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Implementation of Wave Dissipation by Vegetation in STWAVE

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the implementation of wave dissipation by vegetation into the nearshore spectral wave model STWAVE (Massey et al. 2011; Smith 2007; Smith et al. 2001).

INTRODUCTION: The influence of vegetation on coastal hydrodynamics is a relatively new field, with a body of literature documenting the dissipation of wave energy by coastal vegetation developing within the last few decades (see Anderson et al. (2011) for a summary). Unfortunately, the effect of vegetation on coastal processes and hydrodynamics is not fully implemented in many numerical models. Standard practice in nearshore wave propagation models, including STWAVE and SWAN, is to account for energy losses due to vegetation using bottom friction source terms. The need to accurately predict coastal hydrodynamics in the presence of natural or nature-based features has led to an increasing demand for models that better capture wave interaction with vegetation. Compounded by a lack of technique and guidance, the beneficial effects of vegetation are often neglected in the analysis, design, and construction of coastal protection.

Theoretical models for estimating wave dissipation based on energy conservation were initially proposed for monochromatic waves (Dalrymple et al. 1984), with later expansions to narrow-banded random waves (Mendez and Losada 2004). One noticeable improvement over the current bottom friction formulations is the capability to describe the vegetation itself. The declared vegetation characteristics are the following: vegetation height, stem diameter, vegetation density, and a bulk drag coefficient calibrated for the specific plant type and hydrodynamic conditions. Calibration of this bulk drag coefficient accounts for many processes not yet fully understood, such as plant motion. The study of its behavior with respect to wave attenuation is currently ongoing. The random wave dissipation model proposed by Mendez and Losada (2004) is the most appropriate for inclusion into STWAVE due to its reasonable representation of the physical processes and feasibility to implement.

FORMULATION: Waves propagating through vegetation dissipate energy due to the work carried out on the vegetation. Assuming the validity of linear wave theory, the conservation of energy is as follows:

$$\frac{\partial EC_g}{\partial x} = -\varepsilon_v$$

where E is wave energy, C_g is group velocity, x is the horizontal distance over which the wave travels, and ε_v is the time-averaged rate of energy dissipation due to vegetation per unit horizontal area. Integrating vertically over the vegetation height (l_s) and assuming ε_v is only a function of the horizontal drag force (inertial component neglected), the definition for the depth-integrated and time-averaged energy dissipation per horizontal area for a vegetation field is given by

$$\varepsilon_v = \int_{-d}^{-d+l_s} F_x u dz$$

where d is water depth and z is the vertical dimension. The horizontal force per unit volume (F_x) is described using a Morison-type equation (Morison et al. 1950):

$$F_x = \frac{1}{2}\rho \tilde{C}_D b_v N u|u|$$

where ρ is the density of water, $\tilde{C}_D$ is a depth-averaged drag coefficient, b_v is stem diameter, N is vegetation density, and u is the horizontal fluid velocity due to wave motion.

Mendez and Losada (2004) modified the Dalrymple et al. (1984) formulation by using a Rayleigh distribution to describe the variation in wave height, yielding the following for random waves:

$$\varepsilon_v = \frac{1}{2\sqrt{\pi}}\rho C_D b_v N \left(\frac{kg}{2\omega}\right)^3 \frac{\sinh^3 kl_s + 3\sinh kl_s}{3k\cosh^3 kd} H_{rms}^3$$

where g is the acceleration due to gravity, k is wave number, ω is wave angular frequency, H_{rms} is root-mean-square wave height, and C_D is an average or bulk depth-averaged drag coefficient that is dependent on hydrodynamic and plant characteristics.

The STWAVE source term for wave damping due to vegetation (S_{veg}) is obtained by expanding the Mendez and Losada (2004) formulation for ε_v to include frequencies and directions (Suzuki et al. 2011):

$$S_{veg} = -\sqrt{\frac{2}{\pi}} g^2 C_D b_v N \left(\frac{\tilde{k}}{\tilde{\omega}}\right)^3 \frac{\sinh^3 \tilde{k}l_s + 3\sinh \tilde{k}l_s}{3\tilde{k}\cosh^3 \tilde{k}d} \sqrt{E_{tot}} E(\omega,\theta)$$

in which $\tilde{k}$ is the mean wave number, $\tilde{\omega}$ is the mean angular frequency, and E_{tot} is the total wave energy. When the vegetation height exceeds the water depth ($l_s > d$), the vegetation height is dynamically set equal to the water depth ($l_s = d$) within STWAVE.

MODEL INPUT. The primary input file for STWAVE is the simulation file (*.sim), and it is within this file that model controls are defined through a series of FORTRAN namelists that specify parameters and run options. For a detailed description, see the STWAVE v6.0 user's manual (Massey et al. 2011). To implement vegetation dissipation into STWAVE, an additional model option IVEG was required in the std_parms namelist. A description of the IVEG option is provided below.

IVEG = Flag to exclude vegetation (IVEG = 0, default option) or include vegetation (IVEG = 1 or 2). Spatially constant vegetation (IVEG = 1) requires specification of vegetation parameters within the simulation file while spatially variable vegetation (IVEG = 2) requires an input file that specifies the vegetation parameters for every grid cell. The vegetation parameters required for both options are the following: average vegetation height, average stem diameter, number of plants per unit horizontal area, and bulk drag coefficient.

