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Session 1: Structures, Materials and the Environment

The general question addressed here is how to ensure an efficient implementation of resources, to minimize environmental and biological impacts and to identify responsibilities. The resources concerned are aquaculture and fishing nets and oil-spill booms from the structural analysis point of view, but equally, software which through numerical modeling will also address the correct way to install structures.

1.1. FEM modeling of flexible structures made of cables, bars and nets

1.1.1. *Introduction*

This presentation concerns finite element method (FEM) modeling devoted to flexible structures, such as fishing gear and fish-farming cages.

The first part gives the basic hypothesis:

– the netting is discretized into triangular finite elements;

– the net twines remain straight in each triangular element;

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– the water current is not affected by the structure;

– Young's modulus is constant in twine traction and in twine compression.

The forces described in mathematical form are due to twine stiffness elongation The virtual work principle is used to relate the force (F) on the 3 vertexes of the triangular element with the position (X) of these vertexes. The equilibrium

$$\boldsymbol{F}(\boldsymbol{X}) = 0 \qquad [1.1]$$

is found using the Newton-Raphson method.

The position at iteration k+1 (X_{k+1}) is found using the position (X_k). The force ($F(X_k)$) and the derivative of force ($F,(X_k)$) at iteration k with the following equation:

$$\boldsymbol{X}_{k+1} = \boldsymbol{X}_k - \boldsymbol{F}(\boldsymbol{X}_k)/\boldsymbol{F}'(\boldsymbol{X}_k)[1.2]$$

Simulations have been carried out for trawls made of diamond and hexagonal meshes, for cod-ends with catch, and for floating fish cages. Comparisons are given when experimental data are available.

1.1.2. *Details of study*

In a flume tank the netting looks like a surface as shown in Figure 1.1.

Two examples of netting structures are shown in Figure 1.2: a fish cage, on the left and a fish trap, on the right.

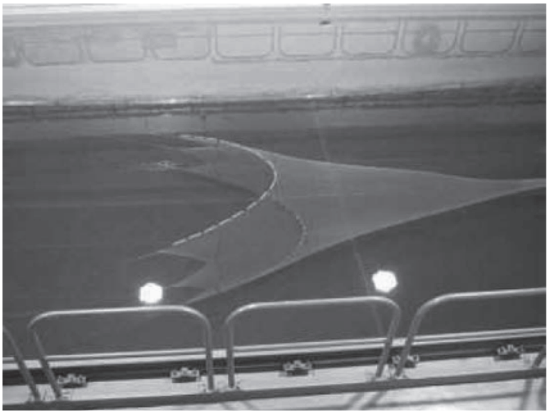


Figure 1.1. *Netting surface*

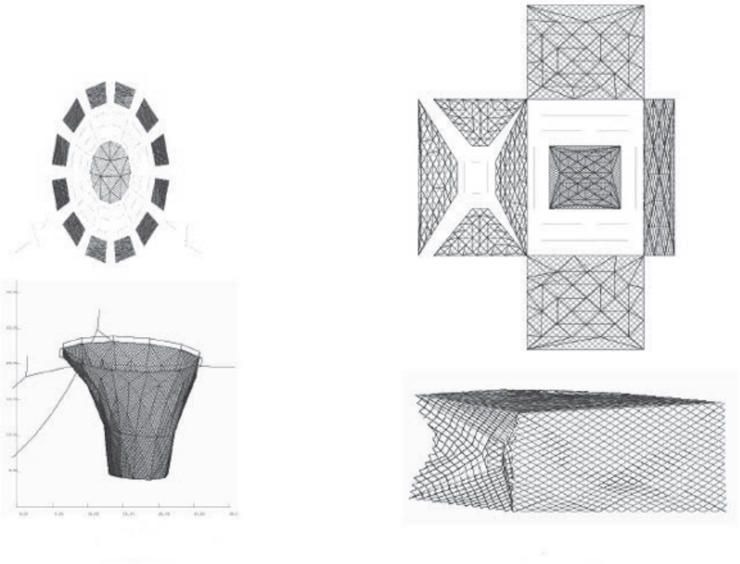


Figure 1.2. *The two netting structures are modeled using triangular elements*

In each triangular element, the twines have the same deformation.

