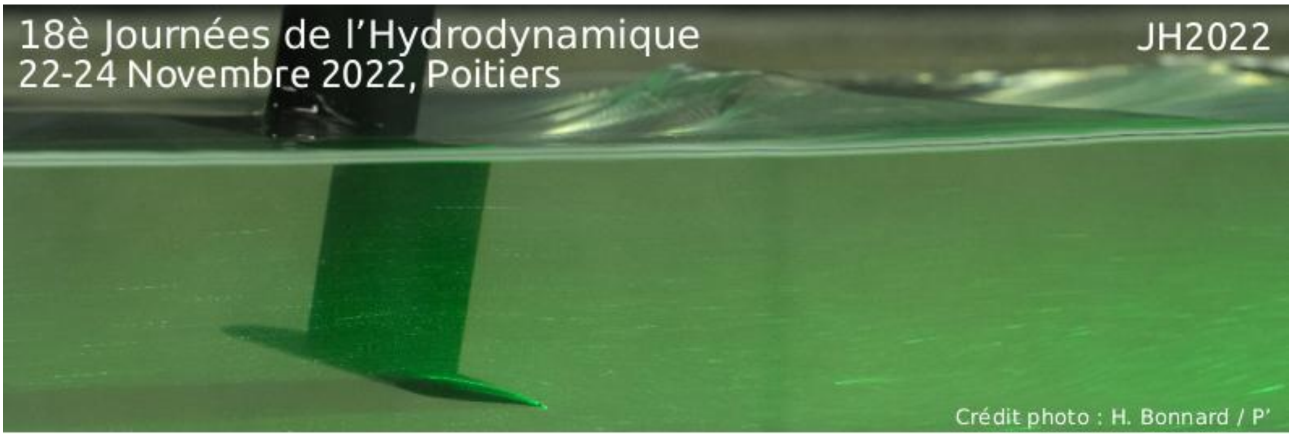

CONFINEMENT DES ALGUES SARGASSES PAR BARRAGE FLOTTANT, DÉFIS STRUCTURELS ET HYDRODYNAMIQUES

SARGASSUM ALGAE CONTAINMENT BY MOORED BARRIER, STRUCTURAL AND HYDRODYNAMIC CHALLENGES

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Résumé

Nous présentons une recherche en hydrodynamique ayant une finalité en santé publique. L'objectif est d'améliorer et évaluer les barrières flottantes amarrées, pour contenir les arrivées massives d'algues pélagiques Sargasses, avant qu'elles ne contaminent fortement l'environnement côtier et ses habitants. Nous basons ce travail sur l'analyse structurale d'une barrière constituée d'un matériau de type filet, et des comportements et charges hydrodynamiques des algues accumulées. L'accumulation du biofilm sur les filets et la complexité de l'environnement marin côtier possèdent de nombreux aléas et composantes géométriques. Nous donnons les tensions issues d'un modèle numérique par éléments-finis, sur une section de barrière, pour une vitesse de courant faible puis modérée.

Summary

We present an hydrodynamic study of public health concerns. The objective is to improve and asses floating barriers moored to contain massive pelagic *Sargassum* algae arrivals, before they highly contaminate coastal environment and population. We base this work on the structural analysis of barrier made of netting material and the hydrodynamic behaviours and loads of accumulated algae. Barrier fouling and complexity of coastal marine environment have numerous randomness and geometrical components. We give the mechanical tensions from a numerical model by finite-elements, in a section of barrier containing algae, for low and moderate current velocities.

I – Introduction

The massive arrivals of *Sargassum* algae are of major concern for most Caribbean countries and islands. Issue from the Atlantic Ocean surface, between Africa and South America, this pelagic floating algal drifts and follows sea current until the Southeast coasts of the Caribbean region. Algae beaching is monitored continuously by direct observations and reporting on maps [1].

References detail several dangers and damages that this algal phenomenon can generate for the suffering population and the environment of these coastal regions [2] [3] [4]. Fig. 1(a) and a zoom on Fig. 1(b) show from a Guadeloupe coast viewpoint, algal rafts drifting in the *Canal des Saintes*, photos taken the 22th of July 2022. These figures show the algae, living organisms with self-buoyancies, nourished by seawater, before their massive beaching. Beached on shore, they rot resulting principally in massive noxious gases emission, Hydrogen sulphide, H_2S.

