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Development of structural modeling techniques for evaluating HDPE plastic net pens used in marine aquaculture

David W. Fredriksson[a,*], Judson C. DeCew[b], Igor Tsukrov[c]

[a]Department of Naval Architecture and Ocean Engineering, United States Naval Academy, 590 Holloway Road, Annapolis, MD 21402, USA
[b]Center for Ocean Engineering, University of New Hampshire, 24 Colovos Road, Durham, NH 03824, USA
[c]Department of Mechanical Engineering, Kingsbury Hall, University of New Hampshire, Durham, NH 03824, USA

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Abstract

Finite-element modeling (FEM) techniques are developed to determine the structural capabilities of net pen flotation structures made of high-density polyethylene (HDPE). The modeling approach uses shell elements and localized failure criteria to predict critical loading conditions. Finite element modeling simulations were performed using values for the modulus of elasticity for weathered HDPE determined from a series of tensile tests. Poisson's ratio and yield stress used with the approach were obtained from standard manufacturers values. To investigate the method, a series of experiments were performed in the laboratory by testing circular sections of HDPE pipe to localized failure ("kinking"). The same test was replicated with the FEM using localized failure techniques. Laboratory and model results were within 16%. A FEM was then built to represent the complex geometry of a net pen flotation structure deployed at an operational fish farm located in Eastport, ME, USA. Simulations were performed using attachment line tension values measured at the site. The goal was to assess flotation pipe stress levels for typical operational conditions. Simulations were also performed to investigate the maximum capabilities of the net pen structure with different attachment line configurations. Quantifying the operational limits will become more important as these systems are considered for more exposed, energetic environments.

Keywords: Coastal aquaculture; Aquacultural engineering; Finite-element analysis; Fish cages

1. Introduction

Most of the existing marine aquaculture installations are presently located in protected near-shore areas. Many in the industry are considering moving operations into exposed sites because of coastal multi-use issues. The development of inshore marine aquaculture technology has evolved over the past several years (decades) primarily through operational experience. It is now common to find flotillas of surface gravity cages constructed using high-density polyethylene (HDPE) pipe in most marine finfish-producing countries. The use of HDPE pipe for this application is advantageous because the components are relatively easy to fabricate and repair, the plastic has outstanding corrosion characteristics and the material is compliant and (historically) inexpensive. As the industry investigates the option of moving to exposed sites, it is unclear how the existing equipment will be able to withstand higher energy environments.

The structural integrity of a surface gravity cage system is investigated as part of a comprehensive study working with a marine aquaculture company facility with 20 deployed net pens. The project included the installation of current meters and load cells to measure the forcing and resulting loads in components of the farm (Fredriksson et al., 2006). The components consist of anchor leg assemblies, net pen attachment lines and HDPE net pen structures. As part of the project, a fluid–structure interaction model (Tsukrov et al., 2003, 2005) was used with the field measurements to assess mooring gear

*Corresponding author. Tel.: +1 410 293 6434.
E-mail addresses: fredriks@usna.edu (D.W. Fredriksson), jcdc@unh.edu (J.C. DeCew), igor.tsukrov@unh.edu (I. Tsukrov).

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operational limits (Fredriksson et al., 2007). In this study, the structural capabilities of the HDPE net pens used to contain the finfish product are examined.

Fish farm component details used in the comprehensive study were obtained from an operational facility located in Eastport, ME, USA (Fig. 1). The Eastport site is located in Broad Cove near the border of New Brunswick, Canada. Deployed at the site is an array of net pens configured in a 5×4 near-surface mooring grid system. It is oriented in a north–south direction and held up with flotation elements (Fig. 2). The surface portion of the farm has the approximate dimension of $219\,\text{m} \times 274\,\text{m}$. Each of the net pens has a nominal radius of 15.9 m.

