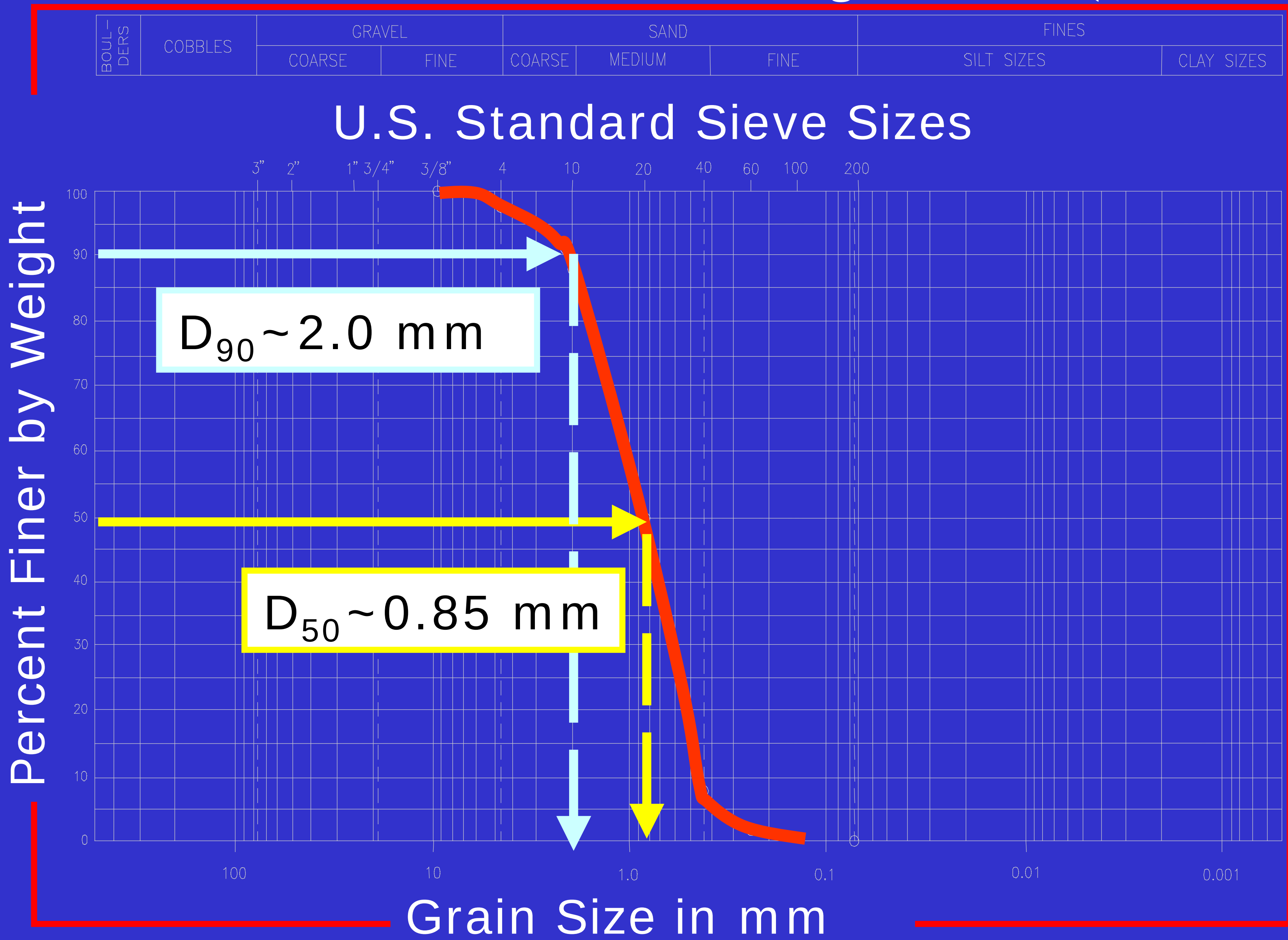
-->Mesh size just allowing grain to pass

Fall Speed: speed at which sediment falls in fluid

--> incorporates sediment density, shape, and fluid characteristics

"Sedimentation Diameter" = diameter of sphere having same density and fall speed

Virginia Beach (foreshore)



CEM Fig III-1-1, p.III-1-6

Sediment Size Classifications

Table III-1-2
Sediment Particle Sizes

ASTM (Unified) Classification[1]	U.S. Std. Sieve[2]	Size in mm	Phi Size	Wentworth Classification[3]
Boulder		4096.	-12.0	
		1024.	-10.0	Boulder
	12 in. (300 mm)	256.	-8.0	
		128.	-7.0	Large Cobble
		107.64	-6.75	
Cobble		90.51	-6.5	
	3 in. (75 mm)	76.11	-6.25	Small Cobble
		64.00	-6.0	

Engineer-developed

Geologist-developed

CEM Table III-1-2, p.III-1-8

Units of Sediment Size

- U.S. Standard Sieve
- Millimeters
- Phi units

$$\Phi = -\log_2 D$$

$$D = 2^{-\Phi}$$

Bulk Properties of Sediments

Clays, silts, muds:

foundation, dredged material, bluffs

Organically-bound sediment (peat):

back bays and tidal wetlands

very compressible

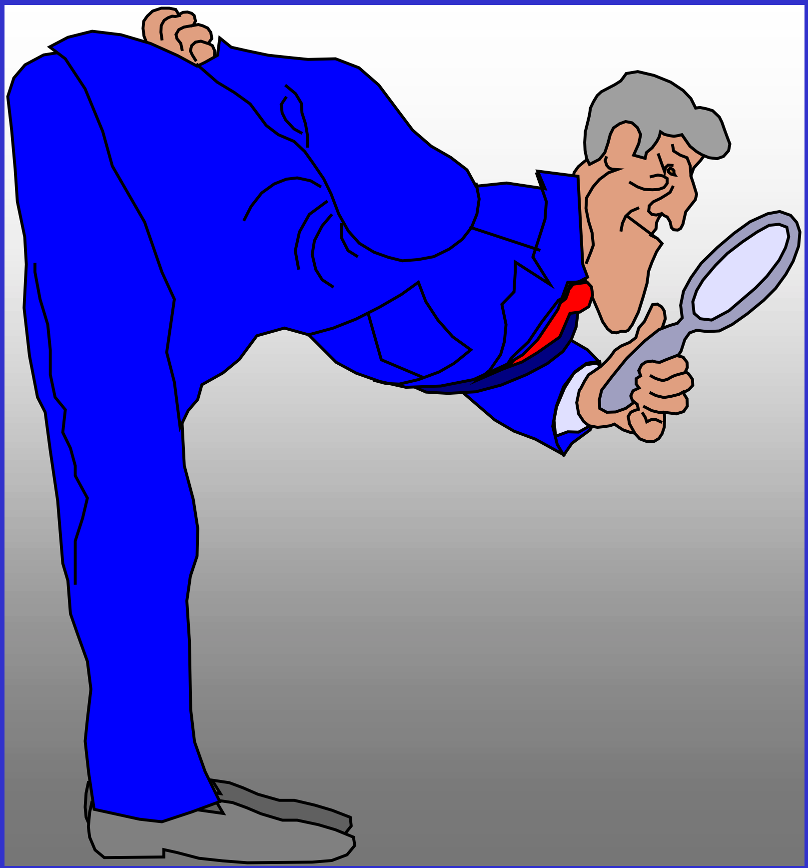
Sand and gravel:

ocean beaches

calcium carbonate sand

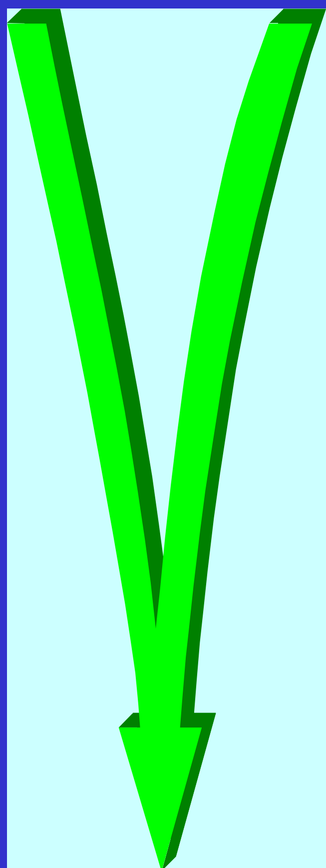
oolites (elliptical in shape)

Experiment



- Settling characteristics of various sediments in water
- Samples A, B, & C

Fall Speed



$W_f = f\ (D, \rho, \rho_s, C_D)$ (Eq. 1-7)

D = grain diameter

ρ = density of water

ρ_s = density of sediment

C_D = drag coefficient

TEST MATERIAL!!

Fall Speed

With all other parameters held constant....

As grain diameter increases, fall speed increases

$$D \uparrow \, , \; W_f \uparrow$$

Which means that the coarsest sediment

will fall the fastest...

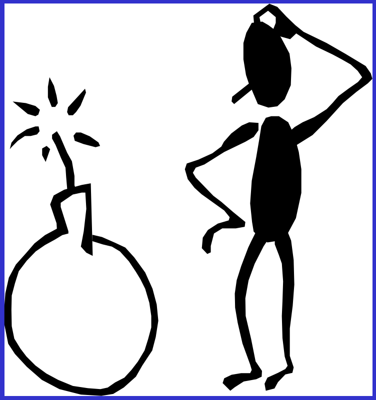
and will tend to remain in the more energetic parts of the profile...

such as where waves plunge on the beach

Longshore Sediment Transport (LST)

Reference: CEM Part III-2

What is LST?



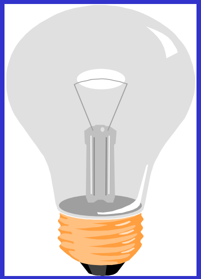
"transport of sediments within the surf zone, directed parallel to the coast"

Shoreward Observer:

Q_R = transport to right

Q_L = transport to left

Longshore Sediment Transport
(CEM III-2)



Why is LST Important?

Dredging requirements: deposition and shoaling in open-coast channels; placement of dredged material

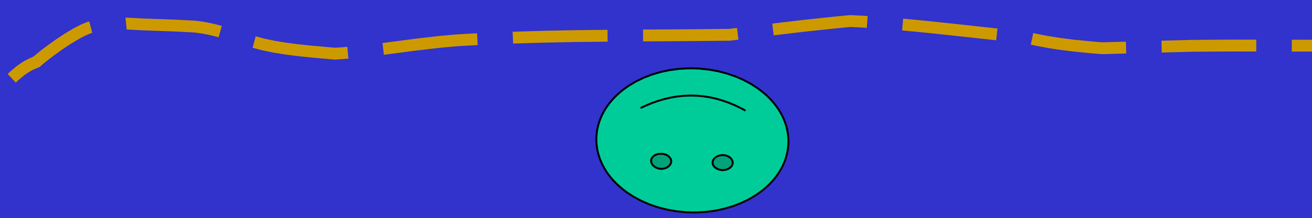
Beach condition: understanding long- and short-term erosion & accretion trends

Coastal projects: designing structures & beach fill to mitigate for beach erosion; designing inlet structures to better operate and maintain channels

Definitions

(expressed as a negative value)

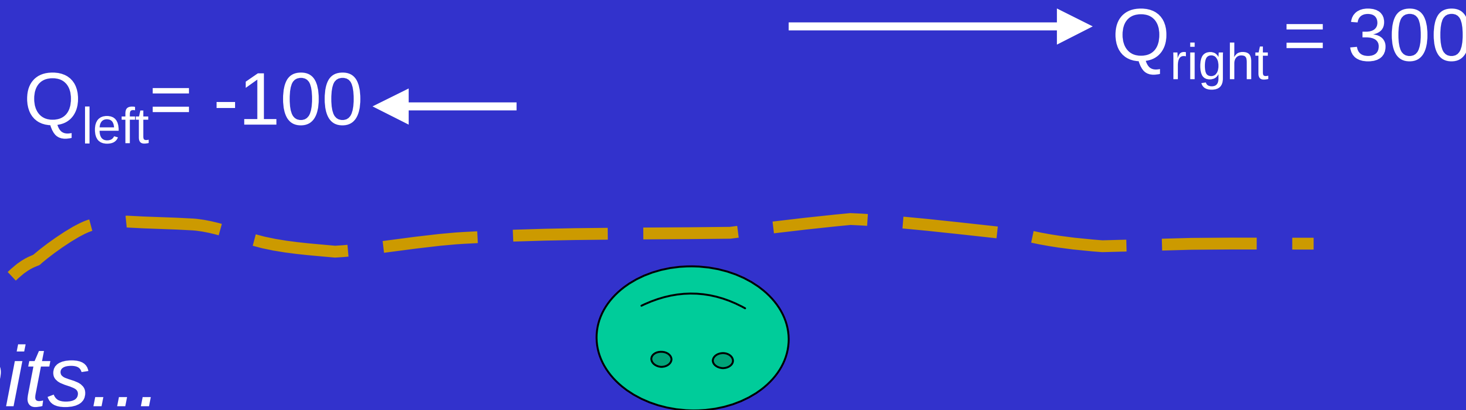
Q_{left} ← → Q_{right}



$$Q_{net} = Q_{right} + Q_{left}$$

$$Q_{gross} = |Q_{right}| + |Q_{left}|$$

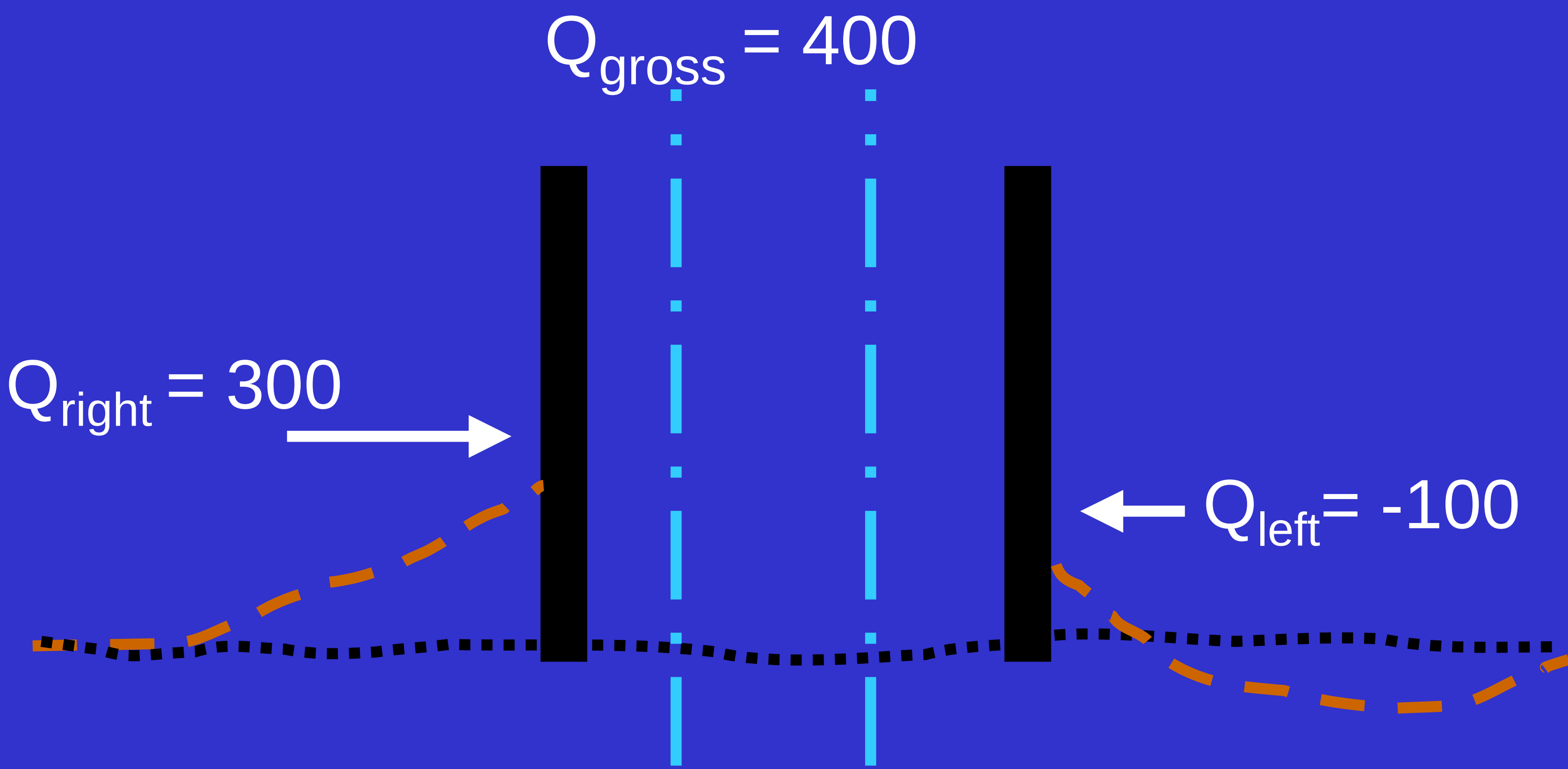
Definitions



Units...
thousands cubic yards per year or
thousands cubic meters per year

$$Q_{net} = Q_{right} + Q_{left} = 300 + -100 = 200$$

$$Q_{gross} = |Q_{right}| + |Q_{left}| = 300 + 100 = 400$$



Longshore Sediment Transport
(CEM III-2)

Estimating Net and Gross Transport Rates

1. Adopt a well-established rate from a nearby site
   - modify based on local conditions

2. Compute from historical data
   - shoreline position, bathymetric change, dredging volumes

3. Calculate using wave and beach data

4. Determine from experimental measurements

1. Adopt a well-established rate from a nearby site (1 of 2)

(see also Table III-2-1)

EAST AND GULF:

Sandy Hook, NJ	380,000 m^3/yr (net)
Cape May, NJ	900,000 m^3/yr (gross)
Ocean City, MD	115,000 m^3/yr (net)
Oregon Inlet, NC	1,600,000 m^3/yr (gross)
Pinellas County, FL	40,000 m^3/yr (net)

1. Adopt a well-established rate from a nearby site (2 of 2)

(see also Table III-2-1)

PACIFIC AND GREAT LAKES:

Santa Barbara, CA	210,000 m^3/yr (net)
Oceanside, CA	160,000 m^3/yr (gross)
Columbia River WA/OR	1,500,000 m^3/yr (gross)
Waukegan to Evanston, IL	40,000 m^3/yr (net)