This presentation focuses on the modeling of fishing gear and on the comparison of numerical and experimental results, carried out in hydrodynamic basins and flume tanks.

The netting drag modeling can be improved in the following way. The parameters are the water speed, the netting solidity and the angle. The possible formulations may be based on Morrison assumptions, Zhan studies [SUN 10], Pichot experimentations [PIC 09], Aarsnes tests [AAR 90] and those based on the pressure drop.

Figure 1.3 shows experimental and numerical results on a net surface dedicated to the improvement of netting drag modeling. The net surface boundary is connected to two tension ropes situated on the corners of its left-hand side, and is weighted on its right-hand side. A comparison between the surface geometries allows us to validate the model.

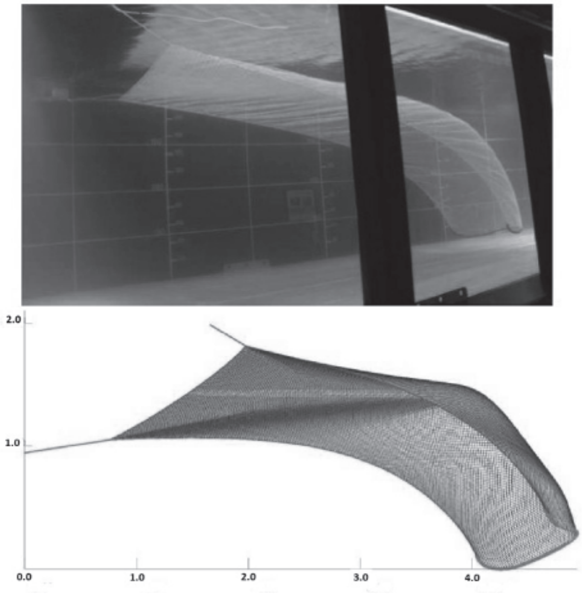


Figure 1.3. *Comparison of net shape with free boundaries under hydrodynamic drag*

A fishing cage is studied by both experimental and numerical modeling. The following figure shows the comparison between test and modeling. This cage is used for aquaculture in open seas.

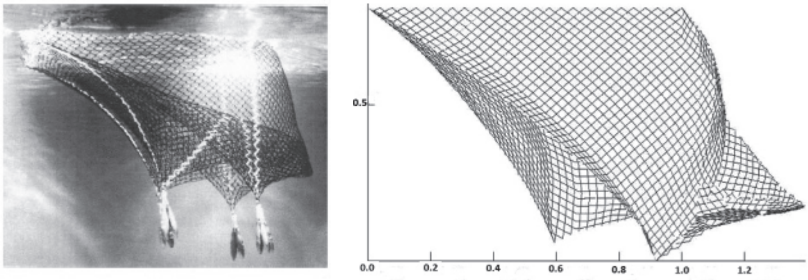


Figure 1.4. *Fishing cage*

To go ahead with the triangular element defined by a set of cable (twine), it is proposed that we use a homogeneous triangular element having three degrees of freedom per node in translation U_i, V_i, W_i and equally three in rotation Θx_i, Θy_i, Θz_i. We highlight the very low level of hydrodynamic drag force at the twine scale.

The discussion reveals the lack of available places in French marine waters for aquaculture plants.

1.2. Oil-boom models and full-scale tests

1.2.1. *Introduction*

Floating barriers named booms are moored during oil spill emergencies in the vicinity of a shore respecting geomorphology and environmental conditions to ensure containment or deviation of hydrocarbon slicks.

The Deepwater Horizon crisis in the Gulf of Mexico saw the largest deployment of containment booms, 4.2 million of feet or 1,280 km. One of the main problems encountered is the difficulty in handling the environmental conditions, the fabric structure performances and limitations, so that a positive response can be given to such a disaster.

