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TOPIC 2
WAVES

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Course Learning Outcomes

Upon completion of this course, students should be able to:

1. Evaluate the properties of offshore and near shore waves and establish design wave specification.
2. Assess currents and tidal processes.
3. Formulate sediment budget and perform shoreline evolution analysis.

- Part 1: Introduction to Ocean Waves
- Part 2: Linear Wave Theory
- Part 3: Nearshore Wave Transformation
- Part 4: Wave Statistics

Part 3: Nearshore Wave Transformation

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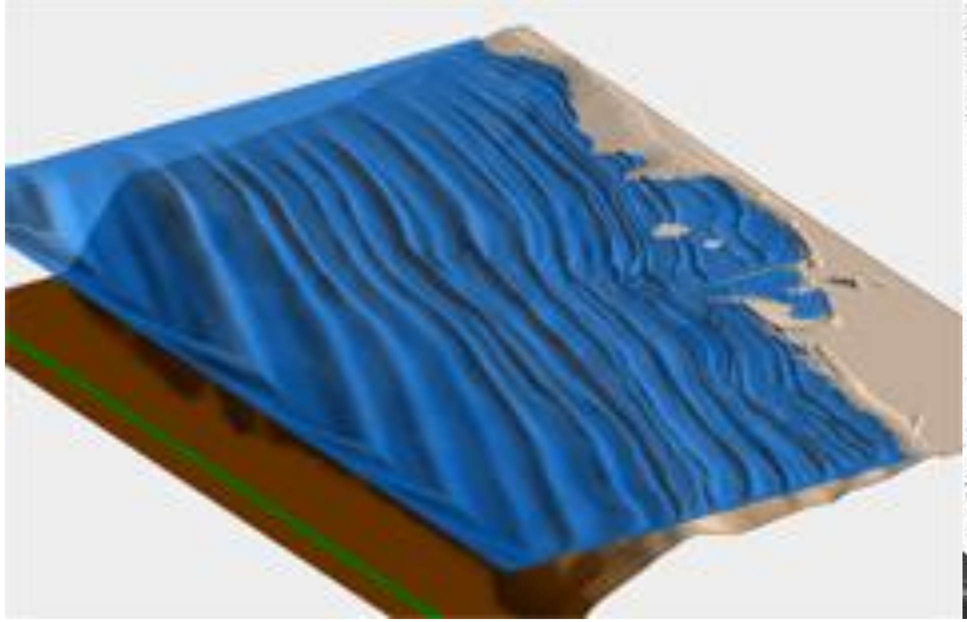
Learning Outcomes

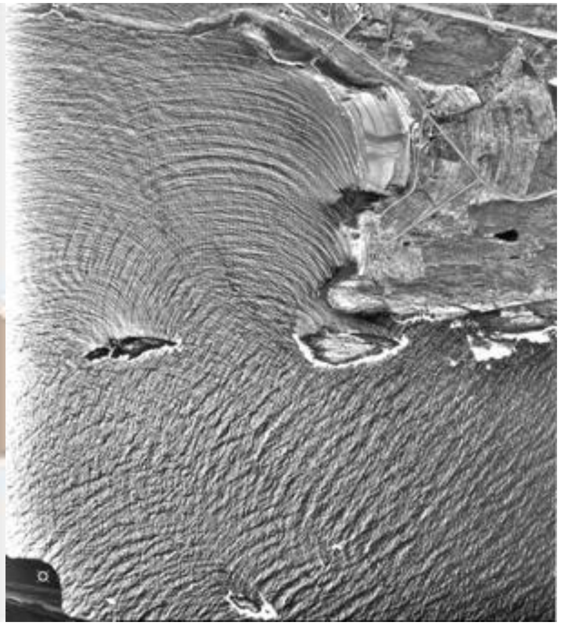
Upon completion of this topic, students should be able:

- To estimate the nearshore wave heights.

Wave Transformation

- Waves transform as they propagate from deep into shallow water.
- Waves propagating through shallow water are strongly influenced by the underlying bathymetry.
- Wave transformation processes:
  - Shoaling
  - Breaking
  - Refraction
  - Diffraction
  - Reflection
  - Wave run-up





Wave Shoaling

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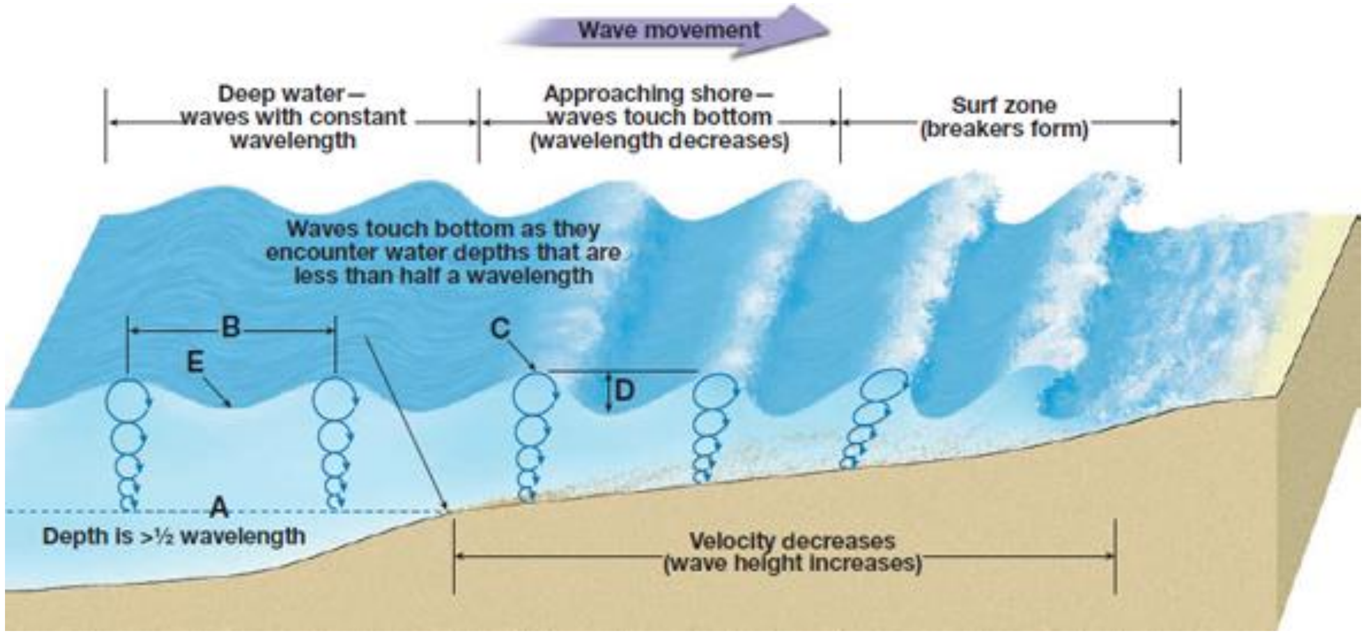
WAVE SHOALING

- As the deepwater wave begins to enter more shallow water ($d/L < 0.5$), it begins to 'feel bottom' and starts to transform.
- The waves are slowed, shortened, and steepened, as they travel from deeper water into more shallow water.



https://johnbarrett.net/2020/11/01/the-science-of-surfing/

Consider a wave front traveling parallel to the seabed contours (i.e. no refraction is taking place). Making assumption that wave energy is transmitted shoreward without losses due to bed friction or turbulence,

$$\frac{P}{P_0} = 1 = \frac{EC_g}{E_0 C_{g0}}$$

The power transmitted forward by a wave in one depth will be equal to that being transmitted at any other depth

Substituting

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

then,

$$\frac{P}{P_0} = 1 = \left(\frac{H}{H'_0}\right)^2 \frac{C_g}{C_{g0}}$$

https://johnbarrett.net/2020/11/01/the-science-of-surfing/

SHOALING COEFFICIENT

The shoaling coefficient, K_s is

$$K_s = \frac{H}{H'_0} = \sqrt{\frac{C_{g0}}{C_g}} = \sqrt{\frac{C_0}{2C_g}} = \sqrt{\frac{C_0}{2nC}}$$

Group velocity factor:

$$n = \frac{1}{2}\left[1 + \frac{4\pi d / L}{\sinh(4\pi d / L)}\right]$$

Deep water, $n = 0.5$; $C_G = 0.5C$

Shallow water, $n = 1$; $C_G = C$

Transitional water, $0.5 < n < 1$

Table C-1 (Shore Protection Manual, 1984)

Table C-1. Continued.

