Estimation of wave attenuation over Posidonia Oceanica

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Abstract

Submerged vegetation, such as seagrasses has the following functions regarding hydrodynamic aspects; wave attenuation, protection of the hinterland from wave attack, stabilizing the seabed. The purpose of the present study is to quantify the effect of submerged vegetation and more specifically of Posidonia oceanica on wave attenuation. The data of large scale experiments, conducted in the CIEM flume of UPC for irregular water waves over artificial P. oceanica meadow, are analyzed. Results show that the wave height attenuation over the meadow, ranges from 10%-35%, depending on the plant characteristics, such as the submergence ratio α=hs/h (hs: meadow height, h: water depth) and plant density N (stems/m2) and the wave period. The effect of these parameters on the wave damping coefficient Kv is quantified. The drag coefficient Cd, characteristic for the P. oceanica is estimated, which can be used for the calculation of the wave attenuation in numerical studies.

1 Introduction

The importance of coastal vegetation, such as seagrasses and salt marshes, regarding biological and physical aspects has been well recognized (Borum et al. 2004). Due to their capacity to alter their environment, seagrasses have been referred to as "ecosystem engineers", because they partly create their own habitat: the leaves attenuate wave and current action increasing sedimentation and the seagrass roots and rhizomes stabilize the seabed.

The most common seagrass species in the Mediterranean Sea is *Posidonia Oceanica*, which can colonize soft substrates such as sand in wave-sheltered areas and also attach to rocks being exposed to relatively high wave energy wind driven currents (Koch et al, 2006). *P. oceanica* seagrass meadows are usually distributed in shallow areas from the surface to a depth of 30-40 m in clear conditions, while the plants density varies from sparse (<150 stems/m^2) found in deeper waters to dense (>700 stems/m^2) (Giraud (1977)). The plant has ribbon-like leaves, 1.0 cm wide and up to 1.0 m long. Regarding the ability to attenuate wave energy, it depends both on the seagrasses characteristics (the seagrass density, the canopy height, the stiffness of the plant and the bending of the shoots) and the wave parameters (wave height, period and direction)

Various studies on wave attenuation due to coastal vegetation have been performed. In Fonseca and Cahalan (1992) flume study of four species of seagrass, the wave attenuation was found 20% - 76% over 1 m length when the plants were occupying the entire water depth. In early theoretical and numerical studies the plants (particularly flexible ones) have been simulated as rigid cylinders with different values to the drag coefficient (Dalrymple et al 1984, Kobayashi et al 1993). Mendez and Losada (2004) developed an empirical model which includes wave damping and wave breaking over vegetation fields on variable depths. Suzuki and Dijsktra (2007) used a VOF model to simulate wave attenuation over strongly varying beds and vegetation fields, where among others they showed that the complex relationship between storm waves and seagrass-induced wave attenuation still needs to be verified. Recently Li and Zhang (2010) developed a 3D RANS model to investigate the hydrodynamics and mixing induced by random waves on vegetation, which is represented as an array of cylinders with the drag coefficient expressed with an empirical relation. Regarding the estimation of the plant's drag coefficient C_d, characteristic of the seagrass plant, an empirical relationship is given with

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the Reynolds number as in Mendez (1999) and Cavallaro et al. (2010) or the Keulegan–Carpenter number (Mendez and Losada, 2004)

In the present work, the data of large scale experiments, conducted in the CIEM flume for irregular waves over artificial *Posidonia oceanica* meadow, are analyzed. The study focuses on the effects of the submergence ratio $\alpha = h_s/h$ (h_s=height of seagrass, h=water depth) and the seagrass density N (stems/m^2) on the wave height attenuation. The effect of these parameters on the wave height damping coefficient, which is often used in literature for wave-vegetation interactions is quantified. An empirical relationship for the drag coefficient C_d related to the Reynolds number, is obtained, characteristic for the plant of *P. oceanica*, which can be useful in numerical studies of wave-submerged vegetation interactions.