2. Compute from historical data (1 of 5)

a. Impoundment by Jetties and Breakwaters

b. Rate of Shoreline Change

   long-term erosion/accretion

   growth of spits

c. Rate of Bathymetric Change

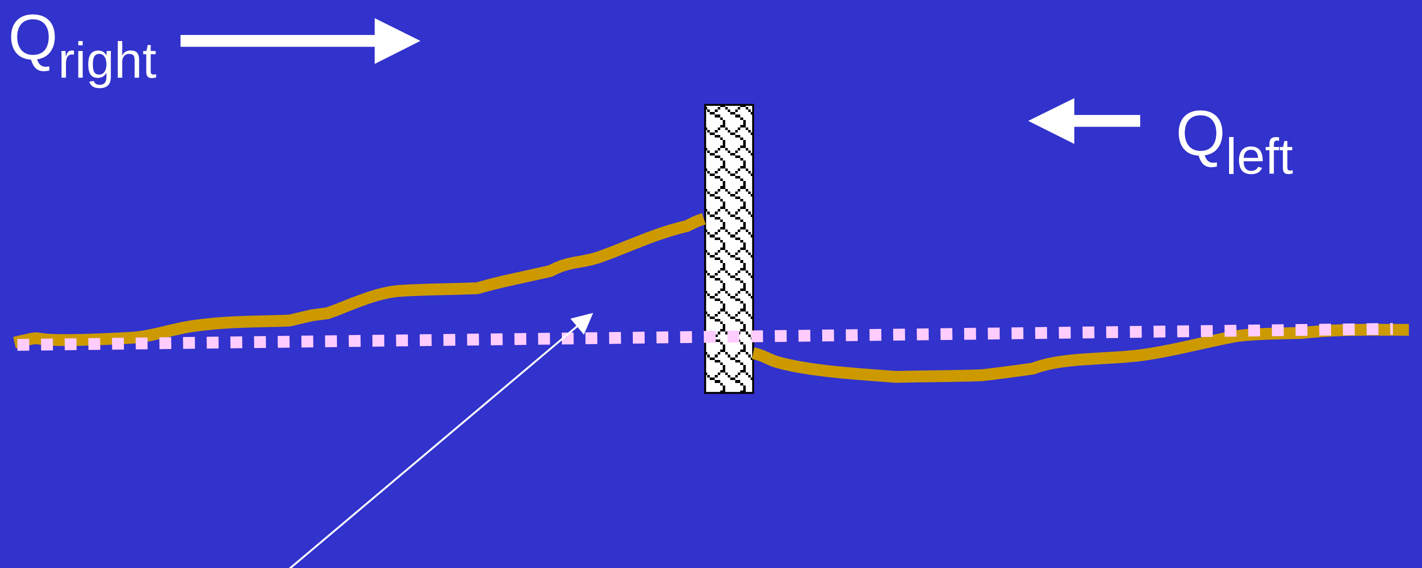
   deposition basin

   rate of channel shoaling

d. Dredging volumes

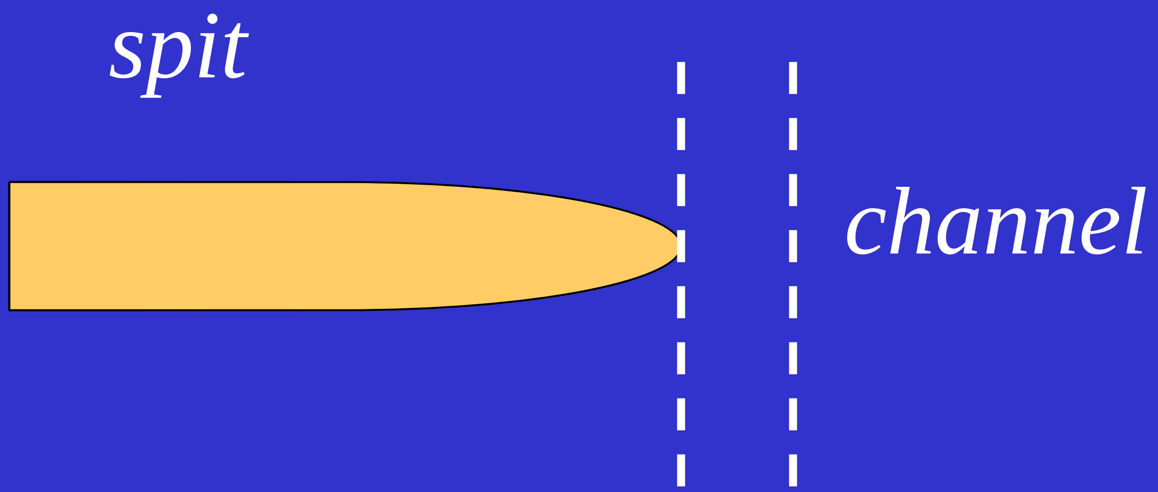
   indicator of gross?

a. Impoundment by Jetties and Breakwaters



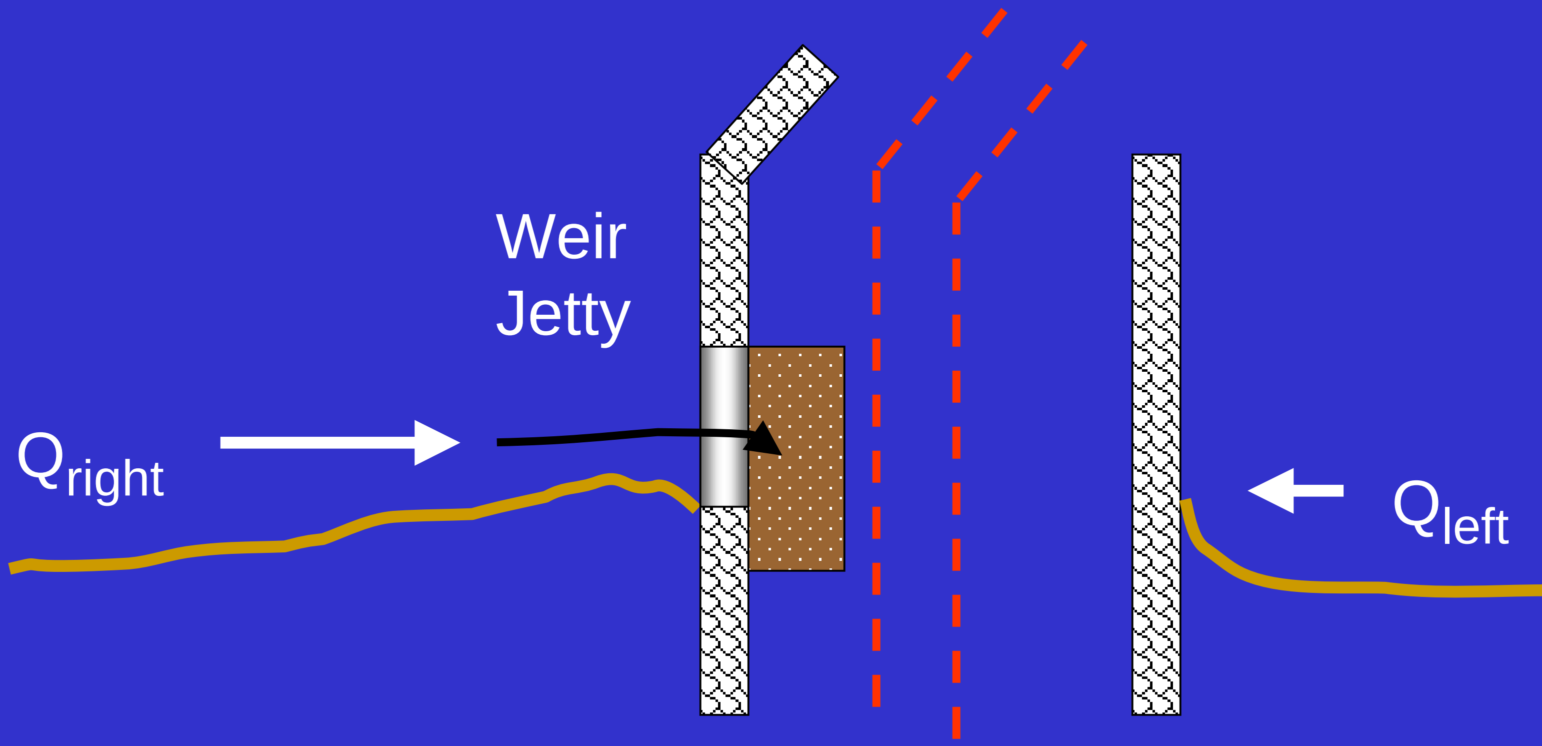
Volume accreted ~ Q_{right}

b. Rate of Shoreline Change



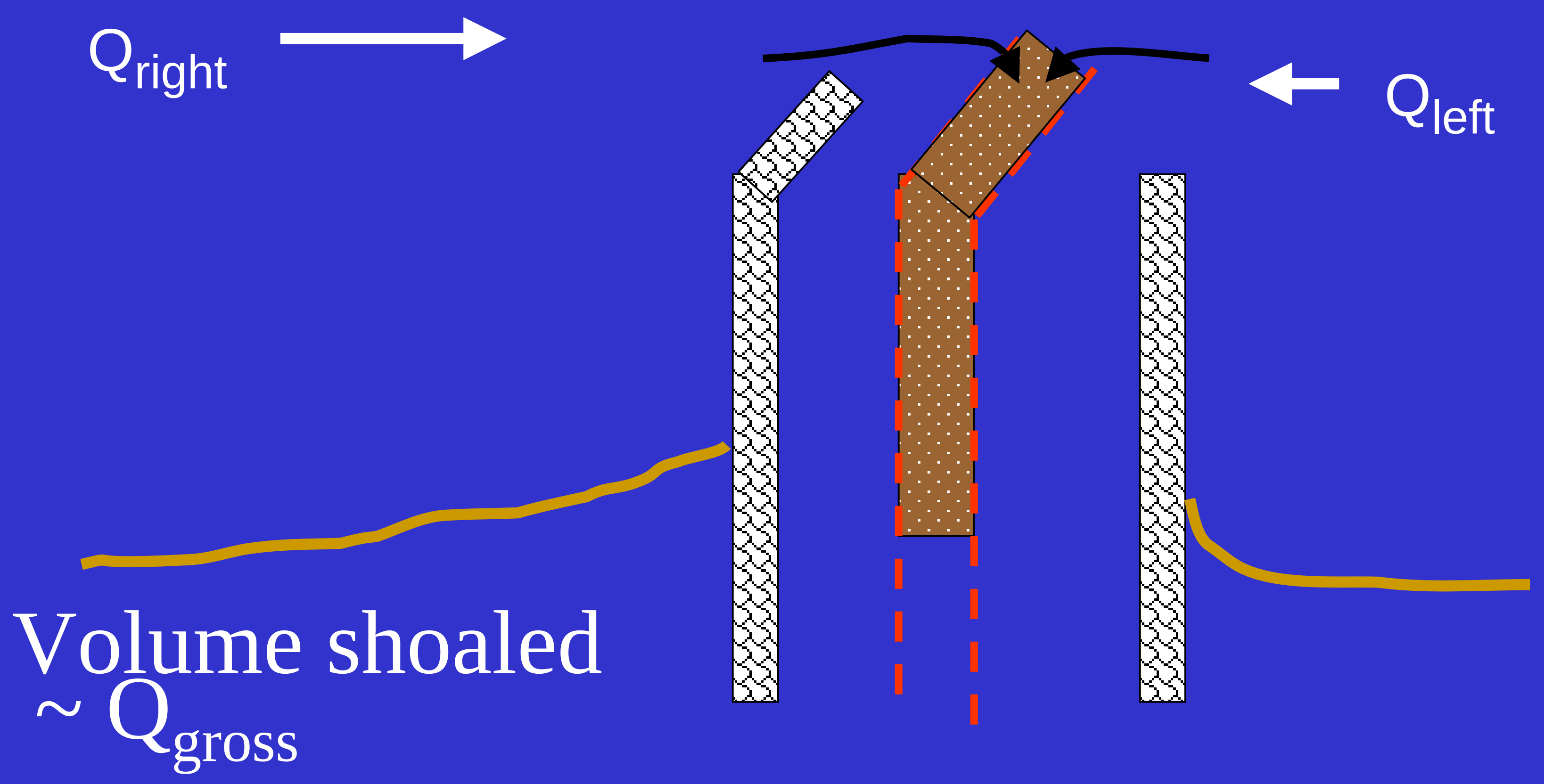
Volume growth ~ Q_{right} or Q_{net}

c. Rate of Bathymetric Change



Volume accreted ~ Q_{right}

d. Dredging volumes



3. Calculate using wave and beach data (1 of 5)

3. Calculate using wave and beach data (2 of 5)

$Q = f\ (H_b, \alpha_b, \rho_s, \rho, n, k)$ (Eq. 2-7b)

H_b = breaking wave height

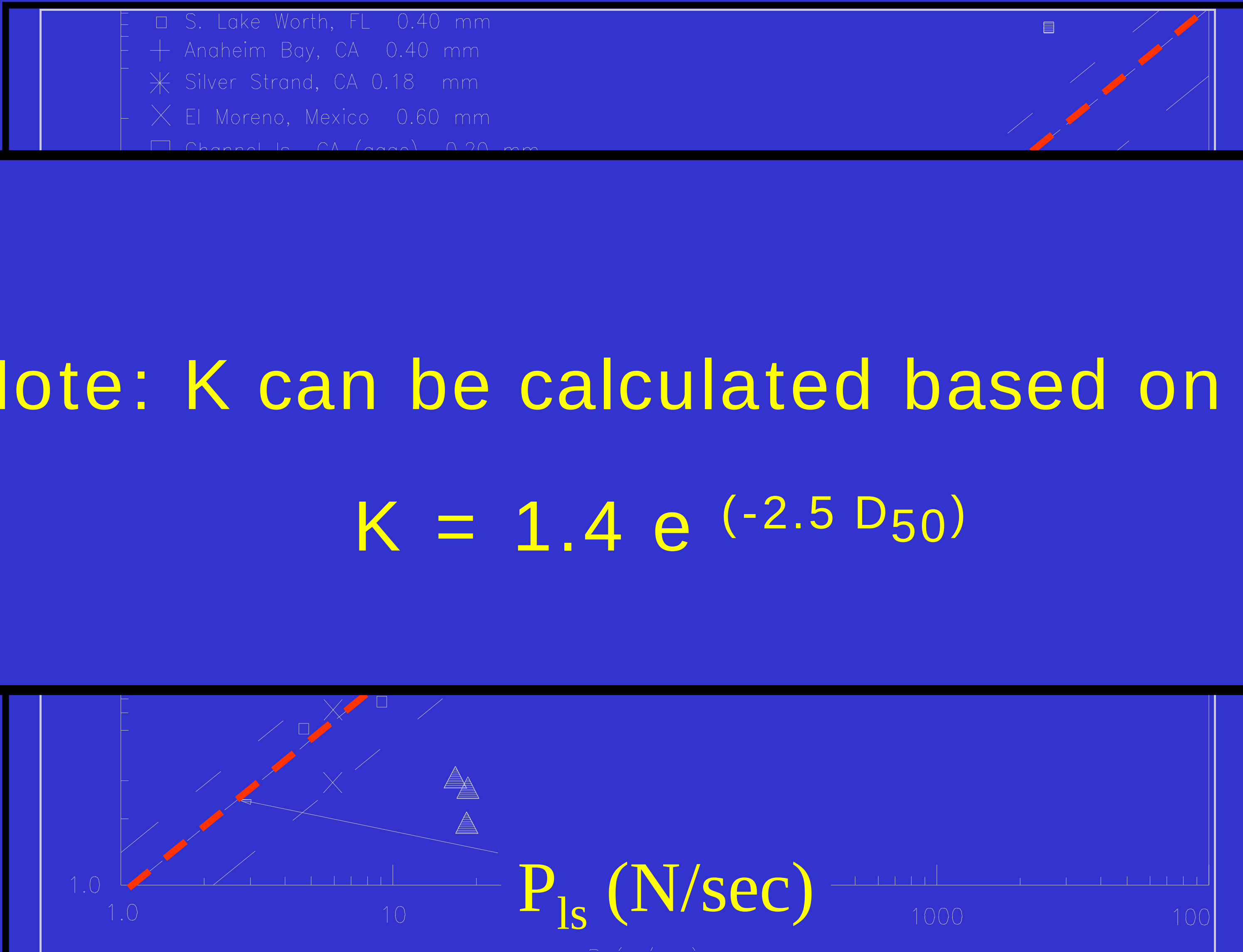
α_b = breaking wave angle relative to shoreline

ρ_s = mass density of sediment

ρ = mass density of water

n = in-place sediment porosity ~ 0.4

Figure III-2-4

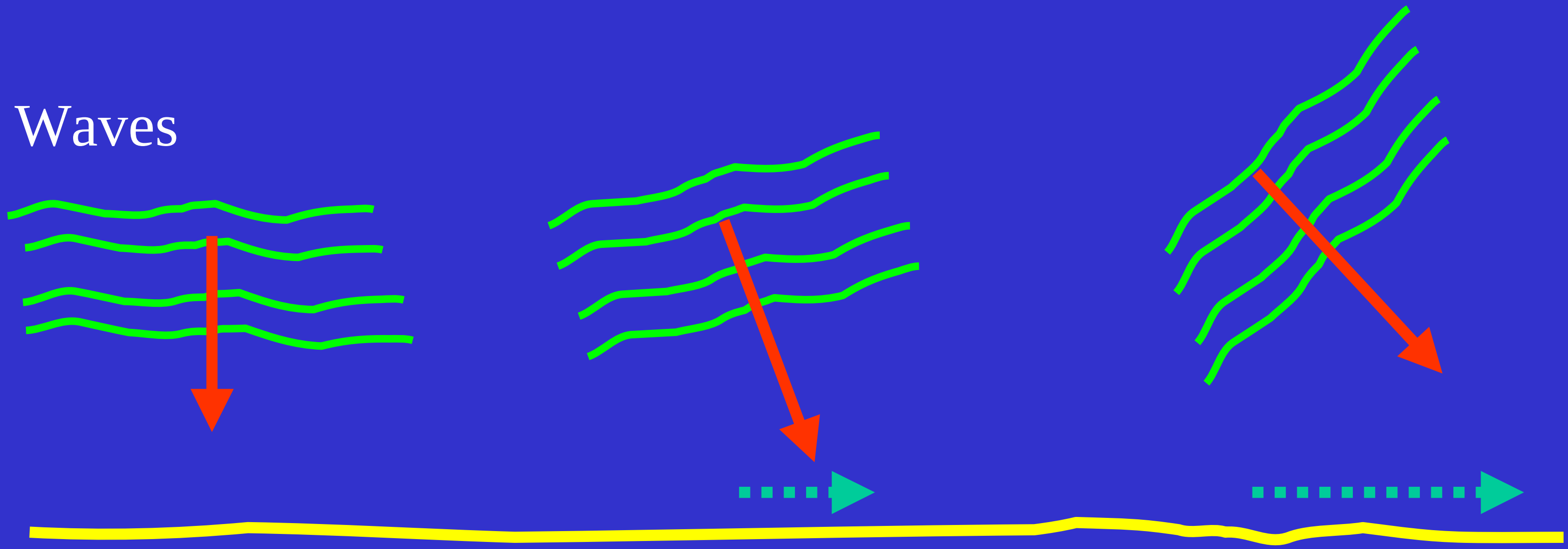


Note: K can be calculated based on D_{50}

$$K = 1.4\, e^{(-2.5\, D_{50})}$$

Importance of α_b

(breaking wave angle relative to the shoreline)



