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MODELING AND SIMULATION OF BOTTOM TRAWL GEARS

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Abstract. *This work compares two numerical methods to calculate the static equilibrium shape of a fishing gear in a uniform current flow. The trawl gear is modeled using 1D elements for the ropes (spring-damper elements) and 2D elements for the panels (triangular finite elements). The algorithm used for the discretization of the net surface is presented, and forces acting on the elements are described. Two simulation methods to find the static equilibrium position of the net are compared using test cases available in the literature: Newton-Raphson iteration and dynamic simulation with artificial damping. Results show that dynamic simulation is more robust, but it is also slower than Newton-Raphson iteration. Both methods have problems derived from the high elastic forces at the initial iterations of the methods, since the material of the net panels is usually under strain in the initial position.*

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1 INTRODUCTION

Bottom trawling [2] is a fishing method where a fishing net (bottom trawl) is towed through the water over the seabed by one or more boats. Bottom trawling is very common in the commercial fishing industry, but it raises many environmental concerns related to selectivity: trawls are non-selective fishing devices, since they catch fish which cannot be sold (illegal size, undesirable species etc.) and eventually ends dead. In addition, bottom trawls also cause physical damage to the seabed.

To overcome this problem, the fishing industry is trying to design new selective bottom trawls with lower environmental impact. The Spanish research project PSE-REDES goes in this direction, joining fishermen, biologists and engineers with the goal of improving the selectivity and the energy efficiency of fishing trawls. The University of A Coruña participates in the project developing numerical methods to simulate and optimize the behavior of trawls, since a flexible and fast simulation tool will be required to test new fishing devices which enhance selectivity.

Traditional bottom trawl gears, see Fig. 1, are complex mechanical systems involving flexible bodies with compound geometry (net), rigid bodies (otter boards and other devices), contact with soft soil and fluid-structure interaction. The vertical opening is obtained by floats placed in the upper edge of the net, while the horizontal opening is obtained by hydrodynamic forces acting on the otter boards.

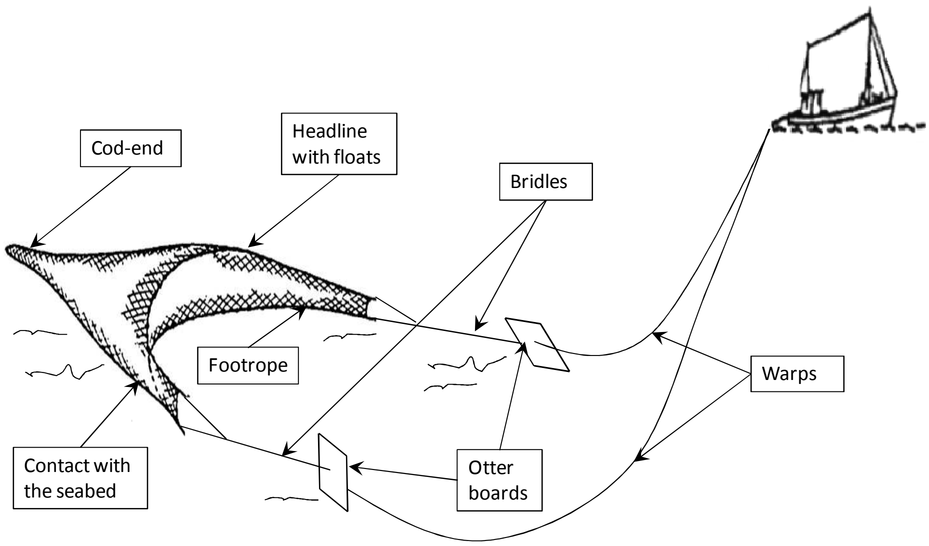

Figure 1: Components of a traditional bottom trawl gear.

The new designs that will be proposed in the project will make the trawl even more complex, introducing rigid and flexible devices in different parts of the structure. In this work we describe the initial approaches taken to simulate the behavior of the flexible net, without taking into account soil contact and fluid-structure interaction.

2 MODELING METHODS

2.1 Input data

A fishing net is made up by a set of polygonal panels (3- or 4-sided) sewed to each other, where some seams are reinforced by strengthening ropes. The net material is anisotropic (Fig 2b).