2 Experimental setup

The experiments were conducted in the CIEM large wave flume (Canal d'Investigació i Experimentació Marítima) at the Universitat Polytecnica de Catalunya, Barcelona. A series of experiments were performed for waves propagating over artificial Posidonia Oceanica patch in intermediate and shallow waters. The CIEM wave flume is 100 m long, 5 m deep and 3 m wide. A sandy slope beach of 1:15 was installed at the end of the flume for the elimination of wave reflection. A 20 m long horizontal and flat sandy area was created in the central part of the flume and the patch of artificial *P. oceanica*, with a total length L=10.70 m and height h_s=0.55 m, was placed above, as shown in Figure 1.

The artificial seagrass meadows were made of polypropylene strips and carefully designed to reproduce the flexibility and buoyancy properties typical of the natural *P. oceanica* plants. Figure 2 shows the dimensions and structure of the mimics. More details about the experimental setup and the artificial plant characteristics can be found in Stratigaki et al. (2010).

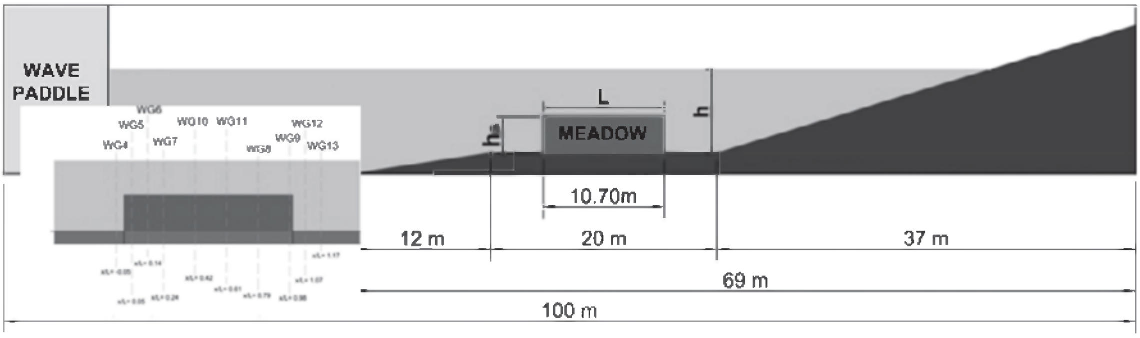

Figure 1: Sketch of the experimental setup of the CIEM flume

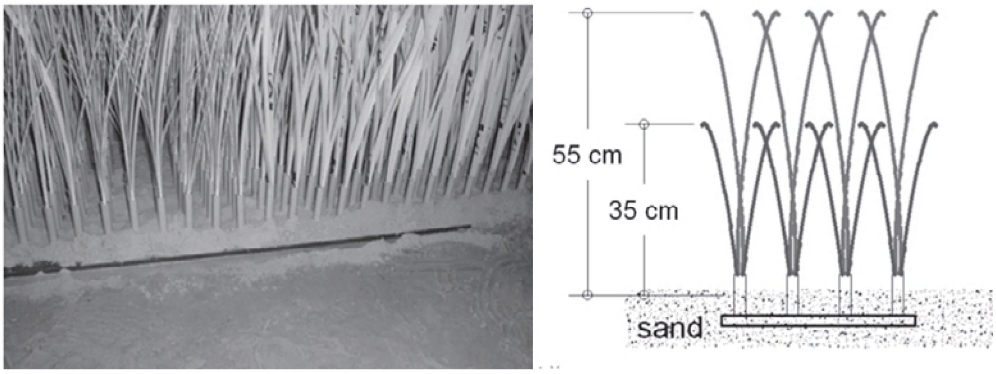

Figure 2: Detail and schematic detail of the artificial Posidonia Oceanica

Wave transformation was monitored by wave gauges distributed along the flume; the location of the wave gauges along the artificial meadow is shown in Figure 1. The experiments were performed for irregular waves over the artificial *P. oceanica* meadow, with four different submergence ratios ($\alpha = h_s/h$ equal to 0.32, 0.37, 0.42 and 0.50) and two seagrass densities

(N=180 and 360 stems/m^2). A summary of the wave and plant characteristics is shown in Table 1.

