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Numerical modelling of bottom trawling ground gear element on the seabed

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ABSTRACT

This paper focuses on the numerical modelling of the interaction between gear components, rockhoppers, in particular and the seabed. This interaction is developed by using the Coupled Eulerian Lagrangian Method (CEL). To demonstrate the rate effect, a 2D finite element model is developed to analyse the pore pressure distribution and soil deformation. In situ soil conditions of the seabed with large deformations require multiphase simulation which is very expensive to investigate numerically. However, fully drained conditions were considered and the results obtained were deemed acceptable for this study. Validation of the numerical model was achieved by means of laboratory experiments undertaken on a 1:5 scaled model. Good agreement between the experimental tests and numerical simulations is found which provides the basis for investigation of the effect of the size of the rockhoppers, their position with respect to the towing direction and the number of discs modelled. A unique expression for the towing force of the segment of rockhopper gear is expressed as a function of the drag force of a single disc, the diameter, thickness, and angle of attack.

1. Introduction

Demersal trawls and Scottish/Danish seines are two of the most deployed types of fishing gear (Fig. 1). A common part for both types of gear is the ground gear which is in direct contact with the seabed over which the gear is towed. These elements are designed to optimize catchability and also to protect the fishing gear and/or prevent it from snagging. Depending on the type of the seabed and species fished, the most common types used are combinations of ‘rockhopper’, chain, rope or bobbins.

In recent years two issues have arisen regarding the contact these gears make with the seabed. The first is concerned with the environmental and ecological impact, on the benthic habitat of towing demersal fishing gear and the second is concerned with the contribution seabed contact makes to the overall fishing gear drag and consequently to the fuel efficiency of the fishing operation.

A number of studies have been undertaken addressing the damaging effects of towed demersal gear on benthic organisms and habitats and on the water column (Clark and Frid, 2001; Kaiser et al., 2002; Løkkeborg, 2005; Dounas et al., 2007), but very few have tried to address the physical mechanisms associated with those processes. Similarly, most studies in relation to gear drag have focused on the hydrodynamic forces acting on the gear and the related net deformations (Priour, 1999; Le Dret et al., 2004) while bottom contact forces have been investigated to a much lesser extent.

However, there have been a few studies that have carried out physical scale modelling experiments related to the contact forces. Folch et al. (2007) produced a model to predict the contact forces between the seabed and the otter board but did not model the deformation and penetration of the sediment. Nouguier et al. (2000) developed a particle model to perform dynamical contact simulations of a non-cohesive granular bed being cut by the motion of a tool. The tool was partially immersed in the granular bed and moved horizontally at a constant speed. The time evolution of the stresses in the bed were analysed where large force fluctuations acting on the tool were obtained. The fluctuations of drag force have a decreasing exponential distribution but the mean force is well fitted with the results of a limit analysis with Coulomb's failure criterion. Palmer (1999) studied the speed effects occurring when blades and ploughs cut the saturated soil. Palmer pointed out that the ploughing forces increase greatly when the plough share forces dilatant soil to deform rapidly but that no such effect is noticed in dry soil. Zhao and Miedema (2001) derived a mathematical model of the cutting forces in saturated sand at large cutting angles. They applied the finite element method to predict the occurrence of boundary soil wedges in saturated soil and to evaluate the interaction between the sand dilatation and the existence of a dead zone in front of the blade. Igland and Søreide (2008) used the ANSYS software package to

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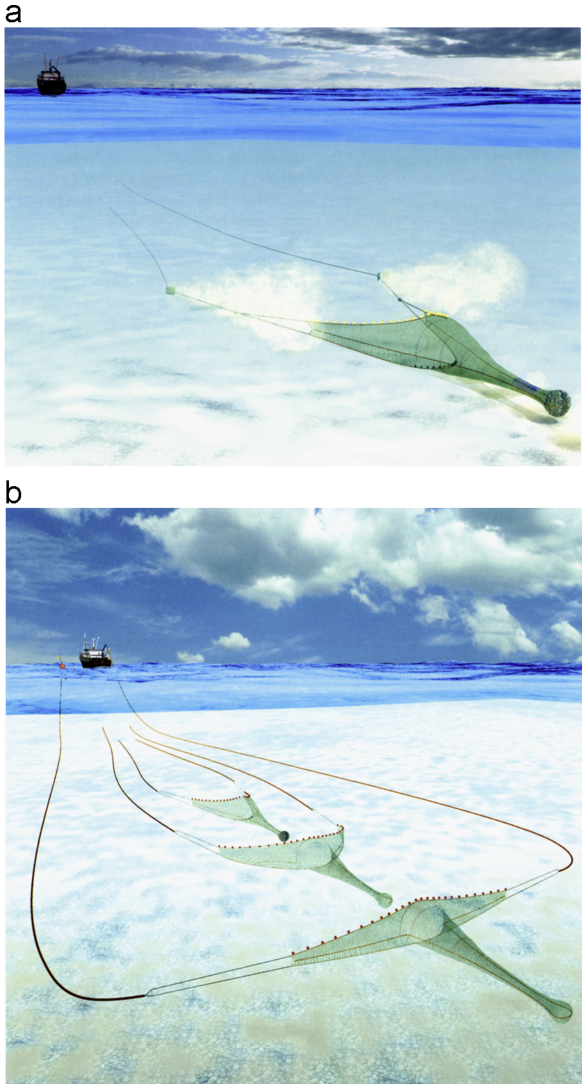