(a)

(b)

Figure 1. Algal rafts drifting in *Canal des Saintes*, (a) seen from *Phare de Vieux-Fort* on the Guadeloupe coast, (b) zoom, the 22th of July 2022, photos Franck Buron.

To contain algae on the sea surface, avoid their beaching, and keep them alive by staying in contact with nutriments in seawater, more or less specific floating barriers have been deployed. Well known to the oil-spill community, when the current becomes too high the containment can fail or even the barrier break. As well as oil-spill barrier, algal barrier can be put at fallback position, denominated "flag", where the barrier creates no-resistance except friction to the current. Algae pollution can then drift freely to the shore, Fig. 2.

Figure 2. In the background, the open algal floating barrier (dark linear object) and in the foreground the massive accumulation of algae on the shoreline, *Baie de Cayol - Le Robert - Martinique*, 27th of August 2022, from a video SargassumMonitoring [5].

Our aim is to study the algae containment and the water flow, acting as a normal pressure on a floating barrier moored on a coastal zone near the shoreline. To achieve this objective, we base our investigation on a floating barrier already existing in the *Antilles Françaises*. This barrier is made of polyethylene netting structure, floats, is weighted on its base and is moored, Fig. 3.

Figure 3. Floating barrier for algae containment or deviation FILET DROM©, each section is 50 m long, until 2 m height, and is moored on bloc, anchor or pile.

Usage of oil-spill booms for algae containment is reported [3]. As opposed to oil-spill boom for which the usage is temporary and lasts the time of the accident and pollution recovery, algal barrier is a permanent structure. A main drawback of this difference is the fouling of the structure by fauna and flora that implies difficult barrier cleaning and disassembling/reassembly costs.

We organize the paper as follows. First, we analyse the representation of the problem where the fluid-algae/structure interaction in its environmental is set. Secondly, we present the hydrodynamic and structural model of the barrier and give numerical results. Finally, we address the perspectives of this work.

II – Problem analysis

We consider as a whole algae contained by barrier in a natural environment [6]. To achieve that goal, we first detail a non-exhaustive list of hazards and randomness that this state could face. Secondly, we discuss of several geometrical aspects allowing a better definition of the domains of interest.

II – 1 Hazards and randomness

It appears clearly during our first investigation to define the fluid flow, algae catch, barrier and moorings, which could affect the near shore environment that we must take into account several random processes and hazards, Table 1.

Barrier and net material		
	clogging by algae	filter obstruction
	fouling	flora and fauna induced
	cleaning	hysteresis, less clean than initial
	break	stress, buoyancy, mooring threshold
	sea current acceleration	bathymetry, meteo and tide
Mooring		dead mass, anchor, bored pile
	drift of dead mass, bloc, anchor	
	chafe of mooring chain	current, tide
Algae catch		
	algae and rafts arrivals	
	accumulation, catch size	
	saturation	algae recovery by ship, shipmen
	algal leakage	over or under barrier
	algal dessication	
	internal mechanical cohesion	
Bathymetry		
	natural variation	erosion, accretion
	artificial variation	
	scour	
	jam	
Meteo		
	storm	
	swell, wind	
Seagrasses		
	dead zone	habitats
	fauna leaving	buried by algal sunk
		sweep by mooring displacement
		light attenuation by algae accumulation

Table 1. Hazards and randomness in algae containment by barrier.

Principal uncertainties enable from the fouling of the barrier, the amount of algae catch and the mooring impact on the seabed habitats. Consequently, we take three *a priori* hypotheses in the model. First, we consider the barrier as non-permeable. The barrier acts like a closed form by fouling and catch, and is forced by an uniform flow pressure along the vertical. Secondly, we neglect the behavior of the mooring line and consider the upper mooring node as a fixed point. Thirdly, we choose in the following two uniform flow velocities, neglecting the seabed interaction. The low one 0.05 m.s-1 corresponds to a sheltered area. The second and moderate velocity 0.35 m.s-1, handles stress increase and corresponds to the classical oil-spill boom efficiency limit.