Table 1: Wave and plant characteristics

Water depth h (m)	Peak wave period T_p (s)	Wave height H_s (m)	Wave length L (m)	h/L	Plant density N (stems/m^2)	Submergence ratio $\alpha=h_s/h$
1.10 1.30 1.50 1.70	2.0 3.0 3.5 4.0 4.5	0.28 0.30 0.35 0.40	5.36-17.34	0.09-0.29	180 360	0.32 0.37 0.42 0.50

3 Analysis of results

3.1 Wave height attenuation

An analytical expression for the wave height decay over submerged vegetation is given in equation (1), as presented in Dalrymple et al. (1984) and Mendez and Losada (2004):

$$H = K_v H_o \tag{1}$$

with H wave height [m]. For irregular waves is the root mean square wave height, H_{rms}

H_o incident wave height before meadow [m]. For irregular waves is $H_{rms,o}$

K_v damping coefficient, defined in equation (2)

$$K_v = \frac{H}{H_o} = \frac{1}{1+\beta x} \tag{2}$$

with β parameter related to the plant and wave characteristics

x distance along meadow [m]

For irregular waves, the conservation of energy equation leads to the following expression for β (Mendez and Losada, 2004).

$$\beta = \frac{1}{3\sqrt{\pi}} C_d b_v N H_o k \left[\frac{\sinh^3 k\alpha h + 3\sinh k\alpha h}{(\sinh 2kh + 2kh)\sinh kh} \right] \tag{3}$$

with C_d average drag coefficient of the meadow

b_v plant area per unit height of each vegetation stand normal to horizontal velocity [m]

k wave number [m^{-1}]

From the above parameters, the difficulty is to estimate the drag coefficient C_d, which is characteristic for each submerged plant's stiffness; work that is performed in paragraph 3.3. In the following figures (Figure 3, 4) the experimental results for the damping coefficient K_v (=H/H_o) are shown, together with the plot of equation (2). The details of each experimental test and the value of C_d as computed are also shown. It can be seen that the experimental wave height distribution along the meadow follows the proposed analytical equation given from theory. The wave damping varies and is related to the plant and wave characteristics as shown in the next paragraph 3.2.