$Q_l = 0$ Q_l increases Q_l greatest

3. Calculate using wave and beach data (5 of 5)

$Q = f\,(H_b, W, V_l, C_f, V/V_o, \rho_s, \rho, n, k)$

(Eq. 2-11, 2-7a)

W = width of surf zone

V_l = measured longshore current

C_f = friction coefficient

V/V_o = dimensionless longshore current

4. Experimental Measurements

Sand tracer

Instruments (Optical Backscatter Sensors, Pumping samplers)

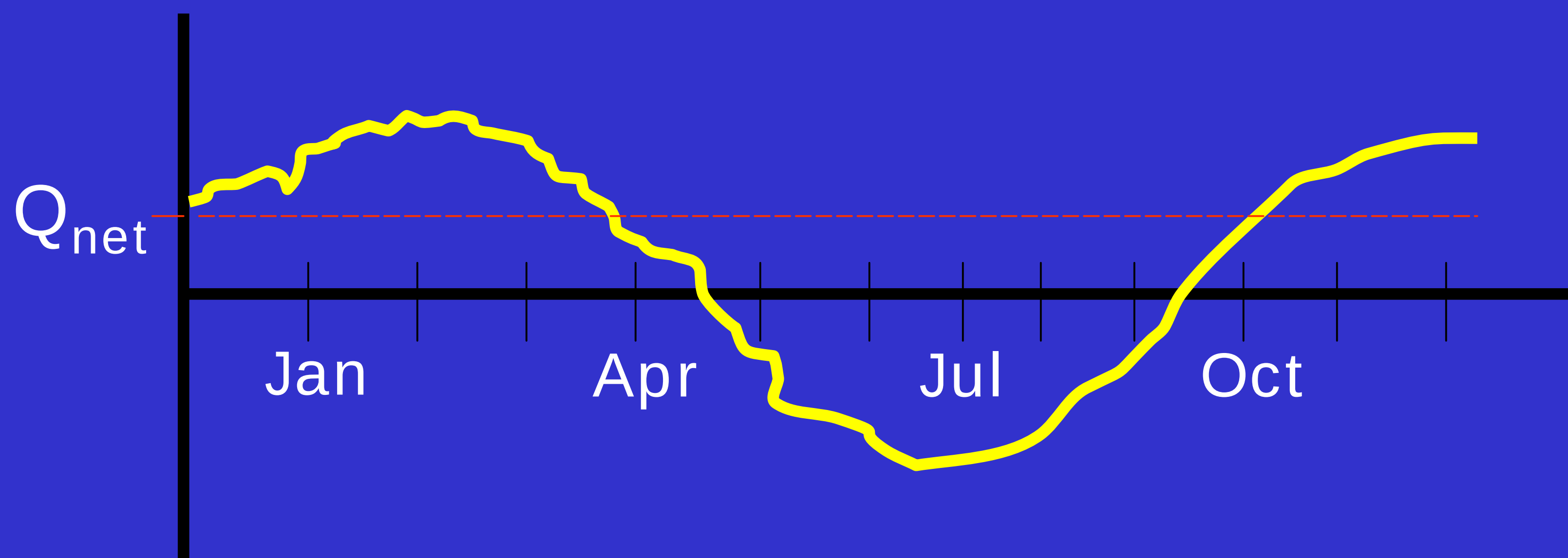
Traps (suspended and bedload)

Temporary structure (e.g., groin)

Characteristics of LST:

Conceptual Yearly Cycle

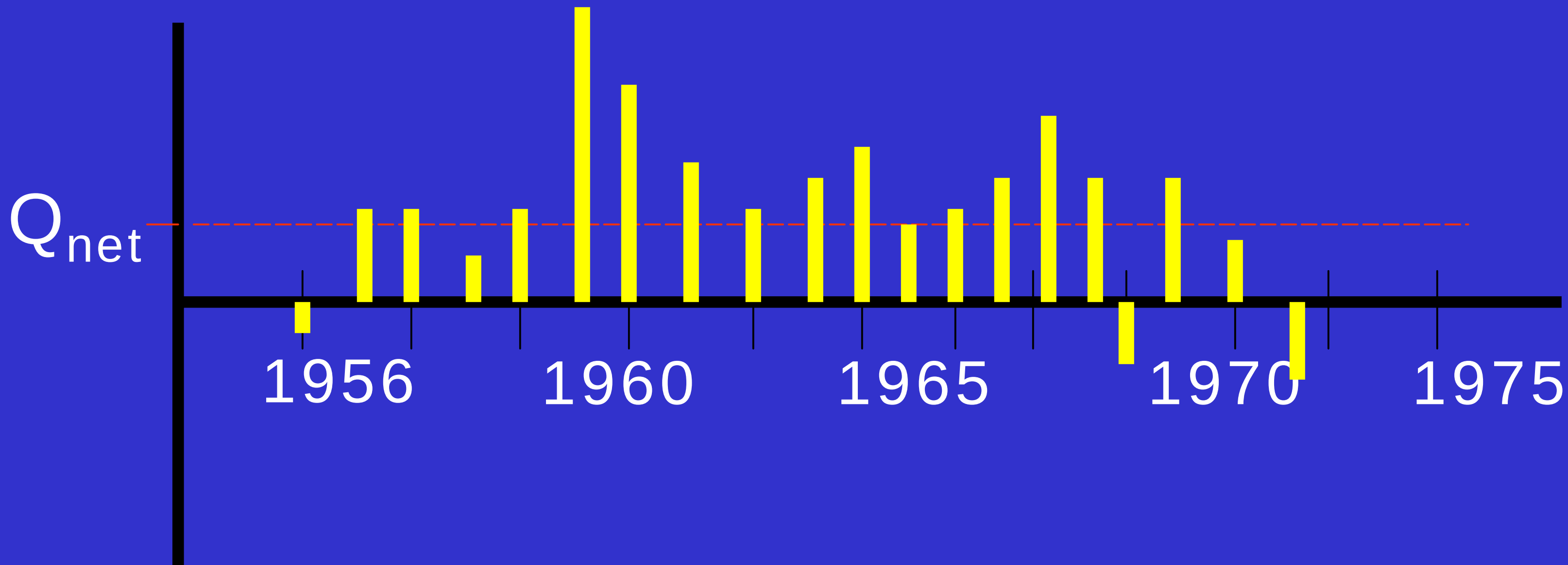
(see Figs III-2-7 and III-2-9)



Characteristics of LST:

Yearly Variation

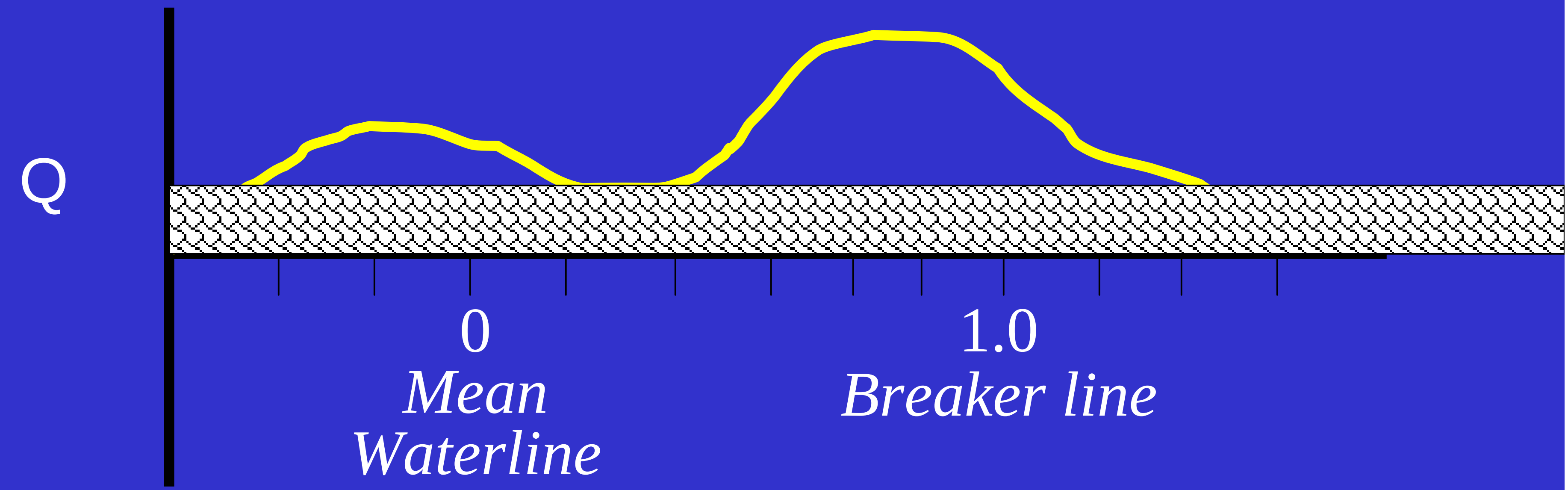
(see Fig III-2-8)



Characteristics of LST:

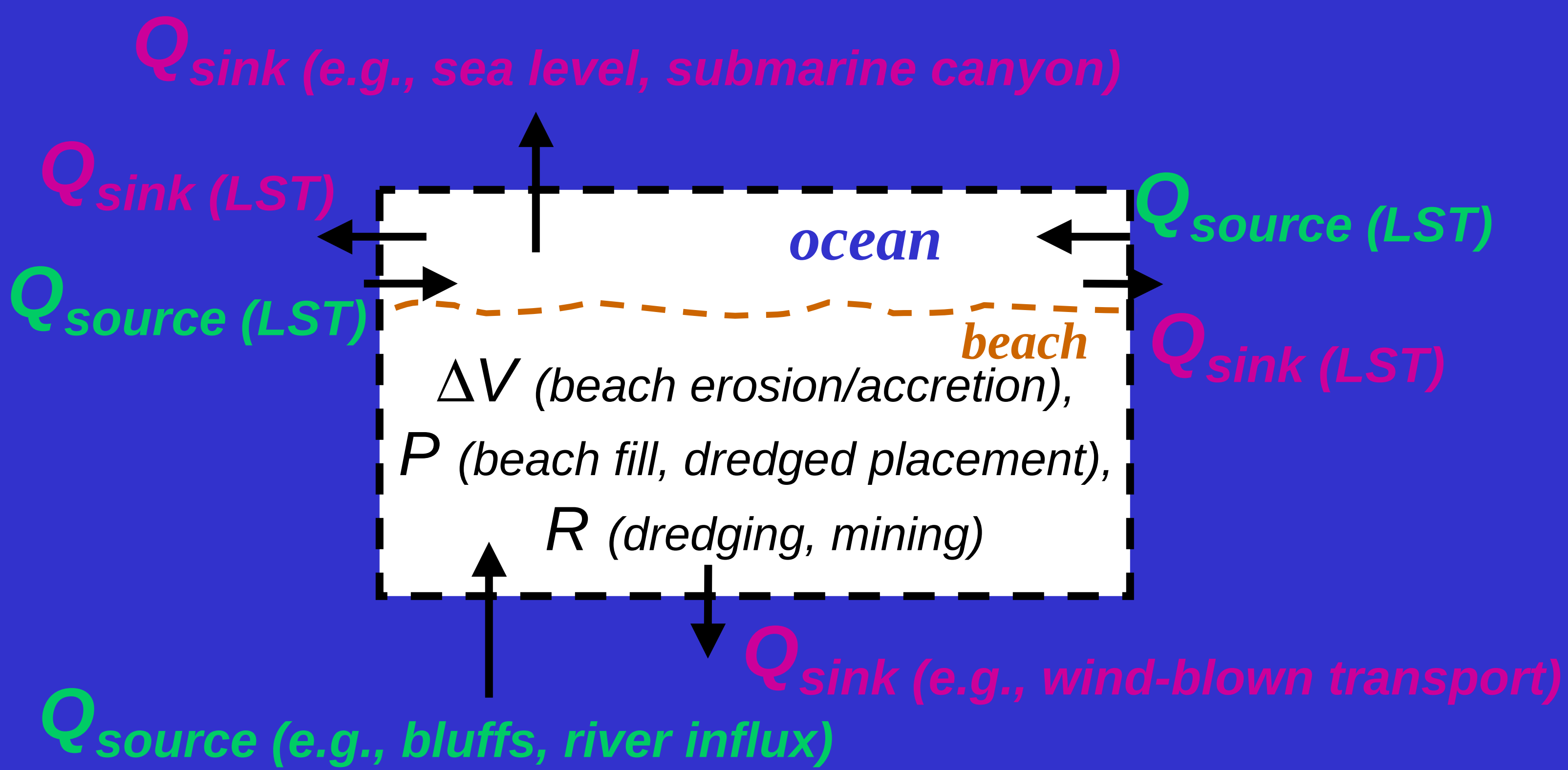
Cross-shore Distribution

(see Fig III-2-21)



Longshore Sediment Transport
(CEM III-2)

Sediment Budgets

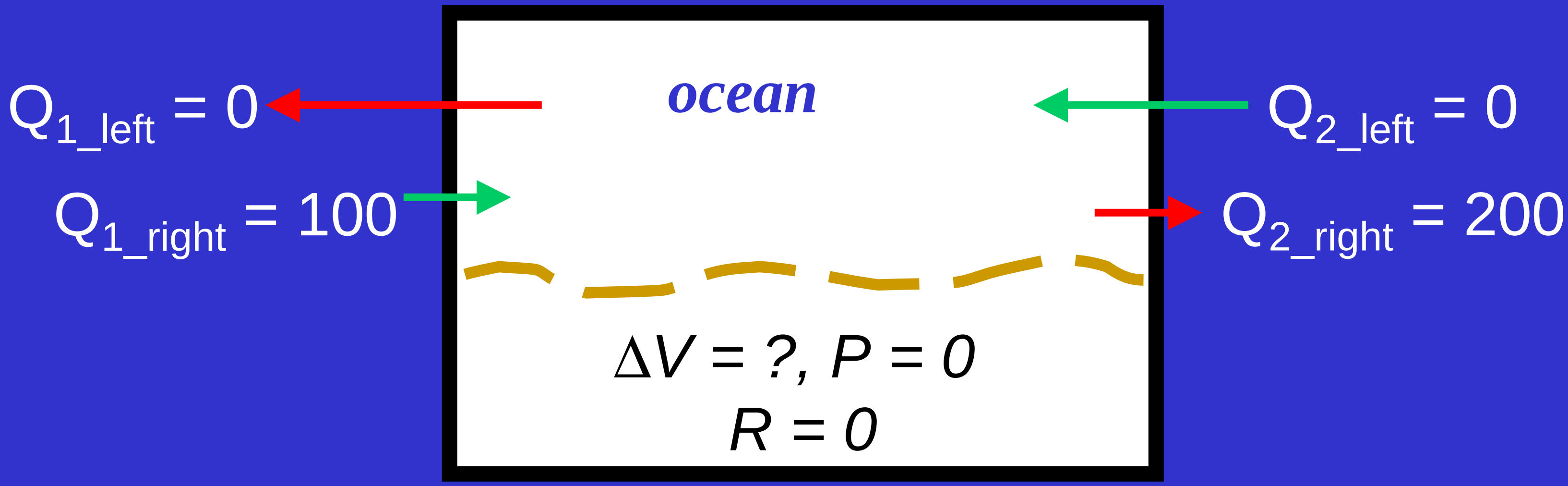


Sediment Budgets

$$\Sigma Q_{source} - \Sigma Q_{sink} - \Delta V + P - R = \textit{Residual}$$

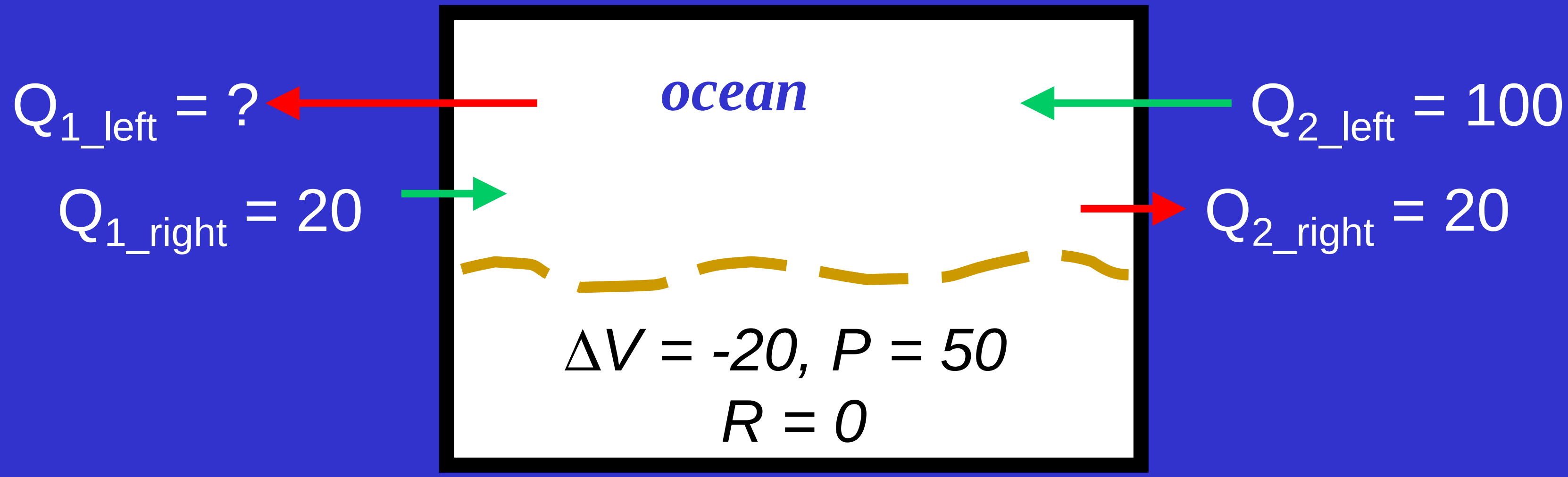
For a balanced cell, *Residual* = 0

TEST MATERIAL!!