II – 2 Abscissae and interfaces

The random processes on algae containment, like catch volume, are numerous. Let us identify the different curvilinear abscissae, which are involved in defining the problem, Table 2.

Barrier and mooring		
	ω	barrier surface, vertical section
	ω_f	fouling part on barrier
	ω_w	washing part after cleaning
	s_a	mooring line between barrier and anchorage
	s_d	drift of anchor on sea bed – “deradage”
	s_r	chafe of chain on sea bed – “ragage”
Algae accumulation and deposition		
	s_c	catch, algae and rafts along barrier and during time, belonging on sea surface
	s_m	algae and rafts moving and drifting on sea surface
	s_s	sunk algae on sea bed
	s^+	algae beaching on shore
	s^-	algae beaching still on water
Near shore environment		
	s	sea surface, waves, water surface
	s_b	sea bed, seawater bottom
	s_e	sea bed erosion, scour
	s_h	seagrasses – “herbiers”
	s_f	fauna zone on sea bed, coral, fauna habitats

Table 2. Curvilinear abscissae on barrier and mooring, algae accumulation and deposition, and near shore environment.

We take another *a priori* hypothesis on algal catch forcing, by avoiding the hydrodynamic forcing of supplementary algal raft arrivals against the algal catch, which already obstructs the barrier net. Is not distinguished the hydrodynamic friction transfer from the catch boundary with the seawater through the internal catch behavior on the barrier. Therefore, in the sequel, we consider only from Table 2, the barrier surface ω , and a mooring device between ω and the fixed head of the mooring line s_a. The fig. 4 illustrates the different kinds of abscissae introduced.

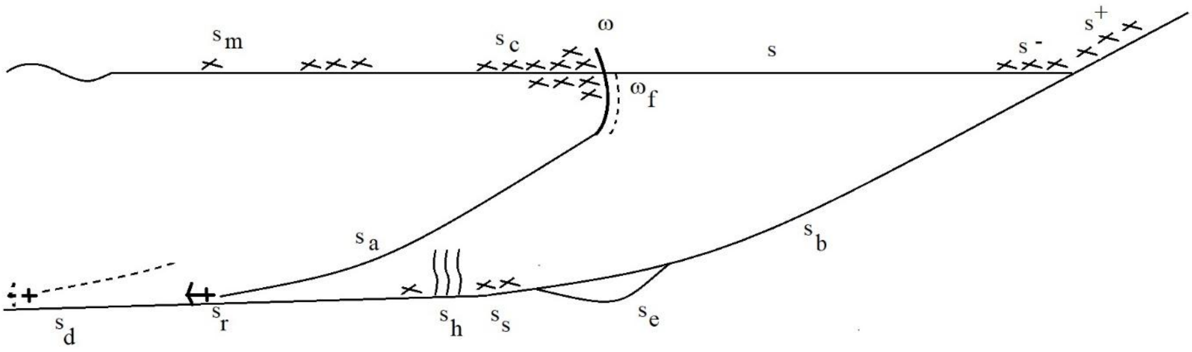

Figure 4. Curvilinear abcissae.

On the top of the algal catch could appear a subdomain, where algae do not stay in contact with seawater, conducting to their desiccation and further sinking. Inside fishing net, the internal mechanics behavior of the catch can be reproduced in lab by a set of small balls having hydrodynamic and structural interactions with trawl codend [7]. Is reported the sea surface wave damping property of algal raft.

We define different kinds of interface and isosurface, located either inside catch domain or at its boundary. More precisely, we present isosurfaces in the catch for the different time of arrivals of drifting rafts. For sunk algae on the seabed, two kinds of interface are introduced, Table 3. The right column indicates the hypothesis on the smooth or non-smooth aspect that we make *a priori* without certainty.