To accommodate the spatially constant vegetation option (IVEG = 1), a new namelist was added called const_veg. The vegetation parameters for the IVEG = 1 option must be defined within the const_veg namelist in the *.sim file. As a reminder, all FORTRAN namelists start with the ampersand symbol (&), followed by the namelist name. Variables assigned to the namelist are then listed along with the assigned value. The end of the namelist is indicated by the slash symbol (/). The const_veg namelist must be specified before the optional namelists, which are indicated by the symbol @ in the STWAVE *.sim file. The required model parameters for the new const_veg namelist are provided in Table 1.

Table 1. Model parameters: Spatially constant vegetation – const_veg namelist.

Parameter	Type	Definition
veg_ls_const	real number	# = average vegetation height [m]
veg_bv_const	real number	# = average stem diameter [m]
veg_N_const	real number	# = vegetation density [stems/m^2]
veg_Cd_const	real number	# = bulk drag coefficient [-]

For the spatially variable vegetation option (IVEG = 2), vegetation parameters for each grid cell are defined using an external input file. The external input filename is specified under the input_file namelist in the *.sim file using the VEG option. The values must be provided in column format, with the following parameters from left to right: average vegetation height, average stem diameter, vegetation density, and bulk drag coefficient. The format is the same as the other global STWAVE files and is read using the following FORTRAN algorithm:

```
do j = NJ, 1, -1
    do i = 1, NI
        read (10, *) veg_ls(i,j), veg_bv(i,j), veg_N(i,j), veg_Cd(i,j)
    enddo
enddo
```

Excerpts of the required changes to the STWAVE simulation file for spatially constant vegetation (IVEG = 1) and spatially variable vegetation (IVEG = 2) are highlighted in Appendix A. An example of the external input file required for spatially variable vegetation (IVEG = 2) is provided in Appendix B.

MODEL VALIDATION

Mendez and Losada (2004). Comparisons of STWAVE to the analytical dissipation model of Mendez and Losada (2004) were completed to confirm correct implementation of the source term. The random wave transformation model for a flat bottom was proposed by Mendez and Losada (2004) as

$$H_{rms} = \frac{H_{rms,0}}{1 + \beta x}$$

with

$$\beta = \frac{1}{3\sqrt{\pi}} C_D b_v N H_{rms,0} k \frac{\sinh^3 k l_s + 3 \sinh k l_s}{(\sinh 2kd + 2kd) \sinh kd}$$

where $H_{rms,0}$ is the root-mean-square wave height incident to the vegetation (x = 0). The root-mean-square wave height is related to the significant wave height (H_{mo}) by

$$H_{rms} = \frac{H_{mo}}{\sqrt{2}}$$

STWAVE simulations were carried out with a water depth (d) of 1.0 meter (m), peak periods (T_p) ranging from 1.5 to 10.0 seconds (s), an incident significant wave height (H_{mo}) of 44.8 centimeters (cm) at the input boundary (x = 0), and a spatially constant vegetation field measuring 100 m in length. The STWAVE domain was a rectangular grid with 50 cells in the alongshore direction, 25 cells in the cross-shore direction, and a 2.0 m grid resolution. The vegetation characteristics were varied each simulation to verify the model accurately captured the response in wave height. The model parameters for all simulations are given in Table 2. Unidirectional, narrow-banded random waves were generated using Texel, Marsen, and Arsole (TMA) shallow-water spectra with a spectral peak enhancement factor (γ) of 10.0 and a directional spreading factor (n) (i.e., $cos^n\theta$) of 50.0. Wave breaking and bottom friction were not simulated to ensure wave energy dissipation was due only to vegetation.

Table 2. Simulation parameters for comparison with Mendez and Losada (2004).

Tp [s]	ls [m]	bv [m]	N [stems/m^2]	C_D [-]
1.5	0.75	0.006	200.0	1.0
3.0	0.25	0.02	250.0	0.2
5.0	1.25	0.1	10.0	0.5
8.0	0.5	0.004	400.0	0.35
10.0	1.0	0.05	100.0	0.7

Figure 1 demonstrates the comparisons between STWAVE and the analytical solution of Mendez and Losada (2004). STWAVE simulations were completed both in half-plane mode (STWAVE-HP) and full-plane mode (STWAVE-FP) to ensure the solutions were consistent. The wave attenuation trends compare well with each other, with only slight differences between the two STWAVE modes and Mendez and Losada (2004). The most noticeable difference was for the shortest peak period (T_p = 1.5 s). These inconsistencies may be a result of the use of the mean period in STWAVE while Mendez and Losada (2004) use the peak period. As these differences are very small, the wave attenuation proposed by Mendez and Losada (2004) for unidirectional, nonbreaking random waves can be closely approximated using STWAVE.

