BET4733 Introduction to Coastal Infrastructure

Waves

by
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Chapter Description

- Expected Outcomes

  Analyze the principles of wave mechanics, tides, littoral processes and coastal sediment transport in methods of shore protection and coastal infrastructures.

- References

1) Kamphuis, J. William, Introduction to Coastal Engineering and Management, Advanced Series on Ocean Engineering-Volume 30, World Scientific, 2010.
2) Reeve D., Chadwick A. and Fleming C. Coastal Engineering-Processes, Theory and Design Practice, CRC Press, 2015.
3) Kim Y.C., Design of Coastal Structures and Sea Defences, World Scientific, 2015.
4) US Army Corps of Engineers, Coastal Engineering Manual, Washington, 1998-now.

CONTENTS

INTRODUCTION

WAVES

ENERGY SOURCE

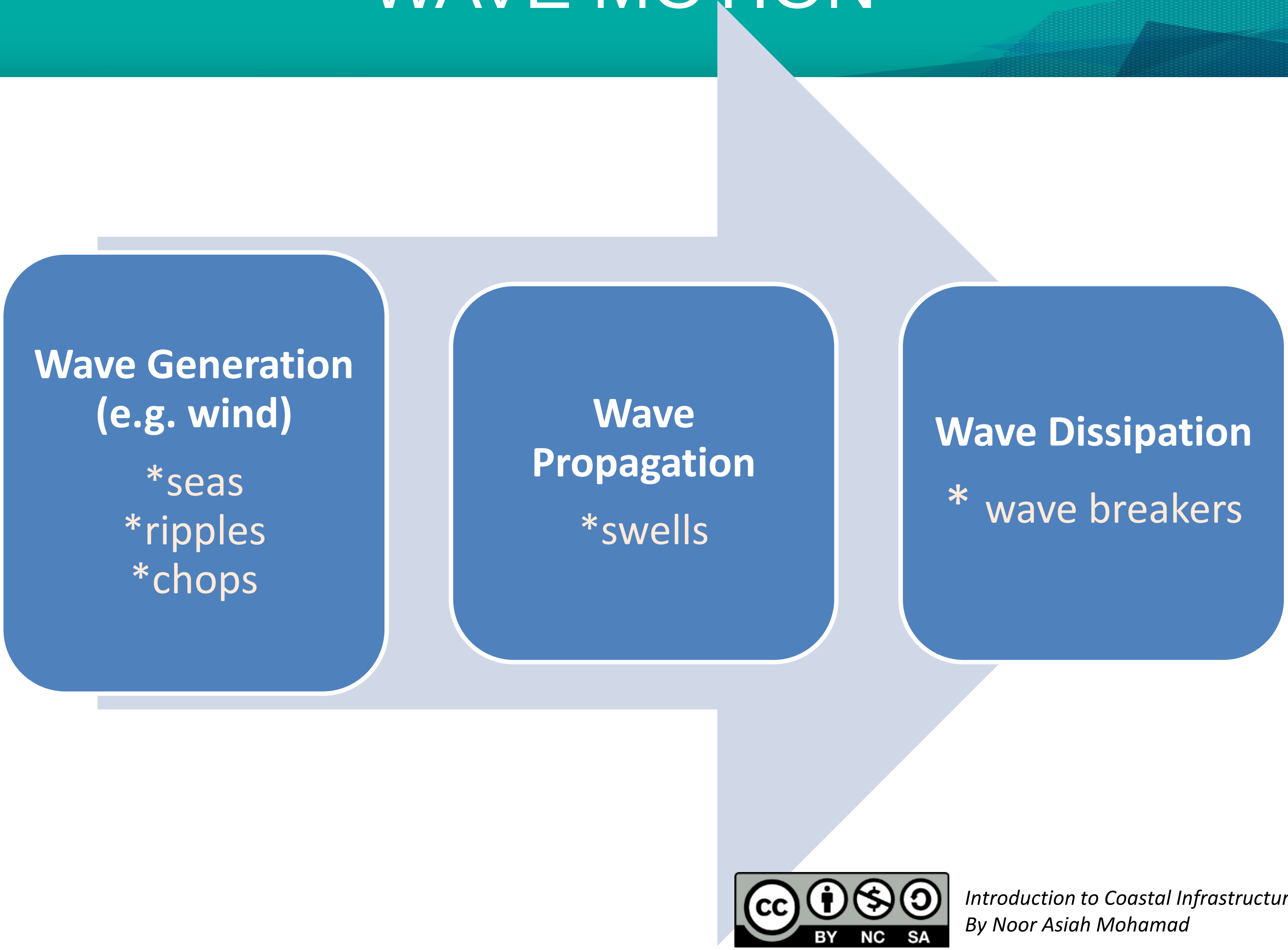
- DETERMINE GEOMETRY AND COMPOSITION OF BEACHES
- INFLUENCES PLANNING AND DESIGN OF COASTAL STRUCTURES

WAVE GENERATION

- Waves are formed by a disturbing force:
  - ❖ Wind
  - ❖ Underwater earthquake/landslides
  - ❖ Change in atmospheric pressure-seiches

- Restoring forces restore water to its restoring state:
  - ❖ Gravity = gravity waves
  - ❖ Surface Tension = capillary waves

WAVE MOTION



Wave Generation (e.g. wind)

