Coastal Engineering Technical Note

COMPUTER PROGRAM: SINWAVES (MACE-11) LINEAR WAVE THEORY PREDICTIONS

PROGRAM PURPOSE: Linear wave theory is often used in practice by coastal engineers to estimate the variations of wave parameters over varying depths. The program "SINWAVES" applies linear wave theory according to the guidance of the Shore Protection Manual (SPM 1984), Dean and Dalrymple (1984), and Skovgaard, et al (1974), to calculate wave conditions at varying depths, estimate breaking conditions and provide functions similar to that of tables C-1 and C-2 of the SPM.

PROGRAM APPLICATION: Input requirements include the wave period(T) and height(H), water depth(h), angle between the wave crest and the bottom contours, and the inverse slope of the seabed. The program allows the user to designate the wave as a deepwater wave or to enter a depth and have the computer determine if a deepwater condition ($d/L > 0.5$, L = wavelength) exists. If deepwater conditions do not exist, an equivalent deepwater wave is calculated. The deepwater wave is checked for a maximum stable steepness of 1/7. If the wave is determined to be unstable, a message is printed and the program is terminated. Snell's law of refraction is used to determine the refraction coefficient, assuming straight and parallel bottom contours. Wavelengths are evaluated at specified depths using a subroutine which solves the linear dispersion equation by iteration. Breaking depth and breaking height are also found by an iterative process, using equations 2-92, 2-93, and 2-94 from the SPM(1984) and the above mentioned wavelength subroutine. It should be noted that this process assumes that linear wave theory applies up to the point of breaking. In actuality, however, waves significantly depart from sinusoidal form as they approach the breaking point. The Ursell parameter, $HL^2/h^3 > 15$ is used to identify depths at which this distortion occurs, and a message is printed suggesting that non-linear wave theory. The Ursell parameter and depth are also used to identify conditions in which linear wave theory is not reliable (i.e., when $HL^2/h^3 > 15$ and $h/L_0 > 0.1$, where L_0 is the deepwater wavelength). In this case a message is printed and the program is terminated (Skovgaard et al, 1974) .

The user is prompted for a depth of interest and may opt for the breaking condition only. If the depth selected is less than the breaking depth, a message is printed, which indicates the breaking depth, and the inability to use sinusoidal wave theory. Then the program requests a new depth of interest. If the depth specified is greater than the breaking depth, the wave length, height, and angle are calculated and printed. In addition the Ursell parameter, phase velocity, group velocity, shoaling coefficient, refraction coefficient, mean energy density, mean energy density, mean energy flux, and a rough estimate of wave setdown based on linear theory are calculated and printed out for the depth. If the depth selected is equal to the breaking depth, the longshore energy flux is also calculated and printed.

Water particle motion and total pressure may be requested. This results in a prompt for the distance of interest below the still water level. Calculations are executed and estimates of the maximum horizontal and vertical particle motion (two times the radius of the particle orbital), the maximum horizontal and vertical particle velocities and the total (including hydrostatic) pressure are displayed. The user may then select another depth of interest. If another depth is not selected, the breaking conditions are printed and the program is terminated.

NOTATION:

H_o = deepwater waveheight (ft or m)

T = wave period (seconds)

Θ_o = deepwater wave angle (angle wave crest makes with the bottom contours in degrees)

ρ = water mass density (1.94 slugs/ft^3 or 1000 kg/m^3 for fresh water and 1.99 slugs/ft^3 or 1026 kg/m^3 for sea water)

h = water depth of interest (ft or m)

z = distance of interest below still water level (ft or m)

m = average slope of sea bed

L_o = deepwater wavelength (ft or m)

c_o = deepwater phase velocity (ft/s or m/s)

c_{go} = deepwater group velocity (ft/s or m/s)

H = wave height (ft or m)

L = wavelength (ft or m)

c = wave phase velocity (ft/s or m/s)

c_g = wave group velocity (ft/s or m/s)

Θ = angle of approaching wave crests with bottom contours (degrees)

K_s = shoaling coefficient

K_r = refraction coefficient

U = Ursell parameter

E = mean energy density (ft-lbs/ft2 or J/m2)

P = mean energy flux (ft-lbs/ft-s or w/m)

Δh = setdown (ft or m)

u_{max} = maximum horizontal water particle velocity (ft/s or m/s)

w_{max} = maximum vertical water particle velocity (ft/s or m/s)

p_z = total pressure (lbs/ft^2 or N/m^2)