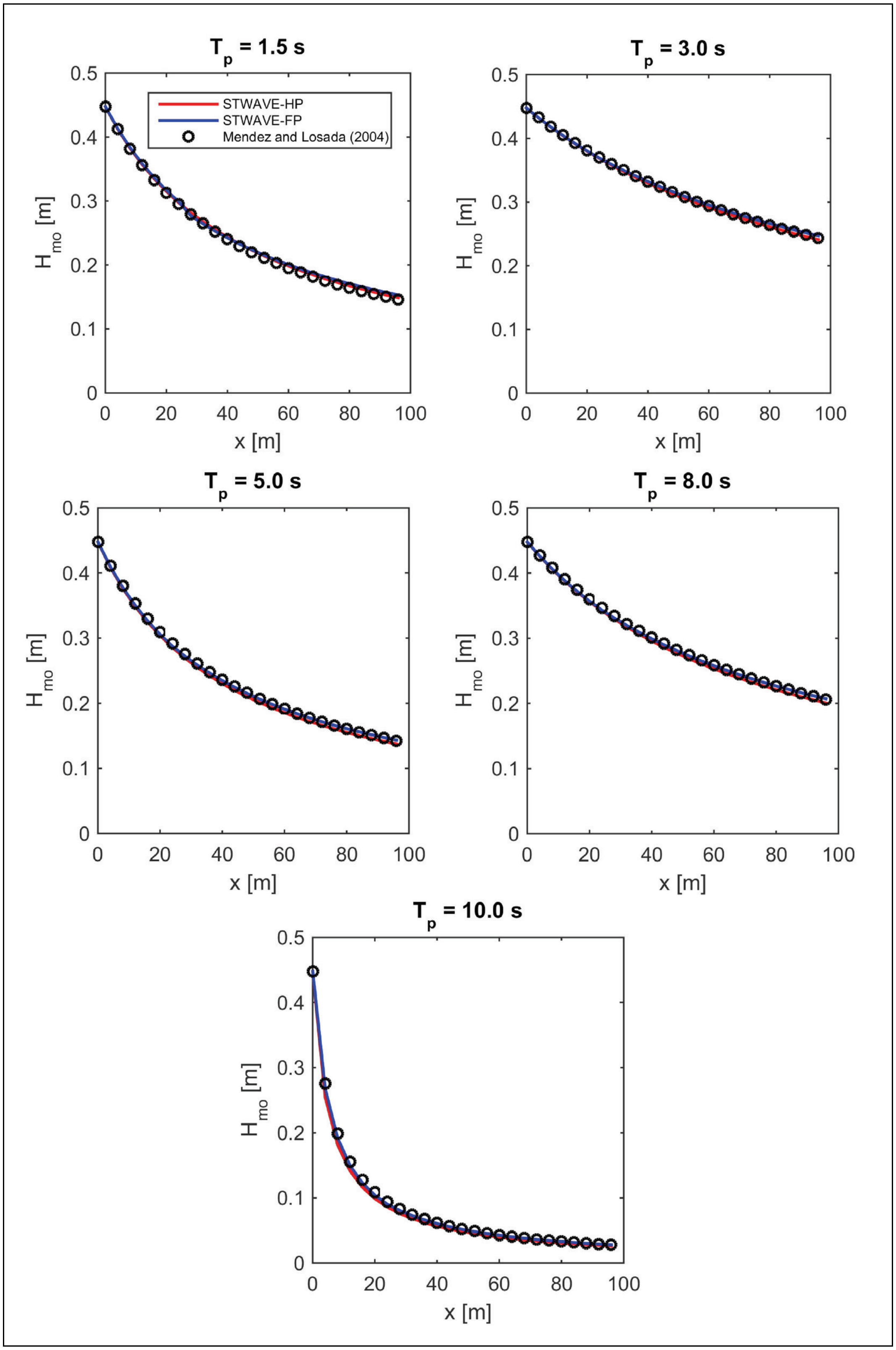

Figure 1. Comparisons of wave height evolution between STWAVE and Mendez and Losada (2004).

SENSITVITY TO SPECTRAL PARAMETERS

Frequency. The sensitivity of the STWAVE solution to differences in the peak enhancement factor (γ) is investigated by comparing TMA spectra of γ = 10.0, considered a narrow spectral value, and γ = 3.3, a common default value. An illustration of the resulting difference in spectral shape is provided in Figure 2. A larger peak enhancement factor (γ) results in a narrower and greater concentration of energy at the peak frequency compared to smaller γ values.

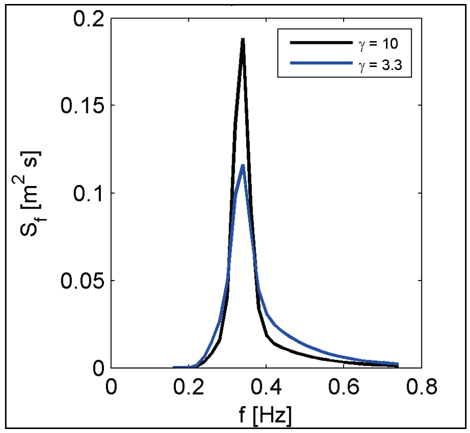

Figure 2. TMA spectra with γ = 10.0 and γ = 3.3 for T_p = 3.0 s.

The simulation parameters shown in Table 2 were kept constant to compare results to those of the Mendez and Losada (2004) evaluation. As seen in Figure 3, the difference in wave dissipation due to changes in peak enhancement factor remained negligible throughout the range of considered periods.

Direction. Differences in wave attenuation due to changes in the directional spreading factor (n) are also investigated. Input spectra for both simulations was TMA spectra with γ = 3.3, with one spectrum generated with n = 50.0, considered a narrow spreading value, and the other with n = 4.0, a standard value. Again, all other simulation parameters remained constant. Energy is distributed over a narrower angle band for larger values of n, as can be seen in Figure 4.