Catch (boundary)			
	interface	catch and barrage	smooth
	interface	catch bottom and water flow - boundary layer	non-smooth
Catch (internal)			
	isosurface	algal groups by time of arrival	smooth ?
	interface	desiccated algae and algae still in water	non-smooth
Sunk algae			
	interface	sunk algae and seawater, eventual jams on sea bed	smooth ?
	interface	sunk algae and sea bed, and seabed habitat dismantled by anchor drift and chain chafe, giving dead zone	smooth ?

Table 3. Algal domains interfaces, surfaces and isosurfaces, with uncertainties on smooth or non-smooth hypothesis.

The desiccation of algae during containment and their further sinking are main issues. Over the sea bottom, anchor or bloc can drift and mooring chain can chafe. Sunk algae cover fauna habitats and flora. Seagrasses can also be dismantled by moorings. Fig. 5 illustrates three interfaces and isosurfaces in the catch domain, and two interfaces, one over and another one under the sunk algae.

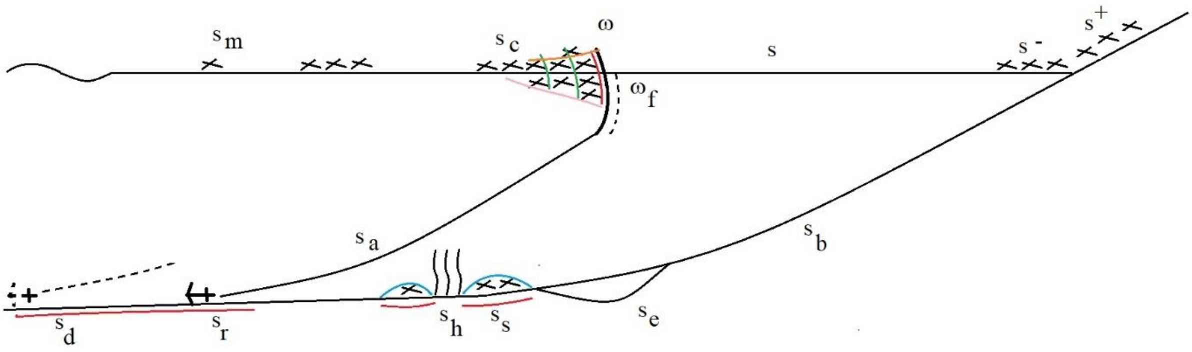

Figure 5. Interfaces and isosurfaces.

The green isosurfaces in the catch domain correspond to the different time of arrivals of algae, indicating their specific weathering stages. The upper orange interface in the catch distinguishes desiccated algae from living algae still in contact with water. The blue interface over sunk algae bounds the flow at the bottom of the seawater domain.

III – Model results

We present the numerical model using the finite-element method and the results on a barrier section moored in a stream of water and algae contained.

III – 1 Numerical model

The domain considered as a barrier section is made of a cylinder closed by two cones, that in a second time, we flattened like a used toothpaste tube. Cylinder is 50 m long and cones are 1 m height. The two triangles, initially the two cones, are rotated 90° along their bases with the cylinder. It generates the two mooring devices between the barrier and the mooring lines heads. We adjust the top of the cylinder at the level of the sea surface, and we block its Z-vertical displacement. The two cone heads become blocked points. For symmetry reason, the two flattened cones displacements are blocked along the barrier X-longitudinal axis.

The surface ω defining the barrier and its two mooring devices is a closed set without boundary.

$$\partial \omega = \varnothing \qquad (1)$$

To avoid interlacing of the two faces of the mesh, we maintain a numerical thickness between them.

The usage of a flattened and closed surface has two explanations. First, we expect that an elastic surface without free boundary is favourable during its non-linear equilibrium resolution, during which flappings are likely to appear. Secondly, for an engineering reason, we think it would be interesting to study the constitution of the algal netting barrier with recycled oyster bags. Empty bags possess this sort of geometry.

Remark: Algal barriers are built generally with two nets. A first one provides the structural stiffness with a surplus of longitudinal reinforcing ropes, and a second one, more flexible, less high, still crossing the free surface.

To reduce stress in floating barrier, usually 7% of excess of barrier length is made, compared to the distance between its mooring points. The initial geometry follows a parabola, 53.5 m long, width point at -9.51 m along Y-upstream axis. Fig. 6 shows the initial quadrilateral finite-element mesh.