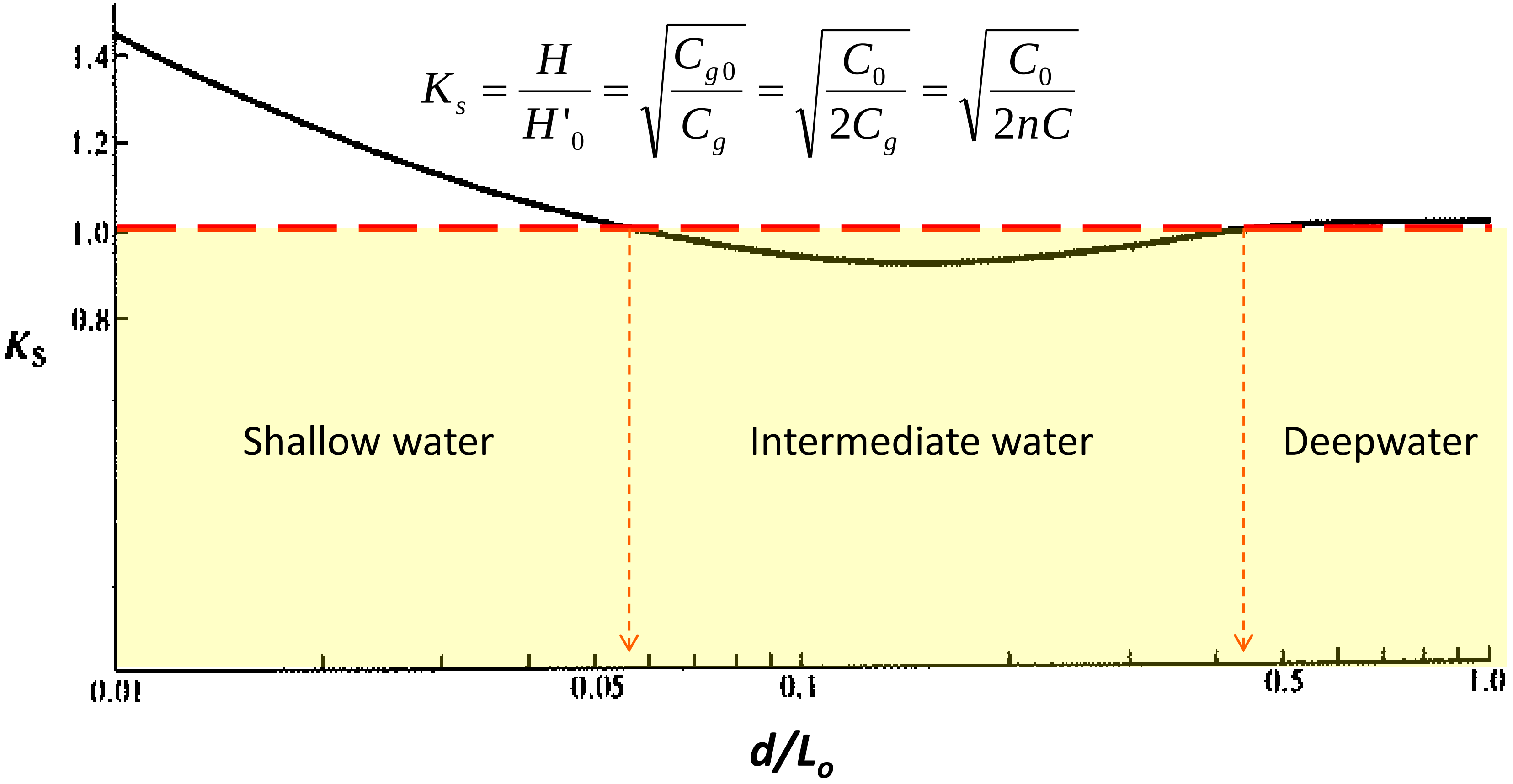
K_s

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
.3300	.3394	2.133	.9723	4.159	4.277	.9583	.2338	4.265	35.58	35.59	.5599	.5444	5.220
.3310	.3403	2.138	.9726	4.184	4.301	.9586	.2325	4.277	35.99	36.00	.5594	.5441	5.217
.3320	.3413	2.144	.9729	4.209	4.326	.9589	.2312	4.288	36.42	36.43	.5589	.5438	5.214
.3330	.3422	2.150	.9732	4.234	4.350	.9592	.2299	4.300	36.84	36.85	.5584	.5434	5.210
.3340	.3431	2.156	.9735	4.259	4.375	.9595	.2286	4.311	37.25	37.27	.5578	.5431	5.207
.3350	.3440	2.161	.9738	4.284	4.399	.9598	.2273	4.323	37.70	37.72	.5573	.5427	5.204
.3360	.3449	2.167	.9741	4.310	4.424	.9601	.2260	4.335	38.14	38.15	.5568	.5424	5.201
.3370	.3459	2.173	.9744	4.336	4.450	.9604	.2247	4.346	38.59	38.60	.5563	.5421	5.198
.3380	.3468	2.179	.9747	4.361	4.474	.9607	.2235	4.358	39.02	39.04	.5558	.5417	5.194
.3390	.3477	2.185	.9750	4.388	4.500	.9610	.2222	4.369	39.48	39.49	.5553	.5414	5.191
.3400	.3468	2.190	.9753	4.413	4.525	.9613	.2210	4.381	39.95	39.96	.5548	.5411	5.188
.3410	.3495	2.196	.9756	4.439	4.550	.9615	.2198	4.392	40.40	40.41	.5544	.5408	5.185
.3420	.3504	2.202	.9758	4.466	4.576	.9618	.2185	4.404	40.87	40.89	.5539	.5405	5.182
.3430	.3514	2.208	.9761	4.492	4.602	.9621	.2173	4.416	41.36	41.37	.5534	.5402	5.179
.3440	.3523	2.214	.9764	4.521	4.630	.9623	.2160	4.427	41.85	41.84	.5529	.5399	5.176
.3450	.3532	2.220	.9767	4.547	4.656	.9626	.2148	4.439	42.33	42.34	.5524	.5396	5.173
.3460	.3542	2.225	.9769	4.575	4.682	.9629	.2136	4.451	42.83	42.84	.5519	.5392	5.171
.3470	.3551	2.231	.9772	4.602	4.709	.9632	.2124	4.462	43.34	43.35	.5515	.5389	5.168
.3480	.3560	2.237	.9775	4.629	4.736	.9635	.2111	4.474	43.85	43.86	.5510	.5386	5.165
.3490	.3570	2.243	.9777	4.657	4.763	.9638	.2099	4.486	44.37	44.40	.5505	.5383	5.162
.3500	.3579	2.249	.9780	4.685	4.791	.9640	.2087	4.498	44.89	44.80	.5501	.5380	5.159
.3510	.3588	2.255	.9782	4.713	4.818	.9643	.2076	4.509	45.42	45.43	.5496	.5377	5.157
.3520	.3598	2.260	.9785	4.741	4.845	.9646	.2064	4.521	45.95	45.96	.5492	.5374	5.154

SHOALING COEFFICIENT

Shoaling effect may be to stretch or concentrate the energy, so it may increase or decrease the wave amplitude.

$$K_s = \frac{H}{H'_0} = \sqrt{\frac{C_{g0}}{C_g}} = \sqrt{\frac{C_0}{2C_g}} = \sqrt{\frac{C_0}{2nC}}$$



SHOALING COEFFICIENT

Shoaling of finite height waves was also derived using the **Cnoidal wave theory.**

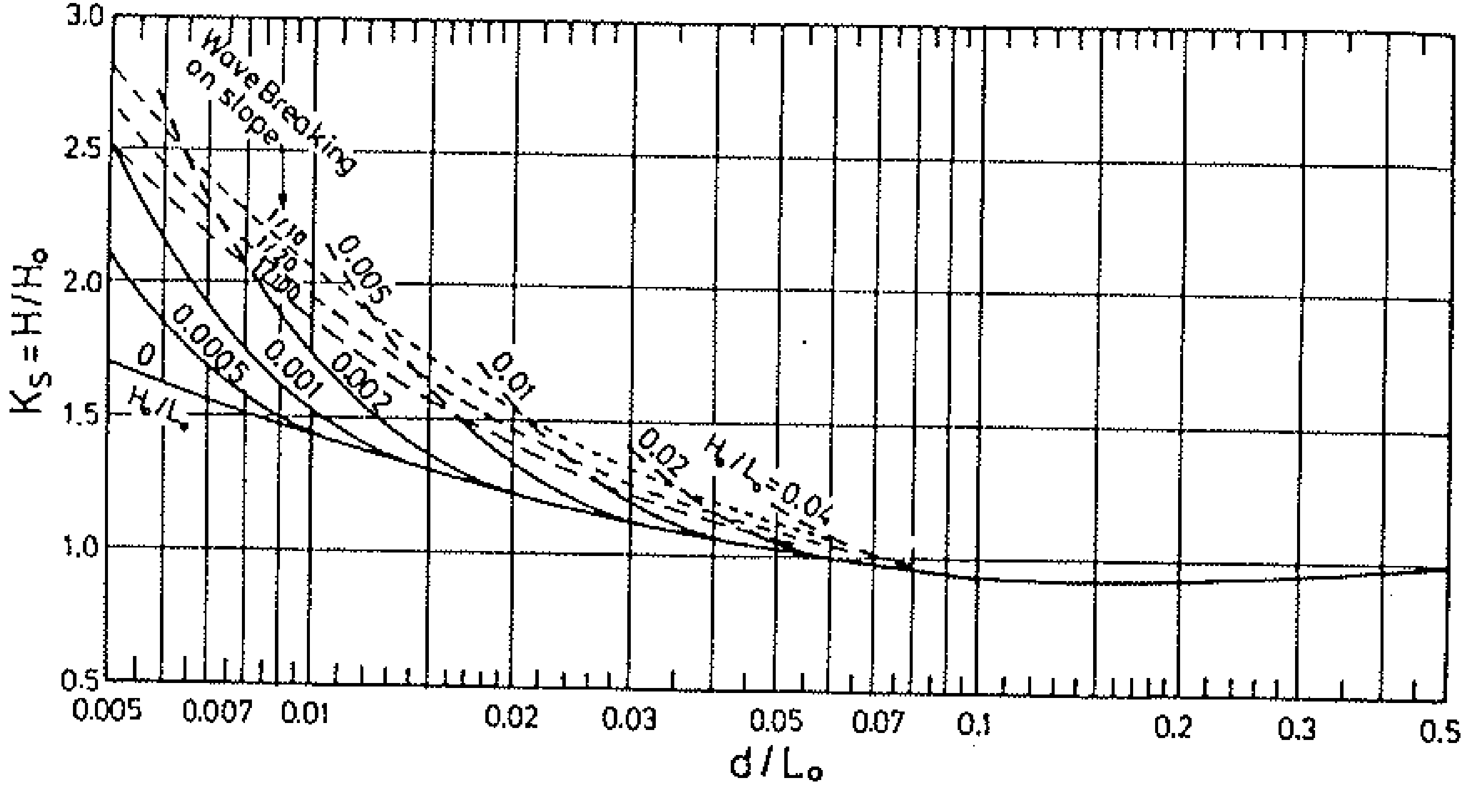
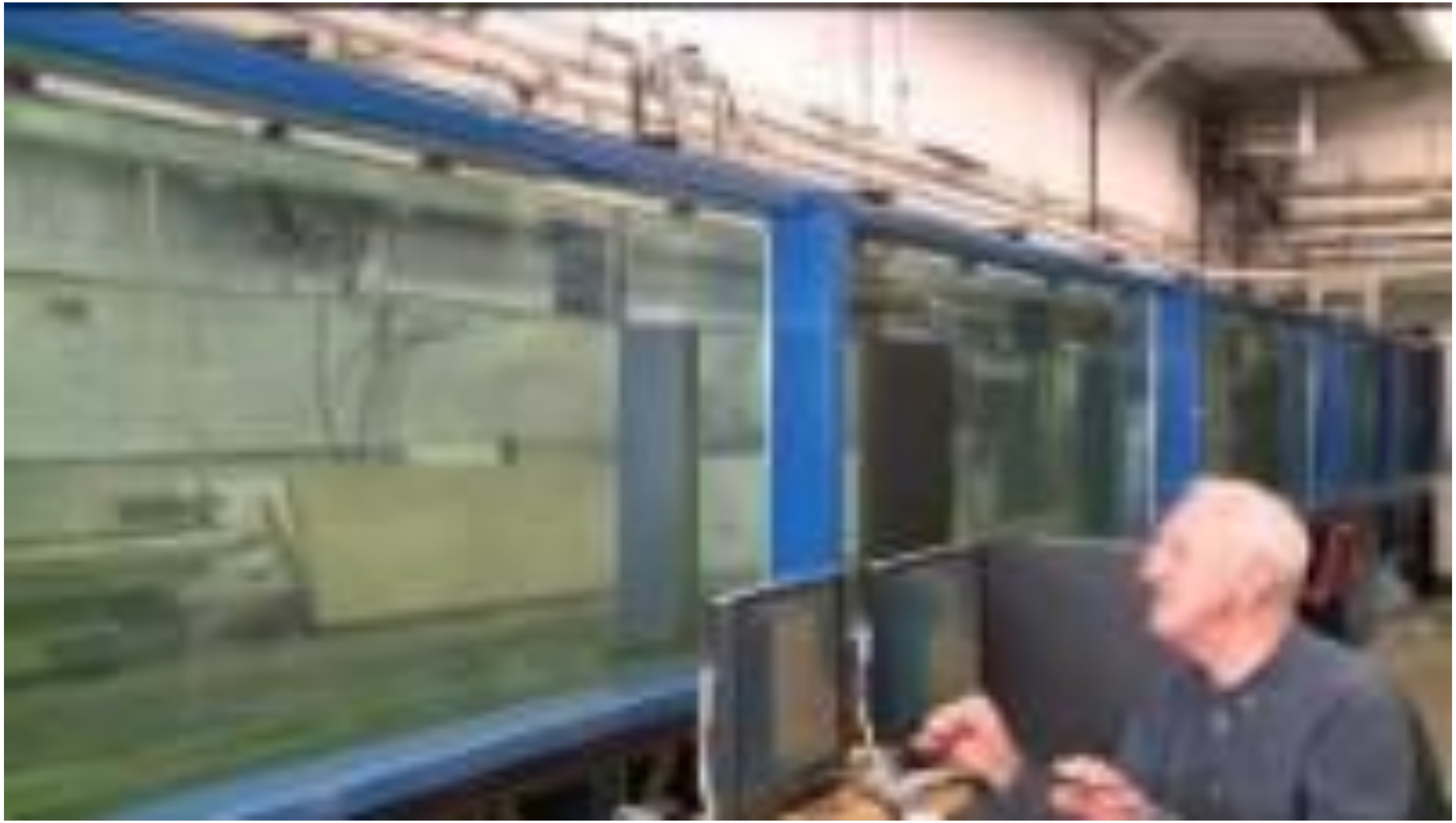


