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Research Paper

Towing cylindrical fishing gear components on cohesive soils

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ABSTRACT

The analysis of penetration into cohesive soils of truncated rigid cylindrical objects that are associated with demersal trawl fishing is presented. Numerical simulations of three-dimensional models were performed using the finite element software ABAQUS to assess the influence that the dimensions, the weight, the cross-sectional geometry and the soil material properties have on penetration and drag. In general, over the parameter ranges examined: there is a non-linear increase in penetration and drag as the weight increases; there is a decrease in penetration and an associated reduction of drag as the Yield stress and Young's modulus increase; and the drag and penetration of aerofoil shaped cylinders are less than those of circular ones of similar weights and dimensions.

The non-dimensional form of the problem is examined and it is demonstrated that the penetration and drag values reduce respectively to expressions that are dependent solely, at least to a first order of approximation, on the non-dimensional weight, suggesting that the problem is essentially two-dimensional in nature and that three-dimensional effects at the edges of the clumps do not play a significant role.

We illustrate how these expressions can be used to evaluate the physical impact of towed gears and ultimately contribute to the development of fishing gears/techniques of reduced impact.

1. Introduction

Towed demersal fishing gears are used globally by the fishing industry to catch species that live on or close to the seabed. A typical trawl gear is shown in Fig. 1 and comprises the trawl warps, otter doors, sweeps, ground gear, clump weight and net. In addition to the impact to the species caught by these gears, it has long been recognised that there are broader ecological and environmental impacts, such as habitat destruction, benthic mortality, nutrient release, suspension of sediment etc. To understand these processes and to be able to assess their wider implications on the benthic ecosystem, it is essential to understand the physical interaction of the individual gear components with the seabed. These interactions are classified as being either geotechnical or hydrodynamic in nature [1]. The penetration, piercing and lateral displacement of the soil can be considered to be geotechnical [2] and the associated pressure and shearing forces may damage benthic infauna and habitat. The turbulent shearing in the wake of the gear components are hydrodynamic and these give rise to the mobilisation of soil into the water column [1,3], which has been related to the release of nutrients and the smothering of benthic organisms [4,5].

A number of studies have explored the physical impact of the components of towed demersal gears on the seabed in laboratory and towing channel experiments. The impact of trawl door scouring on infaunal bivalves has been examined using a full-scale trawl door in a laboratory test tank [6]. Towing channel experiments that relate the penetration of a beam trawl shoe and chain elements to the weight and towing speed of the gear component and to the soil over which it is towed are reported in [7]. A comparison of the impact on sand of a scaled model of a cylindrical clump weight with the results of finite element (FE) simulations are made by [8] and in [9] scaling issues for ground gears are considered by examining the results of small scale trials in a towing channel with the results of full scale experiments at sea.

Numerical models of ground gear elements have also been developed in recent years. A model to predict the contact forces between a trawl door and the seabed is produced in [10], however, their study, did not allow any deformation or penetration of the soil. The ANSYS software package is used in [11] to study the contact between a roller clump and marine pipelines where the seabed is represented as a deformable but impenetrable surface. In [12] the vertical drop of trawl doors into soils of various strengths by

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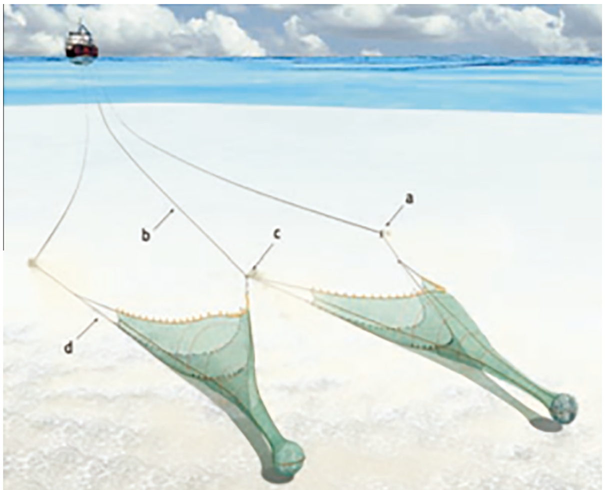