The difference in wave dissipation for a spatially constant vegetation field is shown in Figure 5. Little difference in wave evolution due to changes in directional spreading was observed along the center-axis, with these differences remaining small throughout the range of tested periods, although the n = 4.0 solution is consistently slightly lower than n = 50.0.

The difference in wave dissipation considering a patch of vegetation smaller than the computational grid was also investigated. These computations were completed on a 500 m long by 300 m wide rectangular grid, with a smaller vegetation patch along the center-axis. The vegetation patch was 204 m long, 120 m wide, and located approximately 134 m from the offshore boundary. The water depth remained constant at d = 1.0 m throughout the domain. The modeled incident significant wave height and peak period were H_{mo} = 44.8 cm and T_p = 5.0 s. Local vegetation was constant at l_s = 60.0 cm, b_v = 5.0 millimeters (mm), N = 250.0 stems/m^2, and C_D = 1.0. Simulations were completed using STWAVE-HP.

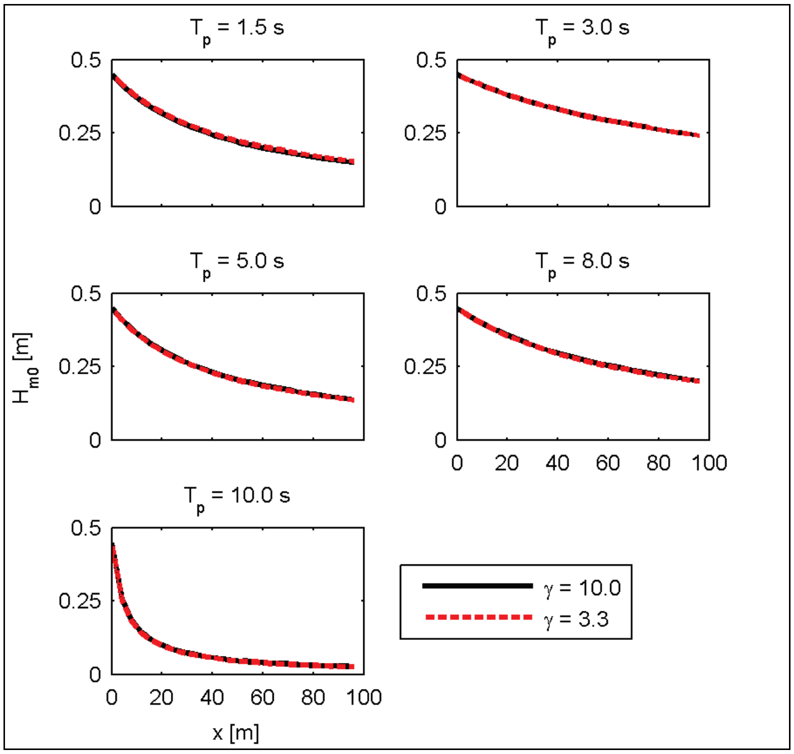

Figure 3. Wave height evolution for TMA spectra with γ = 10.0 and γ = 3.3 and n = 50.0.

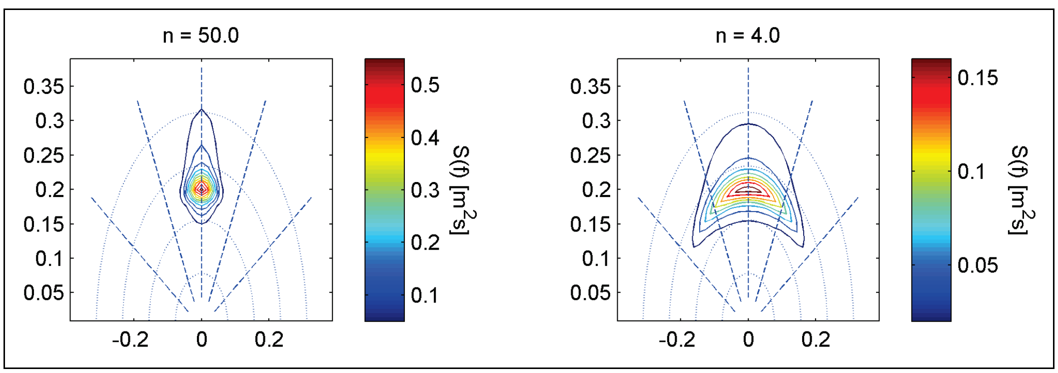

Figure 4. TMA spectra with n = 50.0 and n = 4.0 for T_p = 5.0 s.

Figure 6 and Figure 7 show that the most noticeable difference in wave height is located downstream of the vegetation patch. Reduced wave height is seen behind the patch for n = 50.0 as the waves are impeded and limited in direction. However, waves are able to propagate and reform downstream of the vegetation for n = 4.0 as wave energy is distributed amongst a broader range of directions. This wave behavior is similar to that observed for irregular wave interactions with structures.