ΣQ_{source}	$-\Sigma Q_{sink}$	$- \Delta V$	$+ P$	$-R$	$= 0$
100+0	-(200+0)	- (?)	+ 0	- 0	= 0

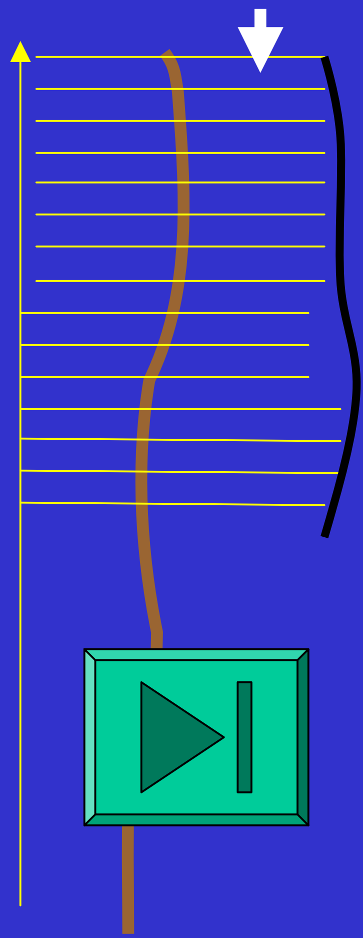
$$\Delta V = -100$$



ΣQ_{source}	$-\Sigma Q_{sink}$	$-\ \Delta V$	$+\ P$	$-R$	$= 0$
100+20	$-(20+Q_{1\_left})$	- (-20)	+ 50	- 0	= 0

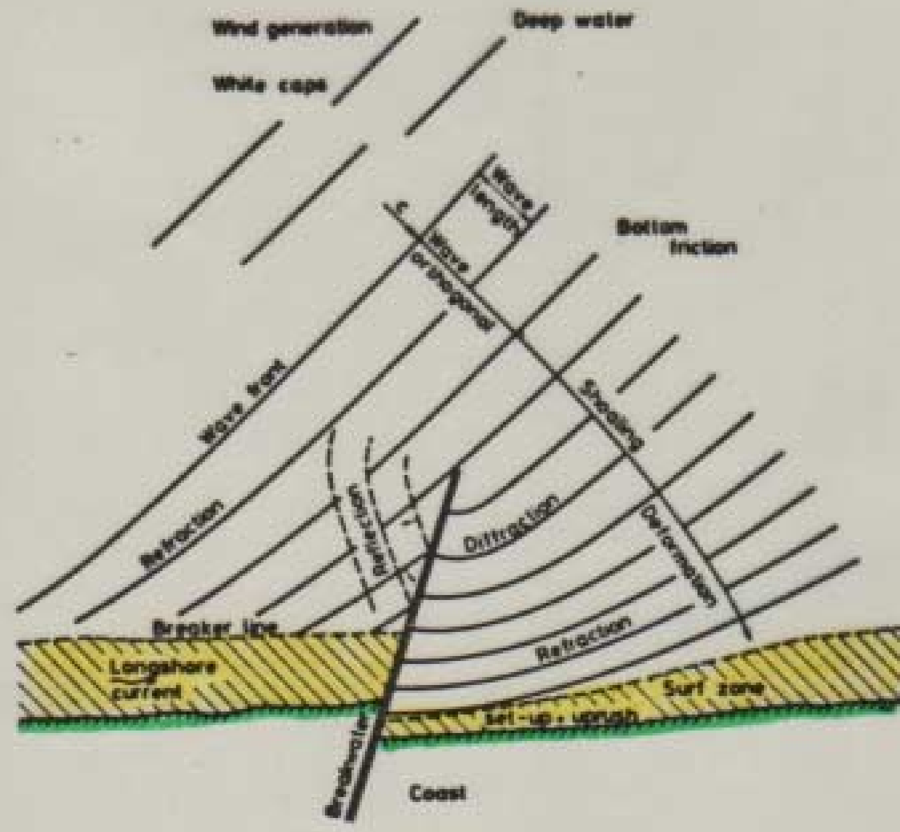
$$Q_{1\_left} = 170$$

Numerical LST Shoreline Change Model -- GENESIS



- predict future, with-project shoreline positions
- essentially a sediment budget for each grid cell
- driven by waves, site characteristics
- can incorporate structures, beach fill

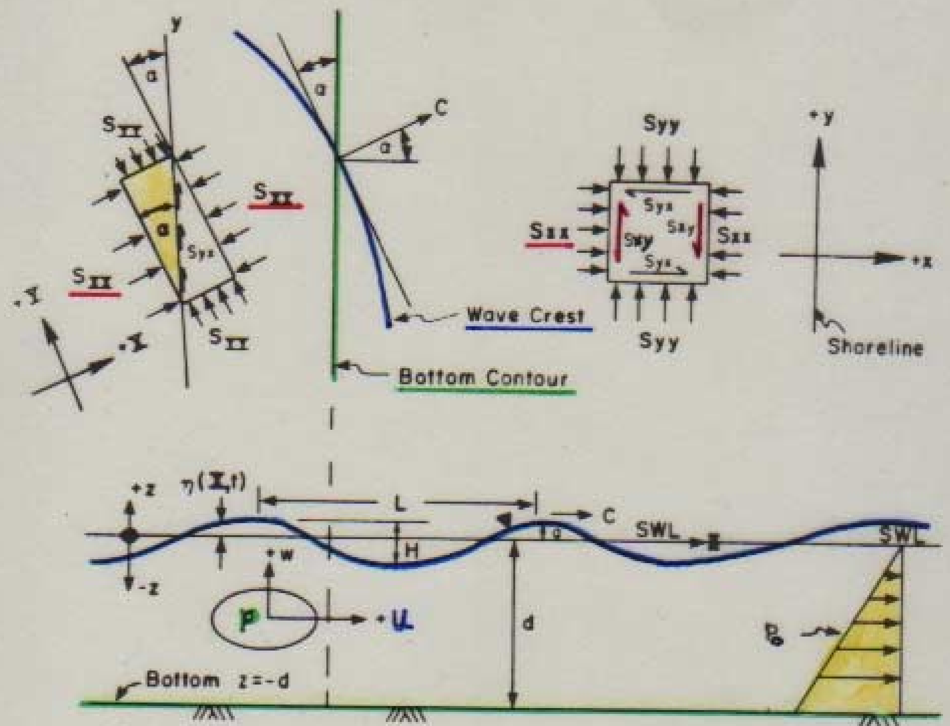
HYDRODYNAMICS OF COASTAL REGIONS



Basco, D.R. (1982) Surf Zone Currents, MR 82-7, USAE, CERC, Waterways Expt. Sta., Sept. (two volumes) also in Coastal Engineering, vol 7 (1983), pp. 331-355.

RADIATION STRESS PRINCIPLES

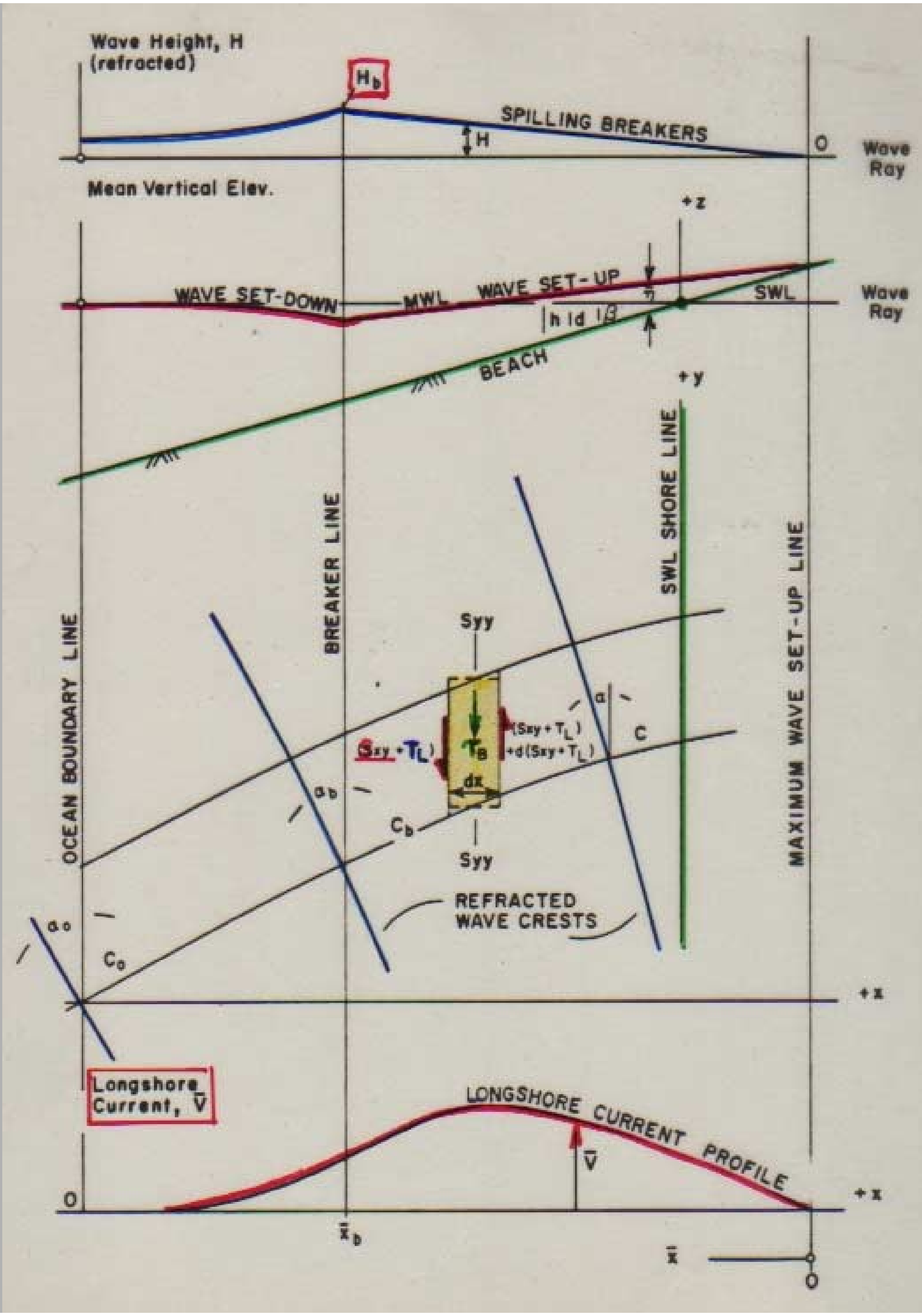
- the time-averaged excess horizontal momentum flux due to presence of water waves.



$$\overline{S_{XX}} \equiv \int_{-d}^{\eta} (p + \rho u^2)\, dz \;-\; \int_{-d}^{0} p_0 \, dz$$

Coordinate Transformation

S_{xx}, S_{yy}, S_{xy}


Wave Height, H
(refracted)
Hb
SPILLING BREAKERS
H
O
Wave Ray
Mean Vertical Elev.
+z
WAVE SET-DOWN
MWL
WAVE SET-UP
SWL
Wave Ray
BEACH
+y
SWL SHORE LINE
BREAKER LINE
OCEAN BOUNDARY LINE
MAXIMUM WAVE SET-UP LINE
Syy
Sxy + TL
TB
(Sxy + TL)
+d(Sxy + TL)
dx
C
Cb
Syy
REFRACTED
WAVE CRESTS
Co
+x
Longshore
Current, V̄
LONGSHORE CURRENT PROFILE
V̄
O
+x
x̄b
x̄
O

Idealized environment for longshore current theory

Wave Field

- Simple, monochromatic gravity wave trains
- Steady-state, incident wave field
- Two-dimensional, horizontally propagating
- Linearized theory and radiation stresses
- Oblique angle of incidence, long wave crests
- Spilling-type breakers
- Constant breaker ratio in surf zone

Idealized environment for longshore current theory

Beach

- Infinite length, straight and parallel contours
- Plane bottom slope
- Gentle slope
- Impermeable bottom

Fluid

- Incompressible
- Homogeneous (no air entrainment)

Current

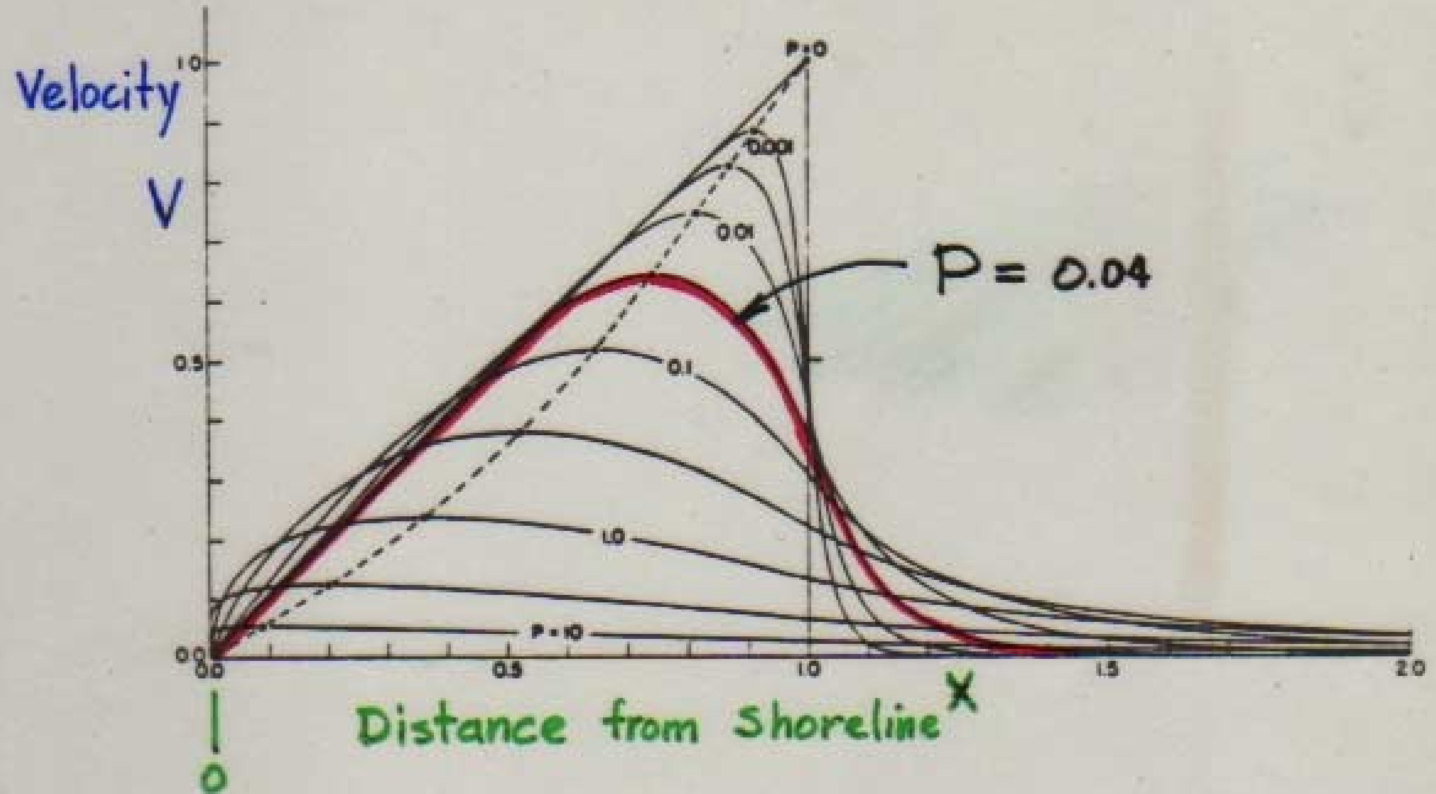
- Depth-integrated, parallel to coastline
- Time-average (one wave period)

Idealized environment for longshore current theory

Neglected Stresses and Accelerations

- No surface wind stress
- No atmospheric pressure gradient
- No Coriolis acceleration
- No tides
- No local (time-average acceleration, I.e., steady flow
- No wave-turbulence interaction stresses
- No bed shear stress outside of surf zone
- No rip currents present
- No wave-current interaction stresses