*seas
*ripples
*chops

Wave Propagation

*swells

Wave Dissipation

* wave breakers

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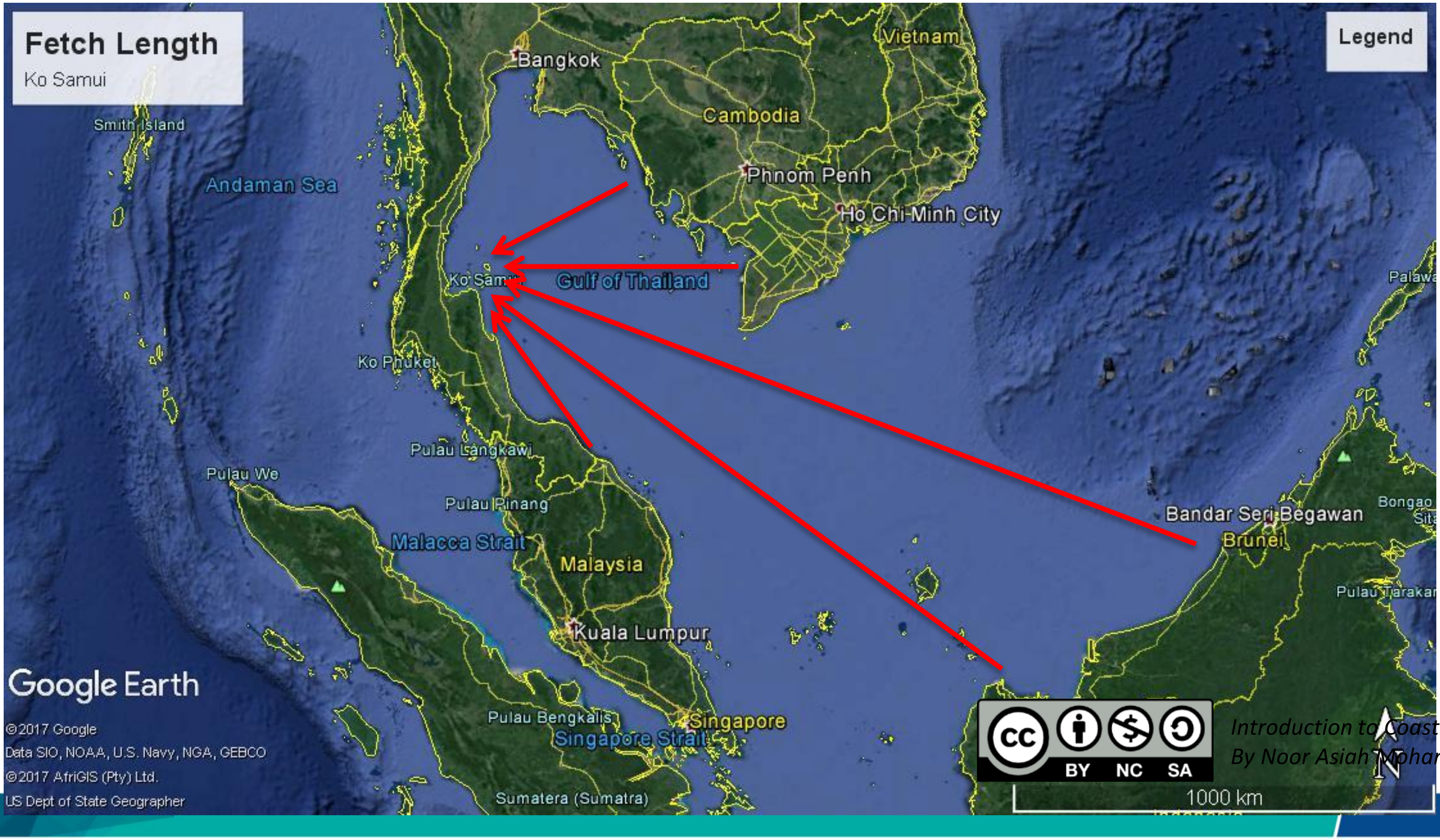
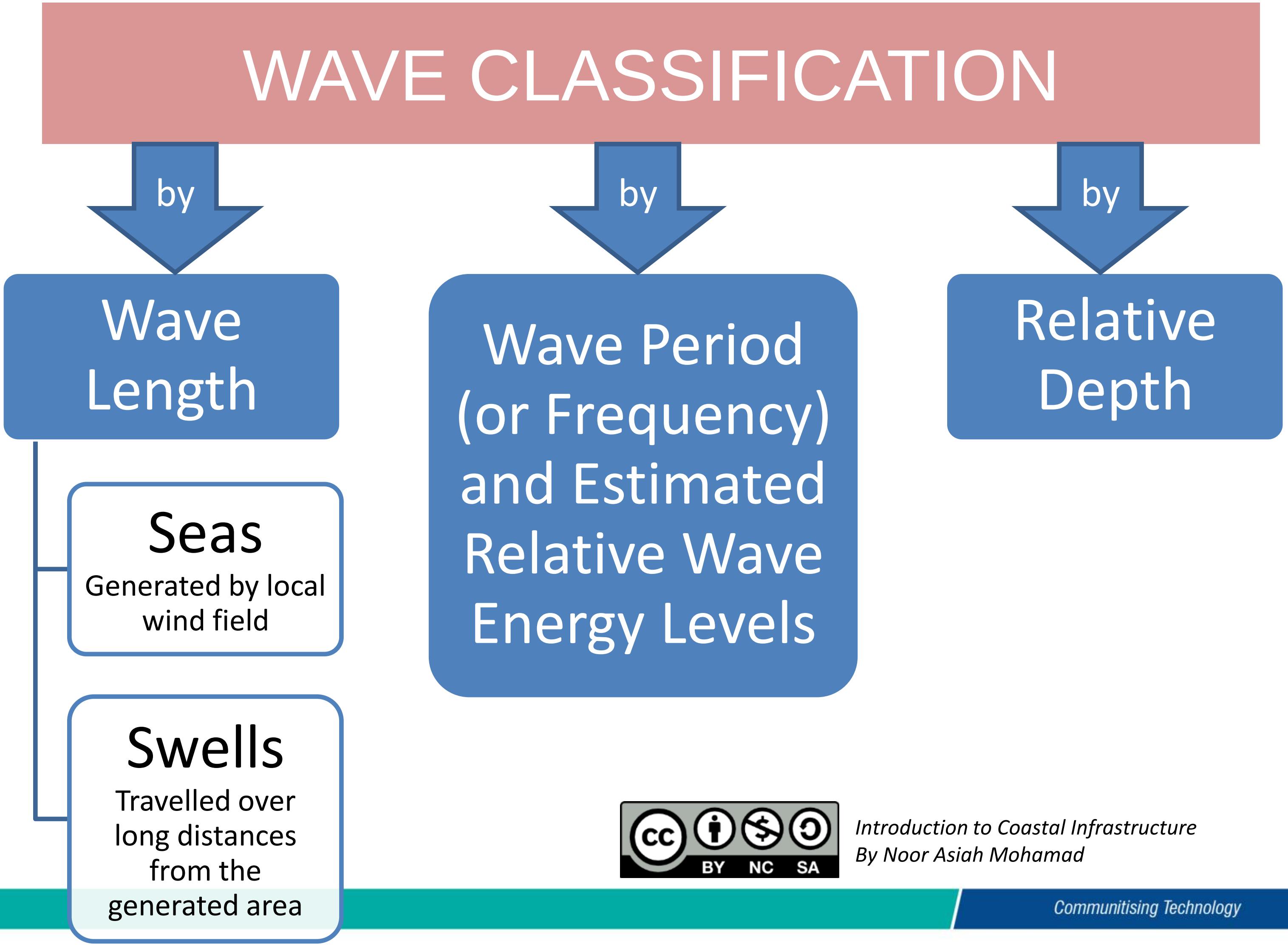
FETCH LENGTH

- Fetch Length: The horizontal distance in the direction of the wind over which a wind generates seas (Glossary of Coastal Terminology, 2012)



WAVE CLASSIFICATION



WAVE CLASSIFICATION

by

Wave Length

- **Seas**
  Generated by local wind field
- **Swells**
  Travelled over long distances from the generated area

by

Wave Period (or Frequency) and Estimated Relative Wave Energy Levels

by

Relative Depth

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WAVE CLASSIFICATION

Deep-water waves:	Transitional water waves:	Shallow water waves:
d/L > 1/2	1/2> d/L > 1/25	d/L < 1/25
L, v and h remain constant over long distances	L and v decrease,wave height “h” increase rounded tops form peaks	Particles at top of wave faster than bottom, and wave breaks

DEEP WATER WAVE MOVEMENT

- In deep water, while wave form moves, water particle below the surface move in stationary circular orbits that get smaller and smaller to a depth of about 0.5 L.