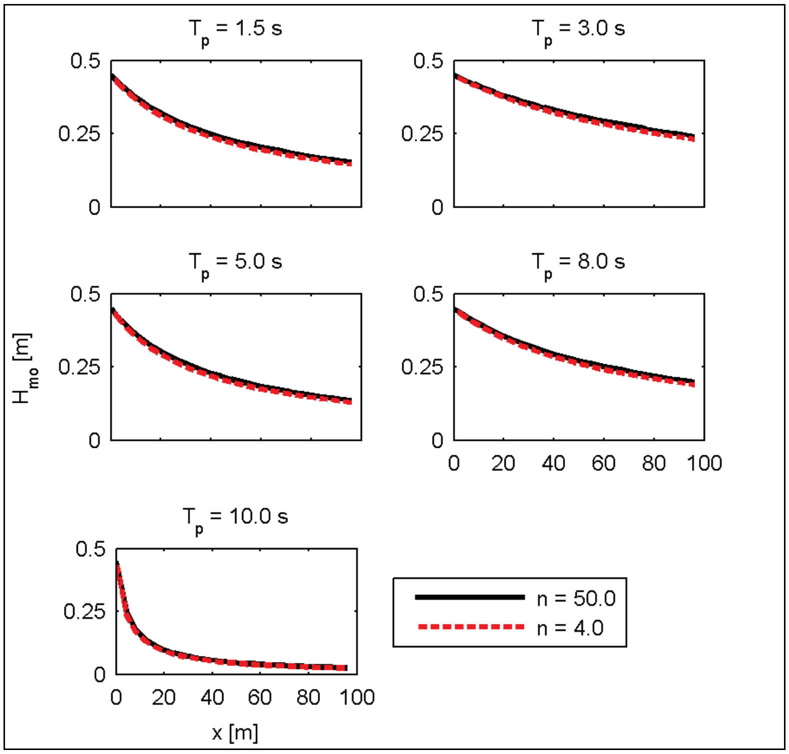

Figure 5. Wave height evolution for TMA spectra with γ = 3.3 and n = 50.0 and n = 4.0.

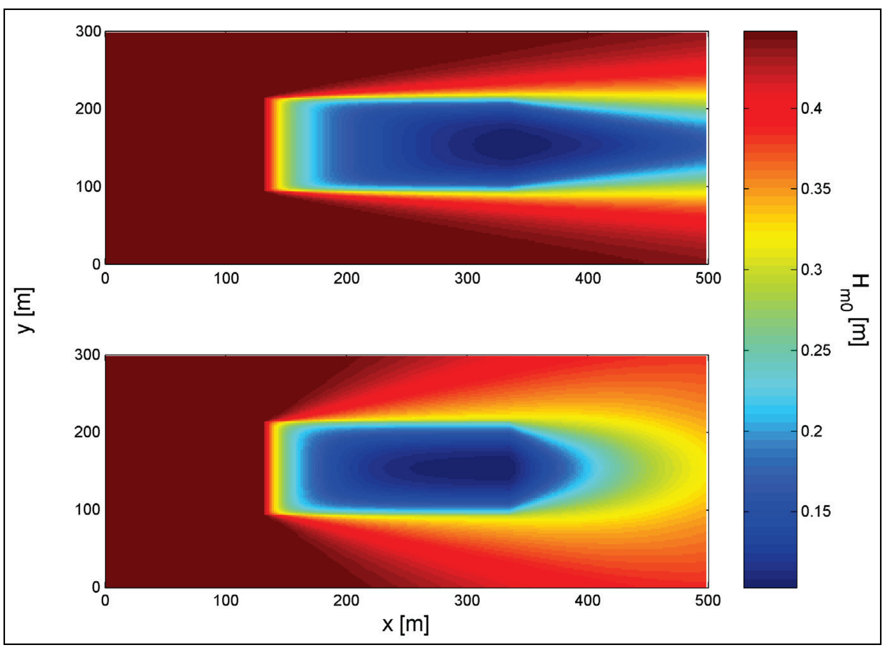

Figure 6. Wave interaction with vegetation patch for TMA spectra with γ = 3.3 and n = 50.0 (top) and n = 4.0 (bottom).

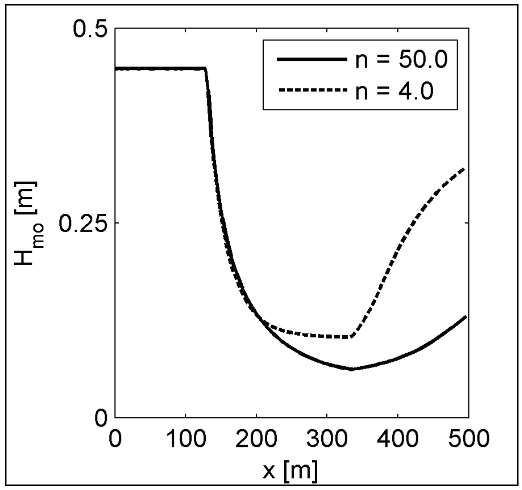

Figure 7. Wave height evolution along center-axis for TMA spectra with γ = 3.3 and n = 50.0 and n = 4.0.