The state of the art concerning oil booms focuses mainly on their hydrodynamic performances. Their behaviors are investigated under current and waves showing the Kelvin–Helmholtz instability of the oil–water interface. The relationship between boom design parameters and the mode of failure of oil containment is studied for a variety of wave and current combinations.

Our approach concerns the structural analysis of the flexible barrier under the external actions provided by the mooring system and the natural environment. To validate our mechanical studies, we describe a validation program based on full-scale experiments. Such ambitious programs have begun with test preparations at the sites of La Rochelle and Lorient (both in France), before the most promising experiment carried out in the Élorn estuary (also in France).

1.2.2. *Details of study*

The junction between two boom elements shown in Figure 1.5 is built on a link between the chain, the leach (black arrow on the figure) and the coated fabric material. The FEM uses a mesh for each of these parts on the barrier.

The emergency planning of the Élorn estuary begins by the inflation of the boom float before towing the barrier on the sea by ship. The following figure shows part of the 200-m-long barrier installed for the Élorn experiment of November 2009.

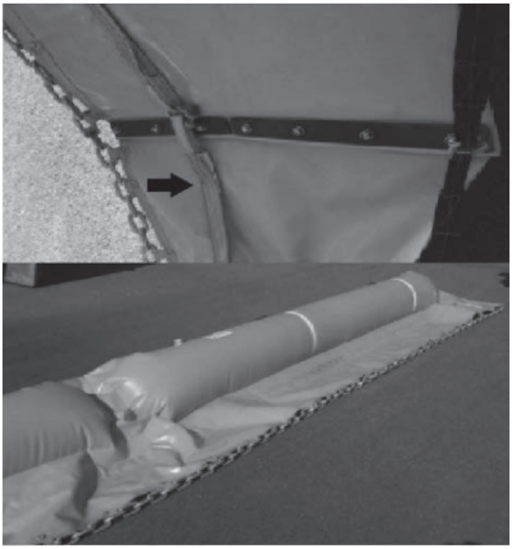


Figure 1.5. *The junction between two boom elements*

Figure 1.6. *Inflated floating part and undersea skirt part of a boom*

To measure the skirt angle under the sea-current action, a skirt angle stick support is fixed on a boom element junction. Figure 1.7 shows such a device where a 2-m-long stick is installed in the metallic tube.

Figure 1.7. *Skirt angle stick support*

Figure 1.8 presents the skirt angle of the boom obtained by the direct measure given by the stick (white arrow in the figure) and the comparison with the threshold 10° value (black arrow in the figure). This threshold has been constructed by using numerical modeling of the oil–water flow around the boom.

Figure 1.8. *The skirt angle is higher than the threshold efficiency value of 10°*

The observation of the skirt angle suggests that an oil leakage by submersion may be observed if this boom configuration is used in the presence of drifting oil pollution.

From a mathematical point of view, our methodology is based on a 1st-order ordinary differential equation (ODE) giving us the curve of a hydrodynamic leach. This Cauchy problem allows an initial tension–angle solution of the three-dimensional (3D) boom surface. The partial differential equation (PDE) of the 3D membrane is based on the elastic membrane equation with Dirichlet boundary condition at the level of float bottom in the vicinity of the sea surface. The FEM uses a four-node bilinear element and the Newton–Raphson method. The convergence of the solution of the nonlinear 3D problem is favored by using the ODE solution. Here we used embedded meshes going from one-dimensional (1D) to 3D domains.

As a result on boom stress we have observed a tension of 107 kg at the far coffer in Figure 1.8, while the 1st-order ODE equation will give 158 kg and the 3D mesh solution 207 kg. These three values indicate the magnitude order of the force applied on the right part of the boom. This force inclines the buoyancy coffer visible on the right in Figure 1.8. This coffer is represented by a circular mark on the upper right in Figure 1.9.