Figure 2.63 Shoaling coefficient H/H_o versus depth ratio d/L_o for various H_o/L_o (Goda 1985)

Silvester & Hsu (1997). 'Coastal Stabilization'. Singapore: World Scientific, pp. 86

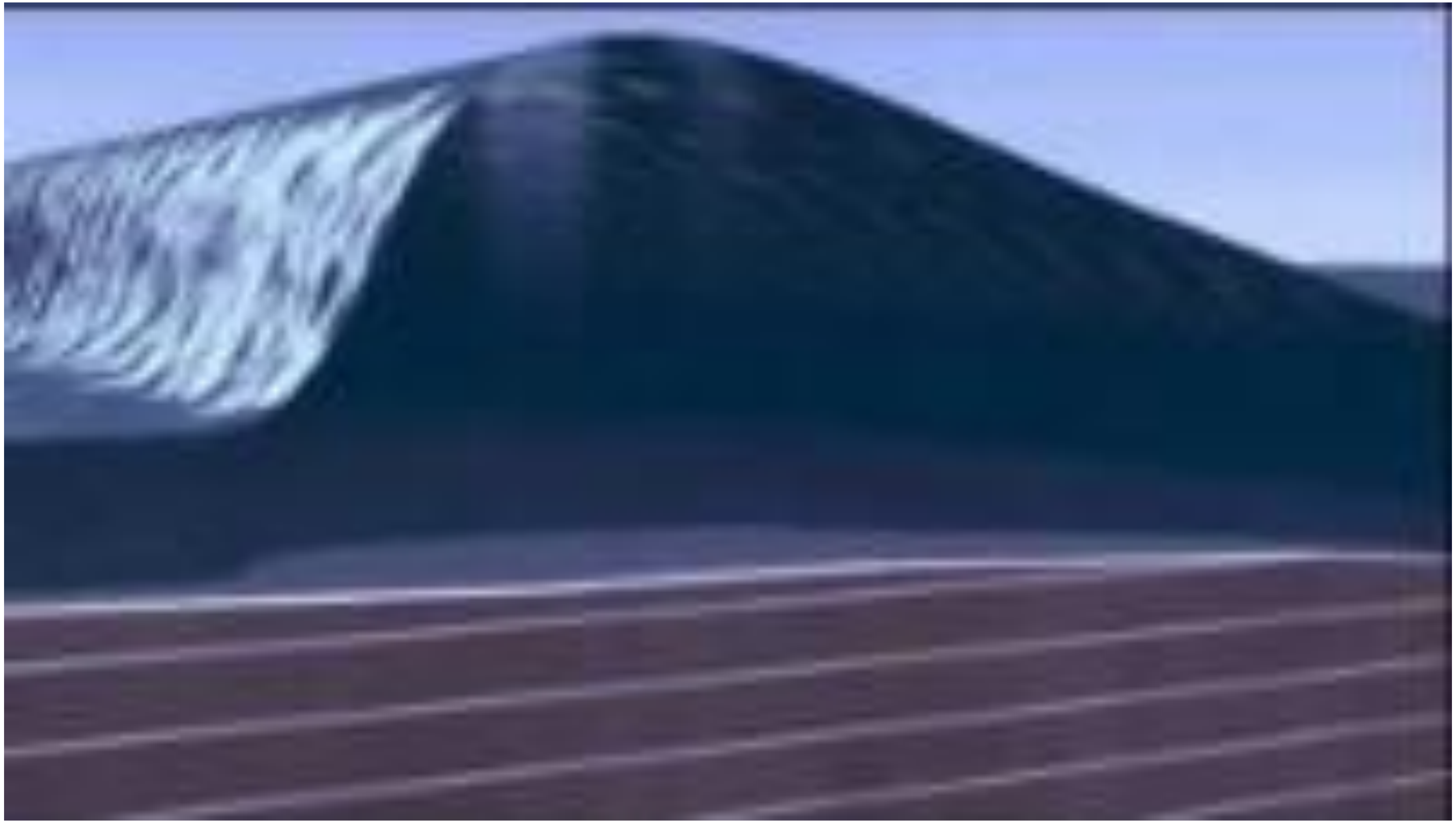
Making Waves in a Flume



Demonstration of Wave Shoaling

https://youtu.be/-m_VDE-BSgc

Formation of Tsunami Waves



https://youtu.be/SlwZzbGh7Cw

BREAKING

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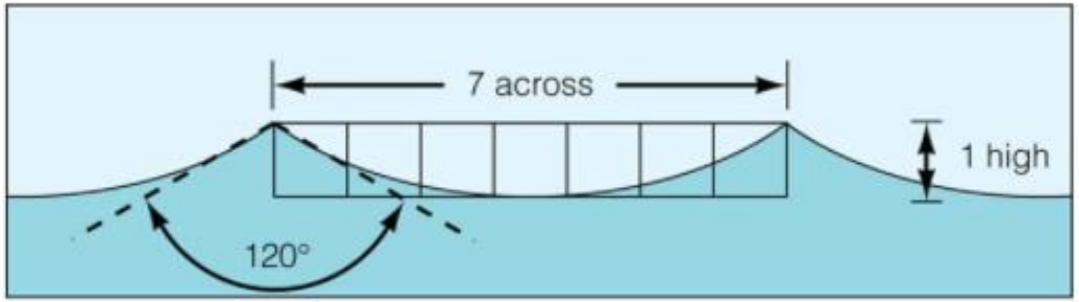
OPEN-WATER WHITECAPS IN DEEPWATER

- Induced by strong winds that increase wave heights rapidly.
- The maximum wave height is limited by a maximum wave steepness for which the waveform can remain stable. Beyond the limiting steepness, the wave begins to break and dissipate a part of their energy.
- Michell (1893) found the limiting steepness to be given by

$$\frac{H_o}{L_o} = 0.142 \approx \frac{1}{7}$$

which occurs when the crest angle is 120°.