- In shallow or transitional water, water particle orbits are elliptical.
- H and L change but T remains constant.
- The waves become steeper and steeper and finally breaks in the surf zone.

WAVE PROPAGATION

- Waves can be affected by the following processes as they move from deep to shallow water:
  - ✓ Shoaling – waves becoming higher (energy is compressed over a shorter distance) as they slow down to move from deeper water to shallower water
  - ✓ Refraction - bending effect of wave crest in order to align with bottom contours or bathymetry
  - ✓ Breaking -
  - ✓ Diffraction - wave energy is laterally transferred along a wave crest as the waves bend around an obstruction
  - ✓ Reflection - wave energy is reflected back to sea as the waves hit into a rigid obstruction such as a breakwater, seawall, cliff or a sloping beach

WAVE BREAKERS

Spilling	Breaking occurs over a distance.
Plunging	Breaking is usually with a crash where smooth splash-up follows
Collapsing	Bubbles & foam are present.
Surging	Little or no bubbles production.

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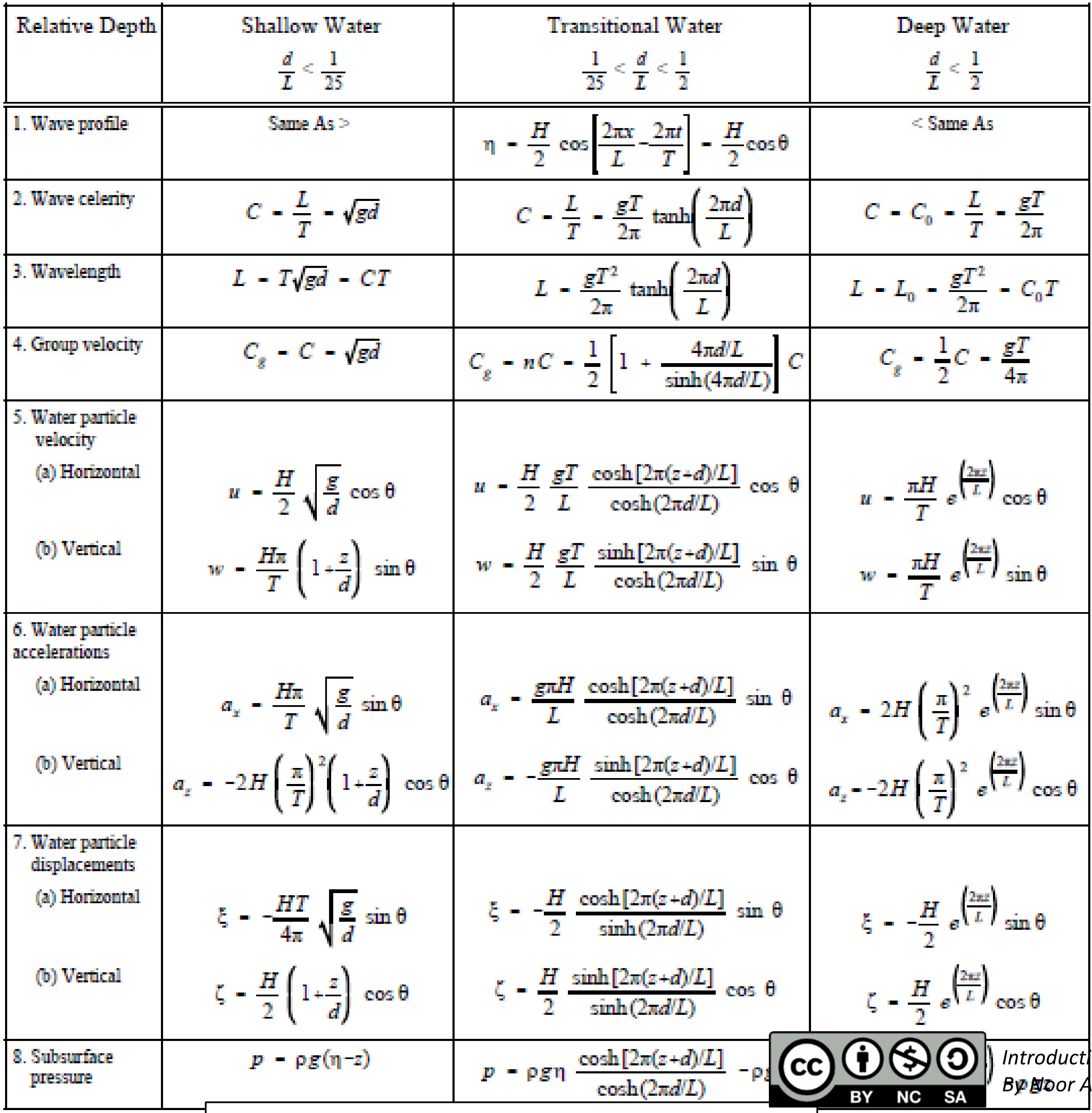
COASTAL ENGINEERING MANUAL USACE

http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/



Relative Depth	Shallow Water $\frac{d}{L} < \frac{1}{25}$	Transitional Water $\frac{1}{25} < \frac{d}{L} < \frac{1}{2}$	Deep Water $\frac{d}{L} > \frac{1}{2}$
1. Wave profile	Same As >	$\eta = \frac{H}{2}\cos\left[\frac{2\pi x}{L} - \frac{2\pi t}{T}\right] = \frac{H}{2}\cos\theta$	< Same As
2. Wave celerity	$C = \frac{L}{T} = \sqrt{gd}$	$C = \frac{L}{T} = \frac{gT}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$C = C_0 = \frac{L}{T} = \frac{gT}{2\pi}$
3. Wavelength	$L = T\sqrt{gd} = CT$	$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$L = L_0 = \frac{gT^2}{2\pi} = C_0 T$
4. Group velocity	$C_g = C = \sqrt{gd}$	$C_g = nC = \frac{1}{2}\left[1 + \frac{4\pi d/L}{\sinh(4\pi d/L)}\right]C$	$C_g = \frac{1}{2}C = \frac{gT}{4\pi}$
5. Water particle velocity			
(a) Horizontal	$u = \frac{H}{2}\sqrt{\frac{g}{d}}\cos\theta$	$u = \frac{H}{2}\frac{gT}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$u = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
(b) Vertical	$w = \frac{H\pi}{T}\left(1+\frac{z}{d}\right)\sin\theta$	$w = \frac{H}{2}\frac{gT}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$w = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
6. Water particle accelerations			
(a) Horizontal	$a_x = \frac{H\pi}{T}\sqrt{\frac{g}{d}}\sin\theta$	$a_x = \frac{g\pi H}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$a_x = 2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$a_z = -2H\left(\frac{\pi}{T}\right)^2\left(1+\frac{z}{d}\right)\cos\theta$	$a_z = -\frac{g\pi H}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$a_z = -2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
7. Water particle displacements			
(a) Horizontal	$\xi = -\frac{HT}{4\pi}\sqrt{\frac{g}{d}}\sin\theta$	$\xi = -\frac{H}{2}\frac{\cosh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\sin\theta$	$\xi = -\frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$\zeta = \frac{H}{2}\left(1+\frac{z}{d}\right)\cos\theta$	$\zeta = \frac{H}{2}\frac{\sinh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\cos\theta$	$\zeta = \frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
8. Subsurface pressure	$p = \rho g(\eta - z)$	$p = \rho g\eta\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} - \rho g$	[illegible]