APPLICATION TO LABORATORY EXPERIMENTS: Two bottom friction dissipation formulations are available in STWAVE, JONSWAP and Manning's n. The vegetation source term was combined directly with the bottom friction terms in order for dissipation to be a function of the individual processes (bottom friction or vegetation) or both processes concurrently (bottom friction and vegetation). To test this formulation, the STWAVE model with vegetation was applied to laboratory measurements of wave attenuation conducted by Anderson and Smith (2014). The experiment was carried out in a 63.4 m long, 1.5 m wide, and 1.5 m deep wave flume. The vegetation zone measured 9.8 m long and was populated with idealized vegetation (Figure 8). The idealized vegetation was constructed from 6.4 mm diameter flexible tubing measuring 41.5 cm long. Two densities, 200 and 400 stems/m^2, were tested for 21 irregular wave conditions with varied wave height, peak period, and water depth. Input spectra for STWAVE were generated from the measured spectra, with all energy focused in the 0-degree angle band as waves were unidirectional.

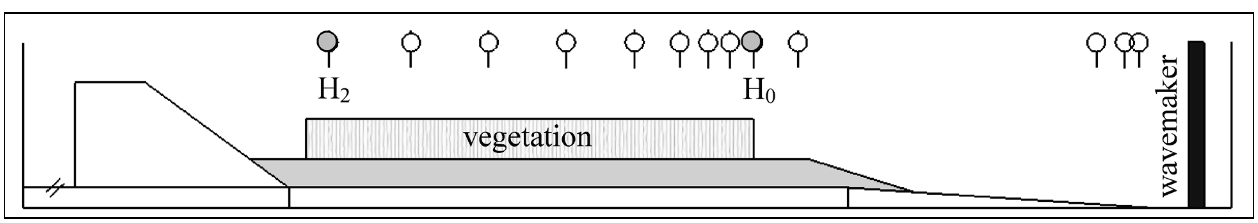

Figure 8. Model setup for Anderson and Smith (2014).

To test the implementation of the dissipation formulation with the measured data, wave dissipation was considered in the following form:

$$\frac{\partial H_{mo}^2}{\partial x} C_g = -\frac{\boldsymbol{C_{bf}}}{\boldsymbol{g}} \left(\frac{\boldsymbol{\omega}}{\sinh \boldsymbol{kh}} \right)^2 \boldsymbol{H_{mo}^2 u_{rms}} - \frac{g^2}{2\sqrt{2\pi}} C_D b_v N \left(\frac{k}{\omega} \right)^3 \frac{\sinh^3 kl_s + 3\sinh kl_s}{3k\cosh^3 kh} H_{mo}^3$$

where the first term on the right-hand side of the equation, shown in bold, is the Manning's *n* bottom friction source term, and the second term is the vegetation source term. The background dissipation due to friction in the flume (C_{bf}), was first solved for by assuming no vegetation:

$$C_{bf} = -\ln\left(\frac{H_2^2}{H_0^2}\right)\frac{g}{u_{rms}}\left(\frac{\sinh kh}{\omega}\right)^2\frac{C_g}{\Delta x}$$

where the root-mean-square horizontal wave velocity (u_{rms}), was defined at the bottom and was calculated as

$$u_{rms} = \frac{H_0}{2\sqrt{2}}\frac{\omega}{\sinh kh}$$

C_{bf} was calculated using the unimpeded control runs (no vegetation), with H_{mo} measured at the gauge immediately incident to the vegetation test section and at the last gauge corresponding to H_0 and H_2, respectively. The location of these gauges of interest is identified in Figure 8.

After estimating the background friction, the drag coefficient due to vegetation was estimated:

$$C_D = \frac{-\ln\left(\frac{H_2^2}{H_0^2}\right) - \frac{C_{bf}}{g}\left(\frac{\omega}{\sinh kh}\right)^2 u_{rms}\frac{\Delta x}{C_g}}{\frac{g^2}{2\sqrt{2\pi}}b_v N\left(\frac{k}{\omega}\right)^3\frac{\sinh^3 kl_s + 3\sinh kl_s}{3k\cosh^3 kh}H_1\frac{\Delta x}{C_g}}$$

Again, H_0 is measured at the gauge immediately upstream of the vegetation test section, and H_2 is measured at the last gauge (downstream end). The input into STWAVE, Manning's *n*, was obtained by rearranging C_{bf}:

$$n_{bf} = \sqrt{\frac{C_{bf}h^{1/3}}{g}}$$

Figure 9 compares the nondimensional wave evolution of STWAVE with a subsample of the flume experiments. The top-left panel shows the wave attenuation with a water depth of d = 30.5 cm, an incident significant wave height of H_0 = 11.3 cm, a peak wave period of T_p =1.25 s, and a stem density of N = 400.0 stems/m^2. The top-right panel shows the wave attenuation with a water depth of d = 45.7 cm, an incident significant wave height of H_0 = 19.2 cm, a peak wave period of T_p = 2.0 s, and a stem density of N = 200.0 stems/m^2. The bottom panel shows the wave attenuation with a water depth of d = 53.3 cm, an incident significant wave height of H_0 = 11.1 cm, a peak wave period of T_p = 1.5 s, and a stem density of N = 200.0 stems/m^2. Overall, STWAVE is able to replicate the wave evolution trend of the experiments well, with a goodness of fit coefficient (R^2) exceeding 0.90 for all comparisons. A major assumption in implementation of vegetation is the linear summation of bottom friction and vegetation losses. This model validation supports that this approximation is appropriate.