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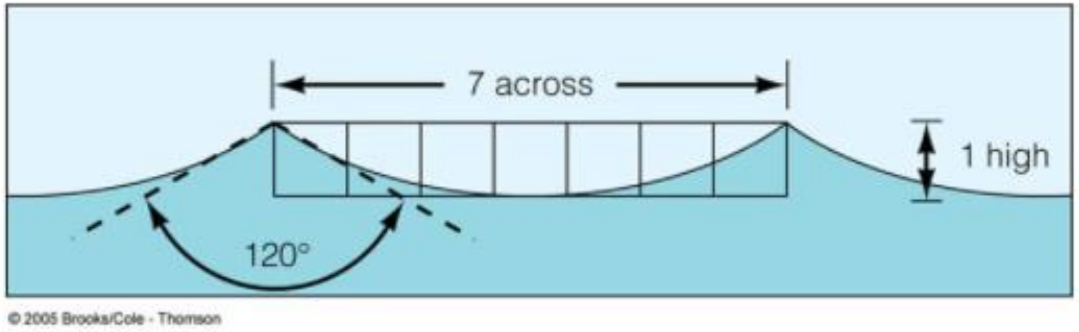
Open-water Whitecaps in Deepwater

- Michell (1893) found the limiting steepness to be given by

$$\frac{H_o}{L_o} = 0.142 \approx \frac{1}{7}$$

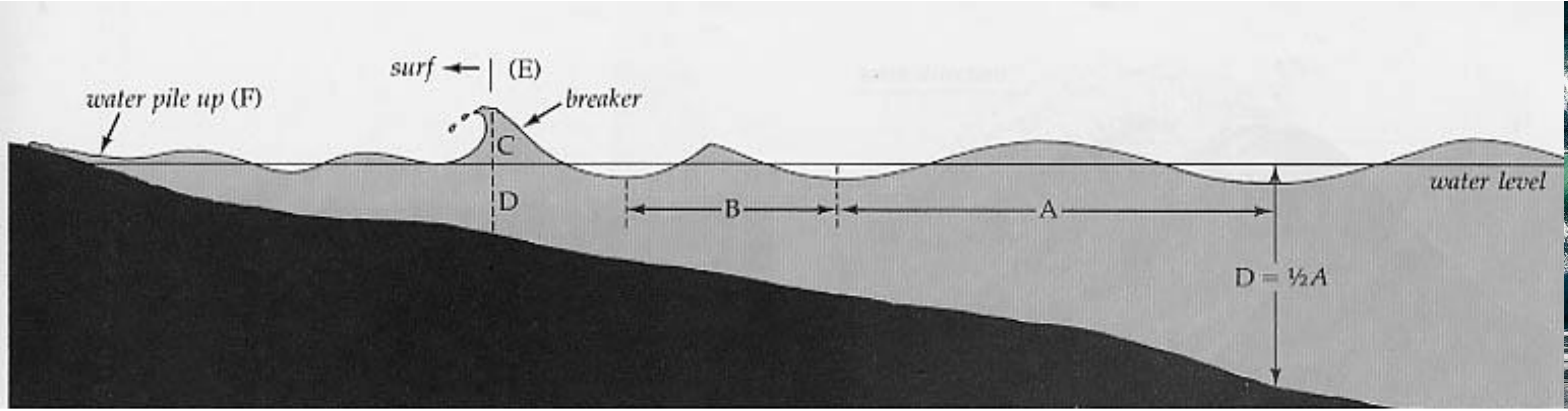
which occurs when the crest angle is 120°.

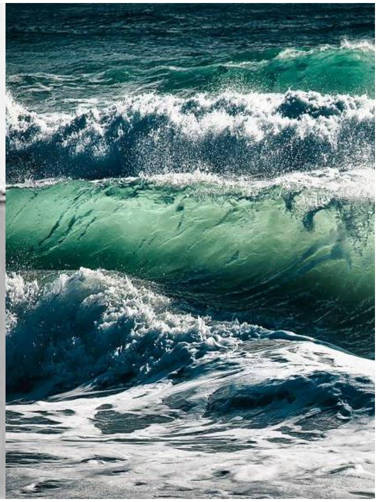


- This limiting steepness occurs when the water particle velocity at the wave crest just equals the wave celerity ($u_c \approx c$).

- A further increase in steepness would result in particle velocities at the wave crest greater than the wave celerity ($u_c > c$) and, consequently, instability.

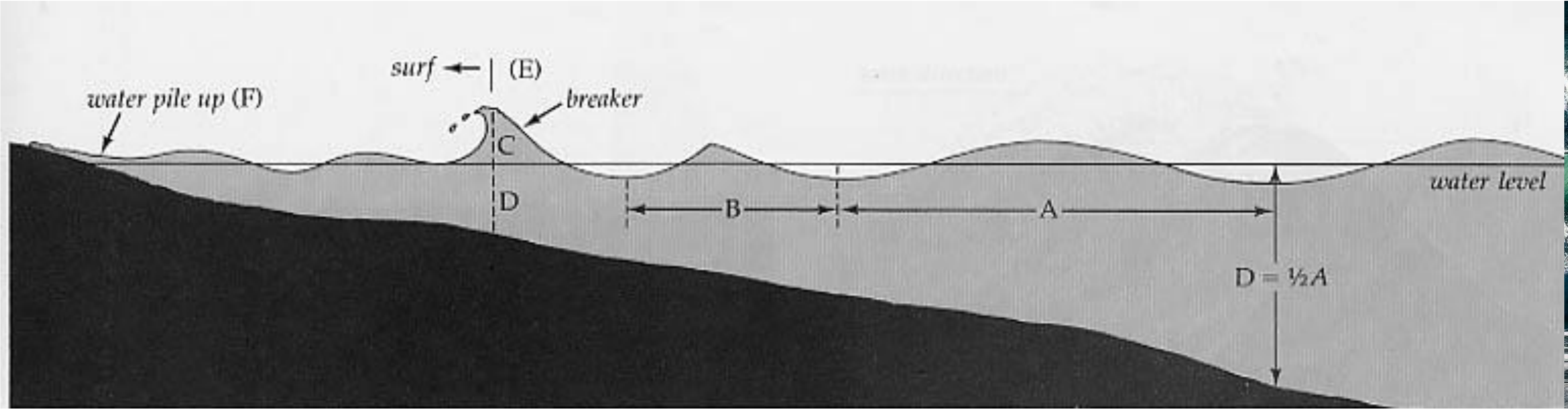
Nearshore Wave Breaking

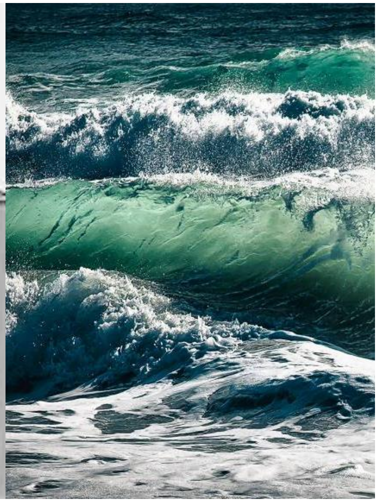




- When wave moves into shoaling water, the limiting steepness is a function of the relative depth d/L and the beach slope m perpendicular to the direction of wave advance.
- Deepwater waves start to feel the bottom when $d/L \approx ½$. The water particle motion reaches to bottom and disturbs sediments. Underwater friction and turbulence at bottom slows the wave and shortens wavelength.

NEARSHORE WAVE BREAKING





- When the wave steepness reaches a limiting steepness, the wave breaks, dissipating energy and inducing nearshore currents and an increase in mean water level.
- Breakers disturb bottom, erode & transport sediments.