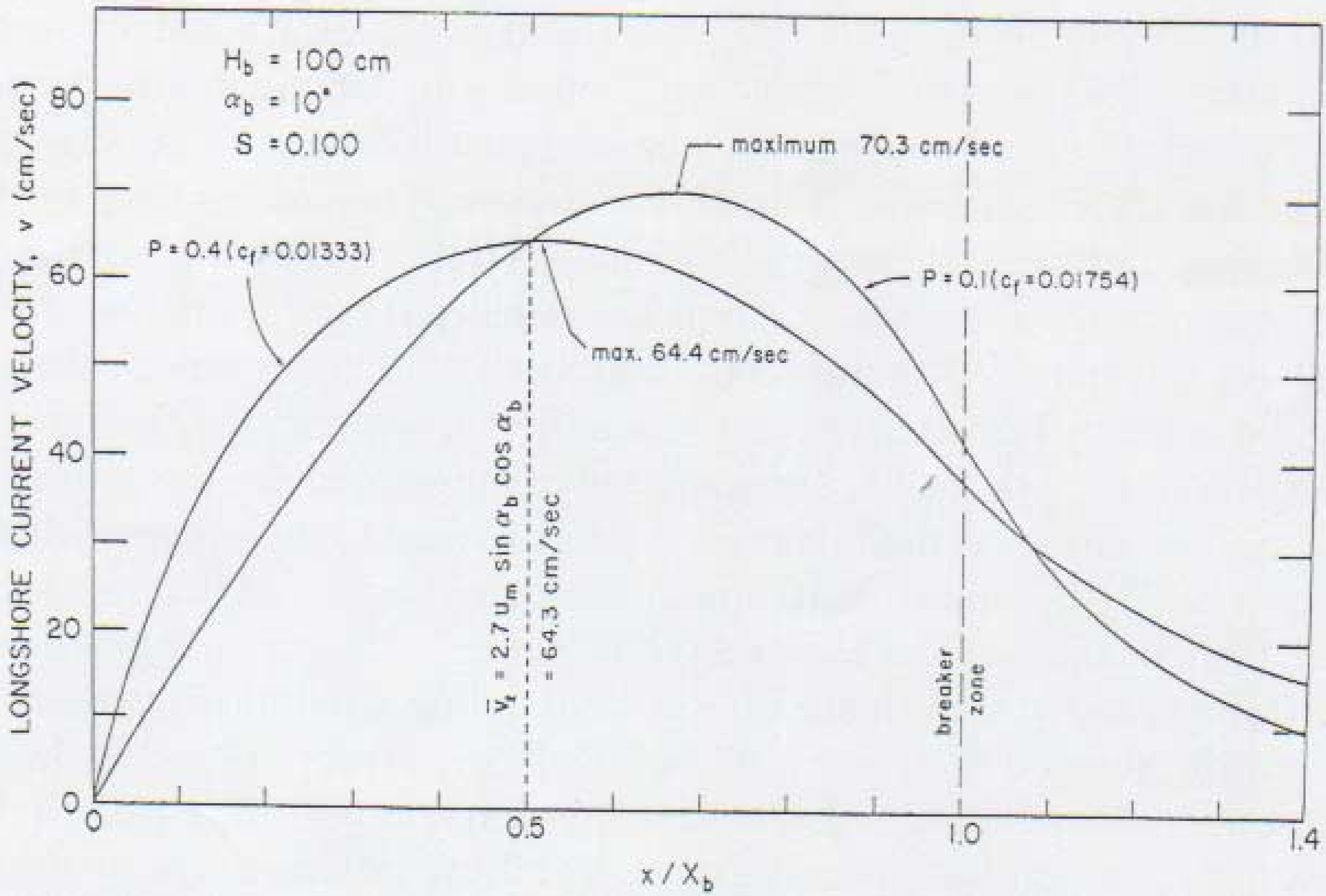
THEORY (Longuet-Higgins, 1970, 1972)



Momentum Balance

$$\frac{d\,S_{xy}}{dx} - \overline{\tau}_B + \frac{d\,T_L}{dx} = 0$$

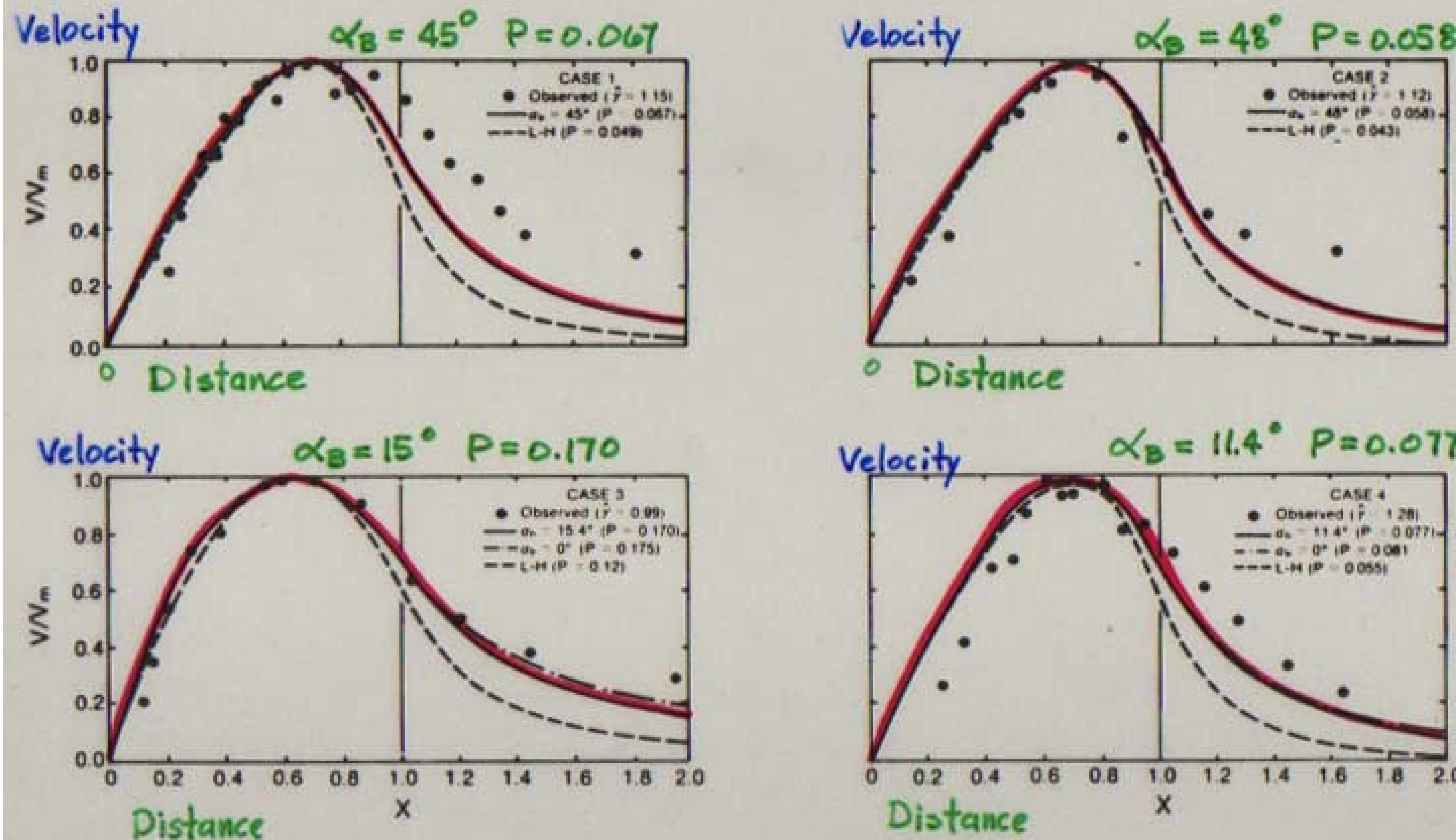
$$P = \frac{N \pi \tan \beta}{C_f\, \gamma}$$

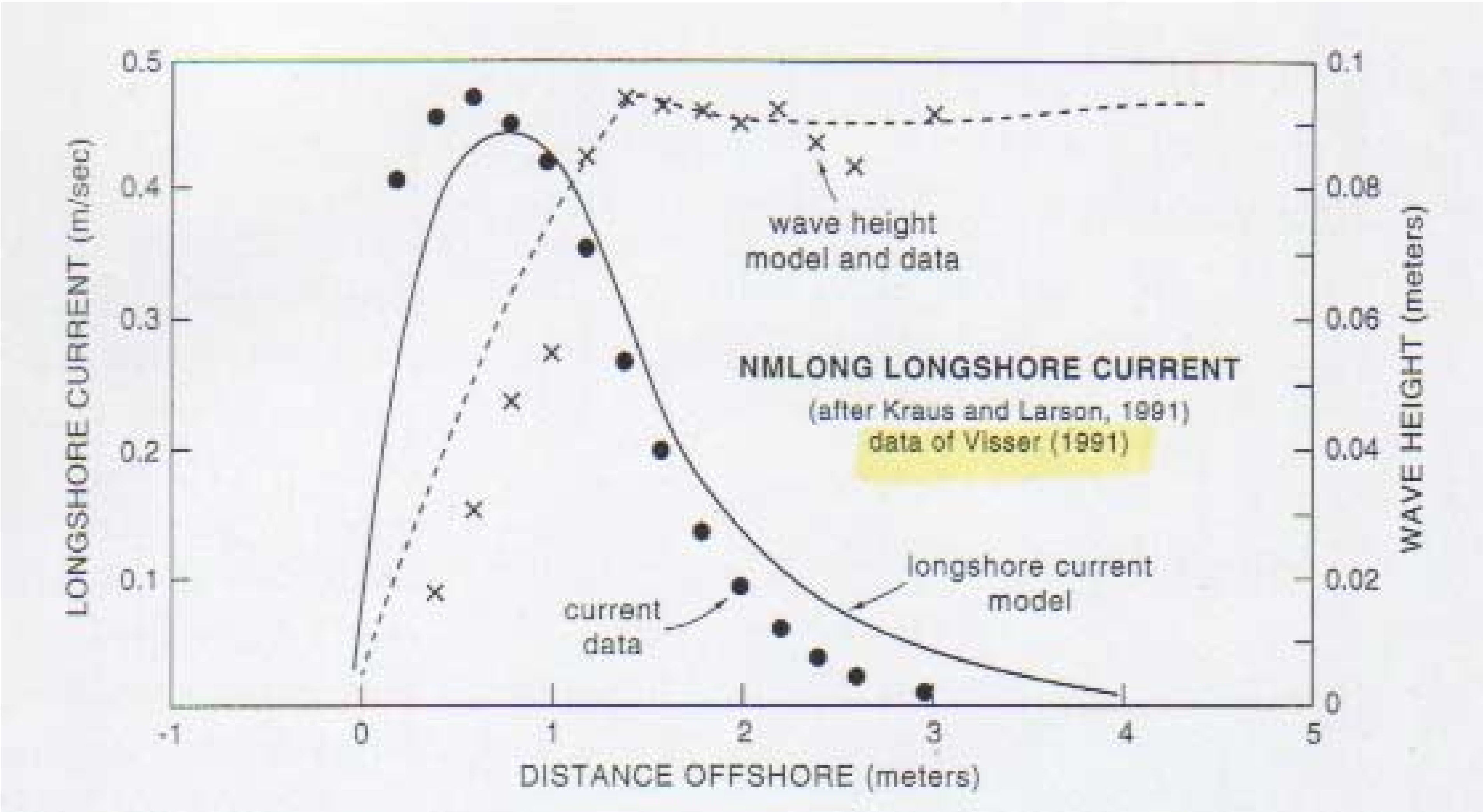


H_b = 100 cm
α_b = 10°
S = 0.100
maximum 70.3 cm/sec
P = 0.4 (c_f = 0.01333)
P = 0.1 (c_f = 0.01754)
max. 64.4 cm/sec
v̄_ℓ = 2.7 u_m sin α_b cos α_b
= 64.3 cm/sec
breaker zone
LONGSHORE CURRENT VELOCITY, v (cm/sec)
x / X_b
0
20
40
60
80
0
0.5
1.0
1.4

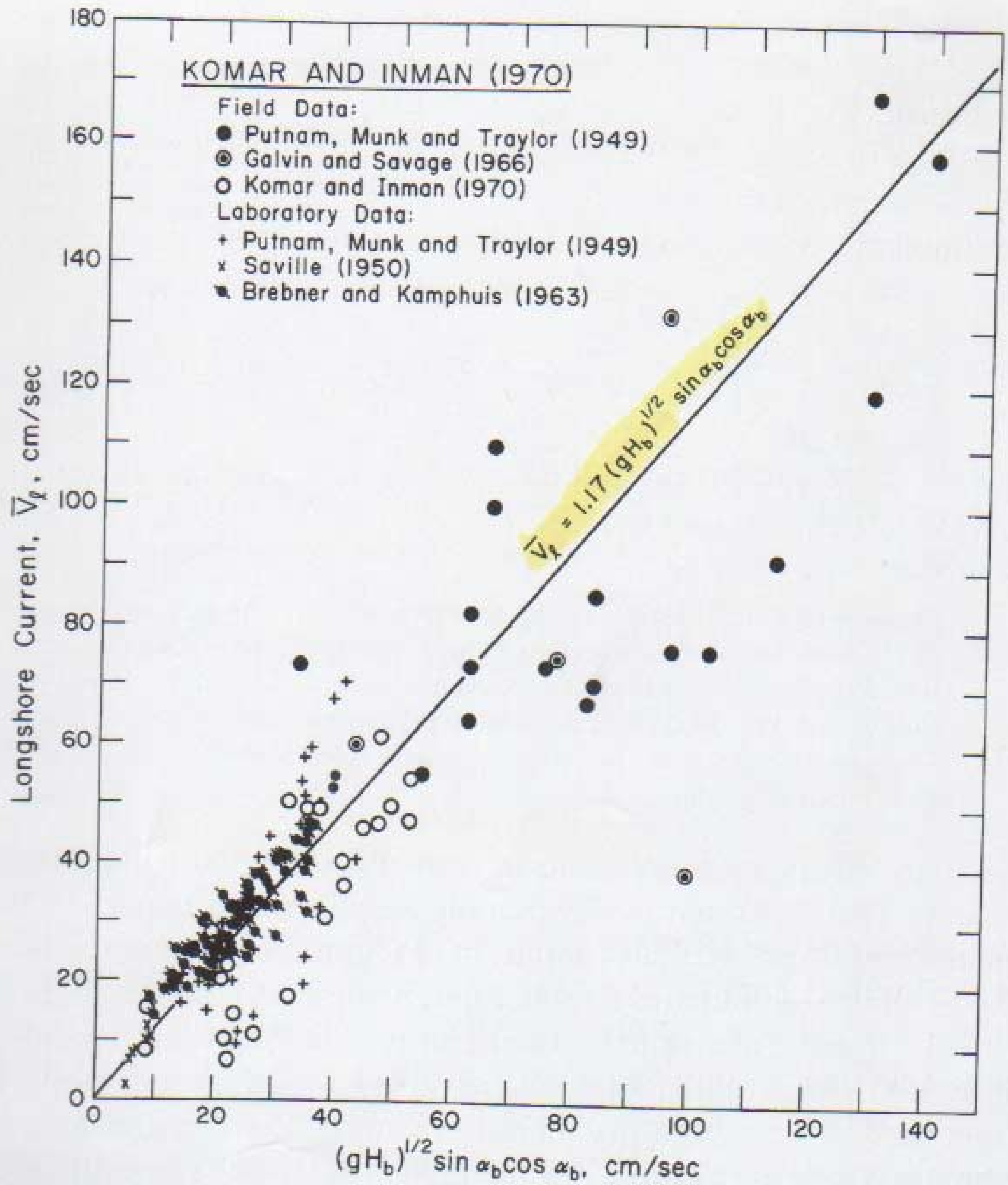
THEORY (Kraus and Sasaki, 1979)

EXPERIMENTS (Mizuguchi, etal. 1978)



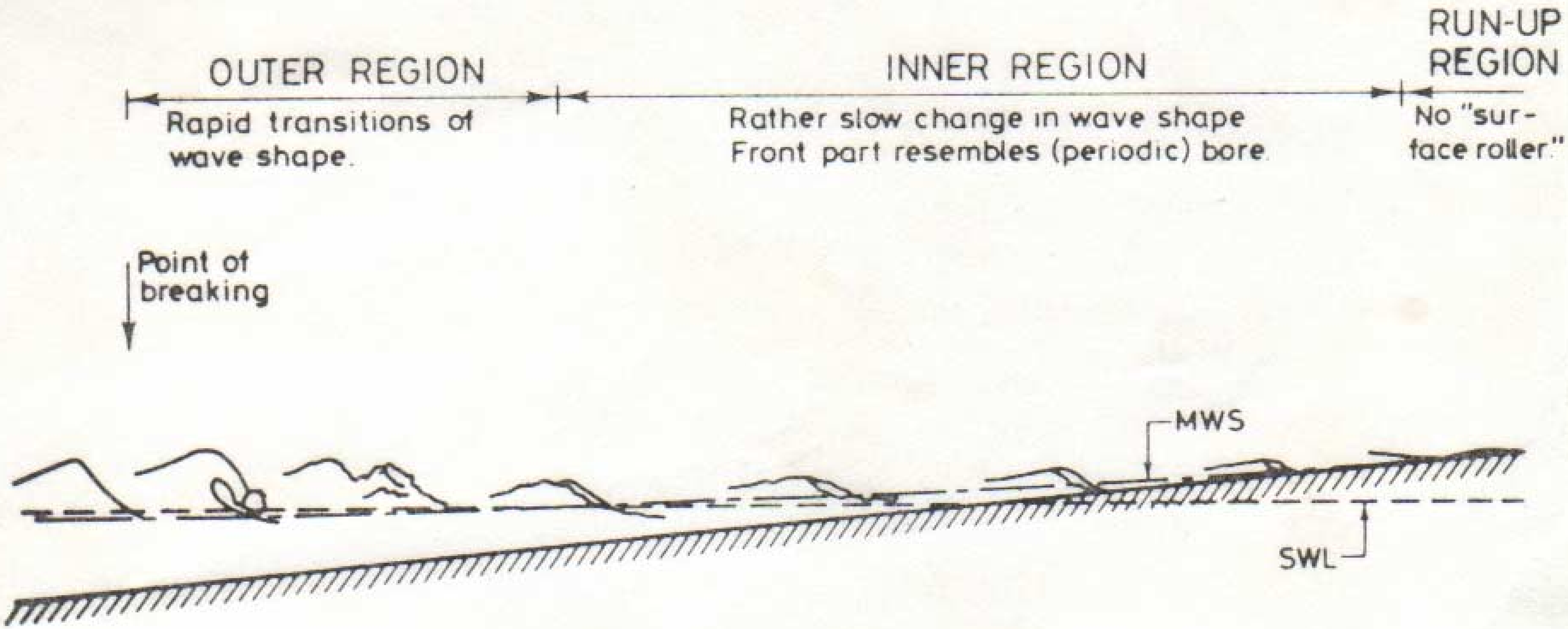


NMLONG LONGSHORE CURRENT
(after Kraus and Larson, 1991)
data of Visser (1991)
wave height model and data
longshore current model
current data
LONGSHORE CURRENT (m/sec)
WAVE HEIGHT (meters)
DISTANCE OFFSHORE (meters)
0.5
0.4
0.3
0.2
0.1
0.1
0.08
0.06
0.04
0.02
0
-1
0
1
2
3
4
5

