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Modelling axisymmetric codends made of hexagonal mesh types

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ABSTRACT

Codends are the rear parts of trawls, which collect the catch and where most of the selectivity process occurs. Selectivity is the process by which the large fish are retained while the small ones are released. The codends applied in many fisheries often consist of only one type of mesh. Therefore it is reasonable to consider these codends as being axisymmetric. Their shapes depend mainly on the volume of catch, on the shape of meshes (diamond, square, hexagonal) and on the number of meshes along and around the codend. The shape of the codends is of prime importance in order to understand the selectivity process. This paper presents a model of deformation of codends made up of hexagonal meshes. Two types of hexagonal meshes have been investigated: the T0 codend where two sides of the hexagons are in axial planes and the T90 codend where two sides are perpendicular to the codend axis. The forces involved in this model are twine tension and catch pressure. A Newton–Raphson scheme has been used to calculate the equilibrium.

1. Introduction

Fishing operations target the largest sized fish mostly. The catch often contains considerable amounts of undersized fish or non-targeted species. This non-target catch could reach one-third of the total marine harvest worldwide (Alverson and Hughes, 1996).

In order to reduce this wasteful bycatch, studies of trawl selectivity have been carried out at sea. But due to the large number of uncontrollable parameters, numerous trials have to be undertaken in order to reach good quality statistics. This leads to expensive studies which are often inconclusive.

To overcome this uncertainty, it is possible to use predictive models of codend selectivity. Such models (e.g. PRESEMO, Herrmann et al., 2006, 2007) have been developed in the last few years and are able to simulate codend selectivity quickly and simply. Even though these tools are based on approximations, their results are often reliable. However, it is important to know the fish behaviour and the mechanical codend behaviour.

To understand better the codend behaviour, it is essential to gather data on the mesh openness along the codend when the catch builds up. This opening also depends on the design of the codend, i.e. the mesh type (diamond, square, hexagonal), the number of meshes around and along, the size of meshes. Two numerical models developed in recent years are already able to assess codend geometries: O'Neill (1997) derives differential equations that govern the geometry of axisymmetric codends for a range of different mesh shapes, and Priour (1999, 2013) has developed a more general three-dimensional finite element method model of netting deformation. Both of these models can take into account the elasticity and flexural rigidity of the twines, the mesh shapes (diamond, square, hexagonal), and the hydrodynamic forces that act on the netting material and catch. Their numerical simulations were compared by O'Neill and Priour (2009) and were found to be very similar.

In a previous paper (Priour et al., 2009), an axisymmetric model of the codend made up of diamond, square or rectangular meshes has been developed by looking at the force balance on the twine elements on a meridian along the codend length. The advantage of this model over those above is that it is easy to implement and its solution does not depend on the use of licensed software.

The diamond mesh codend is the codend type which has traditionally been applied in many trawl fisheries. This type of codend could be modelled by numerical models such as those previously described. In recent decades there has been a tendency to use netting with thicker twine (Herrmann et al., 2013). In this case the use of an ideal diamond shape model is not perfect due to the size of the knots. As mentioned by Sistiaga et al. (2011), a hexagonal mesh model is preferable compared to a diamond mesh model to describe the actual shape of the meshes in the codends (Fig. 2). This means the knots are sides of the hexagon.

In this present paper this previous model (Priour et al., 2009) has been extended to hexagonal meshes. Two types of hexagonal meshes are investigated: the T0 type, where twines are in axial

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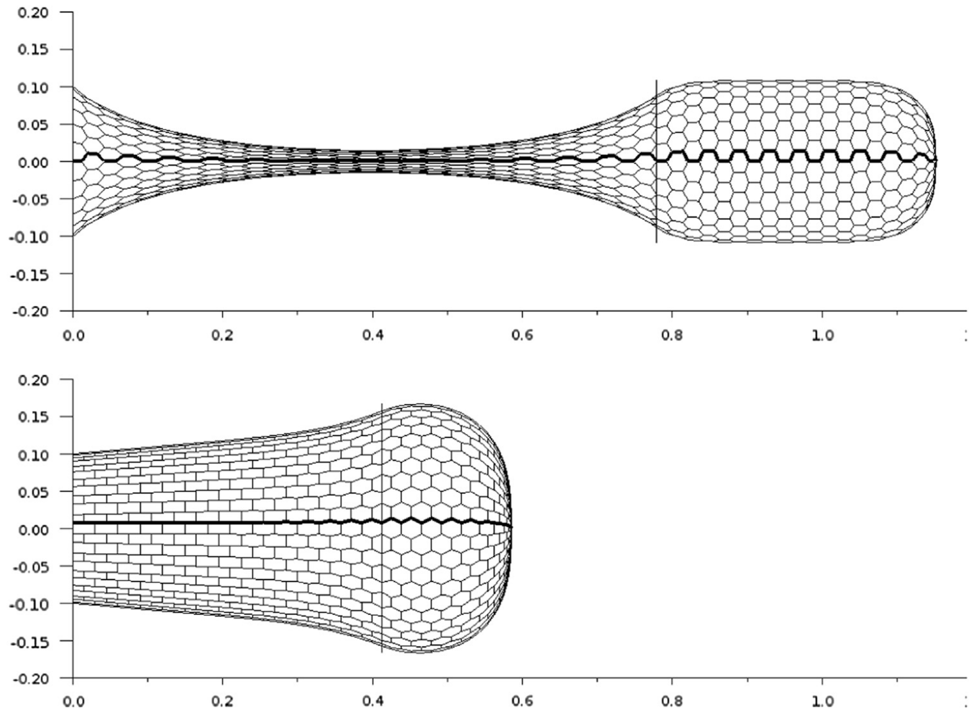