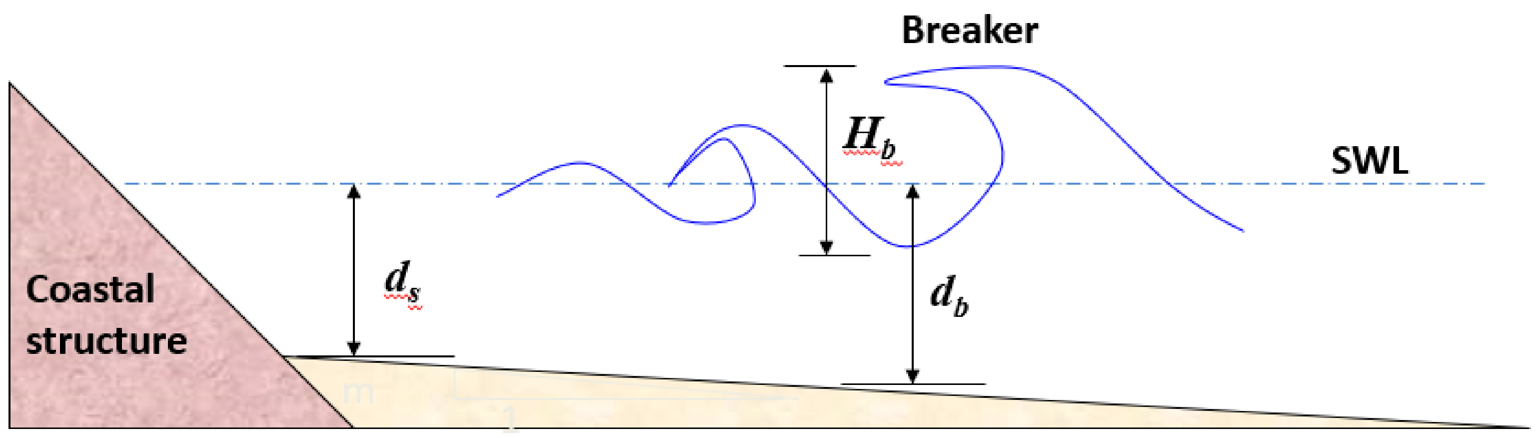
Wave Breaking Demonstration

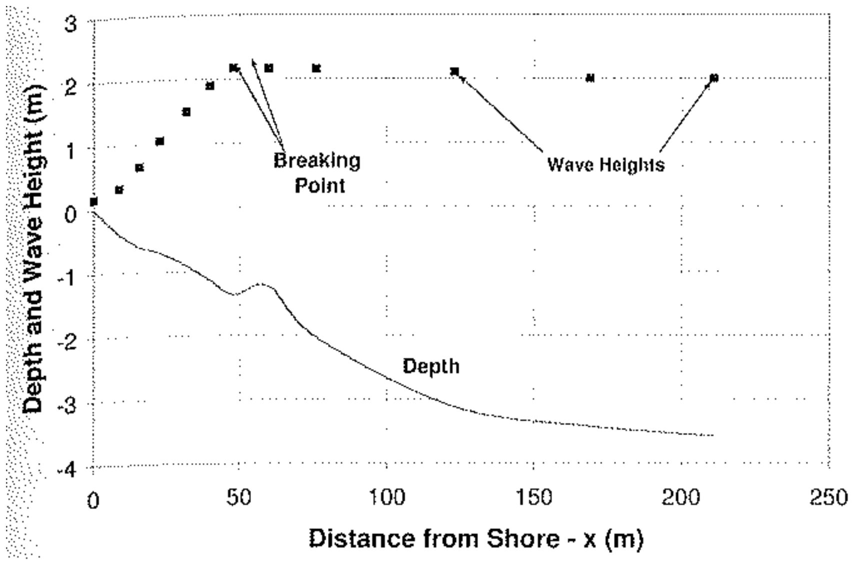
https://youtu.be/ouoodQg3XD0

WAVE BREAKING

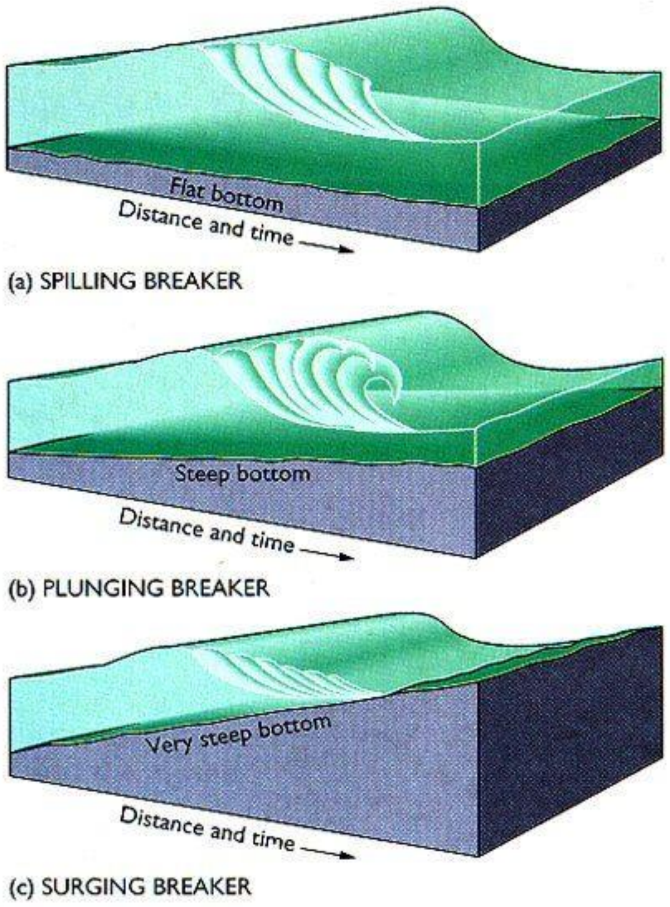
https://youtu.be/BQptkdzvmjE

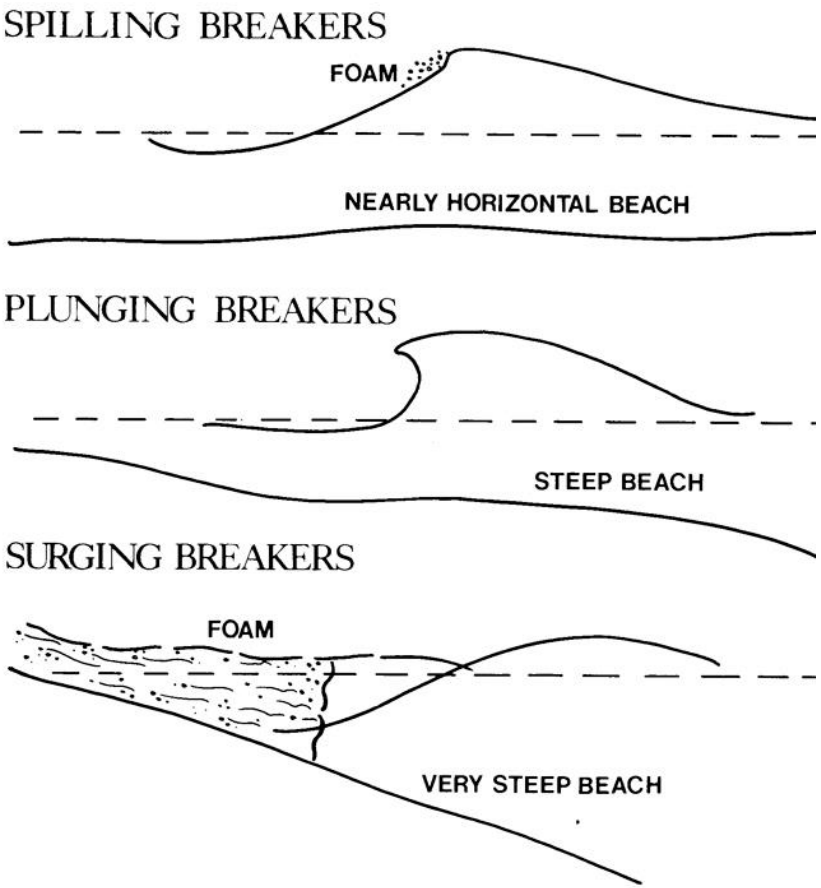
- **Breaking depth d_b** - The depth that is shallow enough to initiate breaking.
- **Breaker height H_b** - The maximum limit of wave height above which the wave becomes unstable and breaks.





Breaker Type



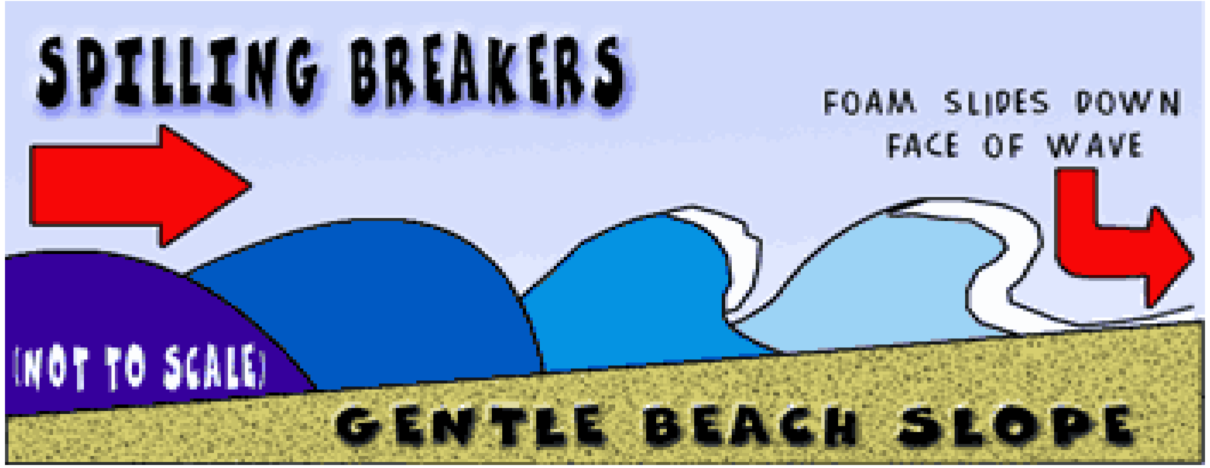


https://www.pinterest.com/joegoofy69/19sportsi-love-to-surf/

https://www.theinertia.com/surf/spilling-surging-plunging-the-science-of-breaking-waves/

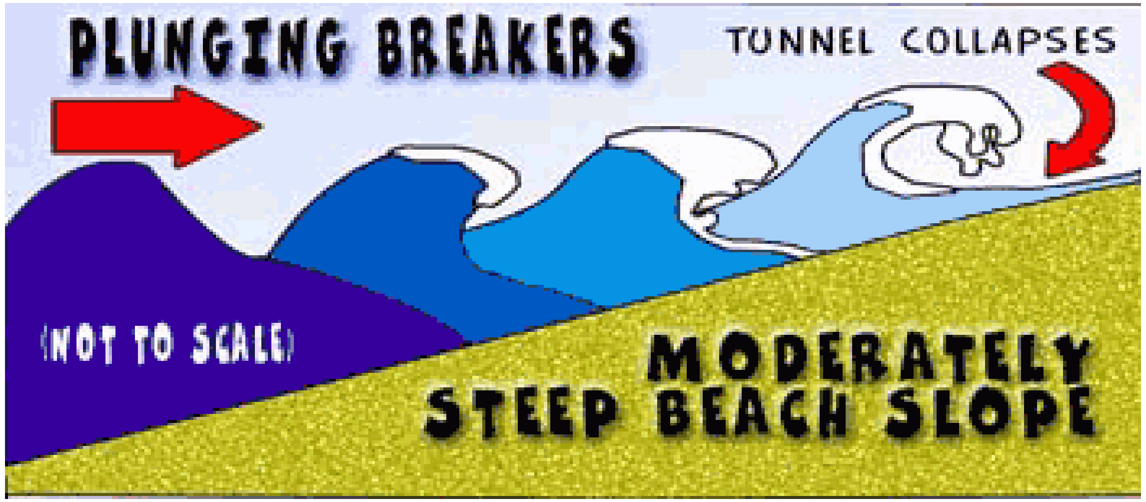
The breaker type is a function of the beach slope m and the wave steepness H/L.