Input data are introduced in different files: the geometry of the trawl, its properties and the

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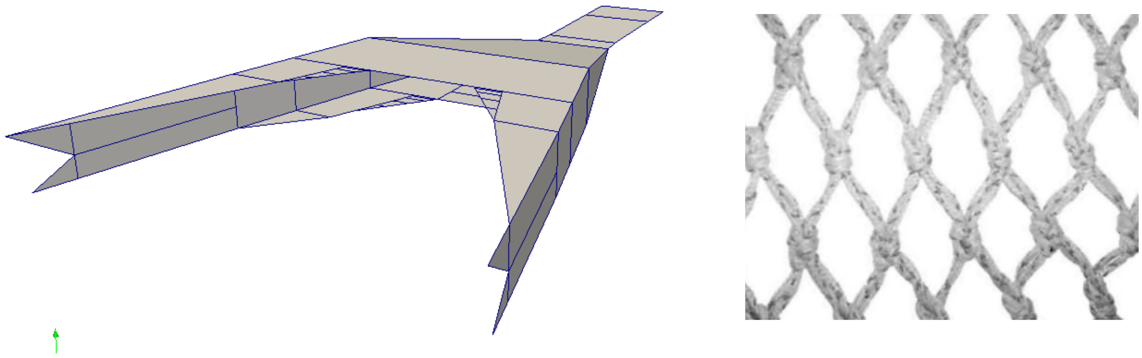
type of numerical analysis to be carried out. In the geometry file, the fishing net is defined as a simple sketch of points, segments and polygons; coordinates don`t have to be accurate. The software associates polygons as net panels and segments as strengthening ropes. A polygonal sketch of a real fishing net is shown in Fig. (2a). The properties file contains the properties of the materials that compound the net (stiffness, density ...) but also other panel features as number of meshes or cuts [3]. Finally, the analysis file includes parameters to control the modeling (for example, mesh discretization size) and numerical simulation.



(a) (b)

Figure 2: Fishing net structure (a) and detail of net material (b).

2.2 Discretization

Different methods to model the structural behavior of fishing nets have been proposed and improved since early nineties. The first attempts modeled the net as a multiple-bar mechanism (Marichal [1] and Theret [7]) or as membrane finite elements (Tronstad [8]). Nowadays, discretization methods can be grouped in two main trends:

The first method [6] describes the mesh as a set of lumped point masses (representing mesh knots) interconnected by one-dimensional spring-damper elements (representing twines). In order to reduce the size of the numerical model, adjacent meshes can be grouped as a single mesh. The discretization of each net panel is a simple task; however, point masses of adjacent panels must be sewed with additional spring-damper elements, and this is a complex task since the cuts of the panel sides do not always match.

The second modeling method [4] uses triangular finite elements to discretize the net. This method gives more flexibility to select the discretization size, and numerical meshes of adjacent panels are automatically connected by shared nodes. Moreover, the sides of the triangles don't have to be parallel to the twines.

In this work we have developed and implemented an algorithm to discretize the net in triangular finite elements. Unfortunately, commercial meshing tools cannot be used to discretize the tridimensional net surface, because they assume that the geometry to be meshed has no strain in its initial position. However, the material in the net is under strain even in the initial position, because panels are stretched when they are sewed to build the net. Since triangular finite elements need some parameters that are calculated in repose situation, we have proposed the following solution:

Undeformed coordinates are defined as a set of 2D coordinates corresponding to the nodes of a panel in repose. Simulation coordinates are the 3D coordinates of the panel nodes during the simulation, initially those given in the input sketch. For each panel, undeformed coordinates are calculated from the panel properties (number of meshes, type of cuts, mesh orienta-

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tion, angle and size). After that, the panel is discretized into triangular elements. Finally, the resulting node coordinates are turned to simulation coordinates by applying a lineal transformation. The discretization steps are described in Fig.(3) and a discretized fishing net is shown in Fig.(4).

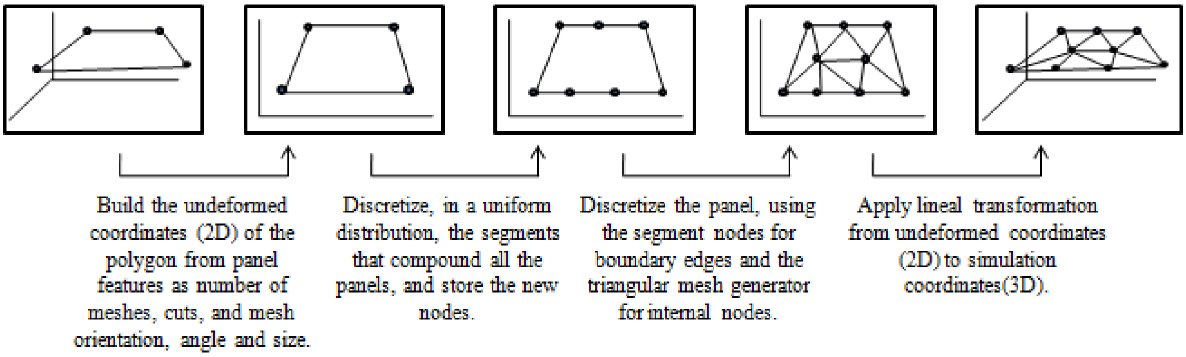

Figure 3: Discretization process for fishing net panels.