Fig. 1. The two types of hexagonal meshes investigated in the paper: the T0 at the top where some twines are in axial planes and the T90 where some twines are in planes perpendicular to the codend axis. The two codends are made up of the same piece of netting (24 by 24 meshes) and the catch covers the same number of meshes (10). The vertical line is the limit of the catch. Due to axisymmetry only one meridian is calculated (highlighted row).

planes (the angle between this axial plane and the axis of the codend is 0°) and the T90 type where twines are in planes perpendicular to the codend axis (the angle between this plane and the axis of the codend is 90°, Fig. 1). Although in most fisheries the codends are T0 type (the knots are in axial planes), in some cases, e.g. Baltic Sea for cod fishery (Anon, 2005), the codends of T90 type are legal (the knots are perpendicular to the codend axis).

This model is supposed to represent usual netting where the knots are large enough to consider their size as one side of the hexagonal mesh. Obviously the six sides of the hexagon are not necessarily equal (Fig. 2).

2. The T0 codend

By assuming axisymmetry, the codend geometry can be determined by examining the nodes belonging to one row of twine along the codend length. This row is highlighted at the top of Fig. 1 and in Fig. 3. This row is called the meridian. The approach consists of three steps. Firstly, the initial position of these nodes, consistent with the boundary conditions, must be defined. Then, the forces acting on these nodes are calculated. Finally, using the Newton–Raphson method (Priour, 2013), the equilibrium position of these nodes is evaluated.

The forces that act on the codend are the twine tensions and the hydrodynamic forces. As shown by O'Neill and O'Donoghue (1997), the hydrodynamic forces that act on the unblocked netting are negligible in comparison with the pressure forces acting on the netting where the catch blocks the meshes. Consequently, it is only necessary to consider the twine tensions and the pressure forces that act in the region of the catch.

2.1. Nodes of the T0 codend

The meridian is such that some nodes of this meridian are in the plane *XOZ*, as shown in Fig. 3. The mesh *i* (trapeze in Fig. 3) is made up of 6 twines and 4 nodes (*ia*, *ib*, *ic* and *id*). The nodes *ja*, *jb*, *jc* and *jd* belong to the same mesh ring but they do not belong to the calculated meridian (highlighted meridian in Fig. 3). In Fig. 3 the node $i-1d$ belongs to the previous mesh $(i-1)$ and the node $i+1a$ belongs to the following mesh $(i+1)$. The nodes of the calculated meridian with suffixes *a* and *d* (e.g. *ia*, *id*, $i-1d$, $i+1a$) belong to the plane *XOZ* (their *y* coordinates are 0 as shown in Fig. 3). The nodes of the calculated meridian with suffixes *b* and *c* (e.g. *ib*, *ic*, $i-1b$, $i+1c$) do not belong to the plane *XOZ*, they are in a radial plane which gives an angle θ with the plane *XOZ*. With

$$\theta = \frac{\pi}{nbr} \tag{1}$$

where θ is the angle between the two radial planes passing by *ia* and *ib* (*Rad*) and *nbr* is the number of meshes around.

The reason is that the neighbouring nodes *ja* and *jd* belong to a radial plane which gives an angle 2θ with the plane *XOZ*. This is due to axisymmetry. Likewise the nodes *jb* and *jc* belong to another radial plane which gives an angle -2θ with the plane *XOZ*. Due to equilibrium, the nodes *ib* and *ic* have to be in a radial plane just between the radial planes of *ja* and *ia*.

From this definition of node positions, we are able to say

$$ia = (ia_x, 0, ia_r)$$

With ia_x the position of *ia* along the *X*-axis and ia_r its radial position,

$$ib = (ib_x, ib_r \sin\theta, ib_r \cos\theta)$$
$$ic = (ic_x, ic_r \sin\theta, ic_r \cos\theta)$$
$$id = (id_x, 0, id_r)$$

where suffix $_x$ refers to the position along the *X*-axis and suffix $_r$ to the radial position.

The position of the neighbouring nodes is

$$ja = (ia_x, ia_r \sin 2\theta, ia_r \cos 2\theta)$$
$$jb = (ib_x, -ib_r \sin\theta, ib_r \cos\theta)$$