Spilling Breaker



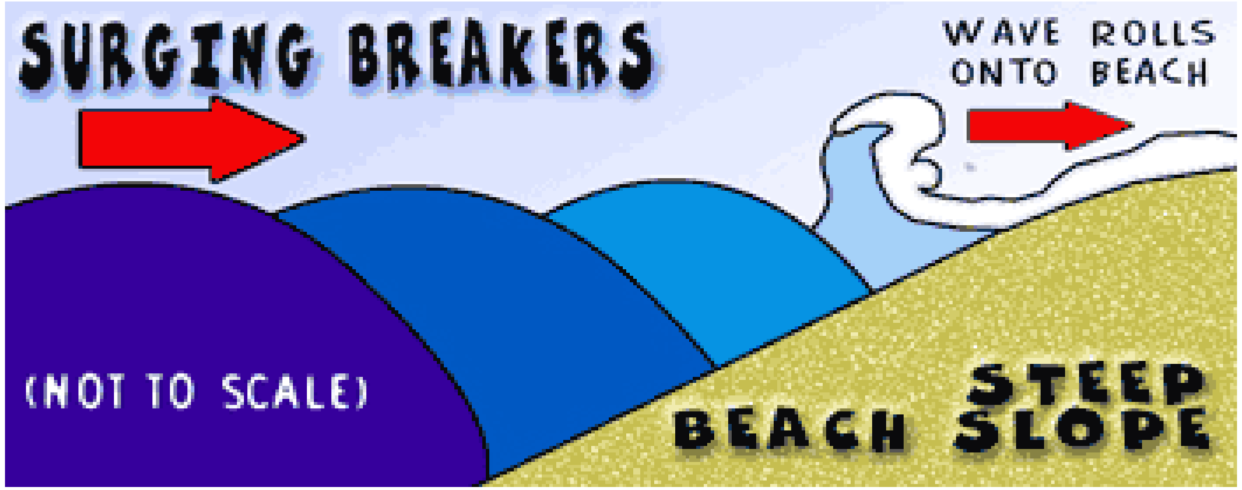
- Occur for high steepness waves on gently sloping beaches.
- Portions of the wave crest appear to break gently (spill), creating foam as it spills down the face of the wave.
- Several wave crests may be breaking simultaneously, giving the appearance of several rows of breaking waves throughout the breaking zone (dissipative beaches).
- Spilling breakers generate less turbulence near the bottom and thus tend to be less effective in suspending sediment.

Plunging Breaker



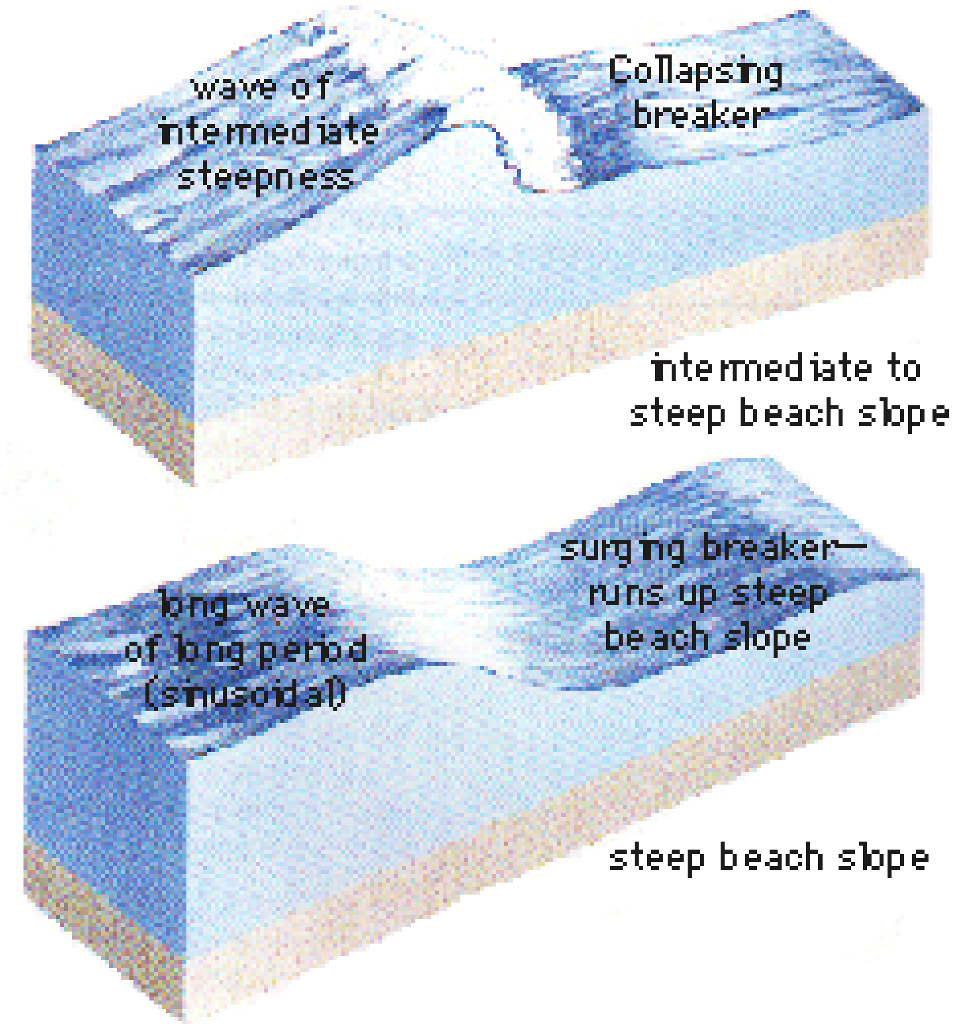
- Occur on steeper beaches and/or for flatter waves.
- Wave curls over forming a tunnel until the wave breaks and plunges down the face of the wave in a violent tumbling action, resulting in high splash and scour into sea bottom.
- Plunging breakers are more commonly associated with swell waves that approach the beach with much longer wavelengths.
- Expert surfers love this type of wave!

Surging Breaker



- Occur on very steep beaches/man-made seawall or for long waves.
- Wave crest remains unbroken and the front face of the wave advances up the steep beach with very little or no breaking.
- The entire face of the wave usually displays churning water and produces foam, but an actual curl never develops.
- Creates the appearance that the water level at the beach is suddenly rising and falling.

Collapsing Breaker



- Breakers in the transition from plunging to surging, occur on steep beaches.
- Wave fronts more or less explodes forwards.
- May be found where swell breaks on steep beaches made up of course materials.
- Beaches with collapsing and surging breakers are often called reflective beaches.

Surf Similarity Parameter

Breaker type may be correlated to the surf similarity parameter, ξ_b

$$\xi_b = \frac{m}{\sqrt{H_b / L_b}}$$

H_b = Breaker height
L_b = Breaker wavelength
m = beach slope = tan β

On a uniformly sloping beach, breaker type is estimated by ξ_b:

Spilling Breaker:	$\xi_b < 0.4$
Plunging Breaker:	$0.4 < \xi_b < 2.0$
Collapsing / Surging Breaker:	$\xi_b > 2.0$

BREAKER INDEX

$$\gamma_b = \frac{H_b}{d_b}$$

H_b = Breaker height
d_b = Depth at breaking

Miche's Limiting Wave Steepness

Miche (1944) describes wave breaking (regular wave) in surf zone when the limiting wave steepness is:

$$\frac{H_b}{L_b} > 0.14 \tanh\left(\frac{2\pi d_b}{L_b}\right)$$

Munk's Breaker Index

Munk (1949) derived several relationships from a modified Solitary Wave Theory:

Breaker height index:

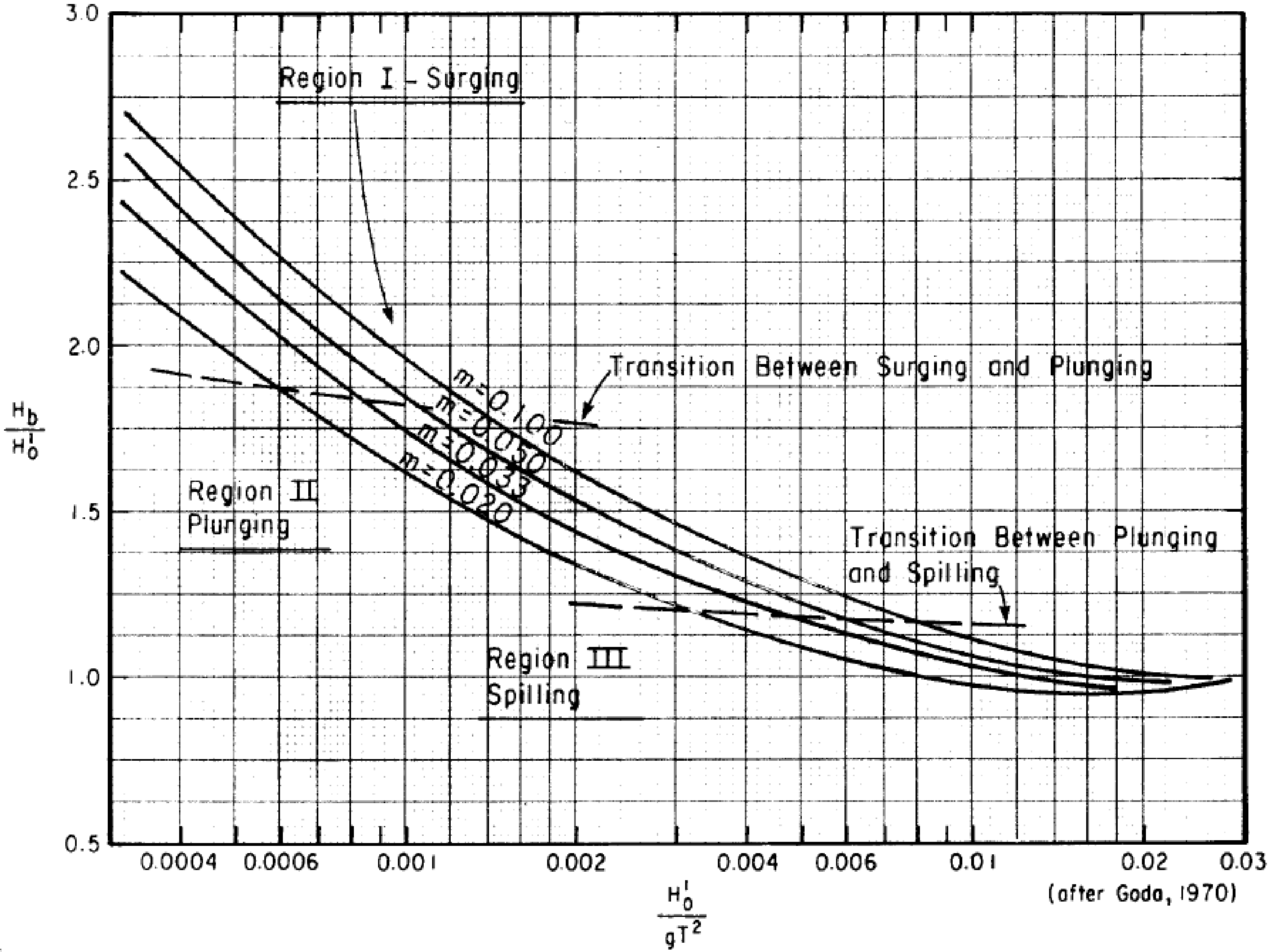
$$\frac{H_b}{H'_o} = \frac{1}{3.3\left(\frac{H'_o}{L_o}\right)^{\frac{1}{3}}}$$