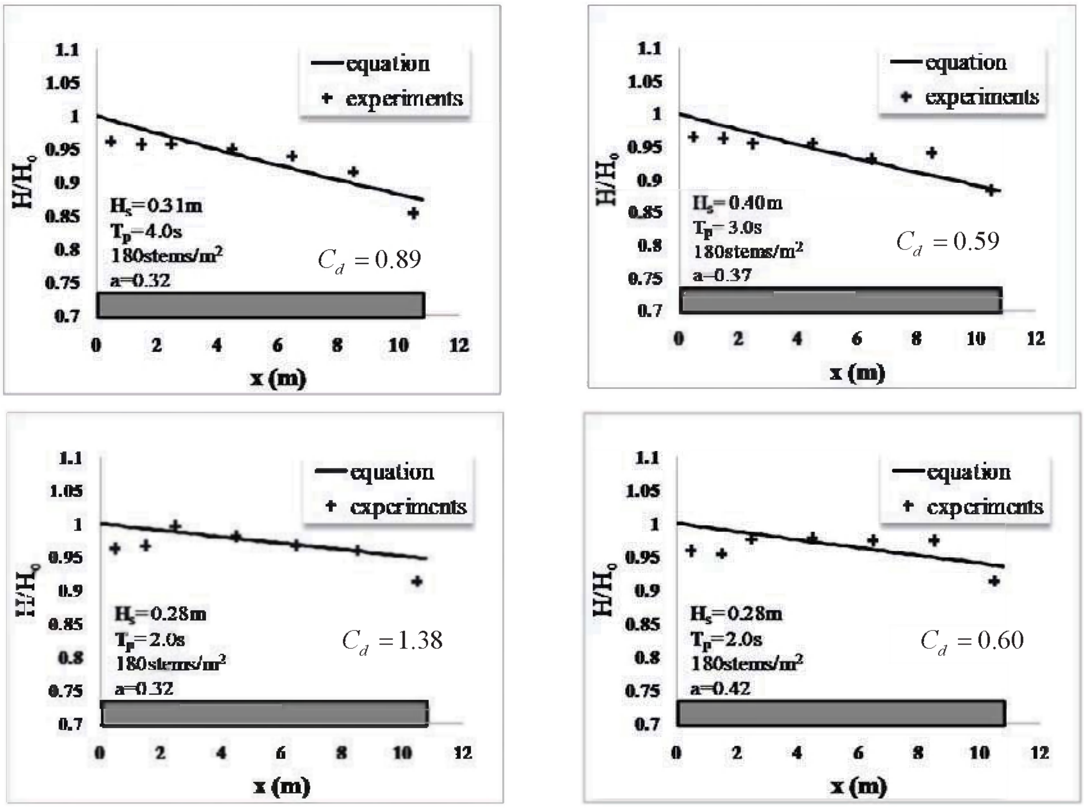

Figure 3: K_v variation over artificial *P. oceanica* meadow (N=180 stems/m^2).

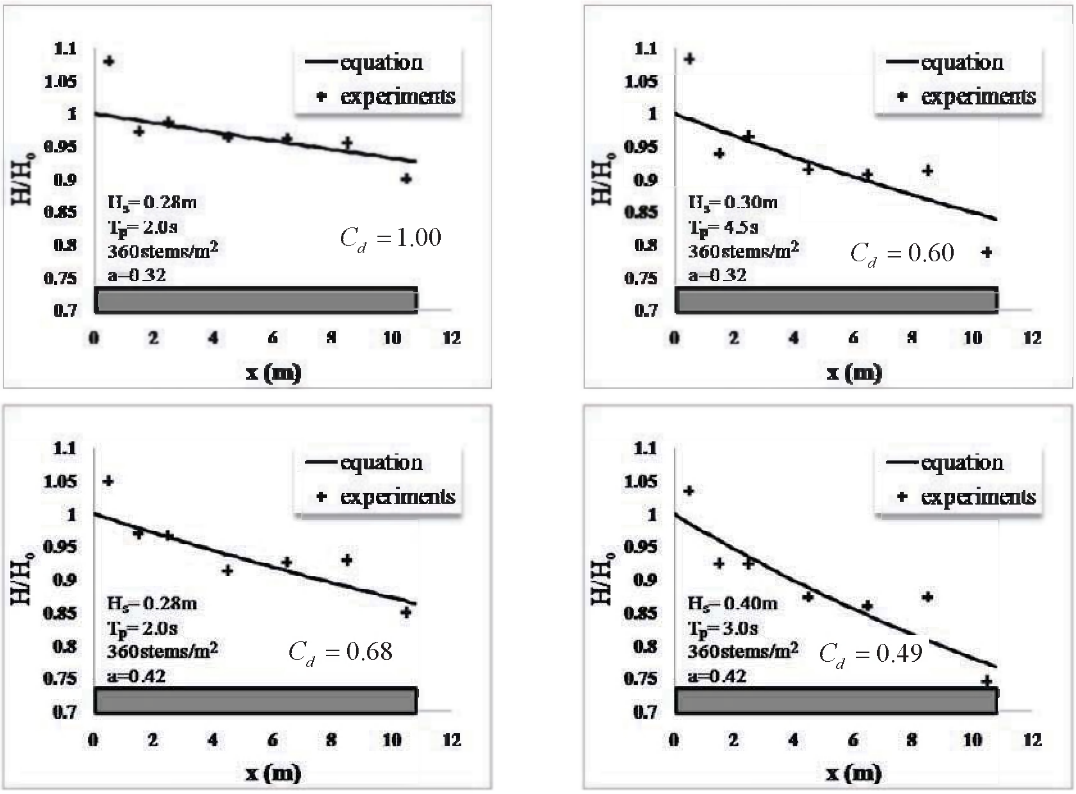

Figure 4: K_v variation over artificial *P. oceanica* meadow (N=360 stems/m^2).