Fig. 1. Twin trawl gear with (a) otter doors, (b) trawl warps, (c) clump weight and (d) sweeps.

analysing the absorption of kinetic energy is studied while a finite element model that can predict the penetration depth, soil displacement and drag force associated with towing individual gear components across the seabed is developed in [2]. Numerical analyses of similar processes have also been used in other applications such as soil cutting and ploughing [13], icebergs scour along the seabed [14] and the indentation and rolling of wheels on both cohesive and frictional soils associated with off-road vehicles in sensitive natural areas [15,16].

Two- and three-dimensional simulations of wheels on soils are carried out in [17] by examining the impact of rigid and rolling cylinders on an elastic-perfectly plastic cohesive material that obeys the von Mises yield condition. A range of aspect ratios (width/radius) are considered by increasing the cylinder width and the authors find: that three-dimensional considerations are important (especially for narrow wheels); that quantitatively similar behaviour was obtained regardless of whether the soil stiffness is homogeneous or varies along the path; and that multiple narrow wheels have less rolling resistance but greater penetration than a single wide wheel. A similar model to investigate the impact of a cylindrical clump weight and an otter trawl door on a cohesive soil was developed by [2] who validated their approach by comparing the results from experimental sea trials with model predictions. Both studies use finite element ABAQUS software package where Arbitrary Lagrangian–Eulerian (ALE) mixed formulation was used.

Here we extend these studies to investigate how the dimensions, the weight, the cross-sectional geometry and the soil material properties affect the drag forces and the penetration into the seabed of cylindrical clumps. To do this, we carry out a large number of simulations using the finite element model of [2], varying, one at a time, the radius, width and cross-sectional geometry of the cylinder and the Young's modulus and the yield stress of the soil, while keeping the other variables constant.

The longer-term aim of this study is to relate the physical impacts of fishing gear components to their resulting environmental and ecological impacts, to assess the effect of towed fishing gears on the ecosystem and to permit the development of fishing gears/techniques of reduced impact.

2. Materials and methods

2.1. Clump weight

Clump weights (Fig. 2) are used in twin trawls to distribute the towing force of the central warp between two gears and are designed to have sufficient weight to ensure that the gears maintain contact with the seabed. They are one of the heaviest individual components and are expected to make a large physical impact. The clump weight used in [2] weighs 9.7 kN in water (including rectangular plate) and comprises ten circular disks with outer and inner radii of 0.295 and 0.055 m respectively, fitted on a

Fig. 2. Example of a clump weight used with twin trawls.

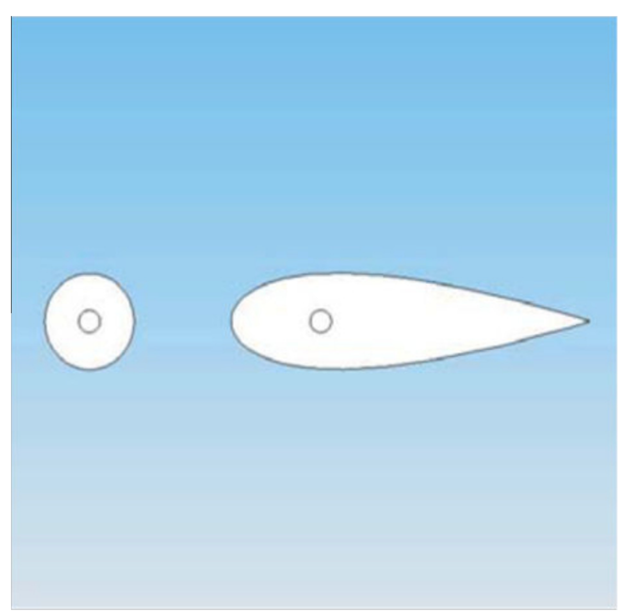

Fig. 3. Cross-sectional geometries of the circular and NACA0025 aerofoil clump weights investigated.