H_b' = breaking height (ft or m)

h_b = depth at breaking (ft or m)

P_{ls} = longshore energy flux (ft-lbs/ft-s or w/m)

g = gravitational acceleration (32.17 ft/s^2 or 9.81 m/s^2)

LIST OF FORMULAE:

$L_o = gT^2/2\pi$

$c_o = Lo/T$

$c_{go} = 1/2\ c_0$

$H = H_o K_s K_r$

$w = 2\pi/T$

$k = 2\pi/L$

$\omega^2 = gk \tanh kh$

$c = (gT/2\pi)(\tanh(kh))$

$c_g = 1/2\ c(1+G)$

$G = 2kh/\sinh 2kh$

$\Theta = \sin^{-1}[(c/c_o)\sin \Theta_o]$

$K_s = (c_o/2c_g)^{1/2}$

$U = HL^2/h^3$

$E = 1/8(\rho g H^2)$

$P = Ec_g$

$\Delta h = GH^2/16h$

$u_{max} = (HgT/2L)(\cosh[2\pi(z+h)/L])/(\cosh[2\pi h/L])$

$w_{max} = (HgT/2L)(\sinh[2\pi(z+h)/L])/(\cosh[2\pi h/L])$

$p_z = \rho g(H/2)(\cosh k[z+h]/\cosh kh) - \rho gz$

$P_{ls} = (\rho g/16)(H^2 c_g \sin 2\Theta)$

$H = H_o K_s k_r$

$K = b - aH_b/gT^2$

$b = 1.56/(1+e^{-19.5m})$

$a = 43.8(1-e^{-19m})$

$h_b = H_b/k$

INPUT:

1. Type of water (salt or fresh)
2. Deepwater wave height or known height at a specific depth (ft or m)
3. Wave period (sec)
4. Deepwater wave angle or known angle at a specific depth (degrees)
5. Depth of interest (ft or m)

6. Distance below still water level of interest (ft or m)

7. Average slope of sea bed

OUTPUT:

1. Known conditions

2. Deepwater conditions

3. Conditions at depth of interest

4. Conditions at breaking

5. Messages indicating deviation for linear theory

SAMPLE PROBLEM: A wave with a period T=10 seconds is propagated shoreward over a uniform slope of 1:100. The wave has a height of 6 ft. in a depth of 18 ft. and its crest is at an angle of 6 degrees to the bottom contours. Find the deepwater wave conditions, the wave conditions at a depth of 13 ft., the water particle motion 3 ft. below the still water level (at 13 ft depth), and the breaking conditions.

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RUN
LINEAR WAVE THEORY ESTIMATES
VERSION 10-85
USE UPPER CASE FOR ALL RESPONSES

PRESS ANY KEY TO CONTINUE

P=PAPER OUTPUT OR S=SCREEN OUTPUT ONLY ? S

DISTANCE MEASUREMENT (F=FEET OR M=METERS) ? F

F=FRESHWATER OR S=SALTWATER ? S

WAVE PERIOD (SECONDS) ? 10

KNOWN WAVE HEIGHT ? 6

DEPTH AT KNOWN WAVE
IF DEEPWATER WAVE HEIGHT, ENTER 999 ? 18

ANGLE OF KNOWN WAVE HEIGHT
(ANGLE OF APPROACHING WAVE CREST WITH BOTTOM CONTOURS)
ENTER '0' IF UNKNOWN? 6

SHALLOW WATER INVERSE SLOPE OF SEABED
(EX. FOR 1:100, ENTER 100) ? 100
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LINEAR WAVE THEORY ESTIMATES

KNOWN CONDITIONS

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SALTWATER
WAVE HEIGHT                  =   6.0 FT =  1.83 M
WAVE ANGLE                   =   6.0 DEGREES
DEPTH                        =  18.0 FT =   5.5
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DEEPWATER CONDITIONS

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WAVE HEIGHT                  =     5.6 FT =  1.70 M
WAVE PERIOD                  = 10.0 SECONDS
WAVE LENGTH                  =   512.0 FT = 156.06 M
WAVE ANGLE                   =  13.4  DEGREES
PHASE VELOCITY               =  51.2 FT/S =  15.61 M/S
GROUP VELOCITY               =  25.6 FT/S =   7.80 M/S
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DEPTH OF INTEREST
IF BREAKING CONDITIONS ONLY, ENTER 9999? 13