Source: Coastal Engineering Manual, USACE

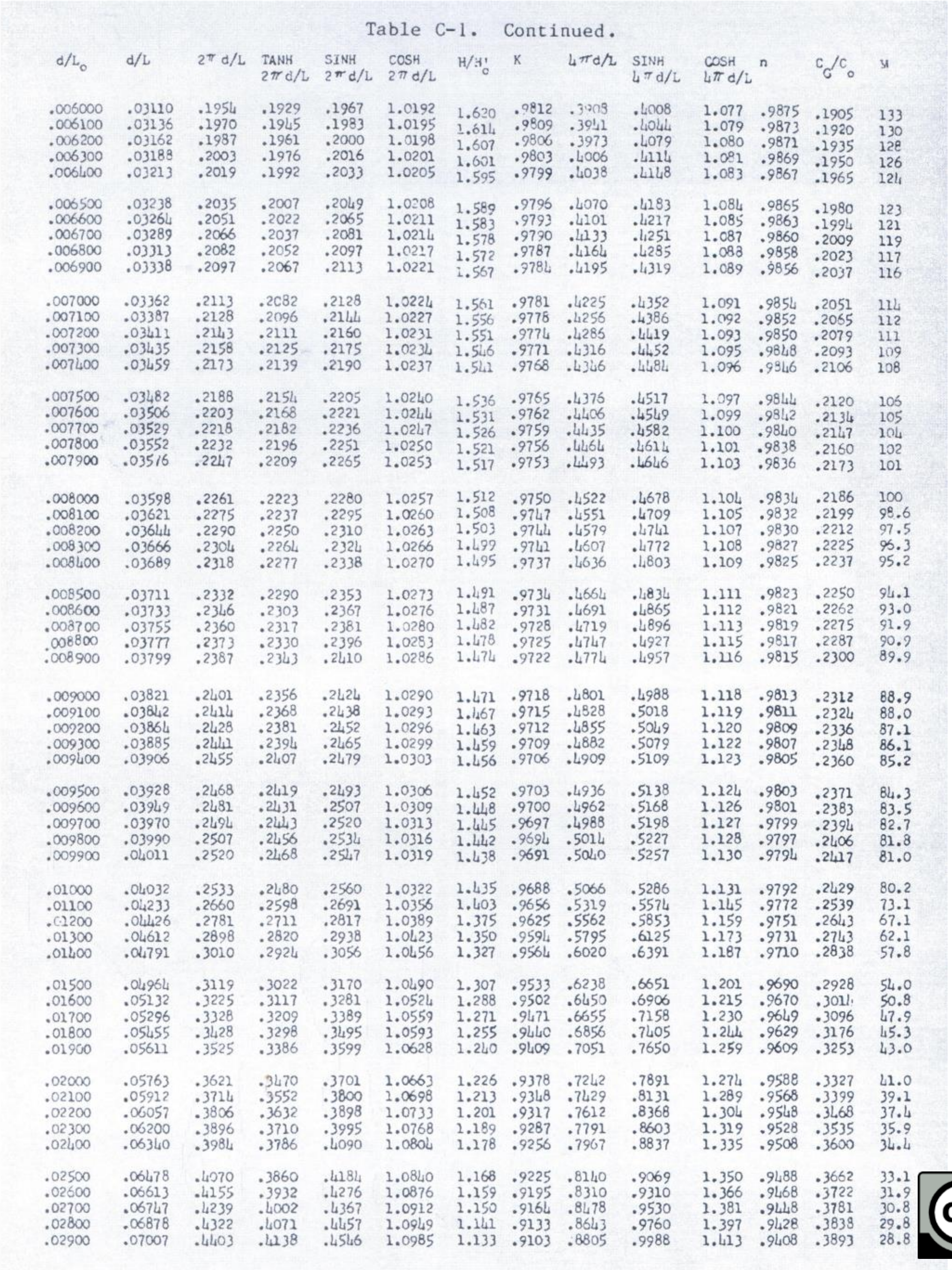
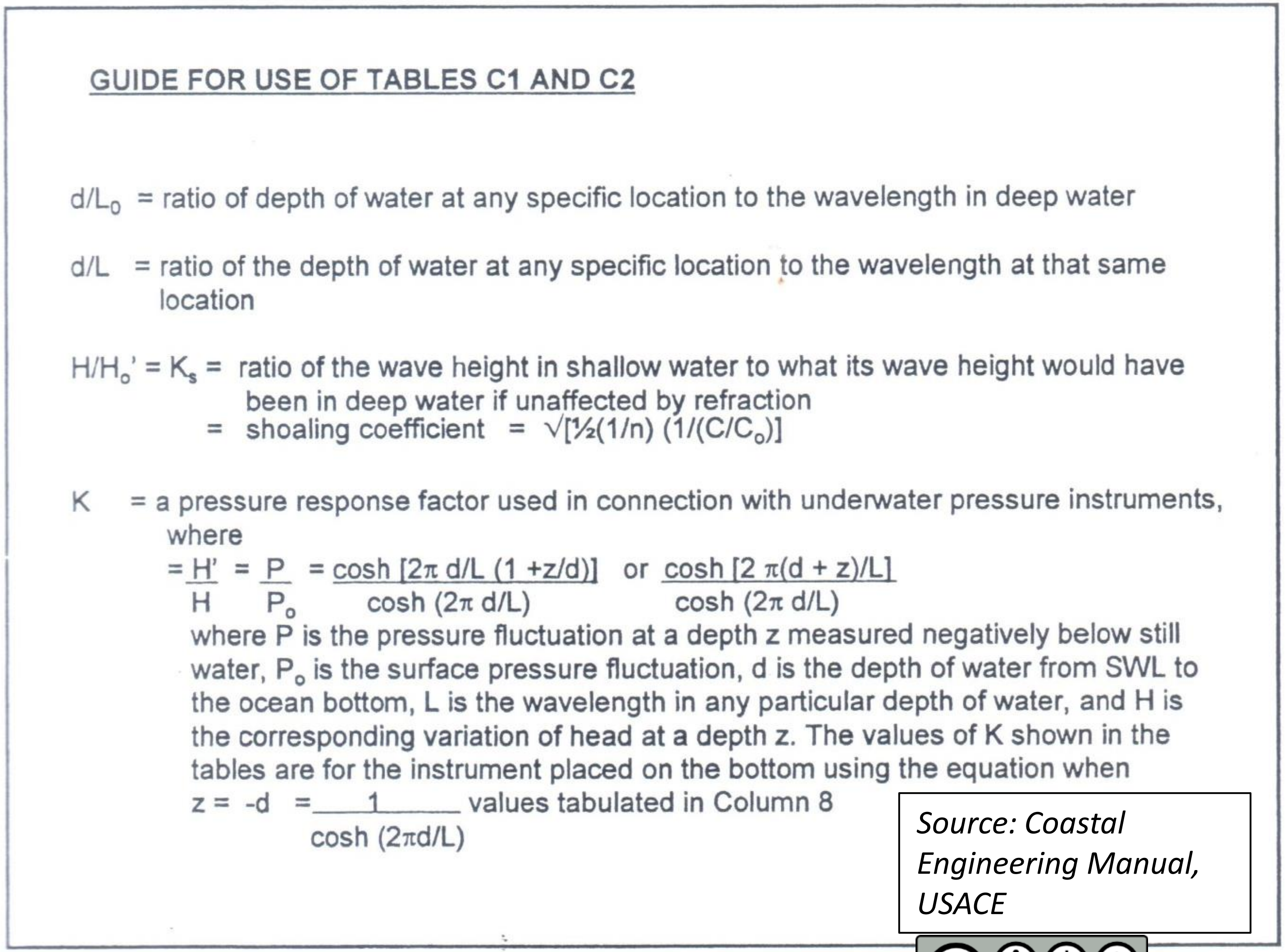


