BOUNDARY LAYER DEVELOPMENT AND SHEAR STRESSES MEASUREMENTS AROUND OYSTER TABLES

Youen Kervella [a,c,*], Grégory Germain [b], Benoît Gaurier [b], Jean-Valéry Facq [b], Florence Cayocca [a], Patrick Lesueur [c]

[a] IFREMER, DYNECO/PHYSED, Centre de Brest, BP 70, 29280 Plouzané, France.
[b] IFREMER, ERT/HO, Centre de Boulogne, 150 quai Gambetta, BP 699, 62321 Boulogne-sur-Mer, France.
[c] Laboratoire M2C Université de Caen-Basse Normandie, CNRS/INSU UMR 6143, 2-4 rue des Tilleuls, 14000 Caen, France
**Corresponding author:* Youen.Kervella@ifremer.fr

Abstract

Oyster tables are artificial obstacles which are laid over muddy or sandy-muddy floors in intertidal areas. This study aims to show the current modifications related to the presence of the oyster table thanks to LDV measurement in a flume tank. Boundary layer development in different geometric configuration is underlined and suggests some important areas of velocity decrease and sediment transport modification. Shear stresses are also calculated near the bottom and around the table. The total shear stress in the water column exhibits an important increase when the flow passes through the oyster table, hence a flow energy decrease through dissipation. This study helps to understand the reasons for the increased sedimentation observed in some natural sites.

Keywords: Oyster table, flume tank, Laser Doppler Velocimetry, boundary layer, shear stress, sediment dynamics.

1. Introduction

An oyster table is a structure made of metallic wire on which porous plastic bags of oysters are laid. This structure which is 100m long by 1m wide is installed over muddy or sandy tidal flats. An oyster farm consists of a set of rows of these tables on a surface area that can reach several squared kilometres. Due to the complex organisation and hydrodynamic context, the impact inherent to this kind of structures has been little investigated so far. The lack of knowledge about the impact of an oyster farm on the flow remains a significant difficulty for the comprehension of sediment transport processes in oyster growing areas.

Since immersed horizontal plates, porous or not, are commonly used in coastal engineering, many references to previous experimental or numerical studies exist. Most of these studies deal with the use of the plate as a breakwater ([9], [1]). In this case, the structures are located close to the free surface and interact efficiently with the incoming waves. When the plates are located close to the bottom, they can be used as wave energy converters ([2], [4]) or as oyster farming structures, which is our study interest. In the latter case, the horizontal iron wire bars on which meshed plastic bags, filled with oysters, are attached can be compared to horizontal plates.

The impact of oyster tables on the wave pattern has been experimentally investigated by Guizien [3]. Nepf et al. [8] studied a movable structure comparable with oyster or mussel farms submitted to a current. They worked on channel flow in the presence of submerged vegetation, measured mean velocity profiles and discussed on turbulence structures. They concluded that the transport is significantly slower in the layer close to the canopy.

The impact on the flow has also been estimated [7], but with a few restrictions: only one configuration and no direct shear stresses measurements. In order to extend this study, we have investigated and compared two configurations: an oyster table parallel to the mean flow direction and a table with an orientation of 15° in the flow. Like previously, the flow characteristics around the overall structure were determined from velocity measurements obtained by Laser Doppler Velocimetry (LDV).

Figure 1: Oyster tables, Mont Saint-Michel Bay, France.

For each configuration, maps of the flow velocity around the table which underline the boundary layer development were first produced. Then, bottom and table-induced shear stresses were measured via turbulent velocity fluctuations. The impact on bottom sediment and on current dissipation is finally discussed.

2. Experimental device and geometric configurations

IFREMER flume tank (figure 2) provides an homogeneous current in the range [0.15 ; 2 m.s^{-1}], with a turbulence rate of the order of 5 % for a 0.5 m.s^{-1} flow. The tank working section is 18 m long, 4 m wide and 2 m deep, with transparent 8 m x 2 m side windows for direct observation.