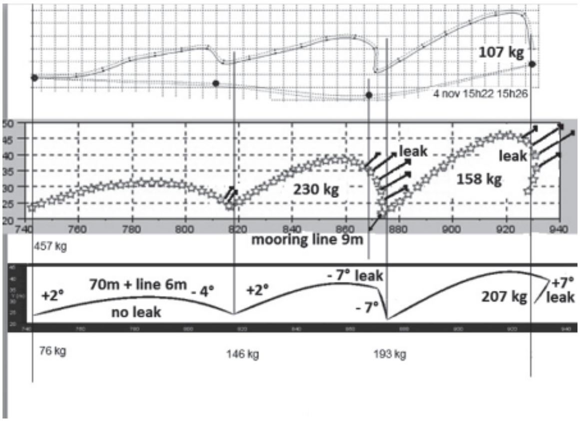


Figure 1.9. *Experimental (top), 1st-order ODE (middle) and 3D membrane PDE solutions*

A comparison of the measurements, 1st-order ODE and 3D PDE solutions are indicated in Figure 1.9. The geometry of the three barrier sections appears to be quite similar. On the 1st-order ODE solution representation the black arrows are the Lee criteria of oil leakage. On the 3D PDE solution, vertical angles of the skirt are indicated at the bottom part of Figure 1.9. Here it belongs to the interval [-7°, +7°]. This suggests that the oil pollution contingency is effective with such barriers under these coastal environment conditions.

The higher skirt angle value in the experiment shown in Figure 1.8, compared to the numerical value given in Figure 1.9, comes from the fact that the stick in the experiment is attached to the boom element junction. In this part of the barrier, the membrane sheet dimension is locally higher than the lengths of the chain and of the leach. As a consequence, a short functional movement appears locally on the element junction and the skirt is de-stretched. This suggests that the boom skirt increases locally.

The floating barriers considered here are static and anchored on the sea bed. The topic concerning the towed barrier, the towing force coming from ships must use another approach based on dynamic modeling. Such a topic has been directly addressed to us by the French Navy.

The bridle between the chain and the leach at each boom end plays a central role in the equilibrium shape of the barrier. Under the action of the sea current the boom skirt can move upstream or downstream. That depends on the chain length, the leach length compared to the boom length. If the chain length is less than the boom length, the skirt will go upstream. If the chain length is higher than the boom length, the skirt will go downstream in the same direction as the current. In the case of the Élorn estuary experiment, the skirt angle of 20° observed suggests that the chain is shorter than the barrier.

1.3. Oil-Spill MOHID models

1.3.1. *Introduction*

The MOHID water modeling system and its main applications are briefly described. The MOHID framework has been built to comprise great flexibility and versatility, developed in such a way that it can be used to study different types of applications in different environments. Oil-spill models can be seen at the top of a chain and, like a predator, if they consume bad input data they will generate bad (or worse) results. As an example, the sea currents can become extremely strong and therefore underestimated; on the other hand, a good atmospheric model resolution may significantly change the quality of the results. These recommendations come from lessons learnt in the DRIFTER project.

The MOHID oil spill module has been used since the Prestige oil spill (2002), where MARETEC-IST was directly involved in the generation of oil spill trajectory forecasts, to support Meteogalicia, the Galician meteorological center. It has more than 2,500 registered users and 150 users use MOHID on a regular basis. The basis of MOHID is to provide applications of coastal hydrodynamics as ecological modeling.

1.3.2. *Details of study*

An example of a coastal grid is given in Figure 1.10.

Another application is risk assessment such as bathing water quality provided for the cities of Barcelona, Biarritz and Sitges. A river catchment study is equally possible such as that given in Figure 1.11.