3.2 Effect of plant and wave characteristics on wave damping coefficient

3.2.1 Effect of submergence ratio hs/h and plant density N

The effect of the submergence ratio on wave attenuation is shown in Figure 5 where K_v is plotted for same wave conditions (H_s= 0.28 m, T_p= 2s) and density N= 360 stems/m^2 and 180 stems/m^2 respectively. For both densities the incident wave height (H_o as measured in x/L= -0.05) is reduced by ~15-25%, with larger attenuation observed for the more dense meadow. It can also be noticed that due to the "plant resistance" to the flow, in the upward side of the meadow, part of the wave energy is reflected and the wave height increases (x/L= 0.05) for the more dense case (360 stems/m^2). The effect of submergence ratio on wave attenuation is also evident.

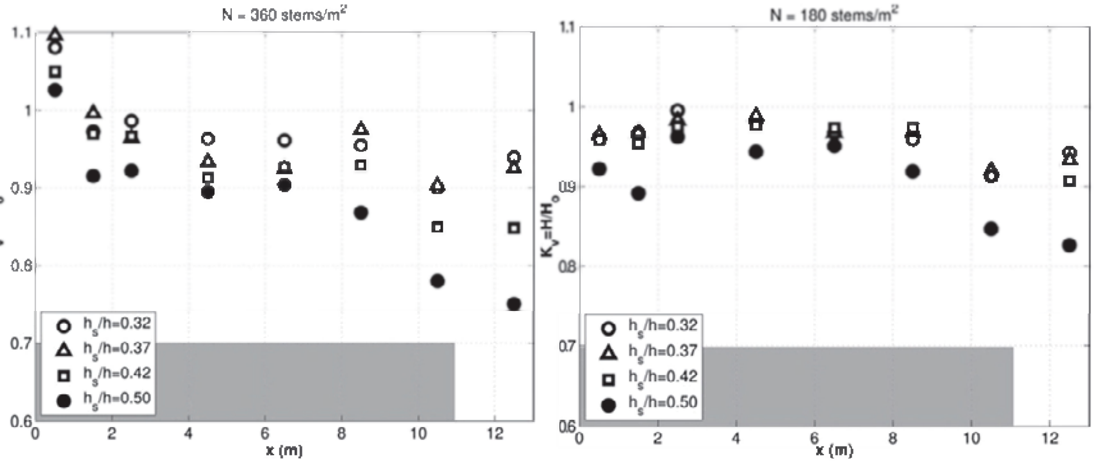

Figure 5: Kv variation over the meadow for various submergence ratios hs/h.
N=360 stems/m2 (left) and N=180 stems/m2 (right).

3.2.2 Effect of wave period T_p

The effect of the wave period T_p on wave attenuation is shown in Figure 6 where K_v is plotted for same plant configuration (N=360 stems/m^2 and 180 stems/m^2 respectively, h_s/h=0.50) and variable wave conditions. The longer waves are mostly attenuated from the artificial meadow with maximum wave attenuation up to 35% observed for T_p=4s and the dense plant (N= 360 stems/m^2).