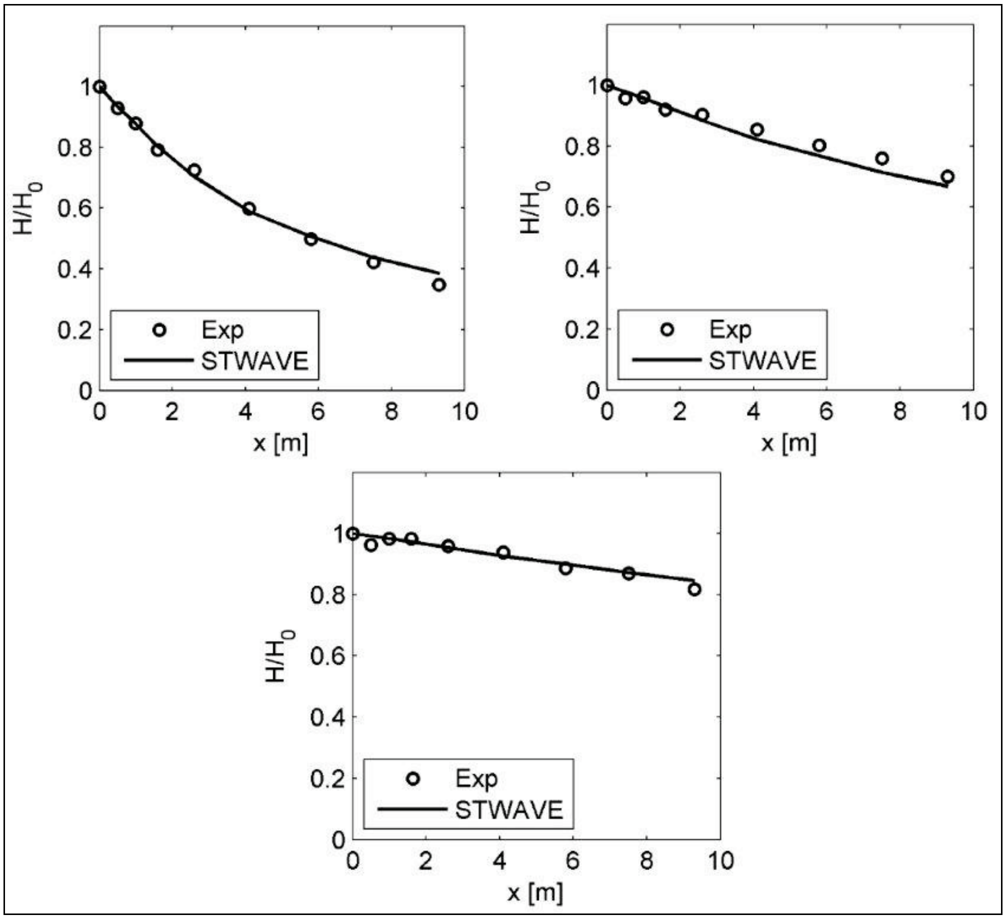

Figure 9. Wave height comparisons of STWAVE and the laboratory results of Anderson and Smith (2014): (top left) d = 30.5 cm, H_0 = 11.3 cm, T_p = 1.25 s, N = 400.0 stems/m^2; (top right) d = 45.7 cm, H_0 = 19.2 cm, T_p = 2.0 s, N = 200.0 stems/m^2; (bottom) d = 53.3 cm, H_0 = 11.1 cm, T_p = 1.5 s, N = 200.0 stems/m^2.

CONCLUSIONS: The analysis, design, and construction of coastal protection often neglect the beneficial effects of natural or nature-based features because insufficient methods are available to capture those benefits. In this technical note, random wave dissipation by vegetation is implemented into the phase-averaged nearshore wave model STWAVE. The vegetation dissipation source term is first validated by comparing model results to the solution of Mendez and Losada (2004) for unidirectional, nonbreaking waves. Following validation, the sensitivity of the model solution to energy distribution in frequency and direction is investigated. The difference in wave height as a result of frequency spread was minute for the range of considered periods. The wave height evolution along the center line of a domain with spatially constant vegetation was also insensitive to differences in directional spreading. However, the global wave solution changes considerably with directional spreading when considering a local vegetation patch, particularly downstream of the vegetation. Finally, combining the vegetation source term with the already existing bottom friction terms in STWAVE was tested using the flume experiments of Anderson and Smith (2014). By first solving for the bottom friction coefficient and then the bulk drag coefficient, a good prediction of wave dissipation was obtained. Since the bulk drag coefficient accounts for many assumptions and processes not yet fully understood, calibration of the bulk drag coefficient is essential to obtain accurate results, and its dependence on hydrodynamics and plant biomechanics requires additional investigation.

SYMBOLS

$\tilde{k}$	mean wave number
$\tilde{\omega}$	mean wave angular frequency
b_v	average stem diameter
C_{bf}	bottom friction coefficient
C_D	average or bulk depth-averaged drag coefficient
$\tilde{C}_D$	depth-averaged drag coefficient
C_g	group speed
d	water depth
E	wave energy
E_{tot}	total wave energy
F_x	horizontal force per unit volume on a stem array
g	acceleration due to gravity
H	local significant wave height
H_{mo}	significant wave height
H_{rms}	root-mean-square wave height
k	wave number
l_s	average vegetation height
n	directional spreading factor
N	vegetation density
n_{bf}	Manning's n
S_{veg}	wave damping due to vegetation source term
T_p	peak period
u	horizontal wave particle velocity
u_{rms}	root-mean-square horizontal wave particle velocity
x	horizontal distance
γ	spectral peak enhancement factor
ε_v	time-averaged rate of energy dissipation per unit horizontal area due to vegetation
ρ	water density
ω	wave angular frequency
z	vertical dimension