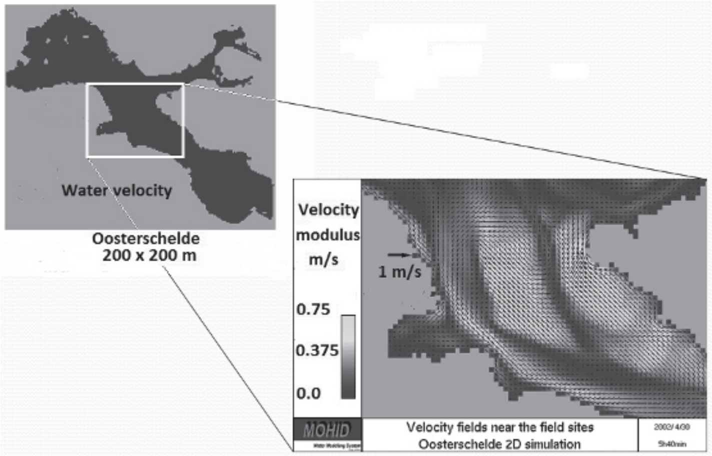


Figure 1.10. *Mesh grid for coastal hydrodynamics*

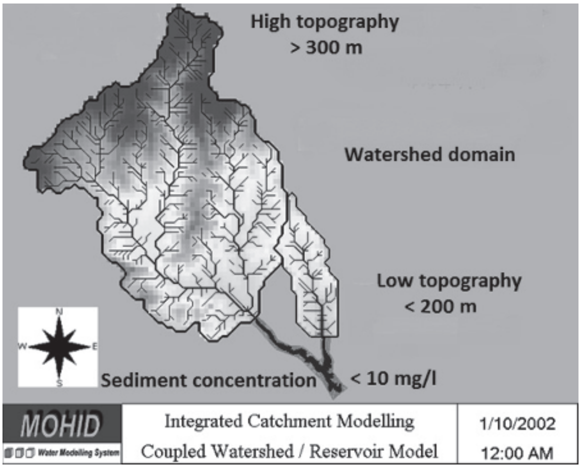


Figure 1.11. *River catchment modeling*

MARETEC-IST generated forecasts in the early stages of the oil spill, and predictions were initially validated *in situ* by the response team, then, by remote sensing, and most recently, by aerial observations. Since then, MOHID has been used operationally in other real accidents and in spill exercises performed by Portugal and Spain, always generating satisfactory results. The oil spill module present in MOHID is a 3D (with vertical movement) trajectory and weathering model, with the ability to run with integrated hydrodynamic solutions, or independently (coupled offline to met-ocean models).

Concerning the Prestige tanker accident in 2002, the oil derive predicted by the model, before the tanker hull breaks into two parts, is presented in Figure 1.12. A comparison can be possible with a well-known ESA ENVISAT satellite image. A good agreement between observation and prediction was observed.

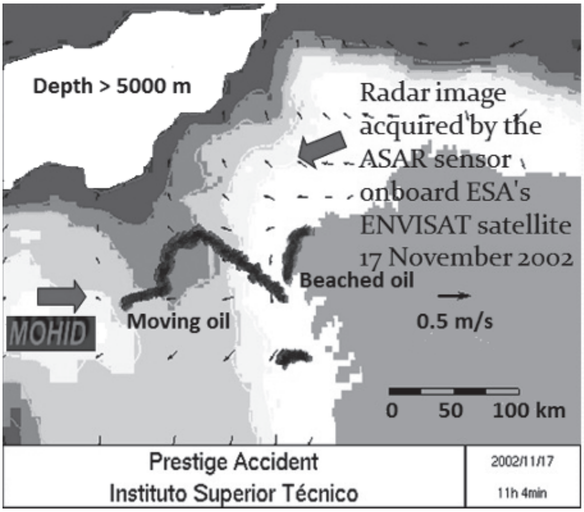
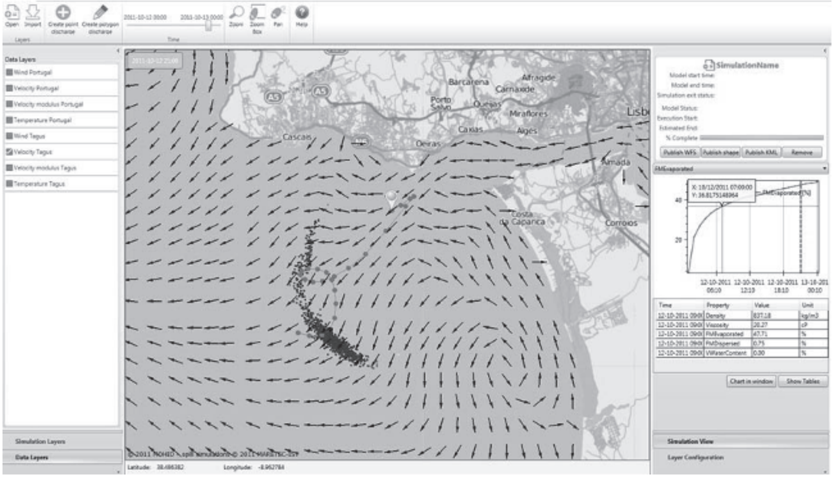