Table C-1. Continued.

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
.006000	.03110	.1954	.1929	.1967	1.0192	1.620	.9812	.3908	.4008	1.077	.9875	.1905	133
.006100	.03136	.1970	.1945	.1983	1.0195	1.614	.9809	.3941	.4044	1.079	.9873	.1920	130
.006200	.03162	.1987	.1961	.2000	1.0198	1.607	.9806	.3973	.4079	1.080	.9871	.1935	128
.006300	.03188	.2003	.1976	.2016	1.0201	1.601	.9803	.4006	.4114	1.081	.9869	.1950	126
.006400	.03213	.2019	.1992	.2033	1.0205	1.595	.9799	.4038	.4148	1.083	.9867	.1965	124
.006500	.03238	.2035	.2007	.2049	1.0208	1.589	.9796	.4070	.4183	1.084	.9865	.1980	123
.006600	.03264	.2051	.2022	.2065	1.0211	1.583	.9793	.4101	.4217	1.085	.9863	.1994	121
.006700	.03289	.2066	.2037	.2081	1.0214	1.578	.9790	.4133	.4251	1.087	.9860	.2009	119
.006800	.03313	.2082	.2052	.2097	1.0217	1.572	.9787	.4164	.4285	1.088	.9858	.2023	117
.006900	.03338	.2097	.2067	.2113	1.0221	1.567	.9784	.4195	.4319	1.089	.9856	.2037	116
.007000	.03362	.2113	.2082	.2128	1.0224	1.561	.9781	.4225	.4352	1.091	.9854	.2051	114
.007100	.03387	.2128	.2096	.2144	1.0227	1.556	.9778	.4256	.4386	1.092	.9852	.2065	112
.007200	.03411	.2143	.2111	.2160	1.0231	1.551	.9774	.4286	.4419	1.093	.9850	.2079	111
.007300	.03435	.2158	.2125	.2175	1.0234	1.546	.9771	.4316	.4452	1.095	.9848	.2093	109
.007400	.03459	.2173	.2139	.2190	1.0237	1.541	.9768	.4346	.4484	1.096	.9846	.2106	108
.007500	.03482	.2188	.2154	.2205	1.0240	1.536	.9765	.4376	.4517	1.097	.9844	.2120	106
.007600	.03506	.2203	.2168	.2221	1.0244	1.531	.9762	.4406	.4549	1.099	.9842	.2134	105
.007700	.03529	.2218	.2182	.2236	1.0247	1.526	.9759	.4435	.4582	1.100	.9840	.2147	104
.007800	.03552	.2232	.2196	.2251	1.0250	1.521	.9756	.4464	.4614	1.101	.9838	.2160	102
.007900	.03576	.2247	.2209	.2265	1.0253	1.517	.9753	.4493	.4646	1.103	.9836	.2173	101
.008000	.03598	.2261	.2223	.2280	1.0257	1.512	.9750	.4522	.4678	1.104	.9834	.2186	100
.008100	.03621	.2275	.2237	.2295	1.0260	1.508	.9747	.4551	.4709	1.105	.9832	.2199	98.6
.008200	.03644	.2290	.2250	.2310	1.0263	1.503	.9744	.4579	.4741	1.107	.9830	.2212	97.5
.008300	.03666	.2304	.2264	.2324	1.0266	1.499	.9741	.4607	.4772	1.108	.9827	.2225	96.3
.008400	.03689	.2318	.2277	.2338	1.0270	1.495	.9737	.4636	.4803	1.109	.9825	.2237	95.2
.008500	.03711	.2332	.2290	.2353	1.0273	1.491	.9734	.4664	.4834	1.111	.9823	.2250	94.1
.008600	.03733	.2346	.2303	.2367	1.0276	1.487	.9731	.4691	.4865	1.112	.9821	.2262	93.0
.008700	.03755	.2360	.2317	.2381	1.0280	1.482	.9728	.4719	.4896	1.113	.9819	.2275	91.9
.008800	.03777	.2373	.2330	.2396	1.0283	1.478	.9725	.4747	.4927	1.115	.9817	.2287	90.9
.008900	.03799	.2387	.2343	.2410	1.0286	1.474	.9722	.4774	.4957	1.116	.9815	.2300	89.9
.009000	.03821	.2401	.2356	.2424	1.0290	1.471	.9718	.4801	.4988	1.118	.9813	.2312	88.9
.009100	.03842	.2414	.2368	.2438	1.0293	1.467	.9715	.4828	.5018	1.119	.9811	.2324	88.0
.009200	.03864	.2428	.2381	.2452	1.0296	1.463	.9712	.4855	.5049	1.120	.9809	.2336	87.1
.009300	.03885	.2441	.2394	.2465	1.0299	1.459	.9709	.4882	.5079	1.122	.9807	.2348	86.1
.009400	.03906	.2455	.2407	.2479	1.0303	1.456	.9706	.4909	.5109	1.123	.9805	.2360	85.2
.009500	.03928	.2468	.2419	.2493	1.0306	1.452	.9703	.4936	.5138	1.124	.9803	.2371	84.3
.009600	.03949	.2481	.2431	.2507	1.0309	1.448	.9700	.4962	.5168	1.126	.9801	.2383	83.5
.009700	.03970	.2494	.2443	.2520	1.0313	1.445	.9697	.4988	.5198	1.127	.9799	.2394	82.7
.009800	.03990	.2507	.2456	.2534	1.0316	1.442	.9694	.5014	.5227	1.128	.9797	.2406	81.8
.009900	.04011	.2520	.2468	.2547	1.0319	1.438	.9691	.5040	.5257	1.130	.9794	.2417	81.0
.01000	.04032	.2533	.2480	.2560	1.0322	1.435	.9688	.5066	.5286	1.131	.9792	.2429	80.2
.01100	.04233	.2660	.2598	.2691	1.0356	1.403	.9656	.5319	.5574	1.145	.9772	.2539	73.1
.01200	.04426	.2781	.2711	.2817	1.0389	1.375	.9625	.5562	.5853	1.159	.9751	.2643	67.1
.01300	.04612	.2898	.2820	.2938	1.0423	1.350	.9594	.5795	.6125	1.173	.9731	.2743	62.1
.01400	.04791	.3010	.2924	.3056	1.0456	1.327	.9564	.6020	.6391	1.187	.9710	.2838	57.8
.01500	.04964	.3119	.3022	.3170	1.0490	1.307	.9533	.6238	.6651	1.201	.9690	.2928	54.0
.01600	.05132	.3225	.3117	.3281	1.0524	1.288	.9502	.6450	.6906	1.215	.9670	.3014	50.8
.01700	.05296	.3328	.3209	.3389	1.0559	1.271	.9471	.6655	.7158	1.230	.9649	.3096	47.9
.01800	.05455	.3428	.3298	.3495	1.0593	1.255	.9440	.6856	.7405	1.244	.9629	.3176	45.3
.01900	.05611	.3525	.3386	.3599	1.0628	1.240	.9409	.7051	.7650	1.259	.9609	.3253	43.0
.02000	.05763	.3621	.3470	.3701	1.0663	1.226	.9378	.7242	.7891	1.274	.9588	.3327	41.0
.02100	.05912	.3714	.3552	.3800	1.0698	1.213	.9348	.7429	.8131	1.289	.9568	.3399	39.1
.02200	.06057	.3806	.3632	.3898	1.0733	1.201	.9317	.7612	.8368	1.304	.9548	.3468	37.4
.02300	.06200	.3896	.3710	.3995	1.0768	1.189	.9287	.7791	.8603	1.319	.9528	.3535	35.9
.02400	.06340	.3984	.3786	.4090	1.0804	1.178	.9256	.7967	.8837	1.335	.9508	.3600	34.4
.02500	.06478	.4070	.3860	.4184	1.0840	1.168	.9225	.8140	.9069	1.350	.9488	.3662	33.1
.02600	.06613	.4155	.3932	.4276	1.0876	1.159	.9195	.8310	.9310	1.366	.9468	.3722	31.9
.02700	.06747	.4239	.4002	.4367	1.0912	1.150	.9164	.8478	.9530	1.381	.9448	.3781	30.8
.02800	.06878	.4322	.4071	.4457	1.0949	1.141	.9133	.8643	.9760	1.397	.9428	.3838	29.8
.02900	.07007	.4403	.4138	.4546	1.0985	1.133	.9103	.8805	.9988	1.413	.9408	.3893	28.8