Fig. 1. Schematic illustration of (a) Single boat demersal trawl and (b) Demersal seine net [1].

investigate the contact between a roller clump and marine pipelines where the seabed was modelled as a rigid surface and the contact between the pipeline and the seabed surface was described by the Coulomb friction model. Although this model can predict the contact loads between the components no estimation of seabed penetration can be obtained due to the rigid nature of the surface and so no studies related to the soil were performed. More recently, Ivanović et al. (2011) developed finite element models of the interaction between the seabed and trawl doors and clump weights using a Lagrangian numerical formulation.

Paschen (Paschen et al., 2002; Paschen, 2005) carried out physical scale modelling studies of the contact forces between the seabed and ropes and chains, examining the morphological changes in the upper seabed layers due to trawl fishing gear as part of EU project, TRAPESE. The penetration during the impact of an otter trawl door on the seabed has also been investigated by Reséguier et al. (2009) by evaluating the absorption of kinetic energy as the door penetrates the soil. This study, which was aimed at investigating the depth of pipe burial required to prevent contact between a pipe and an otter door, considered only vertical dropping of the door into sediments of various strengths and did not consider the sliding of the door over the seabed. The impact of trawl door scouring on infaunal bivalves was examined by Gilkinson et al. (1998). The interaction between the otter trawl door with the seabed was examined in a laboratory test tank using a full-scale trawl door model. It is reported that a furrow of 2 cm was created during the tests and that two out of 42 specimens showed major damage.

To fully appreciate the ecological and environmental impact of towed demersal fishing gears, it is essential to understand the physical mechanisms involved. Such an understanding would permit the assessment of the impact of different towed fishing gear and provide a means of developing gear with reduced impact. In this paper the main focus is placed on the ground gear elements. The ground gear is produced from sections of chains or wire constrained together. There are different types of these components; rubber discs cut from old car tyres, simply rounded large rockhopper discs from truck tyres with heavy fibre rope and moulded rubber wheel rollers (bobbins). The type of ground gear investigated in this study is shown in Fig. 2. A finite element model of rockhopper ground gear has been developed to investigate physical alteration it causes to the seabed. In order to appreciate the behaviour of the sand around the discs, a single disc study was undertaken at the same time. A detailed description of the modelling framework for the disc and rockhopper segment is presented and the model is validated with the data obtained from laboratory experiments undertaken on sand. A numerical study examining the group effect, size of the discs (thickness and radius) was undertaken and a non-dimensional expression for the drag force of this type of ground gear for any geometry and orientation is provided.

2. Numerical modelling

2.1. Finite element method

The numerical modelling of large deformation with the classical finite element method based on the Lagrangian formulation is extremely challenging. The Lagrangian approach has been used in a similar study (Ivanović et al., 2011) but was proven sensitive to mesh distortion and is therefore deemed not suitable sufficient enough to these problems. An Eulerian mesh, however, can overcome the Lagrangian mesh distortion. The differences between Lagrangian and Eulerian meshes are most clearly seen in terms of the behaviour of the nodes. The following sections discuss some of the advantages and limitations of the two approaches in the context of large deformation applications.

2.1.1. Lagrangian formulation

In the Lagrangian formulation, the material coordinates of nodes are time invariant and the nodes coincide with material point trajectories, i.e. no material passes between elements. Element quadrature points remain coincident with the material points in Lagrangian meshes. The main advantage of using a

Fig. 2. Typical rock hoppers for a bottom trawl-net (Crown Copyright and reproduced with the permission of Marine Scotland Science).