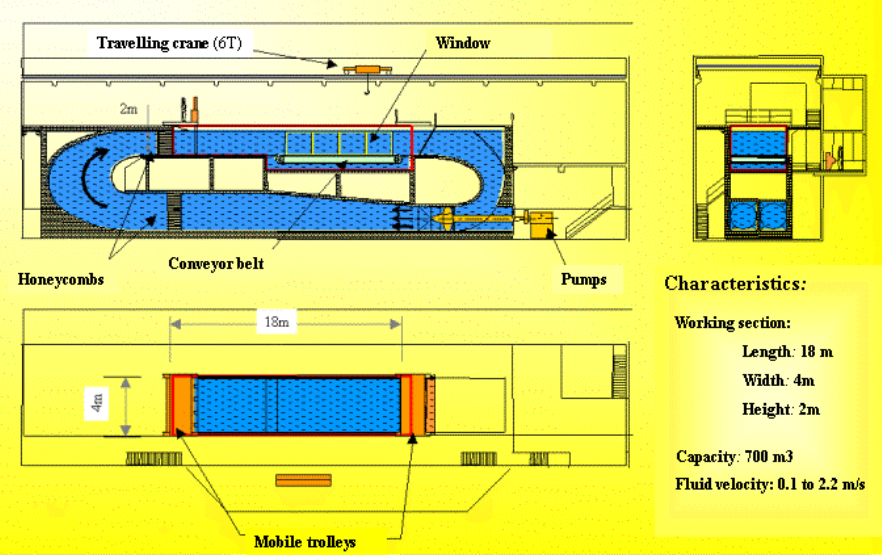


Figure 2: Hydrodynamic water tunnel of Boulogne-sur-Mer (Ifremer).

In the field, an oyster table is typically 100 m long, 1 m wide and 0.7 m high; a good understanding of the sharp current-table interactions drove the choice of a 1/2 scaled model according to Froude similarity. Representing the whole table lengthwise would have required a much greater scale. However, effects of the table length on the flow pattern were investigated through the use of 2 experimental tables 3.6 m and 7.2 m long [7]. A length of 7.2 m gives a good knowledge of the flow interaction with the structure: the length is sufficient enough for the upper boundary layer establishment. These dimensions were also chosen so as to allow multi-orientations in the tank.

The oyster table model was made of 8 mm diameter galvanized iron rod. The oyster bags were manufactured with the same plastic nets as used in the field, but with a 7 mm meshes (half as large as in the field), while the size ratio between reality and experiments was preserved (figure 3). The bags were filled with real pebbles used to simulate oysters. Cylindrical holes were cut out in the middle of few bags in order to allow laser measurements under the table.

In agreement with in-situ measurements [6], the maximum velocity to be investigated was set to 0.4 m.s^{-1}, 5 cm from the bottom. In order to reproduce this magnitude in the flume, water flow with a scaled velocity of 0.28 m.s^{-1} was generated by the propellers, 2.5 cm above the bottom, which induces a velocity of 0.5 m.s^{-1} above the boundary layer. The 2 m water depth used for these tests corresponds to an intermediate value encountered in the field within oyster farms.