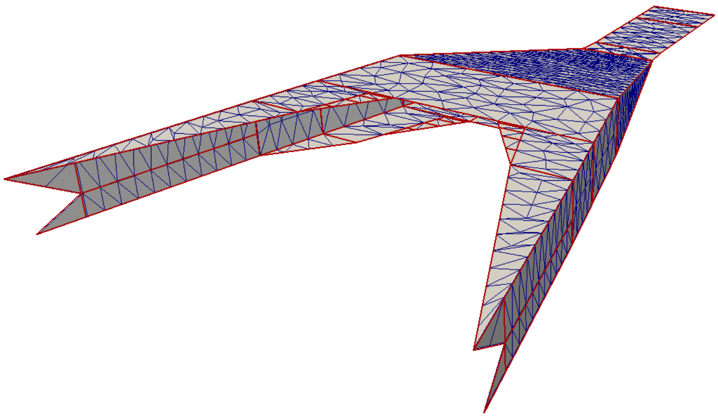

Figure 4: Fishing net discretized into finite triangular elements.

2.3 1D elements

The ropes present in the trawl gear are modeled as simple spring-damper elements, where the forces are expressed as follows:

- Weight and buoyancy.
- Elastic and damping forces: defined as a lineal spring-damper.
- Bending forces between elements: equivalent to a bending momentum *T*, see Fig.(5a) and Eq.(1):

$$T = k / R \tag{1}$$

  Where *k* is the bending stiffness of the rope and *R* is the curvature radius between two elements, approached as the radius of the tangent circumference to the two elements.

- Hydrodynamic drag forces: according to [9], it can be expressed as

$$\mathbf{F_n} = \frac{1}{2}\rho D L C_d \mathbf{V_n} \| \mathbf{V_n} \| \tag{2}$$

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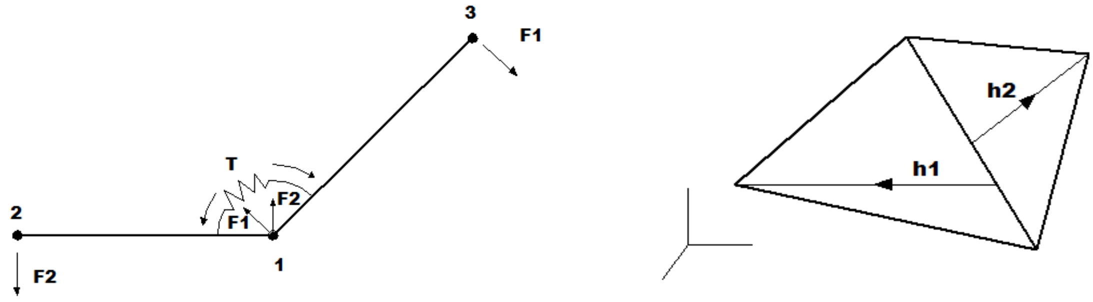
Where ρ, D and L are the density, hydrodynamic coefficient and diameter of the rope and length of the element, and $\mathbf{V_n}$ is the fluid speed normal to the bar element.



(a) (b)

Figure 5: Bending forces in bar elements (a) and application to triangular elements(b).

2.4 2D elements

The triangular finite elements used to discretize the net has been developed by Priour [4]. The element has equivalent behavior to the panel material since two twine directions (called u and v) are defined as a non-orthogonal base from undeformed coordinates. The main hypothesis in the element formulation is that the strain on each element is constant and u and v twines are supposed to displace in parallel to themselves. Moreover, the sides of the triangles don't have to be parallel to the twines. The forces on the element are the following:

- Weight and buoyancy.
- Elastic forces due to twines. Priour [4] has modeled them as an accumulation of elastic forces for all twines in an element.
- Resistance to opening. It is an elastic force due to the bending in knots, since considering knots as joints is not an accurate approach, particularly in large nets. Priour [5] has proposed a formulation based on the momentum *C* created by u and v twines, which can be described as

$$C = H(\alpha - \alpha_0) \tag{3}$$

  Where H is the couple stiffness, α is the half mesh angle and α_0 is the half mesh angle in repose.