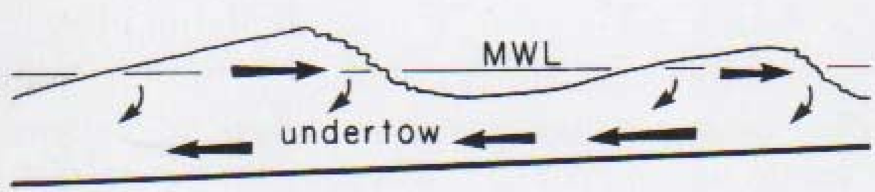


KOMAR AND INMAN (1970)
Field Data:
Putnam, Munk and Traylor (1949)
Galvin and Savage (1966)
Komar and Inman (1970)
Laboratory Data:
Putnam, Munk and Traylor (1949)
Saville (1950)
Brebner and Kamphuis (1963)
$\overline{V}_\ell = 1.17 (gH_b)^{1/2} \sin\alpha_b \cos\alpha_b$
Longshore Current, $\overline{V}_\ell$, cm/sec
$(gH_b)^{1/2} \sin\alpha_b \cos\alpha_b$, cm/sec
0
20
40
60
80
100
120
140
160
180

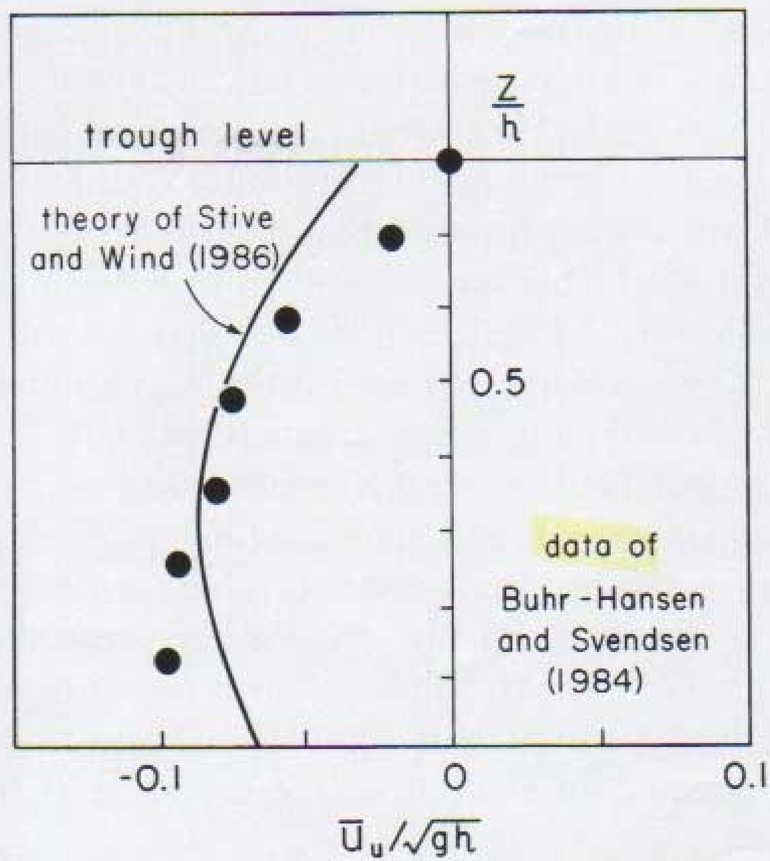
SURF ZONE WAVE

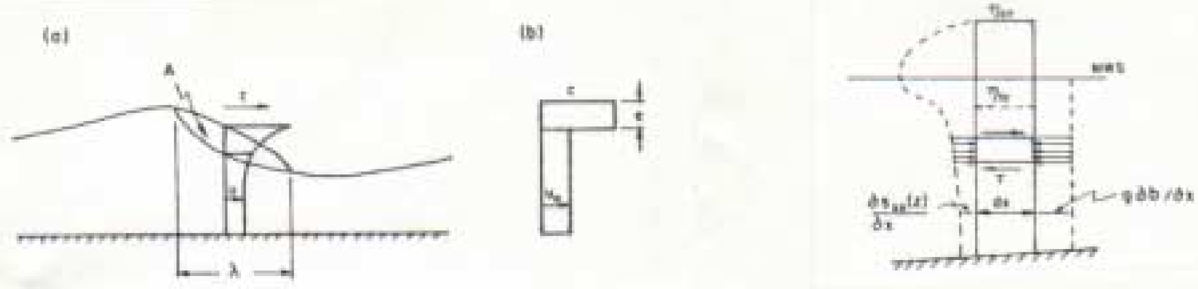


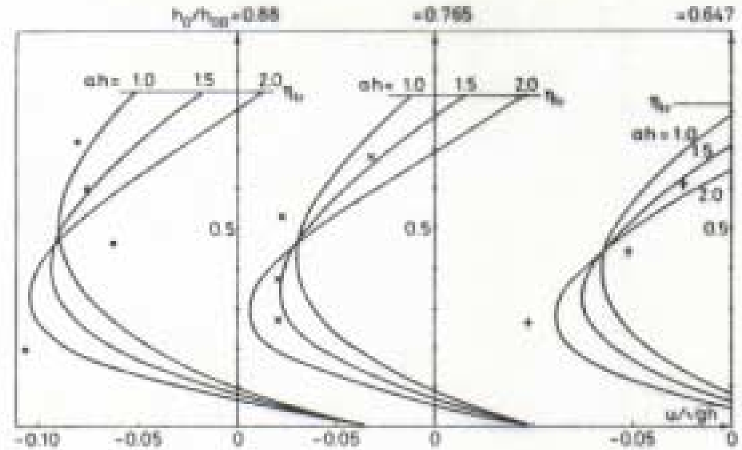
A UNDERTOW

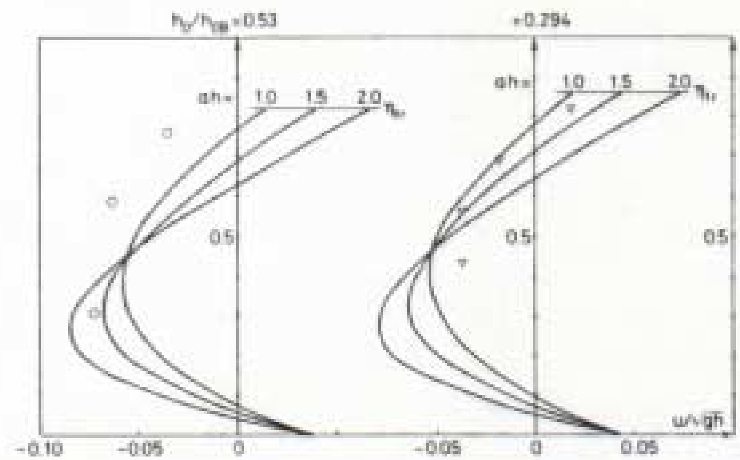


B MEASURED VELOCITIES




(a)
A
λ
(b)
MWS


h_0/h_{0B}=0.88
=0.765
=0.647
ah= 1.0 1.5 2.0
0.5
-0.10
-0.05
0
0.05


h_0/h_{0B}=0.53
=0.294
ah= 1.0 1.5 2.0
0.5
-0.10
-0.05
0
0.05

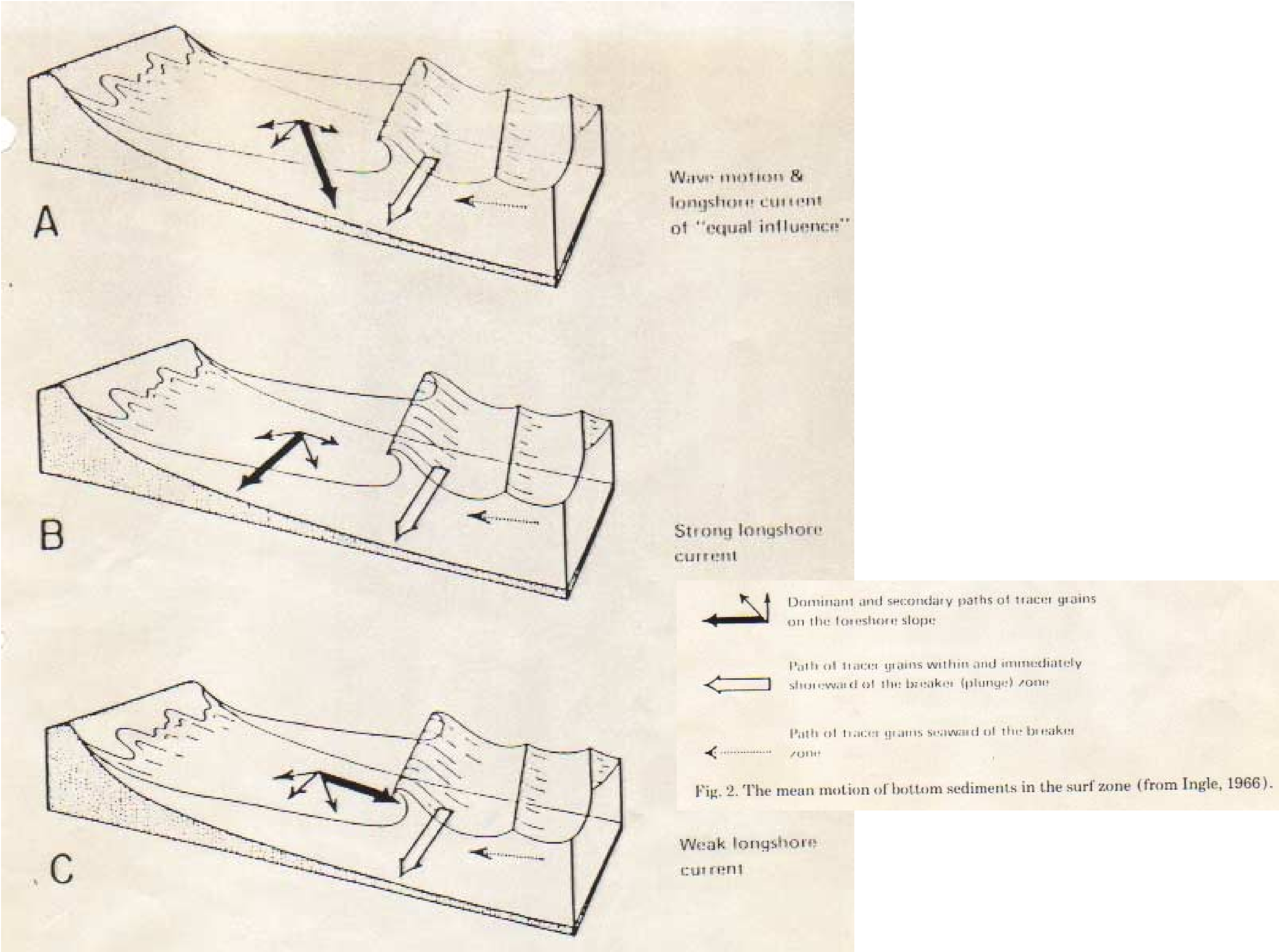


Fig. 2. The mean motion of bottom sediments in the surf zone (from Ingle, 1966).

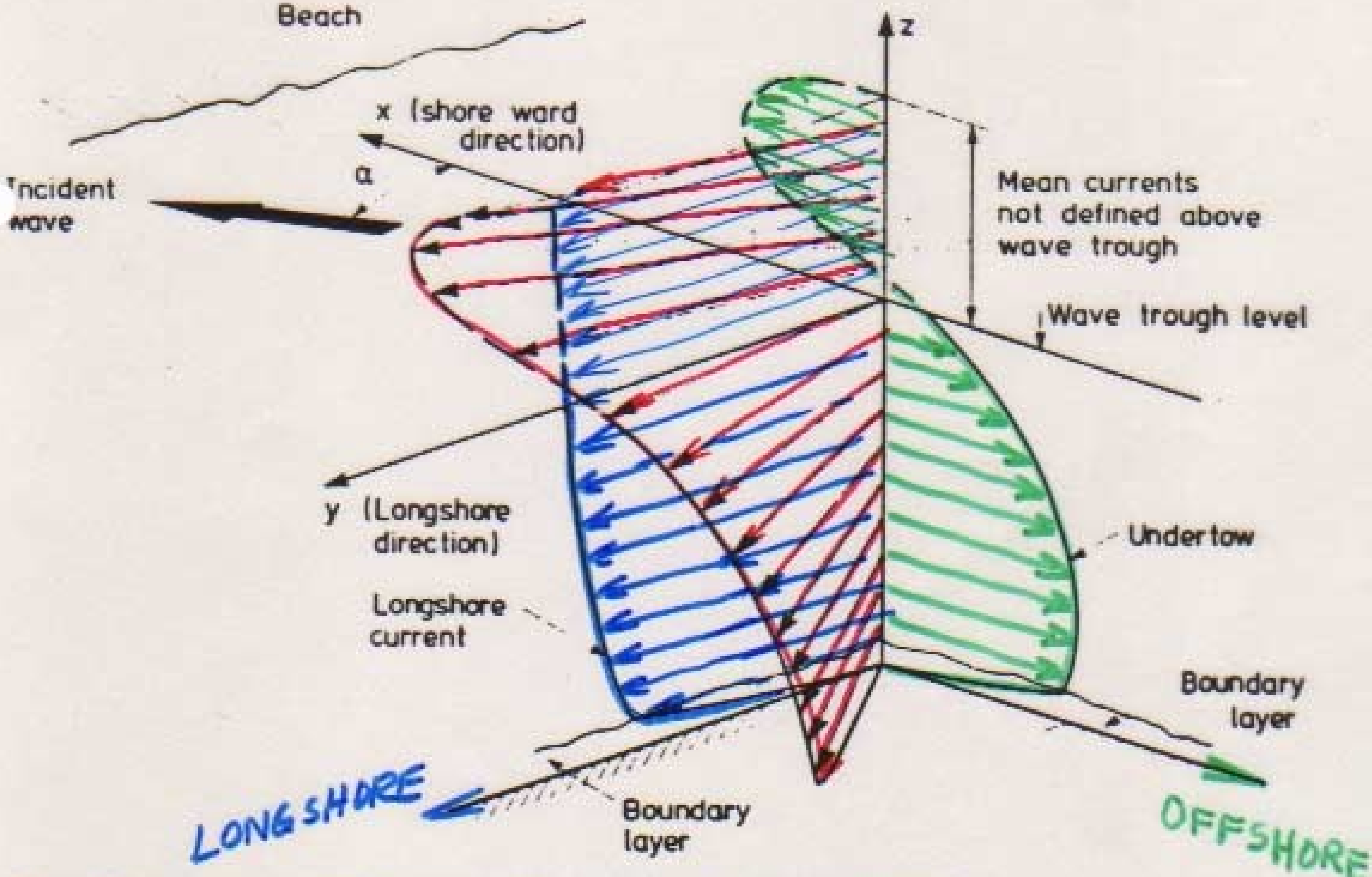
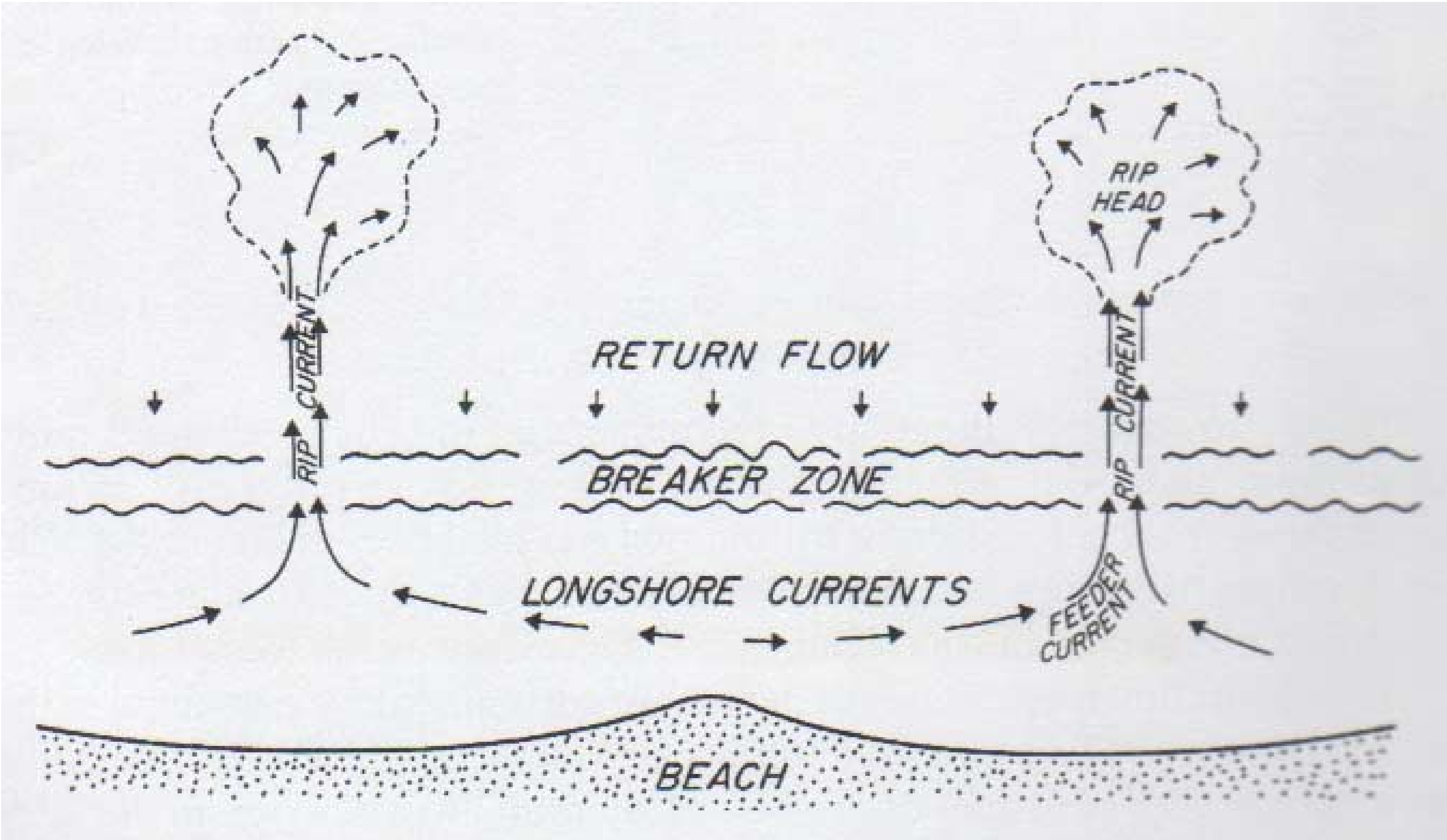
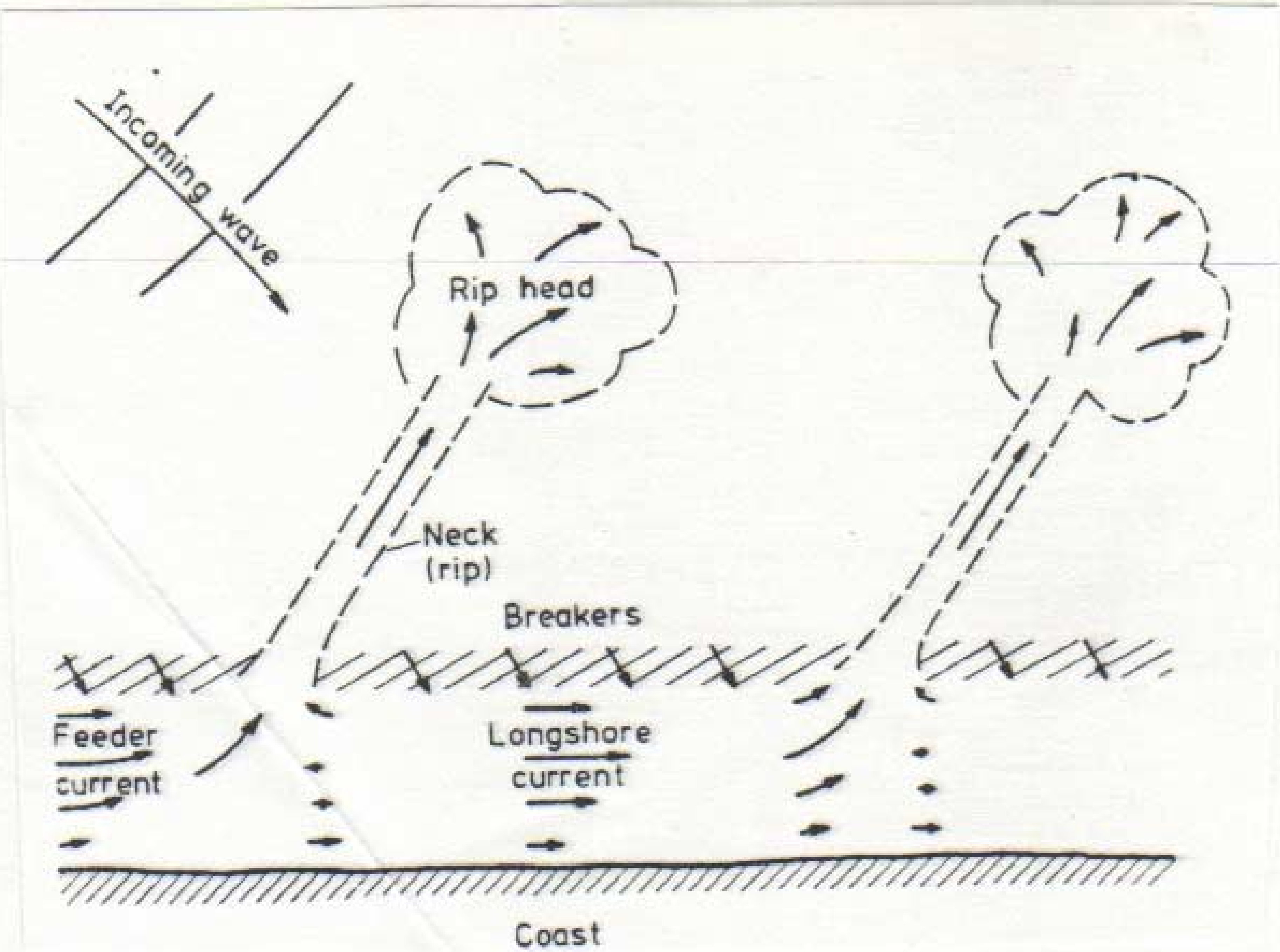
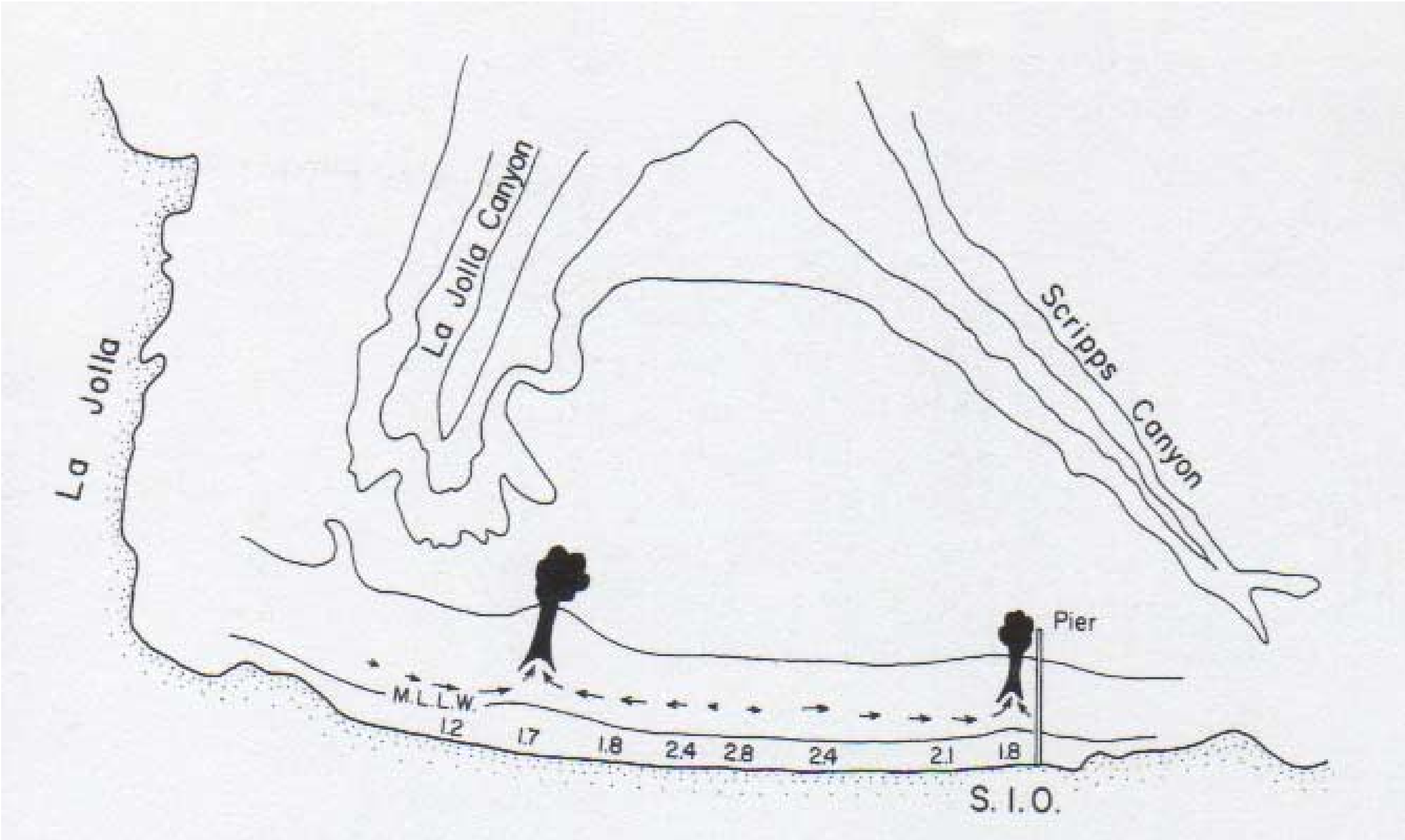