The aquaculture site in Broad Cove is influenced by the extreme tides of the Bay of Fundy (Dudley et al., 2000). The predominant forcing on the farm components is a result of the tidal currents. The tidal currents interact with the nets and HDPE pipe components to create drag forces. The loads on each net pen are transferred to the mooring grid system, ground tackle and anchors using sets of attachment lines (y-lines). To quantify the forcing at the site, a current meter was installed at an exterior farm location (see the focus area in Fig. 2). In addition to the current meter, four load cells were installed on the West (W), Southwest (SW), East (E) and Southeast (SE) y-lines. Instrument positions and y-line components are shown superimposed on the aerial photograph in Fig. 2.

Each of the 20 net pens at the site is circular and is constructed with HDPE pipe. The surface flotation rim structure of each net pen consists of two concentric rings of pipe with a nominal diameter and thickness of 323 and 19.8 mm, respectively. The pipes are held together by passing them through 48 brackets constructed of two larger pipe sections (diameter = 406 mm, thickness = 6.9 mm). The brackets also incorporate a handrail support assembly made with 114 mm diameter pipe with a thickness of 5.7 mm with vertical and angled members through which a circular "handrail" is passed. These components are shown in Fig. 3 (a load cell recorder strapped to one of the net pen stanchions is also shown in the figure).

For most deployments at this site, the net pen components have been specified appropriately through years of operational experience. However, the actual capabilities of these components are rarely quantified. If the same structures are to be deployed in a more energetic environment, the point of failure will need to be predicted to prevent escapement, which can have dire economic and environmental consequences. Therefore, the objective is to develop a technique for predicting the structural integrity of the flotation structure of HDPE net pens. The technique is developed utilizing a combination of laboratory and computer model experiments. Using the technique, finite-element modeling (FEM) simulations are performed for loading conditions at the Broad Cove site. The same model is then used to investigate maximum

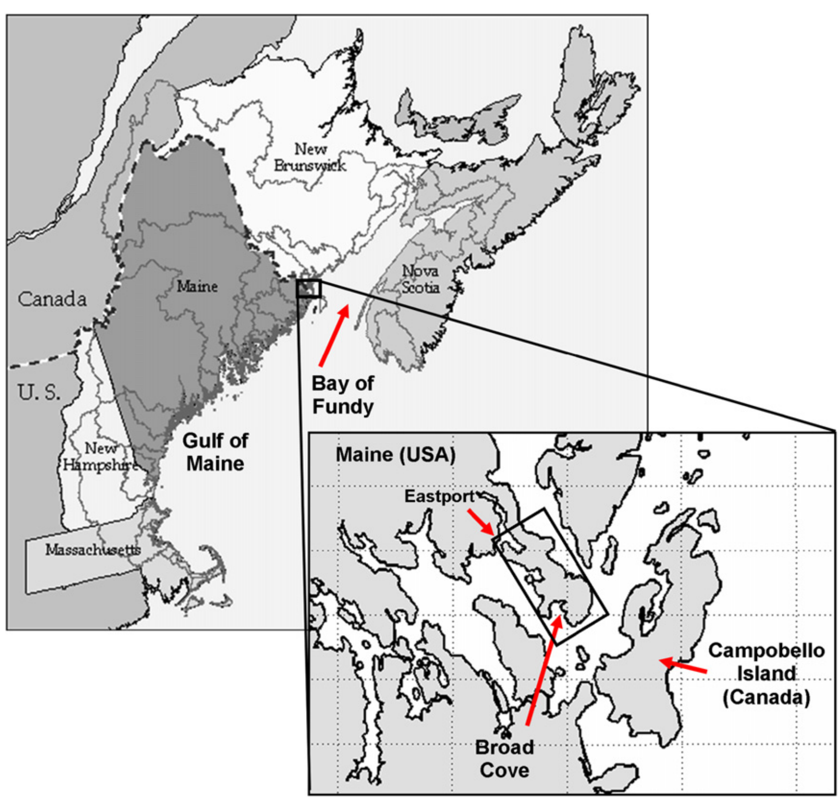

Fig. 1. The Broad Cove fish farm is located in Eastport, ME, USA.