

WAVE PROPAGATION OVER *POSIDONIA OCEANICA*: LARGE SCALE EXPERIMENTS

Panayotis Prinos(1), Vasiliki Stratigaki(2), Eleonora Manca(3), Inigo Losada(4), Javier Lopez Lara (4), Mauro Sclavo(5), Ivan Caceres(6), Agustin Sanchez-Arcilla(6)

- (1)Dept. of Civil Engineering, Aristotle University of Thessaloniki, Greece, E-mail: prinosp@civil.auth.gr
(2)Dept. of Civil Engineering, Ghent University, Belgium, E-mail: Vasiliki.Stratigaki@UGent.be
(3)National Oceanography Centre, Southampton, UK, E-mail : e.manca@noc.soton.ac.uk
(4)Dept. of Civil Engineering, University of Cantabria, Spain, E-mail: losadai@unican.es
(5)Institute of Marine Sciences, Venice, Italy, E-mail: mauro.sclavo@ismar.cnr.it
(6)Lab. Of Maritime Engineering, Universitat Politècnica de Catalunya, Spain, E-mail: agustin.arcilla@upc.edu

Posidonia oceanica meadows are considered to be of high importance to the environmental conservation in the Mediterranean Sea, supporting a highly biodiverse habitat and protecting from coastal erosion. In the CIEM wave flume of LIM/UPC (Barcelona, Spain) large scale experiments have been conducted for measuring wave attenuation, transmission and energy dissipation over artificial *P. oceanica* in intermediate and shallow waters. The effects of submergence ratio hs/D (hs = height of seagrass, D = water depth) and seagrass density (number of stems per squared meter) on the above characteristics are investigated. Mean velocities above and within the simulated *P. oceanica* are measured and the wave induced flow within the seagrass, which influences processes such as nutrient uptake, waste removal and larval dispersion, is estimated. A meadow with a total length of 10.70 m was constructed using polypropylene artificial plants. Measurements of wave height at different locations along the meadow indicate attenuation of waves for three different submergence ratios (hs/D), two seagrass densities (stems/m²) and various wave conditions. Results are also analysed with regard to the wave induced flow within the field and the effects of hs/D and seagrass density on mean flow characteristics are investigated based on measurements of mean velocities taken within the meadow.

1. INTRODUCTION

Posidonia oceanica is a species of seagrass endemic to the Mediterranean Sea and included in the Barcelona convention list of protected species. This marine plant forms large underwater meadows that are considered to be of high importance to the environmental conservation of the region which they occupy, supporting a highly biodiverse habitat and protecting from coastal erosion. *P. oceanica* seagrass meadows are distributed in shallow areas from the surface to a depth of 30.0-40.0 m in clear conditions, while it colonises sandy substrata, rocky shores and old matte reefs.

The effects of seagrasses on unidirectional flows are well studied at different scales in the field (Neumeier and Ciavola, 2004), in laboratory flumes (Ghisalberti and Nepf, 2002, 2008; Poggi et al., 2004; Ciraolo et al., 2006; Luhar et al., 2008) and in numerical studies (Choi and Kang, 2004; Li and Yan, 2007), while much less is known about the interaction between seagrass and waves. Effects of the vegetation canopy on water flow have been investigated during field studies (Koch and Gust, 1999; Verduin and Backhaus, 2000; Gacia and Duarte, 2001). Wave attenuation due to vegetation and flow conditions over and within vegetation fields have been investigated experimentally (Dubi, 1995; Lovas and Torum, 2001; Ota et al., 2004; Augustin et al., 2009) and numerically (Dean and Bender, 2006; Chen et al., 2007; Li and Yan, 2007; Suzuki and Dijkstra, 2007).

Only small scale experiments have been performed dealing with currents and *Posidonia oceanica* (Folkard, 2005). The issues that are examined in this work, include the verification of the wave-*P. oceanica* interaction and the estimation of the wave induced flow within the vegetation field, as well as the detailed flow characteristics close to water/seagrass interface. The research was carried out in the CIEM wave flume (Canal d'Investigació i Experimentació Marítima) at UPC Barcelona (Universitat Politècnica de Catalunya). Objectives of the experiments were the measurement of wave attenuation, transmission and energy dissipation over artificial *P. oceanica* during low and high energy

events in intermediate and shallow waters. The effects of submergence ratio h_s/D (h_s = height of seagrass, D =water depth) and seagrass density (stems/ m^2) on the above characteristics are investigated. Measurements of wave height at different locations along the meadow (seaward, front, middle, end and shoreward of *P. oceanica* field) indicate attenuation of waves along the meadow for three submergence ratios h_s/D equal to 0.5, 0.423 and 0.323, two seagrass densities (180 and 360 stems/ m^2) and various wave conditions. Results are also analysed with regard to the wave induced flow within the meadow and the effects of h_s/D and seagrass density on mean flow characteristics are investigated based on measurements of mean velocities taken within the artificial seagrass field.