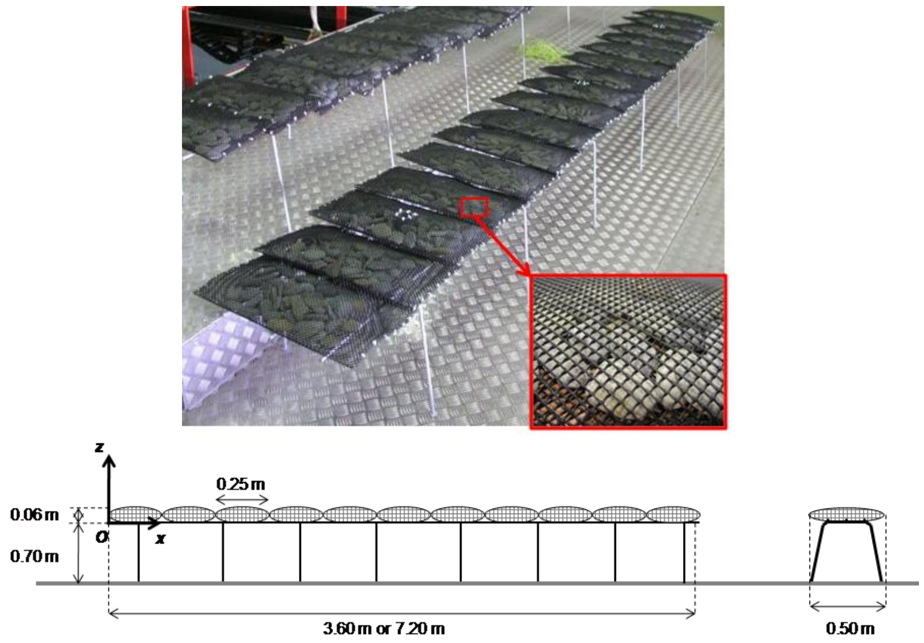


Figure 3: Oyster table model

A two-component Laser Doppler Velocimeter (LDV) was used to characterize the flow around the table: LDV is a laser-based method used to measure the flow velocity at a given point, thanks to Doppler Effect. The laser beam generator emits two pair of beams, one for each velocity component being measured, which intersect at a known distance from the probe. When two coherent, collimated laser beams intersect, they form an interference fringe pattern. The intersection location defines the measurement region. The spacing between interference fringes is a known function of the laser wavelength and the separation angle between the two laser beams. Small tracer particles are used to follow the fluid flow through the measurement region by means of laser light reflection (when passed through a fringe). The seeding particles used for our experiments are 15 µm diameter silver particles. The velocity can be calculated from the reflection frequency and the spacing between interference fringes. The available LDV device allows to measure two velocity components thanks to two wavelengths (514.5 nm and 488 nm) as described in Pichot et al. [2]. The velocity components: u, v and w are measured along the (Ox, Oy) or (Ox, Oz) directions.

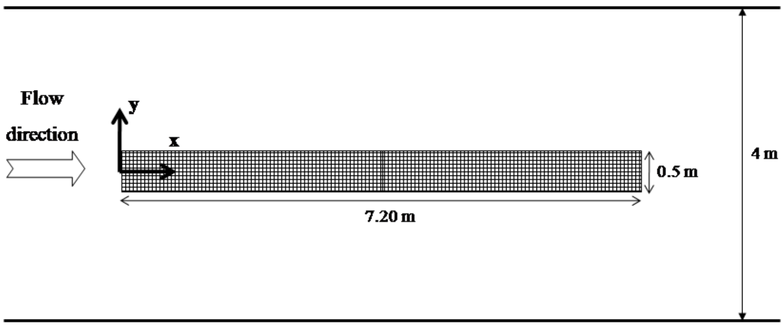
A particular feature of the LDV measurements is that the number of data recorded in a given time window is strongly dependent on the local seeding conditions: measurements are only possible when a particle moves across the measurement volume. Some regions therefore allow high frequency acquisitions (exceeding 35 Hz); whereas close to the walls or near recirculating zones, the acquisition rate falls to very low values (lower than 5 Hz). In order to achieve the most homogeneous sampling possible, an inhibit method was used and data was recorded under time control rather than sample length control. This technique allowed to obtain a sample length never exceeding 100 seconds (which is an order of magnitude larger than the time scale of the flow fluctuations) with a number of data points per sample never exceeding 3500. The long time span allows an accurate estimate of average values for velocity and turbulence intensity.

Two different configurations were investigated in order to evaluate the incidence effect (figure 4):

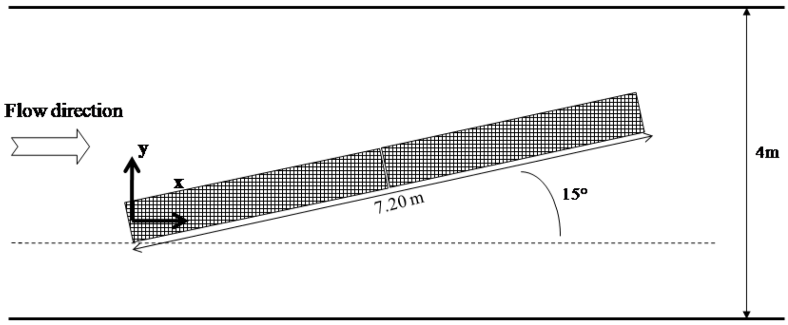
- In configuration A, the oyster table direction is parallel to the mean flow direction. 33 vertical and 9 horizontal velocity profiles were performed upstream, along and downstream the table structure. Each vertical profile consists of 17 measurement locations. In each location, the longitudinal (u) and the transversal (v) components of the flow velocity were simultaneously measured during 100 seconds (uv-profiles).