Source: *Coastal Engineering Manual, USACE*



GUIDE FOR USE OF TABLES C1 AND C2

d/L_0 = ratio of depth of water at any specific location to the wavelength in deep water

d/L = ratio of the depth of water at any specific location to the wavelength at that same location

$H/H_o' = K_s$ = ratio of the wave height in shallow water to what its wave height would have been in deep water if unaffected by refraction
= shoaling coefficient = $\sqrt{[\frac{1}{2}(1/n)\,(1/(C/C_o)]}$

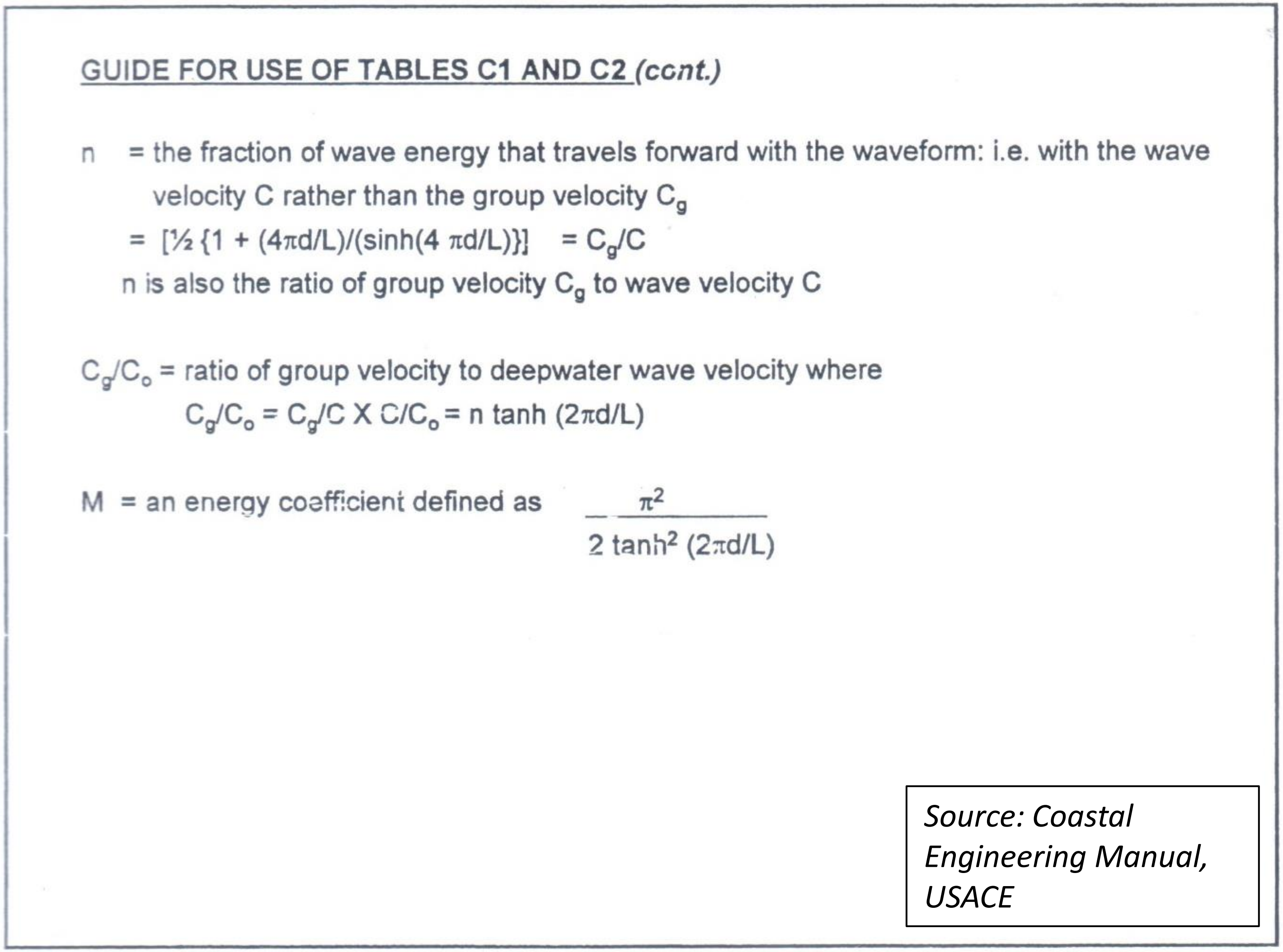
K = a pressure response factor used in connection with underwater pressure instruments, where