2. EXPERIMENTAL PROCEDURE AND MEASUREMENTS

The experiments were carried out in the CIEM wave flume (100.0 m long, 3.0 m wide and 5.0 m deep). A seagrass meadow was constructed (10.70 m long) by artificial polypropylene plants and was placed on the sandy horizontal part of the flume bed as shown in Fig.1.a.

Each artificial plant is composed of 4 polypropylene stripes (1 pair 35cm and 1 pair 55cm long) and is inserted in a stiff rod (10.0 cm long), made of PVC (Fig. 1.b). The plants are placed in holes drilled into plastic boards (Fig.1.c). The experiments were conducted for two different meadow configurations, 360 and 180 stems/ m^2 , forming a non-staggered and a staggered pattern, respectively. Following Giraud (1977) classification (Buia et al., (2003)) the first density is representative of a very dense *P.oceanica* meadow, while the second one corresponds to a very sparse *P.oceanica* field.

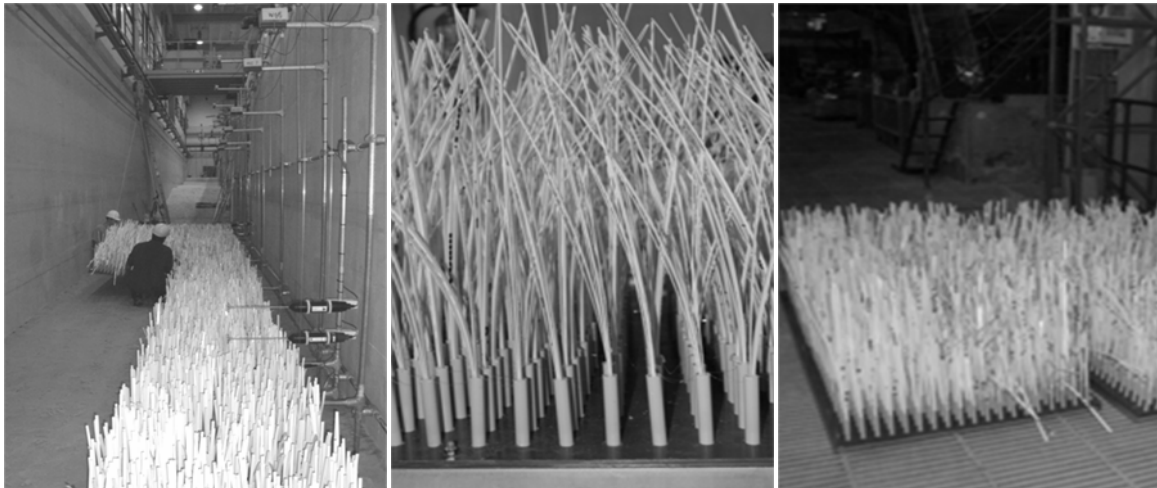


Figure 1. Artificial *Posidonia oceanica*: a) the *P.oceanica* meadow under construction, b) detail of the mimics, c) detail of meadow patches

The material used for the artificial plants (PVC foam) was selected for simulating accurately the real *P.oceanica* leaves (Table 1). The values of the characteristic non-dimensional parameters for prototype and laboratory conditions are indicated in Table 2, where: ρ_F =fluid density; ρ_S = solid density; E =Modulus of Elasticity; U =characteristic velocity; L = maximum cross-sectional dimension of the plants (plant height) and l = minimum cross-sectional dimension of the plants (plant width). Those parameters are calculated given that the average density of fresh water is $\rho = 1000 \text{ kg/m}^3$ (laboratory) and the density of seawater is 1025 kg/m^3 (prototype).

Ghisalberti and Nepf (2002) have used a different non-dimensional parameter λ_1 , defined as:

$$\lambda_1 = \frac{(\rho_F - \rho_S)h^3}{Et^2} \quad (1) \quad \text{where } h, t = \text{length and thickness of leaves, respectively.}$$

However such a relationship does not account for the effect of flow velocity. Based on the above relation the parameter $\lambda_{1,m}$ is within the limits $0.33h^3 < \lambda_{1,m} < 0.5h^3$ and respectively the $\lambda_{1,p}$ is within $0.23h^3 < \lambda_{1,p} < 13.7h^3$.