Breaker depth index:

$$\frac{d_b}{H_b} = 1.28$$

GODA'S BREAKER INDEX

Goda (1970) developed the relative breaker height (H_b/H'_o) relating the beach slope (m) and the incident wave steepness (H'_o/gT^2).



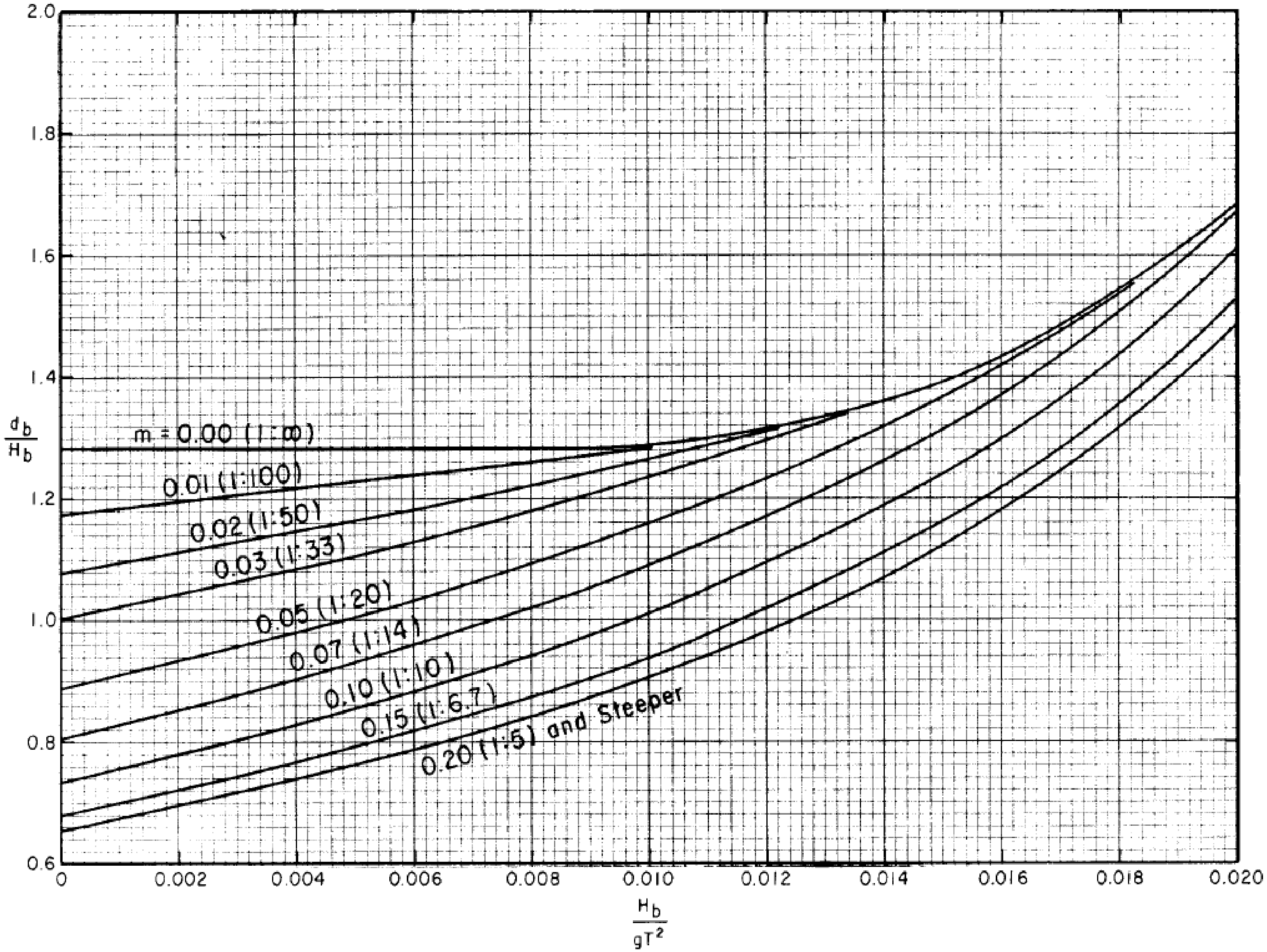
Goda's Breaker Depth Index

Goda (1970) developed an empirical relationship between H_b/d_b and d_b/L_o for various beach slopes:

$$\frac{H_b}{d_b} = 0.17\frac{L_o}{d_b}\left(1 - e^{-\left[\frac{1.5\pi d_b}{L_o}\left(1 + 15m^{\frac{4}{3}}\right)\right]}\right)$$

WEGGAL'S BREAKWATER DEPTH INDEX

Weggel (1973) developed empirical relationships between d_b/H_b and H_b/gT^2 for various beach slopes m:



USACE (1984) expressed the Weggel's results in the following equations:

$$\frac{H_b}{d_b} = \left(c_1 - c_2 \frac{H_b}{gT^2} \right)$$

where

$$c_1 = 43.75(1 - e^{-19m})$$

$$c_2 = \frac{1.56}{(1 + e^{-19.5m})}$$

Kamphuis' Breaker Index

Kamphuis (1991) proposed two criteria for irregular waves:

1. Wave steepness criterion:

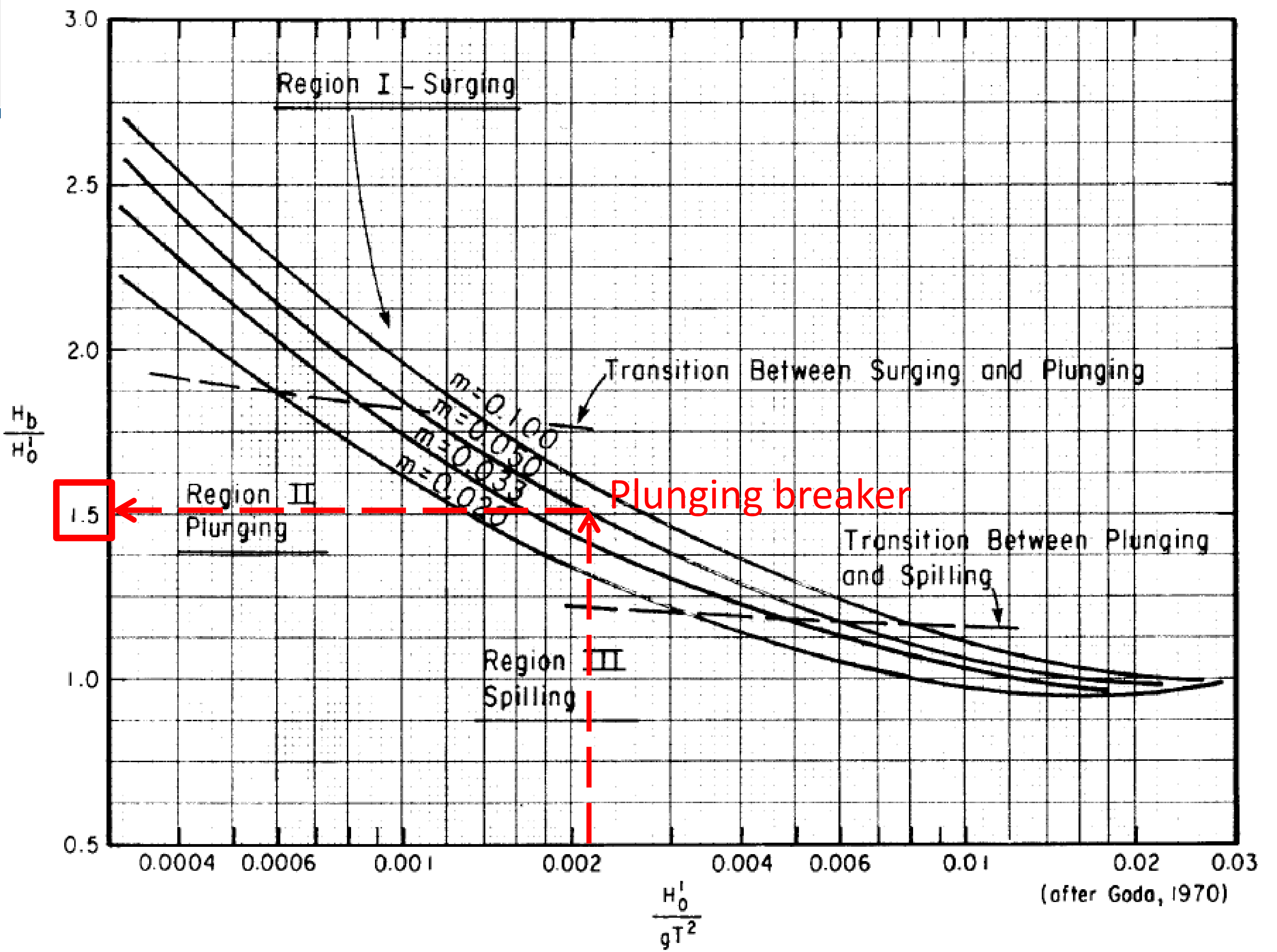
$$H_{sb} = 0.095 e^{4m} L_{bp} \tanh\left(\frac{2\pi d_b}{L_{bp}}\right)$$

2. Depth limited criterion:

$$\frac{H_{sb}}{d_b} = 0.56 e^{3.5m}$$

Problem 4

Given a beach having 1:20 slope; a wave with unrefracted deepwater height H_o' = 2.10 m and a period T = 10 s. Determine the breakwater height and the depth at which breaking occurs.