Furthermore, 4 vertical velocity profiles measuring simultaneously the longitudinal (u) and the vertical (w) components of the flow velocity were performed along the table during 420 seconds in order to compute shear stresses (uw-profiles). This data acquisition time is long enough to get convergence on the calculation of the shear stress (based on the velocity fluctuations) figure 5.

- In configuration B, the angle between the oyster table direction and the mean flow direction equals 15°. 66 uv-profiles and 5 uw-profiles were performed around the table.



Configuration A



Configuration B

Figure 4: Geometric configurations used in the flume tank (top views).

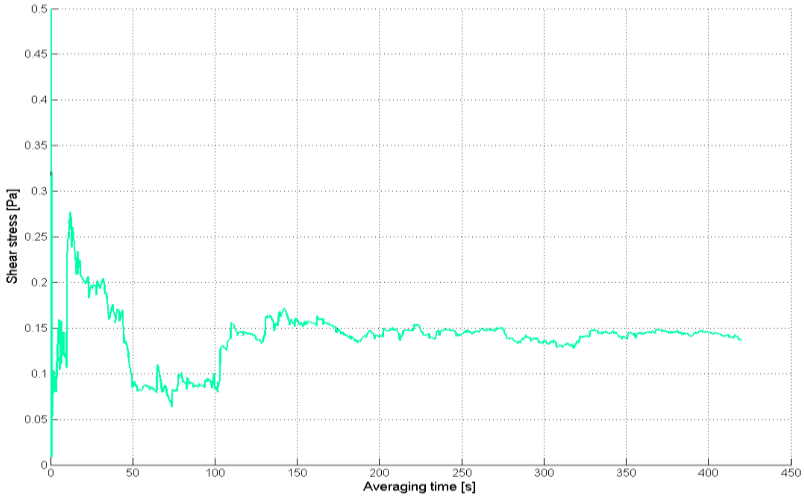


Figure 5: Shear stress convergence according to the averaging time

3. Comparison of the boundary layer development for configurations A and B

The configuration A (Oyster table parallel to the mean flow) was investigated in a previous experimental study [7]. Authors highlight an asymmetric development of the boundary layers and an important decrease in flow velocity around the oyster table which suggests the existence of preferential areas for silting up and suspended matter fragmentation under the table.

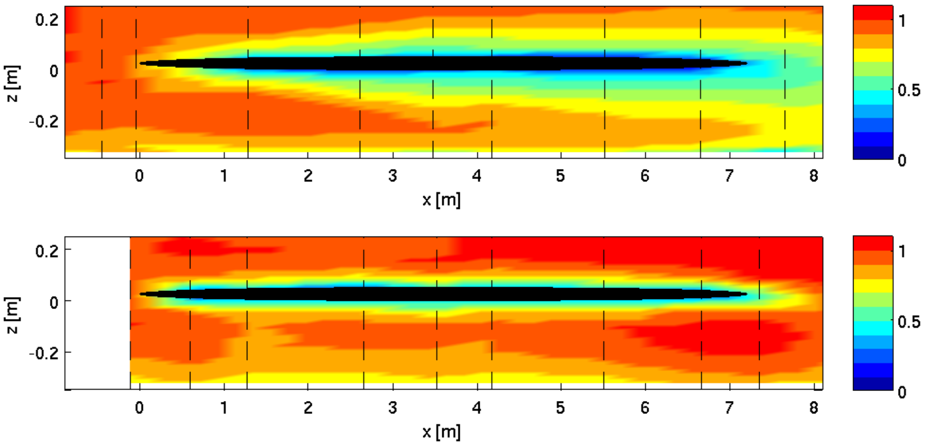


Figure 6: Normalized longitudinal velocities on the median vertical plane for a 7.20 m table in configuration A (top) and in configuration B (bottom). Dotted lines represent LDV measurement locations.