Figure 1.12. *Comparison of MOHID modeling and ESA satellite observation*

Since 2004, MARETEC-IST has also participated in different European research projects related to oil spills, focusing on the Atlantic area. Relevant research projects directly associated with oil spills are called DRIFTER, EASYCO, ARCOPOL and ARCOPOL+. These projects allowed the update of weathering algorithms, the calibration of the Lagrangian model, the development of innovative modeling tools, and the creation of guidelines and procedures for better interoperability between models and data.

Some of these tools will be presented, including web-based and desktop Lagrangian spill simulators (integrating offline met-ocean forecasts from several different institutions in the Atlantic area), or a Dynamic Risk Tool software application providing real-time and historic shoreline risk maps and levels, and also risk of accidents for each vessel.

A desktop spill simulator resulted from the ARCOPOL project. An example of the view of an oil spill trajectory is given in Figure 1.13.



Time	Property	Value	Unit
12-10-2011 09:0	Density	837.18	kg/m3
12-10-2011 09:0	Viscosity	28.27	cP
12-10-2011 09:0	FMEvaporated	47.71	%
12-10-2011 09:0	FMDispersed	0.75	%
12-10-2011 09:0	VWaterContent	0.00	%

Figure 1.13. *View of a desktop spill simulator*

This tool also takes advantage of interoperability between models, oil spill simulations, Automatic Identification System (AIS) monitoring systems, statistical data and coastal vulnerability (Environmental Sensitivity Index and Socio-Economic Index).

The MOHID Oil-Spill Module simulates water movement by using a Lagrangian approach. The spatial evolution of oil tracers included the sea currents (hydrodynamic model), the wind-drag transport (at the sea surface), the wave-induced transport (Stokes drift), the random movement, the diffusive transport, the mechanical spreading, the oil droplet entrainment (vertical dispersion) and the ascending velocity due to buoyancy. The time evolution of oil tracers can be forwarding or backtracking, allowing, for example, pollution source localization.

The 3D vertical movement of oil–water flow can be described by a mixed layer depth, depending on the breaking wave height [TKA 02]. The oil droplet size is described by different authors [REE 99, DEL 93]. The oil ascending velocity depends on density differences and droplet diameter (Stokes formula).

Future work and improvements in the MOHID oil-spill model will focus on the oil weathering processes. These are computed by using a set of independent tracers. Each tracer has its own specific properties. A new emulsification process has been defined by Fingas [FIN 04]. A review on dissolution and shoreline interaction is a means of progress. The improvement of the moving grid concept is equally encouraged.

The use of the operational model MOHID allows us to reduce the impact of marine pollution. Its efficiency is guaranteed by three intrinsic properties, versatility, interoperability and operationality. The model must respond to an operational request, so that it can be used effectively as a counter-pollution tool. The data on sea current and wind velocity concerns meteorological prediction tools which can be obtained from different platforms. Nevertheless, these data must have the property to be easily assembled together. This enables us to fill the model data structure. This must provide simple and relevant information to the operators. The integrative role of such systems is fundamental. As other examples of integration, we can cite the geo-localization data, from satellites, on pollution discharge into the sea, rivers or sewers.

From the numerical point of view, we use mobile grids which allow us to consider the most interesting zone of the marine flow. The coastal sensitivity defines a boundary condition upon the coastal flow.

1.4. References

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