CONDITIONS AT DEPTH OF INTEREST

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DEPTH                        =    13.0 FT =    3.96 M
SLOPE OF SEABED              =  1: 100
WAVE HEIGHT                  =     6.4 FT =  1.95 M
PERIOD                       =   10.0 SECONDS
WAVE LENGTH                  =   199.1 FT =   60.67 M
URSELL PARAMETER             =  115.48
WAVE ANGLE                   =   5.2  DEGREES
PHASE VELOCITY               =  19.9 FT/S =   5.97 M/S
GROUP VELOCITY               =  18.9 FT/S =   5.75 M/S
SHOALING COEFFICIENT         = 1.165
REFRACTION COEFFICIENT       = 0.988
MEAN ENERGY DENSITY          =       328 FT-LBS/ FT^2 =     4782 J/M^2
MEAN ENERGY FLUX             =      6183 FT-LBS/FT-S =    27505 W/M
SETDOWN                      =      0.2 FT =  0.05 M
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NOTE: NON-LINEAR WAVE THEORIES ARE SUGGESTED FOR BETTER ESTIMATES AT THIS DEPTH.

MAXIMUM WATER PARTICLE MOTION AND TOTAL PRESSURE (Y OR N) ? Y

DISTANCE OF INTEREST BELOW STILL WATER LEVEL? 3

WATER PARTICLE MOTION AND TOTAL PRESSURE

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DISTANCE BELOW STILL WATER LEVEL   =    3.0 FT =   0.91 M
MAXIMUM HORIZONTAL VELOCITY        = 19.5 FT/S =  5.93 M/S
MAXIMUM VERTICAL VELOCITY          =  5.9 FT/S =  1.81 M/S
MAXIMUM HORIZONTAL MOTION          =   62.0 FT = 18.88 M
MAXIMUM VERTICAL MOTION            =   18.9 FT =  5.77 M
MAXIMUM TOTAL PRESSURE             =    390 LBS/FT^2 =    18669 N/M^2
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ANOTHER DEPTH OF INTEREST (Y OR N) ? N

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                    CONDITIONS AT BREAKING
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DEPTH                          =     8.4 FT =     2.56 M
SLOPE OF SEABED                =  1: 100
WAVE HEIGHT                    =     7.0 FT =   2.15 M
PERIOD                         =    10.0 SECONDS
WAVE LENGTH                    =   161.4 FT =    49.20 M
URSELL PARAMETER               =  311.01
WAVE ANGLE                     =    4.2  DEGREES
PHASE VELOCITY                 =  16.1 FT/S =    4.84 M/S
GROUP VELOCITY                 =  15.6 FT/S =    4.75 M/S
SHOALING COEFFICIENT           = 1.281
REFRACTION COEFFICIENT         = 0.988
MEAN ENERGY DENSITY            =       396 FT-LBS/ FT^2 =      5778 J/M^2
MEAN ENERGY FLUX               =       6175 FT-LBS/FT-S =     27467 W/M
LONGSHORE ENERGY FLUX          =     636.5 FT-LBS/FT-S = 2831.3 W/S
SETDOWN                        =     0.3 FT =  0.10 M

NOTE: NON-LINEAR WAVE THEORIES ARE SUGGESTED FOR BETTER ESTIMATES AT THIS DEPTH.

MAXIMUM WATER PARTICLE MOTION AND TOTAL PRESSURE (Y OR N) ? N
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PROGRAM AVAILABILITY: The program is available for the IBM PC on a 5 1/4-in. diskette or as a printed program listing and can be obtained from the Engineering Computer Programs Library, Ms. Gloria J. Naylor 601-634-2581 (FTS 542-2581), U.S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, Mississippi, 39180-0631. A list of notations and formulas can also be obtained. Questions concerning the application of SINWAVES may be directed to Mr. Orson P. Smith at 601-634-2013 (FTS 542-2013) or Ms. Cheryl E. Burke at 601-634-2023 (FTS 542-2023) both of the Coastal Design Branch.

REFERENCES:

Dean, Robert G., and Dalrymple, Robert A. 1984. "Water Wave Mechanics for Engineers and Scientists," Prentice-Hall, Englewood Cliffs, New Jersey.

Shore Protection Manual. 1984. 4th ed., 2 vols, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington DC.

Skovgaard, O., Swendsen, I., Jonsson, I. and Brink-Kjaer, O. 1974. "Sinusoidal and Cnoidal Gravity Waves-Formulae and Tables," Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, Lyngby, Denmark.