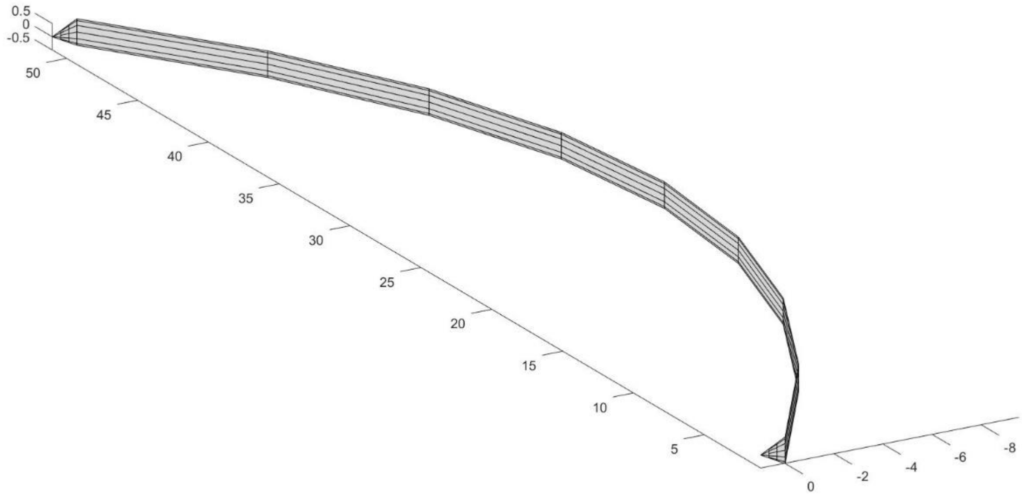

Figure 6. Finite-element mesh, parabolic initial geometry, 158 nodes, 156 elements, flattened cylinder with two cones rotated at 90° giving the mooring devices. X-longitudinal Y-upstream Z-vertical.

Table 4 gives the inputs of the two computations made. We solve the non-linear elastic membrane equation by using height Newton-Raphson iterations for the 0.05 m.s-1 water flow velocity, and ten iterations for 0.35 m.s-1.

Barrier			
	height	1	m
	cord lenght	50	m
	parabola width	9.51	m
	height mooring cone	1	m
	Young modulus by thickness	1_e+6	N.m-1
	Poisson ratio	0.3	
	relative lest	0	kg.m-1
	relative surfasic mass	0	kg.m-2
Pressure			
	volumic mass	1025	kg.m-3
	drag coefficient	1.65	
	velocities	0.05 & 0.35	m.s-1

Table 4. Inputs.

The barrier net material with interlocking algae is assumed to be linear, elastic, isotropic, and low Young modulus. We suppose that a strain of 2% corresponds to a force 1000 N for stretching a band 5 cm wide. We consider the same elastic and hydrodynamic properties on the two faces of the barrier. The numerical distance between the two faces reaches 1 mm.

The hydrodynamic pressure along the barrier surface is non-uniform. It depends on the scalar product between the flow direction and the membrane normal. The drag coefficient corresponds to a net barrier saturated with algae and is 1.65 corresponding to an hermetic vertical plane.

Remark: The lest positioned at the bottom of the barrier, in practice a metal bar, is set to zero. As the displacements are blocked on the top of the barrier, the buoyancy force is set to zero. Removing these forces of gravity allows us to directly obtain the buoyancy force following the vertical on the top of the barrier.

II – 2 Numerical results

Fig. 7 shows the stressmap in the barrier and its two mooring devices, subjected to the velocity 0.35 m.s-1. The maximum of the principal stress is located at the two mooring line heads. The figure colour unit is N.m-1. The barrier principal stress increases up and down near its ends.