ADDITIONAL INFORMATION: This CHETN was prepared as part of the Wave Dissipation by Vegetation for Coastal Protection work unit in the Flood and Coastal Systems R&D Program and was written by Mary E. Anderson (*Mary.Anderson@usace.army.mil*) and Jane Smith (*Jane.M.Smith@usace.army.mil*) of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). The Program Manager is Dr. Cary Talbot, and the Technical Director is William Curtis. This CHETN should be cited as follows:

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REFERENCES

Anderson, M. E., J. M. Smith, and S. K. McKay. 2011. *Wave dissipation by vegetation*. ERDC/CHL CHETN-I-82. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.erdc.usace.army.mil/chetn*.

Anderson, M. E., and J. M. Smith. 2014. Wave attenuation by flexible, idealized salt marsh vegetation. *Coastal Engineering* 83: 82–92.

Dalrymple, R. A., J. T. Kirby, and P. A. Hwang. 1984. Wave diffraction due to areas of energy dissipation. *Journal of Waterway, Port, Coastal, and Ocean Engineering* 110(1): 67–79.

Massey, T. C., M. E. Anderson, J. M. Smith, J. Gomez, and R. Jones. 2011. *STWAVE: Steady-state spectral wave model user's manual for STWAVE, version 6.0.* ERDC/CHL SR-11-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Mendez, F. J., and I. J. Losada. 2004. An empirical model to estimate the propagation of random breaking and nonbreaking waves over vegetation fields. *Coastal Engineering* 51: 103–118.

Morison, J. R., M. P. O'Brien, J. W. Johnson, and S. Schaaf. 1950. The force exerted by surface waves on piles. *Petroleum Transactions* 189: 149–154.

Smith, J. M., A. R. Sherlock, and D. T. Resio. 2001. *STWAVE: Steady-state spectral wave model user's manual for STWAVE, version 3.0*. ERDC/CHL SR-01-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, J. M. 2007. *Full-plane STWAVE with bottom friction: II. Model overview*. ERDC/CHL CHETN-I-75. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.erdc.usace.army.mil/chetn*.

Suzuki, T., M. Zijlema, B. Burger, M. C. Meijer, and S. Narayan. 2011. Wave dissipation with layer schematization in SWAN. *Coastal Engineering* 59: 64–71.

APPENDIX A

Example STWAVE simulation file with IVEG = 1 (constant vegetation)

```
# STWAVE_SIM_FILE
# written from SMS 11.1.5 64-bit
#
#
################################################
#
# Standard Input Section
#
&std_parms
 iplane = 0,
 iprp = 1,
 icur = 0,
 ibreak = 0,
 irs = 1,
 nselct = 50,
 nnest = 0,
 nstations = 0,
 ibnd = 0,
 ifric = 0,
 idep_opt = 1,
 isurge = 0,
 iwind = 0,
 i_bc1 = 2,
 i_bc2 = 3,
 i_bc3 = 0,
 i_bc4 = 3,
 iveg = 1
/
…
#
# Constant Vegetation
#
&const_veg
 veg_ls_const = 1.5
 veg_bv_const = 0.04,
 veg_N_const = 200,
 veg_Cd_const = 0.5
/
…
```

Example STWAVE simulation file with IVEG = 2 (VARIABLE vegetation)

```
# STWAVE_SIM_FILE
# written from SMS 11.1.5 64-bit
#
#
###############################################
#
# Standard Input Section
#
&std_parms
 iplane = 0,
 iprp = 1,
 icur = 0,
 ibreak = 0,
 irs = 1,
 nselct = 50,
 nnest = 0,
 nstations = 0,
 ibnd = 0,
 ifric = 0,
 idep_opt = 1,
 isurge = 0,
 iwind = 0,
 i_bc1 = 2,
 i_bc2 = 3,
 i_bc3 = 0,
 i_bc4 = 3,
 iveg = 2
/
…
#
# Input Files Section
#
&input_files
 DEP = "vegtest.dep",
 SPEC = "vegtest.eng",
 VEG = "veg.in"
/
…
```

APPENDIX B

EXAMPLE STWAVE GLOBAL VEG INPUT FILE FOR IVEG = 2 (VARIABLE VEGETATION)

```
# STWAVE_SPATIAL_DATASET
#
&DataDims
 DataType = 0,
 NumRecs = 1,
 NumFlds = 4,
 NI = 50,
 NJ = 15,
 DX = 2.0,
 DY = 2.0,
 GridName = "vegtest.sim"
/
#
&Dataset
 FldName(1) = "Average vegetation height",
 FldUnits(1) = "m",
 FldName(2) = "Average vegetation diameter",
 FldUnits(2) = "m",
 FldName(3) = "Vegetation density",
 FldUnits(3) = "stems/m^2",
 FldName(4) = "Bulk drag coefficient",
 FldUnits(4) = "",
 RecInc = 1
/
IDD veg
1.5 0.04 200 0.5
1.5 0.04 200 0.5
1.5 0.04 200 0.5
1.5 0.04 200 0.5
1.5 0.04 200 0.5
…
```