$$= \frac{H'}{H} = \frac{P}{P_o} = \frac{\cosh\,[2\pi\, d/L\,(1 + z/d)]}{\cosh\,(2\pi\, d/L)} \quad \text{or} \quad \frac{\cosh\,[2\,\pi(d + z)/L]}{\cosh\,(2\pi\, d/L)}$$

where P is the pressure fluctuation at a depth z measured negatively below still water, P_o is the surface pressure fluctuation, d is the depth of water from SWL to the ocean bottom, L is the wavelength in any particular depth of water, and H is the corresponding variation of head at a depth z. The values of K shown in the tables are for the instrument placed on the bottom using the equation when

$$z = -d \quad = \frac{1}{\cosh\,(2\pi d/L)}$$ values tabulated in Column 8

Source: Coastal Engineering Manual, USACE



GUIDE FOR USE OF TABLES C1 AND C2 *(cont.)*

n = the fraction of wave energy that travels forward with the waveform: i.e. with the wave velocity C rather than the group velocity C_g

$= [\frac{1}{2}\{1 + (4\pi d/L)/(\sinh(4\pi d/L)\}] = C_g/C$

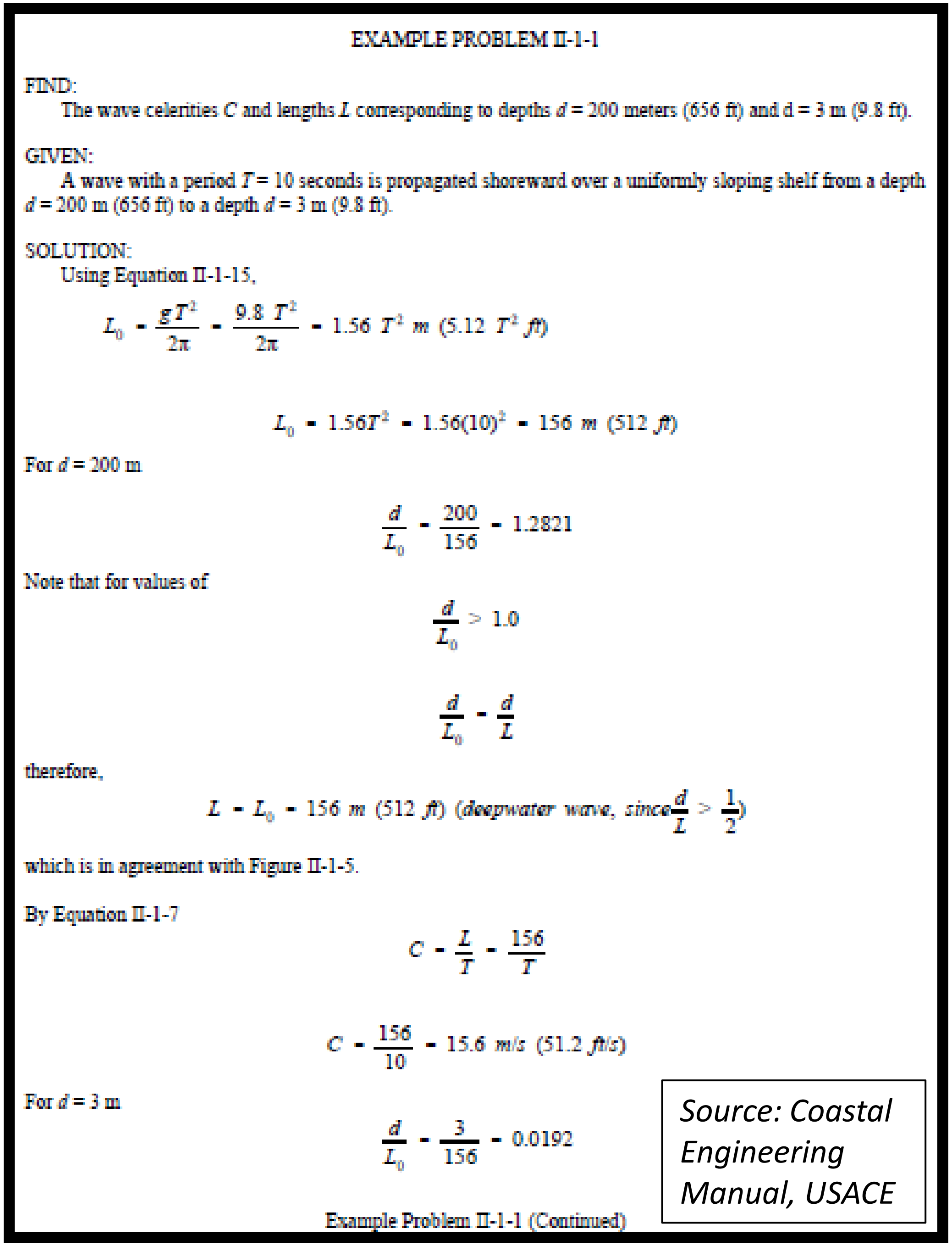
n is also the ratio of group velocity C_g to wave velocity C

C_g/C_o = ratio of group velocity to deepwater wave velocity where

$C_g/C_o = C_g/C \times C/C_o = n \tanh(2\pi d/L)$

M = an energy coefficient defined as $\dfrac{\pi^2}{2\tanh^2(2\pi d/L)}$

Source: Coastal Engineering Manual, USACE



EXAMPLE PROBLEM II-1-1

FIND:

The wave celerities *C* and lengths *L* corresponding to depths *d* = 200 meters (656 ft) and d = 3 m (9.8 ft).