For regular and irregular waves three different submergence ratios ($h_s/D = 0.500; 0.423; 0.323$) and two seagrass densities (360 and 180 stems/ m^2) were tested for wave heights ranging between 0.35 and 0.55 m and wave periods from 2 to 4 s. Measurements of wave height and velocities are taken at several locations along the *P. oceanica* meadow. A series of 14 Resistive wave gauges and 6 Acoustic

wave gauges which were deployed along the flume was used for the measurement of the wave heights. Vertical arrays of current-meters and 1 Aquadopp profiler were also installed. Eight ADVs and four EMCs are arranged in three vertical profiles, in front and within the meadow.

Table 1. Properties of Artificial and Natural *Posidonia oceanica* leaves

Artificial	Natural (Folkard et al., 2005)
Modulus of Elasticity= 0.903 GPa	Modulus of Elasticity= 0.41-0.53 GPa
Density=550-700 kg.m ⁻³	Density=800-1020 kg.m ⁻³
Thickness =1.0 mm	Thickness = 0.2 mm

Table 2. Non-dimensional Parameters for Prototype and Laboratory Conditions

Definition of non-dimensional parameters	Prototype	Laboratory
Mass ratio, M: $M = \rho_F / \rho_S$	$1.005 < M_p < 1.281$	$1.429 < M_m < 1.818$
Slenderness number, S: $S = L/l$	$S_p = S_m = S$	
Cauchy number, C_Y : $C_Y = \frac{\rho_F U^2}{E} S^3$	$1.934 * 10^{-6} < C_{Y,p} / U^2 S^3 < 2.5 * 10^{-6}$	$C_{Y,m} / U^2 S^3 = 1.107 * 10^{-6}$

3. RESULTS AND CONCLUSIONS

In order to evaluate the effects of the seagrass density, the relative submergence and the wave characteristics on wave propagation, the variation of wave height along the *P. oceanica* meadow and velocity profiles are calculated for different seagrass densities, h_s/D and wave conditions.

Examining the effect of seagrass density (stems/m²) on wave height along the meadow for regular waves, we result in significant wave attenuation at the shoreward end for the higher density (360 stems/m²). The reduction reaches 40% for the high submergence ratio ($h_s/D = 0.500$), for $H_0 = 0.425$ m (H_0 , measured value of wave height in front of the meadow) and $T_p = 2.0$ s (Stratigaki et al., 2009a), while for the lower submergence ratio of $h_s/D=0.423$ and for wave conditions, $H_0 = 0.420$ m and $T_p = 3.0$ s, the reduction in wave height at the end of the seagrass is approximately 25% (Stratigaki et al., 2009b). Damping of wave height depends on seagrass density and appears to be increased with increasing seagrass density for the same submergence ratio and wave conditions.

The effect of the submergence ratio on wave height along the meadow can be observed especially at the end of the meadow where the wave height for the highest submergence ratio ($h_s/D=0.500$) is reduced approximately 28%, for 180 stems/m², $H_0 = 0.377$ m and $T_p = 2.0$ s (Stratigaki et al., 2009b). In cases where higher meadow density (360 stems/m²) was used, the reduction is found to be approximately 40% for $h_s/D=0.500$ and for the same wave conditions, indicating clearly the effect of submergence ratio on wave attenuation (Stratigaki et al., 2009a). Increasing the relative water depth and therefore decreasing the submergence ratio (h_s/D) results to lower decay of the incident wave height along the seagrass meadow (for the same meadow density and wave conditions). Also, a greater wave decay along the meadow was found for shorter wave periods especially at the shoreward end (for the same wave height, submergence ratio and seagrass density).

The maximum orbital velocity (U_{max}), which is obtained from the peak value of the phase averaged velocities, in the lower part of the canopy is reduced compared to the values in front of the vegetation mimics. This reduction increases with distance inside the artificial *P. oceanica* field. At the location of the seagrass patches, U_{max} peaks just above the canopy or in the upper canopy. The variation from the theoretical distribution of U_{max} is more significant in the meadow with denser configuration, especially in the upper part of the canopy where velocities are smaller than in the less dense canopy. An increase of submergence ratio (h_s/D) results in enhanced U_{max} reduction, in particular inside the meadow. Longer wave periods produce a more important velocity reduction in the lower canopy.

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