The merging of the table-induced and the bottom-induced boundary layers under the table creates areas where velocity attenuation exceeds 30 % from the table level to the bottom (figure 6, top). For an incoming flow with an angle of 15° (figure 6, bottom), a slight velocity decrease (up to 20 % of local attenuation) is observed under the table, in the first meters, while a velocity increase occurs close to the end. In this configuration, areas of important velocity decrease are moved away from under the table, as underlined on figure 9. So, the orientation of the table towards the main current direction is essential in the field for sediment transport.

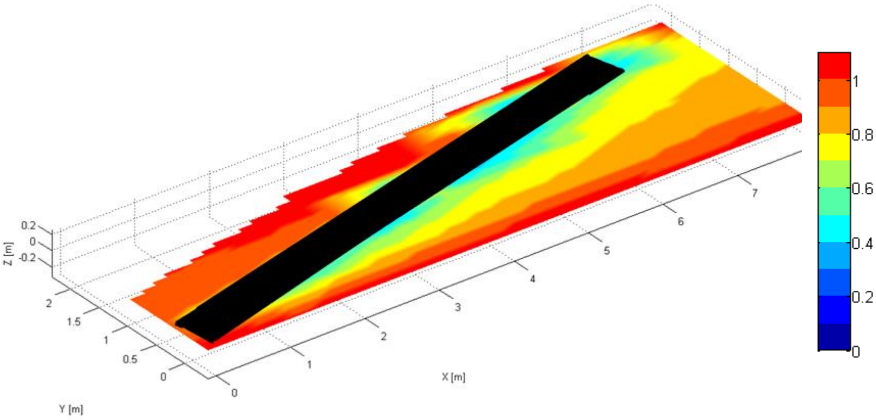


Figure 7: Normalized longitudinal velocities on an horizontal plane at the table level for a 7.20 m table (Configuration B).

In the configuration A, the wake of the table regularly expands according to the transverse component and stays close to the table [7]. In the configuration B, the table's wake broadening is shown in the horizontal LDV cartography at the table level (figure 7). Note the asymmetry of this wake and this important expansion according to the direction perpendicular to the table. Some areas exhibit very large decelerations: up to 40 % of velocity decrease close to the table and up to 30 % of velocity decrease behind this table, while there are acceleration areas (in red) around the wake of the order of 10 % of the upstream velocity.

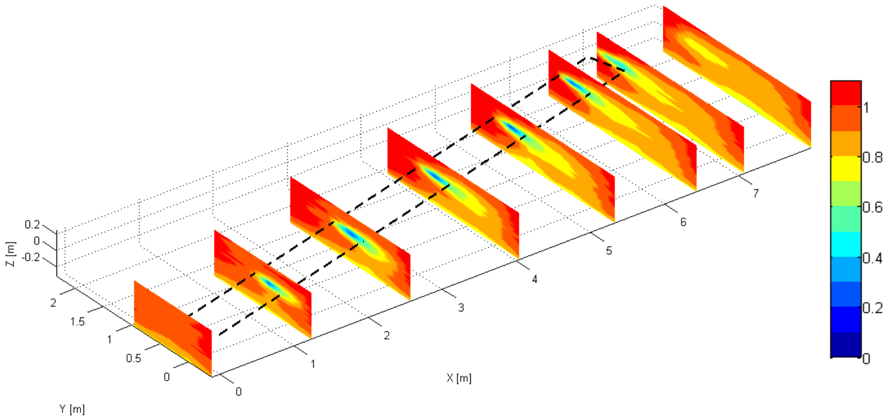


Figure 8: Normalized longitudinal velocities on vertical transverse planes along a 7.20 m table.