- Bending between triangles. It can be defined in the same way that for 1D elements in Eq.(1), but replacing the bar elements by the altitude of the neighbor triangles, see Fig. (5b). The bending stiffness *k* has to be calculated in each triangle boundary, as a linear combination of the bending stiffness of the two directions of bending in the net material.
- Hydrodynamic drag force. The drag force for a twine is defined in Eq.(2) for a bar element. For triangular elements, the drag force of all the twines in *u* direction (n_u) and all the twines in *v* direction (n_v) are accumulated:

$$\mathbf{Fdrag} = n_u \mathbf{F_u} + n_v \mathbf{F_v} \tag{4}$$

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3 SIMULATION METHOD

3.1 Newton-Raphson

The equilibrium shape of a net modeled with triangular finite elements is usually obtained through a Newton-Raphson iteration, as described by Priour [4]. The non-linear system to be solved is:

$$\mathbf{F}(\mathbf{q}) = 0 \tag{5}$$

Where **F** is the nodal force vector which accumulates the contributions of the different kind of forces described above and **q** is the nodal coordinate vector in equilibrium. The system has $3 \cdot nnodes$ equations (nodal forces projected in x, y and z directions) and the same number of variables (x, y and z coordinates per node).

$$\mathbf{F}'(\mathbf{q}_i)(\mathbf{q}_{i+1} - \mathbf{q}_i) = -\mathbf{F}(\mathbf{q}_i) \tag{6}$$

While this approach works quite well with simple models, it has some weakness. First, if none of the above-mentioned element forces are neglected, **F** becomes highly non-linear and the Jacobian matrix $\mathbf{F}'$ becomes extremely complex, resulting in poor computational performance. Second, some kind of forces do not depend on node positions (for example, weight and buoyancy), and therefore they do not contribute to the Jacobian matrix; as a results, the Newton-Raphson iteration gets lost when these forces are high compared with others.

3.2 Dynamic Simulation

As an alternative method to find the equilibrium shape of a net modeled with triangular finite elements, we employ dynamic relaxation using damped numerical integration schemes. The aim of this method is to avoid the calculation of the Jacobian matrix, and to improve the robustness of the Newton-Raphson iteration.

The equations of motion of the whole system are:

$$\mathbf{m}\ddot{\mathbf{q}} = \mathbf{F}(\mathbf{q}) \tag{7}$$

Dynamic equilibrium is obtained using a damped numerical integration scheme, particularly we have started the tests using the implicit single-step Newmark method:

$$\mathbf{q}_{i+1} = \mathbf{q}_i + h\dot{\mathbf{q}}_i + \frac{h^2}{2}\left[(1-2\beta)\ddot{\mathbf{q}}_i + 2\beta\ddot{\mathbf{q}}_{i+1}\right] \tag{8}$$

$$\dot{\mathbf{q}}_{i+1} = \dot{\mathbf{q}}_i + h\left[(1-\gamma)\ddot{\mathbf{q}}_i + \gamma\ddot{\mathbf{q}}_{i+1}\right] \tag{9}$$

Where $\mathbf{q}$, $\dot{\mathbf{q}}$ and $\ddot{\mathbf{q}}$ are the position, speed and acceleration of nodes, **m** is the mass of the net associated to a node, *h* is the time step, β and γ are the Newmark parameters and take the following values based on the damping coefficient χ:

$$\chi = -0.3 \tag{10}$$

$$\beta = \frac{(1-\chi)^2}{4} \tag{11}$$

$$\gamma = \frac{(1-2\chi)}{2} \tag{12}$$

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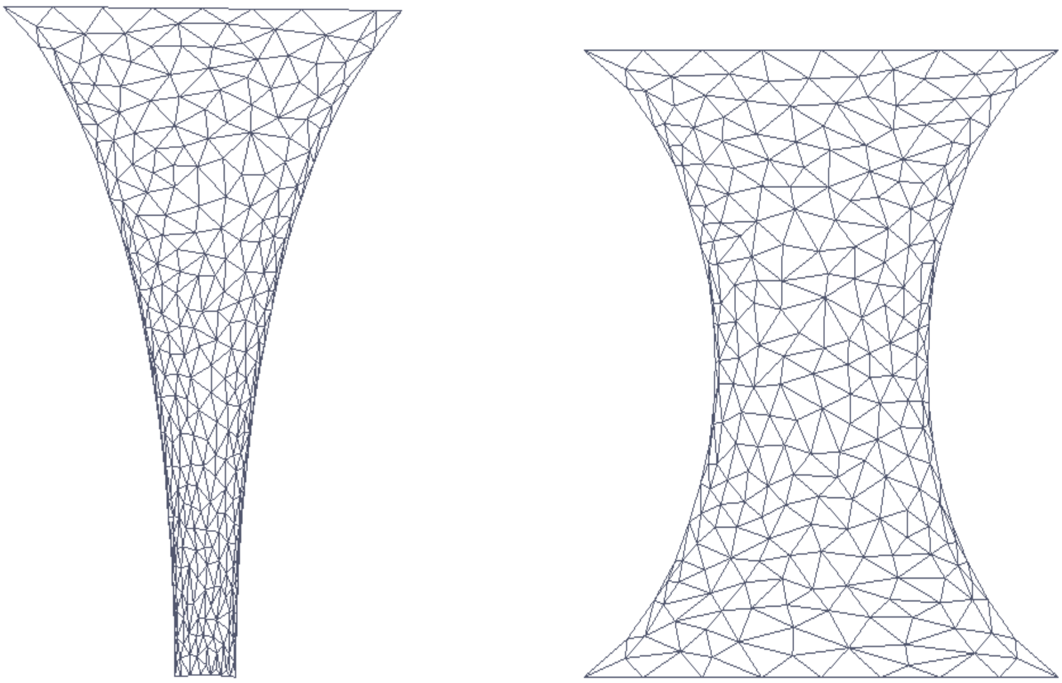
The fixed point method is used (predictor and corrector schemes) and $\ddot{\mathbf{q}}_{i+1}$ is calculated from the equation of motion Eq.(7).

4 RESULTS AND DISCUSSION

The two simulation methods described in the previous section have been tested with several simple models in order to get insight about their behavior. Figure (6) shows the equilibrium shape of two test cases proposed by Priour [4]. The obtained results agree very well with those published in the literature ([4],[5]).

The first case, shown in Fig.(6a), is a rectangular panel attached to a top boundary condition and tightened by its own weight. The panel is rectangular (40x40 1.2 m sized meshes), twine stiffness is 10000 N, twine diameter 0.01 m, density of the material is 2000 kg/m^3. The boundary condition is 32 m long.

The second case, shown in Fig.(6b), is designed in order to see the influence of the resistance to opening. The net is held on his top and bottom boundaries forming a 0.48 m x 0.54 m rectangle. The net is made of a 61x50 5.7 mm sized meshes, the twine diameter is 0.1 mm, the stiffness is 10 N, the resistance to opening is 0.001 Nm/rad and the density of the material is 2000 kg/m^3.



(a) (b)

Figure 6: panel in dead weight (a) and panel stretched by top and bottom boundary conditions(b)

Regarding the Newton-Raphson iteration, this approach works quite well with simple test cases, but it has some weakness. First, if none of the above-mentioned element forces are neglected, **F** becomes highly non-linear and the Jacobian matrix **F'** is extremely complex, resulting in poor computational performance. Second, since weight and buoyancy forces do not depend on node positions, and hydrodynamic drag forces only depend on element orientation, these forces have little or no contribution to the Jacobian matrix; as a result, the Newton-Raphson iteration gets lost frequently and sometimes the Jacobian matrix becomes nearly sin-

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gular.

Regarding the dynamic simulation, this method proved to be more robust than the Newton-Raphson iteration. Artificial damping forces have to be included in the dynamic equations in order to stabilize the model, and the time step must be small ($h \leq 1.0$E-3 s); as a consequence, the method is also slower than the Newton-Raphson iteration. An advantage of this method is that it does not solve any linear equation system, and therefore it is more suited to parallelization.

5 CONCLUSIONS AND FUTURE WORK

In this work two methods have been implemented to find the equilibrium position of a fishing net modeled with the triangular finite element proposed by Priour [4]: the Newton-Raphson iteration and the dynamic simulation with artificial damping.

Both methods presented problems due to the high elastic forces at the beginning of the iterations caused by the inaccurate initial position: in the case of the Newton-Raphson iteration, the Jacobian matrix becomes nearly singular at some iterations, resulting in too large iteration steps and forcing to re-start the method frequently; in the dynamic simulation, the time-step used in the numerical integration must be reduced. In both cases, the computation time is increased. In the future, several strategies will be tested to overcome this problem. In addition, the models based on triangular finite elements will be tested with models based on lumped masses.

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