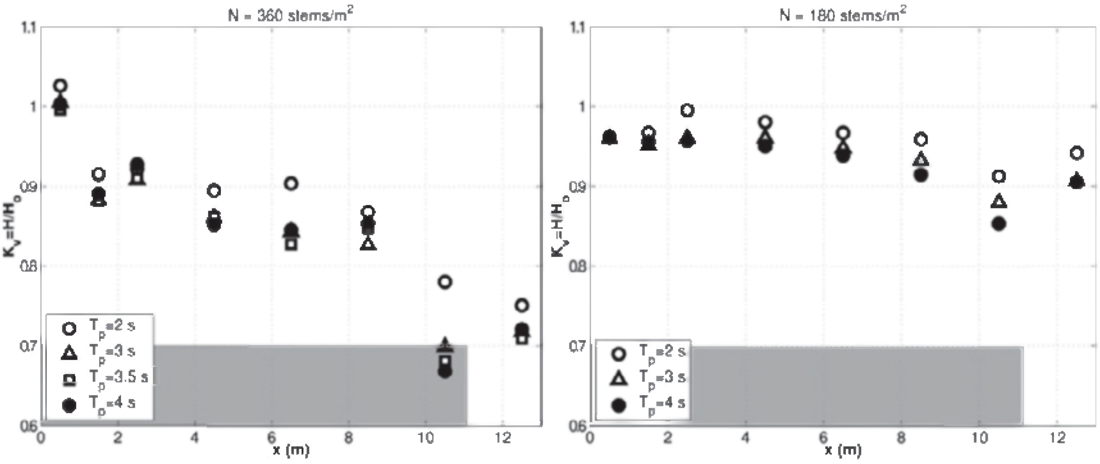

Figure 6: Kv variation over the meadow for various Tp.
N=360 stems/m2 (left) and N=180 stems/m2 (right).

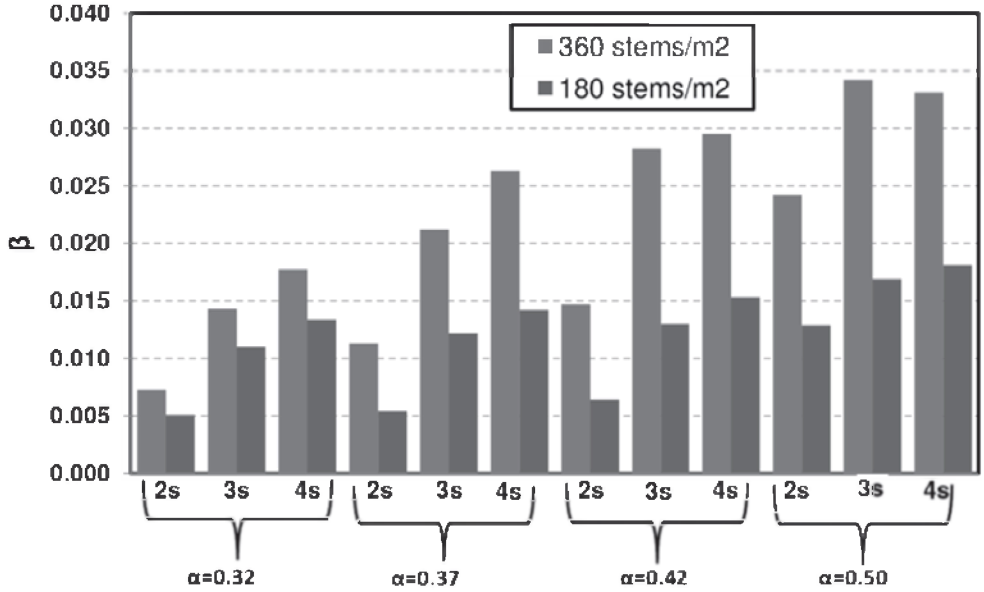

Figure 7: β parameter variation for various experimental configurations

The effect of the above characteristics on the β parameter which is used for the calculation of the damping coefficient K_v is shown in Figure 7, where values of β range from 0.005 to 0.035. It is shown that a 50% increase of the submergence ratio, α (from 0.32 to 0.50) results in average 117% increase of β. Also a 100% increase of the plant density, N (from 180 to 360) results in average 80% increase of β. The effect of the wave period is also significant since a 100% increase of T_p (from 2s to 4s) results in average 115% increase of β.