This wake broadening is confirmed by the vertical LDV cartographies along the table (figure 8). Note the interaction between this wake, created by the table, and the bottom boundary layer. A large 3 dimensional area is created along and at the back of the table within decelerations up to 20 %. Just behind the table, the width of this area is stabilized to 1.50 m after 4 m table length.

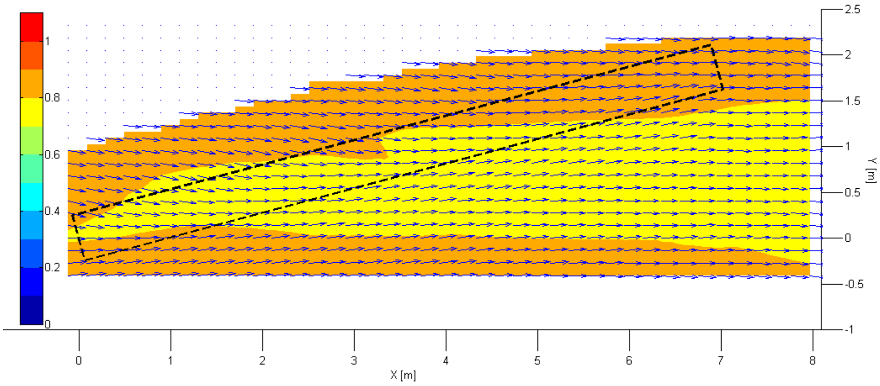


Figure 9: Normalized longitudinal velocities and velocity vectors on an horizontal plane at 5 cm from the bottom for a 7.20 m table.

Figure 9 highlights the development of the bottom boundary layer which is highly influenced by the oyster table presence: a large area from 20 % to 30 % of velocity decrease is created under the table wake at 5 cm from the bottom.

The velocity vectors are also shown on this figure. For sake of visualisation, a transverse exaggeration is applied on the velocity field (the transverse component of the velocity is multiplied by 10). The angle between the main flow and the table direction equals 15°. Just after the table, the main flow is deviated in the same direction as the table orientation, and then comes back to the main direction after the trailing edge of the table. The magnitude of this flow deviation under the table increases from the bottom to the table level.

The horizontal expansion of the wake suggests the occurrence of interactions in realistic configurations where several rows of oyster tables are present. This point should be investigated in the future.

4. Comparison of the shear stresses measurements for configurations A and B

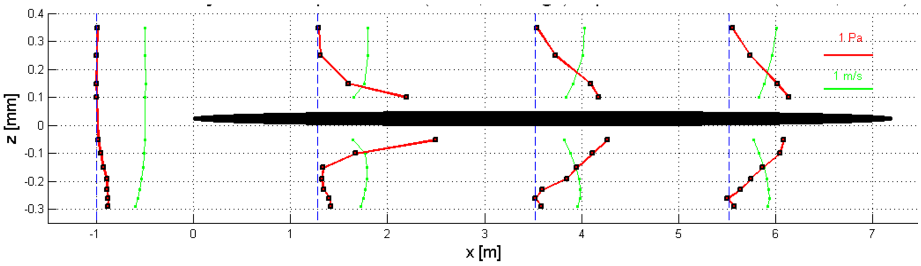


Figure 10: Reynolds shear stresses (red lines) and longitudinal velocities (green lines) on the median vertical plane along a 7.20 m table n configuration A. Dotted lines represent LDV measurement locations.

When performing uw-profiles, velocity fluctuations along the horizontal and vertical velocity components (respectively u' and w') were recorded at each time. Shear stresses were calculated using the Reynolds shear stress method, also defined as the covariance method:

$$\tau = \rho \overline{u'w'}$$

Values of shear stresses are computed at 4 locations (table 1): one profile upstream the table, without the influence of the structure, and 3 profiles along the table. At each location, shear stresses are calculated close to the bottom (τ_{bottom}) and for the whole water column (τ_{total}, define as the sum of the bottom shear stress, the lower table-induced and the upper table-induced shear stresses). In the field, bottom shear stress can be determine by means of high-frequency velocimeter (ADV) and the values encountered on flat cohesive sediment in a similar context of mean flow velocity are of the same order than our values (figure 11).