Fig. 1. Three-dimensional resultant mean velocities in the surf zone.

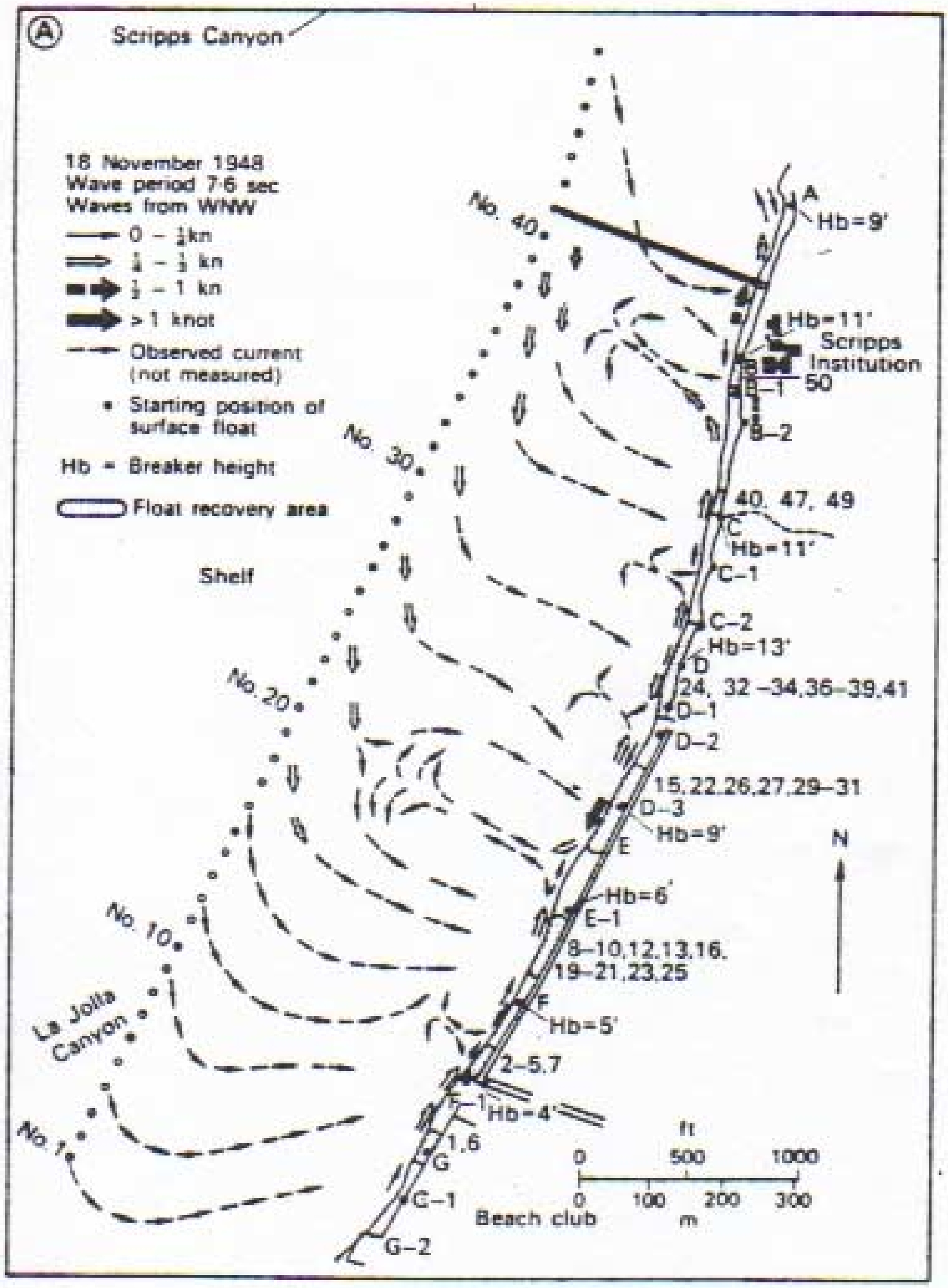

RIP HEAD
RIP CURRENT
RIP CURRENT
RETURN FLOW
BREAKER ZONE
LONGSHORE CURRENTS
FEEDER CURRENT
BEACH



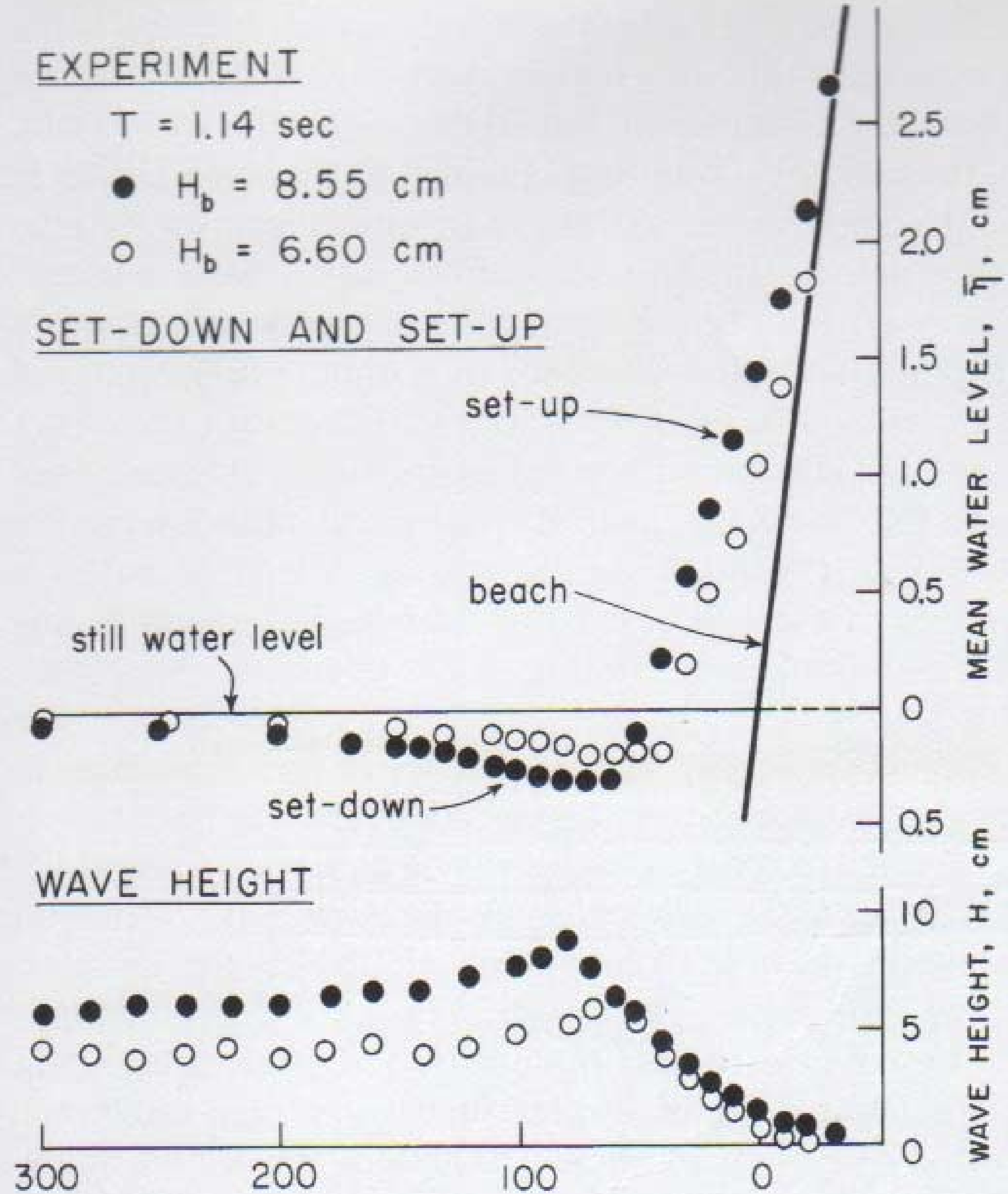
Incoming wave
Rip head
Neck (rip)
Breakers
Feeder current
Longshore current
Coast



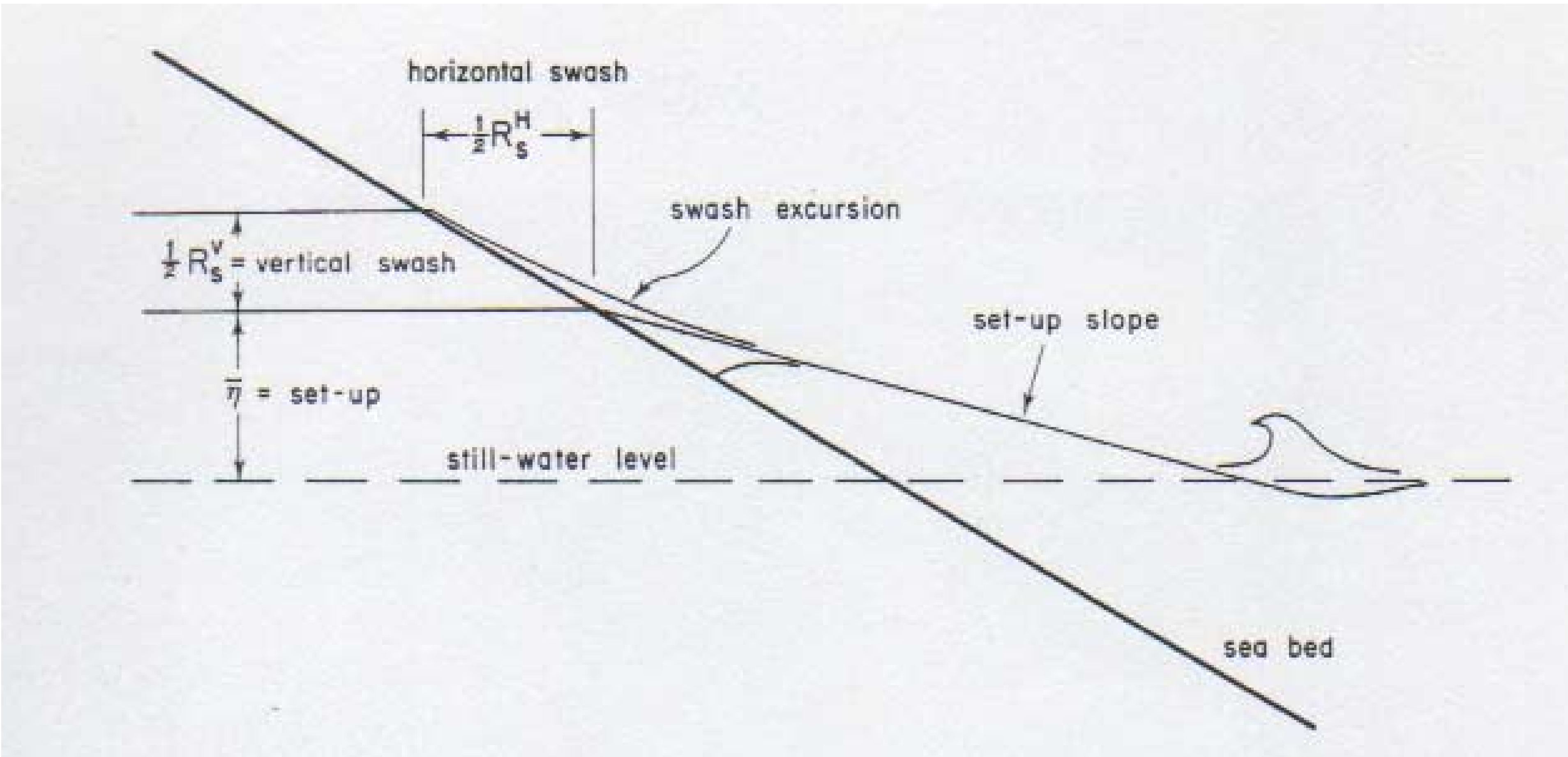
La Jolla
La Jolla Canyon
Scripps Canyon
Pier
M.L.L.W.
1.2
1.7
1.8
2.4
2.8
2.4
2.1
1.8
S. I. O.