3.3 Estimation of C_d

As shown above, the average drag coefficient of the meadow, C_d, is the most important parameter for the calculation of the damping coefficient. C_d is usually related to the Reynolds number, Re, as in equation (4)

$$C_D = a + \left(\frac{\beta}{\mathrm{Re}}\right)^{\gamma} \tag{4}$$

where the coefficients α,β,γ depend on the plant characteristics (shape of leaves, length and thickness of leaves, density, modulus of elasticity, stiffness) with values found in literature shown in Table 2, while the Reynolds number is given from equation (5)

$$\mathrm{Re} = \frac{u \cdot b_v}{\nu} \tag{5}$$

with	u	characteristic velocity, taken as the maximum horizontal velocity at the meadow edge and calculated from linear wave theory, as shown in equation (6)
	v	kinematic viscosity of water, $\nu = 10^{-6}$ m^2/s

$$u = \frac{\pi \mathrm{H}}{\mathrm{T}} \frac{\cosh(k \cdot h_s)}{\sinh(kh)} \tag{6}$$

Table 2: Values of coefficients α,β,γ found in literature

Study	α	β	γ
Mendez et al (1999) – rigid plant	0.40	2200	2.2
Cavallaro et al (2010) – swaying plant	0	2100	1.7
Present study – swaying plant	0.10	2100	1.0

Figure 8 shows the measured C_d values against the Reynolds number, together with the plot of Eq. (4) for the coefficients α, β and γ taken from Mendez et al. (1999) study on rigid plants and Cavallaro et al. (2010) on *P. oceanica* artificial meadow. The Reynolds number considered in the present study varies from 1000-3200, while in the above mentioned studies it varies from 200-15500. In the experimental results a best fit curve is shown with the respective coefficients shown in Table 2. It should be noticed that the validity of such a relationship is subject to the efficient modeling of the mechanical properties of the artificial plant used. Results from other experimental studies on wave and submerged vegetation interaction (Augustin et al., 2009) show that such a correlation can be poor. This might be due to the fact that also other parameters affect the average C_d such as the submergence ratio (Mendez et al., 2004) and the stems density (Huang et al. 2011).

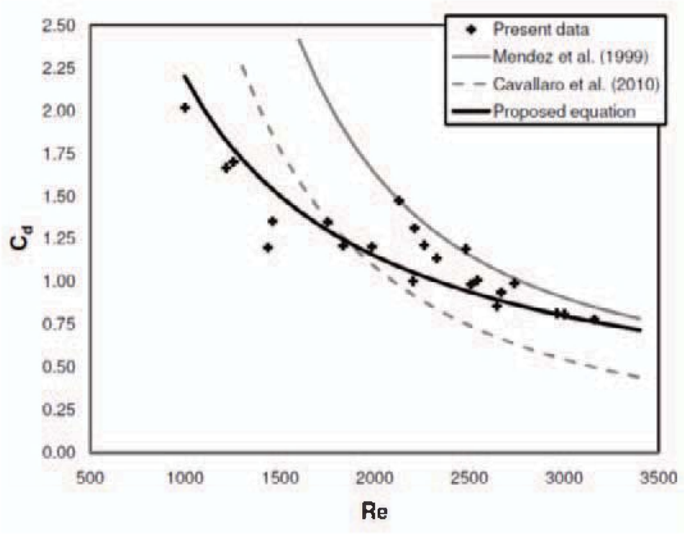

Figure 8: Variation of C_d with Reynolds number.