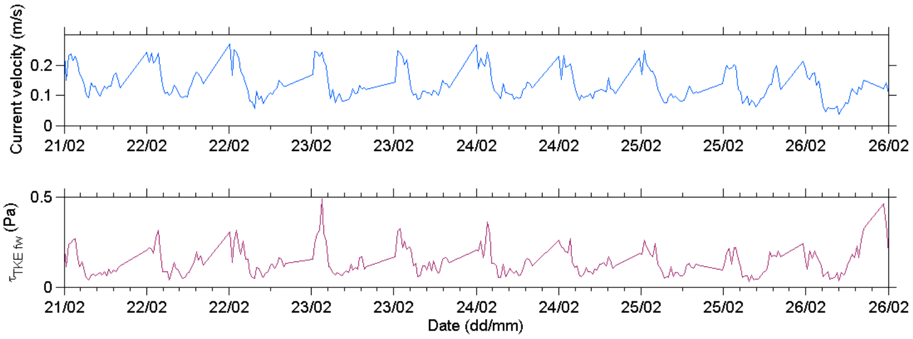


Figure 11: current velocity (m.s-1) and bottom shear stress (Pa) measured in the field 5 cm above the bed in Mont Saint-Michel Bay.

In contrast, total shear stress remains difficult to measure on the whole water column when coastal structures are present and experimental measurement are so needed.

Table 1: Bottom shear stresses and total shear stresses upstream and along the table in configuration A.

	upstream	1,29 m	3,52 m	5,50 m
τ_{bottom} (Pa)	0,25	0,25	0,14	0,14
τ_{total} (Pa)	0,25	4,45	2,95	2,58

On one hand, we can note a slight decrease of the bottom shear stress under the table after a few meters. This decrease, surely due to the interaction between the bottom boundary layer and the lower table-induced boundary layer, is not really significant and measurements of velocity fluctuations need to be carried out closer to the bottom.

On the other hand, the total shear stress is multiplied by 18 over the first meters of the table and by 10 close to the middle or the end of this table. This increase of the total shear stress value means an area of important energy dissipation of the flow when it goes through the table. This dissipation will be of great interest in the case of the flow going through an oyster farm of several squared kilometres.

At a smaller scale, the increase of the shear stress close to the table will play an important role in the vertical transport of larvae and nutrients and create important areas of fragmentation [7]. The shear stress created by the macroscopic roughness of the table will increase turbulence and modify the rate of fluid transport. It will affect immigration rates of animals [5].

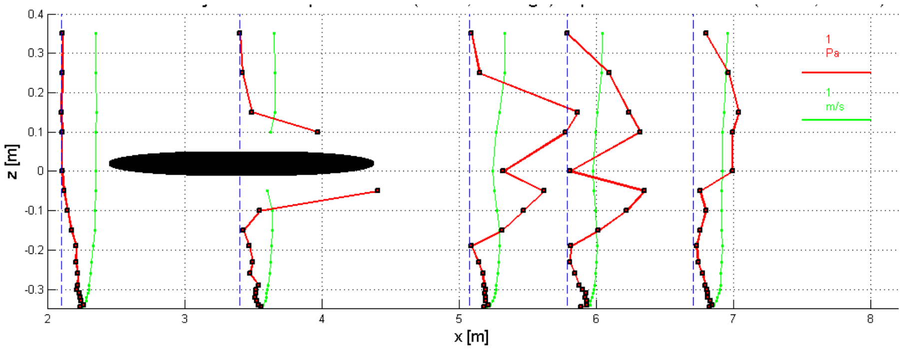


Figure 12: Reynolds shear stresses (red lines) and longitudinal velocities (green lines) on the median vertical plane along a 7.20 m table in configuration B. Dotted lines represent LDV measurement locations.

For the determination of the shear stresses on configuration B, velocity profiles measured by LDV have been extended down to 5 mm from the bottom (against 60 mm in the previous configuration) figure 12.