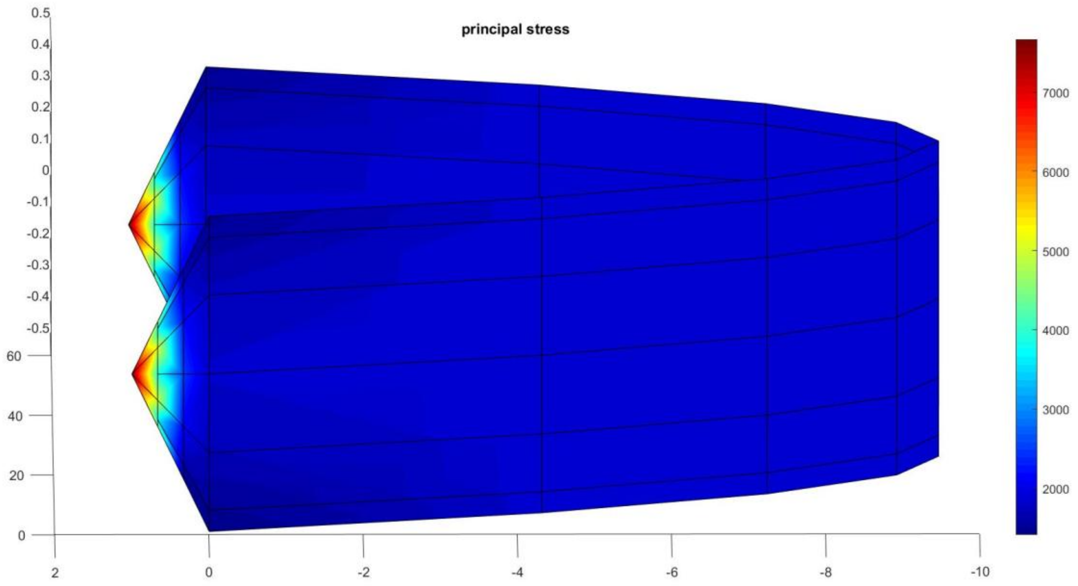

Figure 7. Stressmap (N.m-1) in the barrier, velocity 0.35 m.s-1.

Table 5 gives outputs at the ends and in the middle of the barrier for the two computed velocities.

Barrier curve on sea surface (m)		X=0	X=L/2	X=L
	Initial		-9.51	
	v=0.05m.s-1		-9.38	
	v=0.35m.s-1		-9.49	
Buoyancy Z-vertical force (N)				
	v=0.05m.s-1	-0.6		-0.6
	v=0.35m.s-1	-29		-29
Mooring Y-resultant (N)				
	v=0.05m.s-1	-48.8		-48.8
	v=0.35m.s-1	-2387.2		-2387.2

Table 5. Outputs.

The barrier middle moves back because of the non-equilibrium shape of the parabola to balance the hydrodynamic pressure. The force balancing the buoyancy is negative at both ends of the top of the barrier, especially for the higher velocity. Adequate ballasting weight must be provided.

The hydrodynamic flow puts tension on the two mooring line heads, depending on the velocity. It requires planning buoyancies at mooring line heads and sufficient horizontal strength of the anchorages.

IV – Perspectives

A *Sargassum* raft has a non-smooth aerial surface and a non-smooth under water surface. A possible improvement concerns the drift force assessment with surrounding fluid flows. The algal catch windage must be taken into account during sea breezes.

The algal catch recovery by specialized vessel is of major concern. As skimmer pumping oil contained by booms, the hydrodynamic behavior of algae removal and storage on board could be studied. Available techniques should be optimised.

In laboratory, we propose the following investigations.

- To avoid polyethylene (plastic) material put into the environment, we would study recycling wood material for barrier floats for example, as well as natural woven fiber for nets.
- To improve algae recovery, we suggest a dynamic model of shorten towed barrier.
- To set the hydrodynamic forcing, the boundary layer on catch bottom and the internal catch behavior could be observed.

In situ, these subjects remain:

- The choice of a site to carry out the experiments.
- The adaptation of environmental and social legislations and regulations to install a barrier and have operators working safely on sea and land.
- Do not leave the municipalities alone facing massive algal arrivals, by gathering means and ensuring their availability at regional level.

Acknowledgements We thank the fruitful exchanges at the origin of this work, with DEAL Martinique and mission sargasses, Direction de la Mer de la Martinique, and Parc Naturel Marin de Martinique.

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