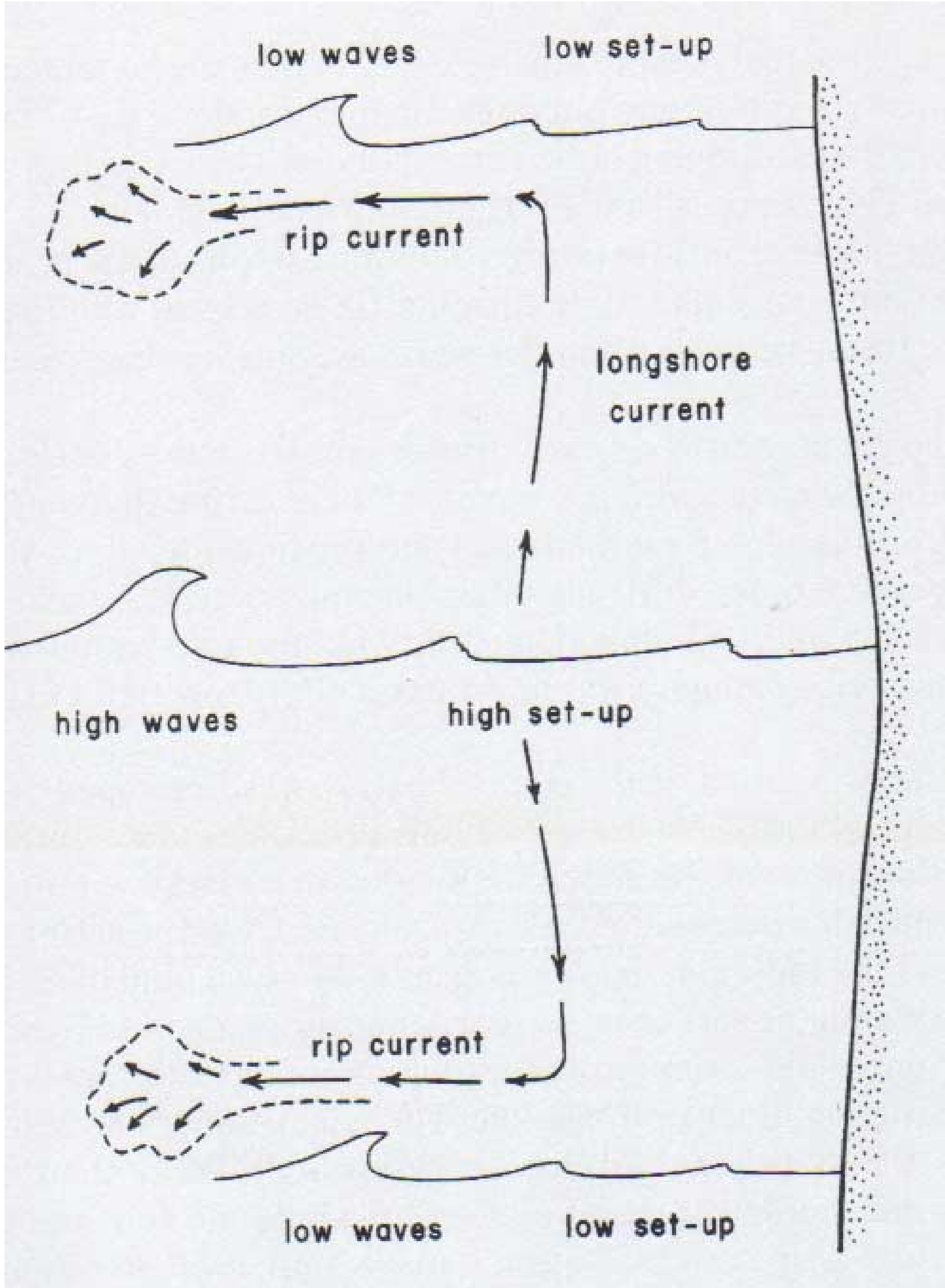


(A)
Scripps Canyon
18 November 1948
Wave period 7·6 sec
Waves from WNW
0 – ¼ kn
¼ – ½ kn
½ – 1 kn
> 1 knot
Observed current (not measured)
Starting position of surface float
Hb = Breaker height
Float recovery area
Shelf
No. 40
No. 30
No. 20
No. 10
No. 1
La Jolla Canyon
A
Hb=9'
Hb=11'
Scripps Institution
B
B-1
50
B-2
40, 47, 49
C
Hb=11'
C-1
C-2
Hb=13'
D
24, 32–34,36–39,41
D-1
D-2
15,22,26,27,29–31
D-3
Hb=9'
E
Hb=6'
E-1
8–10,12,13,16,
19–21,23,25
F
Hb=5'
2–5,7
F-1
Hb=4'
1,6
G
G-1
G-2
Beach club
N
ft
0
500
1000
0
100
200
300
m

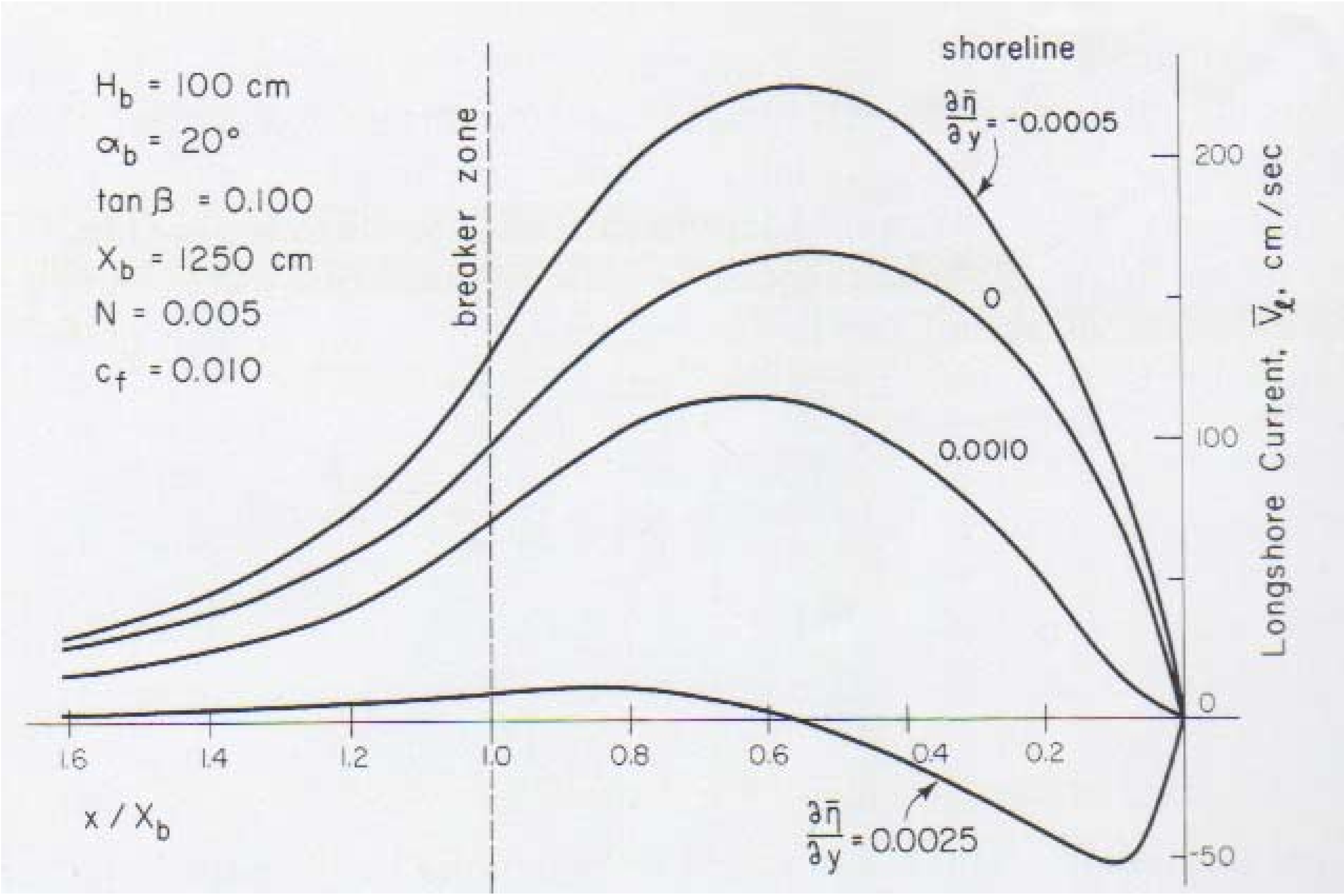


EXPERIMENT
T = 1.14 sec
● H_b = 8.55 cm
○ H_b = 6.60 cm
SET-DOWN AND SET-UP
set-up
beach
still water level
set-down
WAVE HEIGHT
MEAN WATER LEVEL, η̄, cm
2.5
2.0
1.5
1.0
0.5
0
0.5
WAVE HEIGHT, H, cm
10
5
0
300
200
100
0


horizontal swash
½ R_s^H
swash excursion
½ R_s^v = vertical swash
set-up slope
η̄ = set-up
still-water level
sea bed

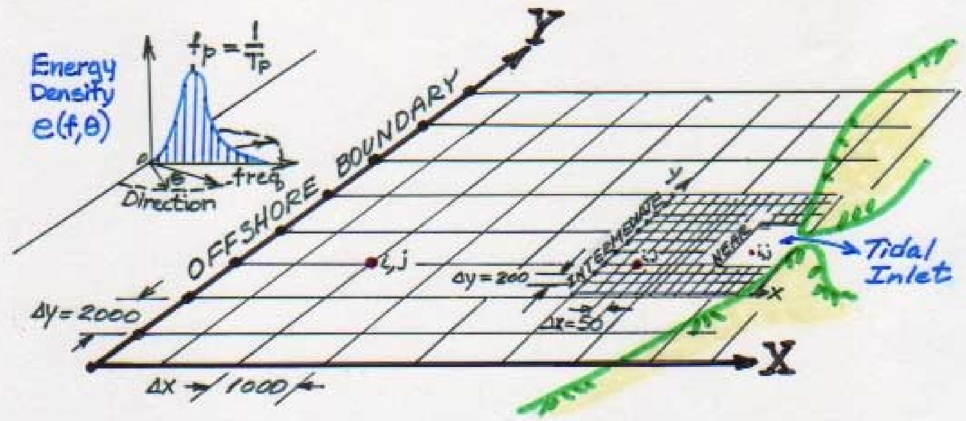


low waves
low set-up
rip current
longshore
current
high waves
high set-up
rip current
low waves
low set-up



H_b = 100 cm
α_b = 20°
tan β = 0.100
X_b = 1250 cm
N = 0.005
c_f = 0.010
breaker zone
shoreline
$\frac{\partial \bar{\eta}}{\partial y}$ = -0.0005
0
0.0010
$\frac{\partial \bar{\eta}}{\partial y}$ = 0.0025
200
100
0
-50
Longshore Current, $\bar{V}_\ell$, cm/sec
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
x / X_b

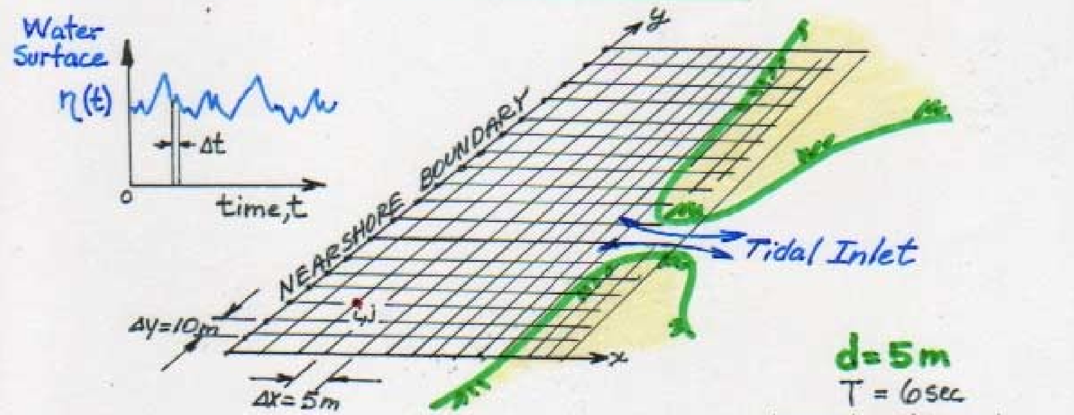
PHASE-AVERAGED MODELS

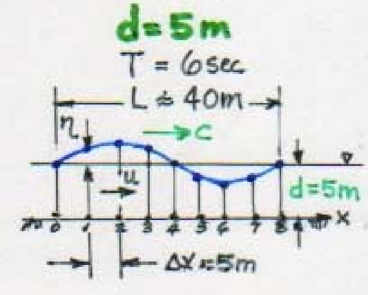


Model Calculates - Steady State

$e\,(f,\theta,x,y)$
$H_{mo}\,(x,y,\theta)$
$T_p\,(x,y,\theta)$
$\theta_m\,(x,y)$

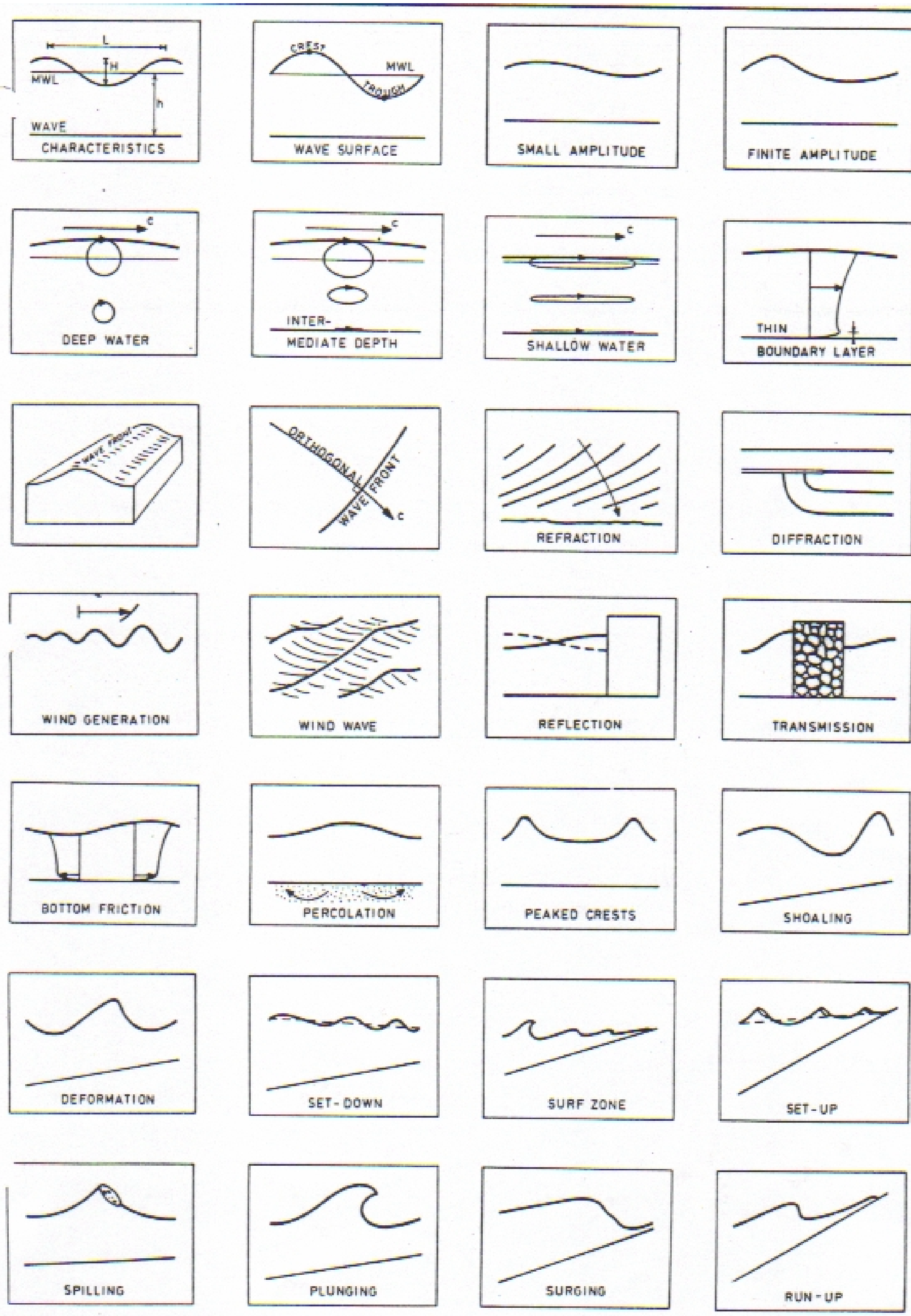
PHASE-RESOLVING MODELS





Model Calculates - Time Marching

$\eta\,(x,y,t)$
$u\,(x,y,t)$
$v\,(x,y,t)$



L
H
MWL
h
WAVE
CHARACTERISTICS
CREST
MWL
TROUGH
WAVE SURFACE
SMALL AMPLITUDE
FINITE AMPLITUDE
c
DEEP WATER
c
INTER-
MEDIATE DEPTH
c
SHALLOW WATER
THIN
BOUNDARY LAYER
WAVE FRONT
ORTHOGONAL
WAVE FRONT
c
REFRACTION
DIFFRACTION
WIND GENERATION
WIND WAVE
REFLECTION
TRANSMISSION
BOTTOM FRICTION
PERCOLATION
PEAKED CRESTS
SHOALING
DEFORMATION
SET-DOWN
SURF ZONE
SET-UP
SPILLING
PLUNGING
SURGING
RUN-UP