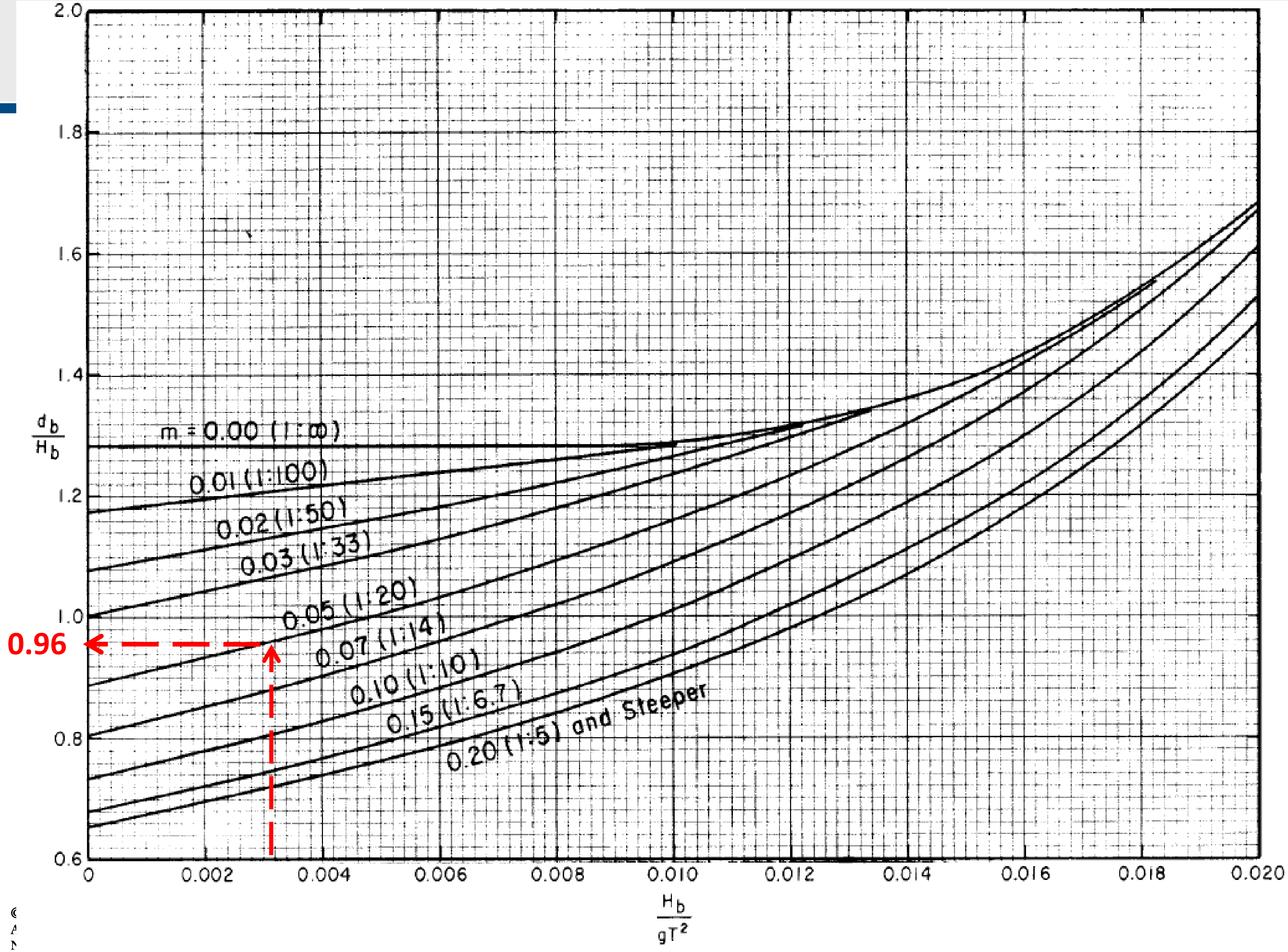


$$\frac{H'_o}{gT^2} = \frac{2.10}{9.8(10)^2} = 0.00214$$

1:20 (m = 0.05)

$H_b / H'_o = 1.50$

$H_b = 1.50(2.10) = 3.15$ m

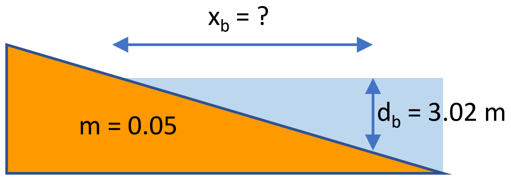


1:20 (m = 0.05)

$$\frac{H_b}{gT^2} = \frac{3.15}{9.8(10)^2} = 0.00321$$

$$\frac{d_b}{H_b} = 0.96$$

$$d_b = 0.96(3.15) = 3.02 \text{ m}$$



$m = 0.05 = 3.02 / x_b$

$x_b = 60.4$ m

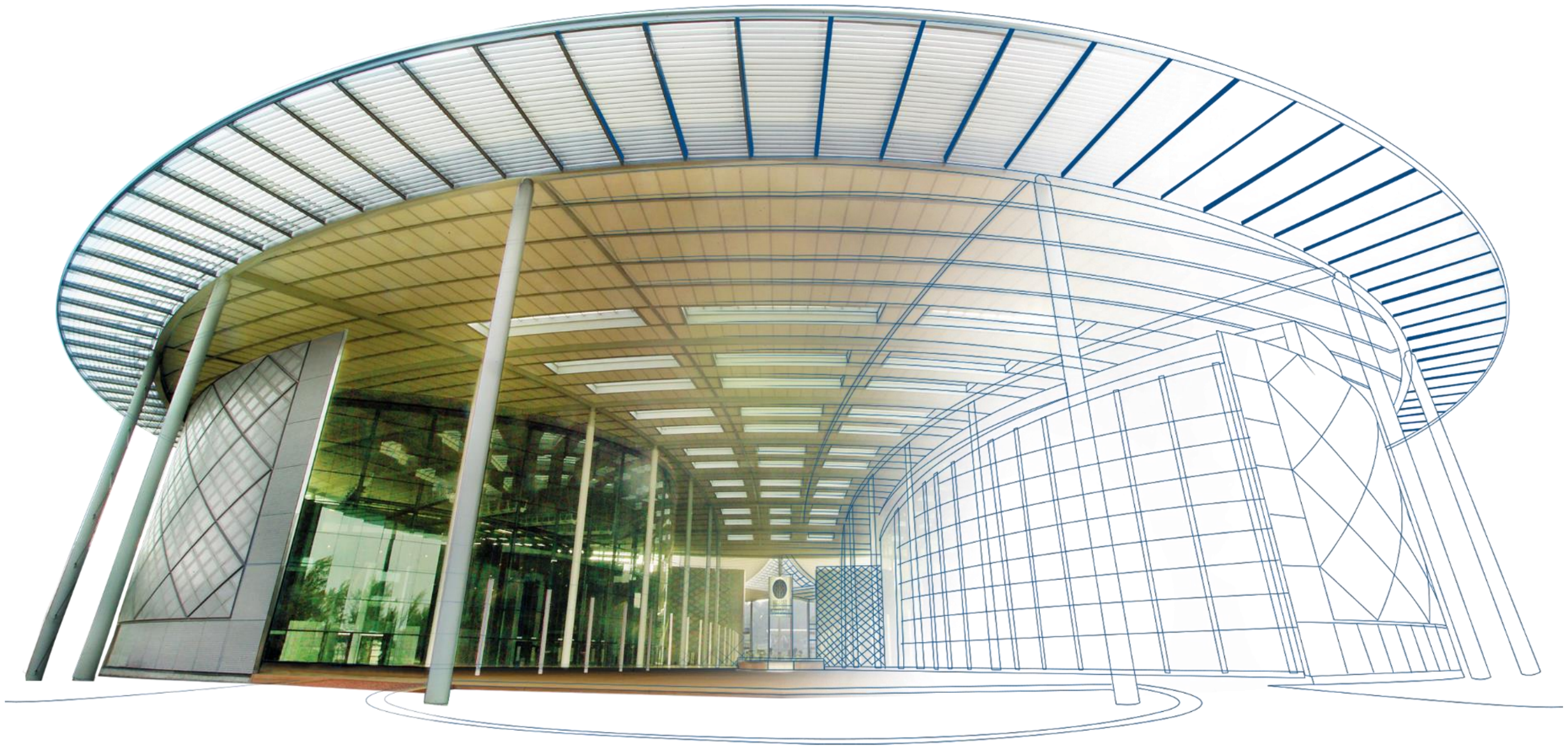
PROBLEM

A wave in deep water has 3 m high and 10 s period moving towards the shore with a slope of $m = 0.02$. Determine

- breaker height
- type of breaker
- breaker depth
- breaker length
- wave celerity at breaking
- distance of breaker line from the shore

Kind Reminder

1. Student attendance using MS PowerApps
2. T&L satisfaction poll



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