Table 2: Bottom shear stresses and total shear stresses along the vertical median plane in configuration B

	upstream	X=3,40 m	X=5.08 m	X=6.71 m
τ_{bottom} (Pa)	0,32	0,27	0,27	0,27
τ_{total} (Pa)	0,32	3,4	2,9	1,4

The bottom shear stress slightly decreases again under and downstream the table. A more important decrease could be probably noticed in another vertical plane parallel to the median vertical plane (see the area of velocity decrease close to the bottom near the table on figures 8 and 9).

As for the total shear stress, its upstream value is multiplied by 11 when the flow is passing through the table (intersection between the median vertical plane and the table). Then this value is multiplied by 9 1.50 m downstream this intersection and by 4 3 m further (table 2). The same conclusions as in the configuration A can be drawn about energy dissipation. Downstream the intersection, the total shear stress decreases but in a configuration with several parallel tables, like in the field, we do not know how the flow and the boundary layer induced by the first table presence will interact with the second and the third tables and what will be the consequences on the total shear stress and the dissipation. Some numerical studies are necessary to investigate these configurations.

5. Conclusion

The impact of an oyster table on the flow within several geometric configurations has been experimentally investigated.

In each configuration, important areas of velocity decrease have been highlighted, from the table level to the bottom. In terms of sediment transport, it involves a decrease of the sediment transport rate and preferential areas of silting up whose location depends on the orientation of the table towards the main flow direction. Moreover, in configuration B, modifications of the flow direction under the oyster table have been underlined close to the bottom, which confirms the in-situ measurements [6]. Moreover, the horizontal extent of the wake behind the table shows that it is fundamental to model, experimentally or numerically, several tables in order to understand the hydrodynamic interactions inherent to the succession of structures.

Shear stress measurements reveal that there is no consistent modification on the bottom, i.e. no direct impact on the bottom sediment but there is an increase of the total shear stress which leads to energy dissipation by turbulence. This energy dissipation will involve an overall flow decrease, and in turn modifications of sediment transport patterns at a greater spatial scale.

A numerical study to model the impact of an oyster table on the flow will be of great interest to give information at a natural structures scale. This kind of modeling will be helpful for the parameterization of coastal hydrodynamics models.

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References

[1] Brossard, J., Perret, G., Blonce, L. and Diedhiou, A., 2009. *Higher harmonics induced by a submerged horizontal plate and a submerged rectangular step in a wave flume*. Coastal Engineering, vol. 56, pp. 11-22.

[2] Carter, R.W., 2005. *Wave energy converters and a submerged horizontal plate*. Thesis of University of Hawaii.

[3] Guizien, K., 1996. Etude du champ d*e vitesses sous une et plusieurs plaques soumises à la houle et immergées près du fond*, mémoire de DEA, 1996.

[4] Graw, K.U., 1993. *Shore protection and electricity by submerged plate wave energy converter*, European Wave Energy Symposium, Edinburgh, UK (1993), pp. 1–6.

[5] Hendriks, I. E., van Duren, L. A. and Herman, P. M. J., 2006. *Turbulence levels in a flume compared to the field: Implications for laval settlement studies*. Journal of Sea Research, vol. 55, pp. 15-29.

[6] Kervella, Y., Cayocca, F., Verney, R.., Jestin, H., Bassoullet, P., Cann, P., Le Hir, P. and Lesueur P. *The impact of oyster structures on hydrodynamics in a macro- tidal environment*. To be submitted.

[7] Kervella, Y., Germain, G., Gaurier, B., Facq, J.-V., Brevers, M., Cayocca, F. and Lesueur, P., 2009. *Experimental study of the near-field impact of an oyster table on the flow*. Submitted to European Journal of Mechanics b. Fluids.

[8] Nepf, H. And Ghisalberti, M., 2008. *Flow and transport in channels with submerged vegetation*. Acta Geophysica, vol. 56, pp. 753-777.

[9] Patarapanich M., 1984. *Maximum and zero reflection from submerged plate,* Journal of Waterway, Port, Coastal, and Ocean Engineering, vol. 110, 1984.

[10] Pichot, G., Germain, G., Priour, D., 2008. *On the experimental study of the flow around a fishing net*, European Journal of Mechanics B/Fluids.