GIVEN:

A wave with a period *T* = 10 seconds is propagated shoreward over a uniformly sloping shelf from a depth *d* = 200 m (656 ft) to a depth *d* = 3 m (9.8 ft).

SOLUTION:

Using Equation II-1-15,

$$L_0 = \frac{gT^2}{2\pi} = \frac{9.8\ T^2}{2\pi} = 1.56\ T^2\ m\ (5.12\ T^2\ ft)$$

$$L_0 = 1.56T^2 = 1.56(10)^2 = 156\ m\ (512\ ft)$$

For *d* = 200 m

$$\frac{d}{L_0} = \frac{200}{156} = 1.2821$$

Note that for values of

$$\frac{d}{L_0} > 1.0$$

$$\frac{d}{L_0} = \frac{d}{L}$$

therefore,

$$L = L_0 = 156\ m\ (512\ ft)\ (deepwater\ wave,\ since \frac{d}{L} > \frac{1}{2})$$

which is in agreement with Figure II-1-5.

By Equation II-1-7

$$C = \frac{L}{T} = \frac{156}{T}$$

$$C = \frac{156}{10} = 15.6\ m/s\ (51.2\ ft/s)$$

For *d* = 3 m

$$\frac{d}{L_0} = \frac{3}{156} = 0.0192$$

Example Problem II-1-1 (Continued)

Source: Coastal Engineering Manual, USACE

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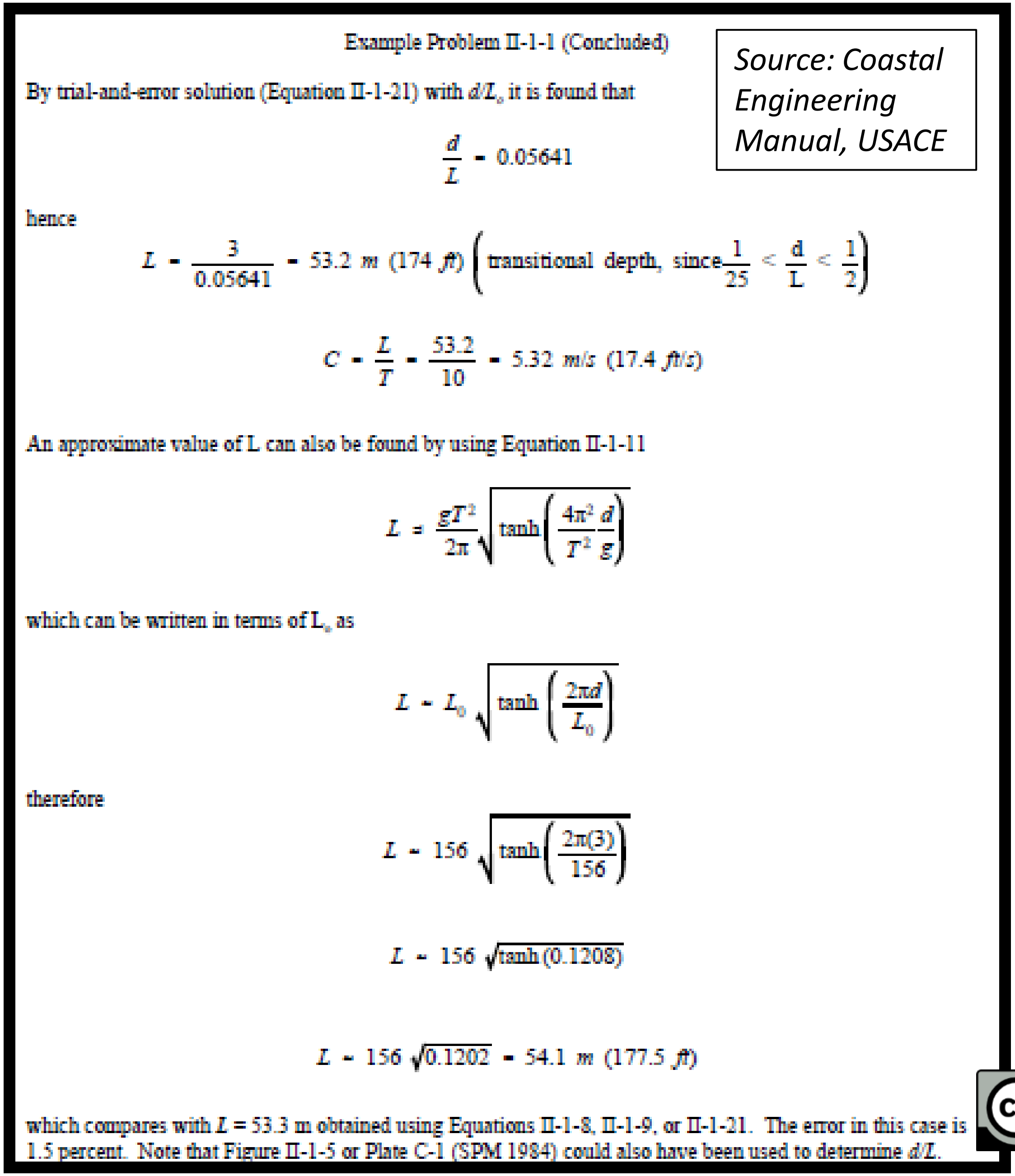

Example Problem II-1-1 (Concluded)

By trial-and-error solution (Equation II-1-21) with d/L_o it is found that

$$\frac{d}{L} = 0.05641$$

hence

$$L = \frac{3}{0.05641} = 53.2\ m\ (174\ ft)\ \left(\text{transitional depth, since} \frac{1}{25} < \frac{d}{L} < \frac{1}{2}\right)$$

$$C = \frac{L}{T} = \frac{53.2}{10} = 5.32\ m/s\ (17.4\ ft/s)$$

An approximate value of L can also be found by using Equation II-1-11

$$L = \frac{gT^2}{2\pi} \sqrt{\tanh\left(\frac{4\pi^2}{T^2}\frac{d}{g}\right)}$$

which can be written in terms of L_o as

$$L = L_0 \sqrt{\tanh\left(\frac{2\pi d}{L_0}\right)}$$

therefore

$$L = 156 \sqrt{\tanh\left(\frac{2\pi(3)}{156}\right)}$$

$$L = 156 \sqrt{\tanh(0.1208)}$$

$$L = 156 \sqrt{0.1202} = 54.1\ m\ (177.5\ ft)$$

which compares with $L = 53.3$ m obtained using Equations II-1-8, II-1-9, or II-1-21. The error in this case is 1.5 percent. Note that Figure II-1-5 or Plate C-1 (SPM 1984) could also have been used to determine d/L.

Source: Coastal Engineering Manual, USACE

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