4 Conclusions

In the present work the effect of *Posidonia oceanica* meadow on wave height attenuation is studied, with the analysis of large scale experimental data. The main conclusions of this study are:

- The wave height is reduced between 10-35% over the artificial *P. oceanica* meadow depending strongly on the plant characteristics and the wave period. More specifically the wave height attenuation increases with increasing submergence ratio, plants density and wave period; longer waves are mostly attenuated from submerged vegetation.
- The wave height distribution over the meadow, expressed with the damping coefficient K_v, follows the proposed analytical formula found in literature, of the form 1/1+βx, where the parameter β depends on the plant and wave characteristics.
- The plants stiffness is an important parameter for estimating the wave attenuation; its effect is included in the estimation of the drag coefficient C_d. Based on the results, an empirical relationship for the drag coefficient C_d related to the Reynolds number, is

obtained, representative of the plant of *P. oceanica*, which can be useful in numerical studies of wave-submerged vegetation interactions.

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6 References

Augustin L.N.; Irish J.L.; Lynett P. (2009): Laboratory and numerical studies of wave damping by emergent and near emergent wetland vegetation. In: Coastal Engineering, Vol. 56, No. 3, pp. 332-340.

Cavallaro, L.; Lo Re, C.; Paratore, G.; Viviano, A.; Foti, E. (2010): Response of Posidonia oceanica to wave motion in shallow-waters - preliminary experimental results. In: Proceedings of the International Conference on Coastal Engineering, 1(32), Shanghai, China [Online], Jan 2011.

Dalrymple R.A.; Kirby J.T.; Hwang P.A. (1984): Wave Diffraction Due to Areas of Energy Dissipation. In: Journal of Waterway Port Coastal and Ocean Engineering, Vol. 110, No. 1, pp. 67-79.

Fonseca M.S.; Cahalan J.H. (1992): A preliminary evaluation of wave attenuation by four species of Seagrass. In: Estuarine, Coastal and Shelf Science, Vol. 35, Issue 6, pp. 565-576.

Giraud G. (1977): Essai de classement des herbiers de Posidonia oceanica (L.) Delile. In: Botanica Marina, Vol. 20, pp. 487-491.

Green E.P.; Short F.T. (2003): World Atlas of Seagrasses, UNEP-WCMC.

Huang, Z.; Yao Y.; Sim S.Y.; Yao Y. (2011): Interaction of solitary waves with emergent, rigid vegetation. In: Ocean Engineering, Vol. 38, pp. 1080-1088.

Kobayashi N.; Raichlen A.W.; Asano T. (1993): Wave Attenuation by Vegetation. In: Journal of Waterway Port Coastal and Ocean Engineering, Vol. 119, No. 1, pp. 30-48.

Koch E.W.; Sanford L.P.; Chen S-N.; Shafer D.J.; Mckee Smith J. (2006): Waves in seagrass systems: Review and Technical recommendations. US Army Corps of Engineers®. Technical Report, ERDC TR-06-15.

Li C.W.; Zhang M.L. (2010): 3D modelling of hydrodynamics and mixing in a vegetation field under waves. In: Computers & Fluids, Vol. 39, Issue 4, pp. 604-614.

Mendez, F. J.; Losada I.J; Losada M. A. (1999): Hydrodynamics induced by wind waves in a vegetation field. In: Journal of Geophysical Research, Vol. 104, 18.383-18.396, doi:10.1029/1999JC900119

Mendez F.J.; Losada I.J (2004): An empirical model to estimate the propagation of random breaking and nonbreaking waves over vegetation fields. In: Coastal Engineering, Vol. 51, No. 2, pp. 103-118.

Stratigaki V.; Manca E.; Prinos P.; Losada I.; Lara J.; Sclavo M.; Caceres I.; Sanchez-Arcilla A. (2010): Large scale experiments on wave propagation over Posidonia oceanica. In: Journal of Hydraulic Research, IAHR, Special Issue of HYDRALAB III (accepted for publication).

Suzuki T.; Dijkstra J. (2007): Wave propagation over strongly varying topography: cliffs & vegetation. In: Proceedings of 32nd IAHR Congress, Venice, Italy (CD-ROM).