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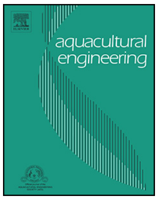

Engineering procedures for design and analysis of submersible fish cages with copper netting for exposed marine environment

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ABSTRACT

Novel design and analysis procedures are needed for engineering of the offshore fish farms utilizing copper alloy netting. Existing technologies developed for fish cages with polymer nets are not directly transferrable to the fish cages with copper netting. In particular, the structural integrity of fish cage/mooring systems, and initial high costs of fish cages with copper netting are two major concerns in the engineering for open ocean aquaculture. We propose the modified engineering procedures, which address these concerns and allow for retrofitting of existing fish farming systems with polymer nets. These procedures are illustrated by considering two case studies: design of a rigid-frame and flexible gravity-type fish cages. Performance of both designs is analyzed after the field trials in the North Atlantic and South Pacific oceans, correspondingly.

1. Engineering challenges for utilization of copper alloy netting in marine aquaculture

In a typical marine aquacultural operation, fish are raised in cages consisting of a buoyant framework with a suspended net chamber (gravity-type cage). Weights are added to the net to help retain its shape and volume. Some cages have rigid superstructure to which the net is attached, eliminating net deformation (for example, SeaStation and AquaPod net pens, see Fredriksson et al., 2004; Loverich and Gace, 1997). The fish cages can be either surface-type or submersible, with the latter design used to mitigate the effects of high-energy surface conditions and improve the fish growing environment. Traditionally, net chambers are made of polymer netting in both inshore and offshore fish farms. Significant improvements in fish farming operations and maintenance can be achieved by substituting polymer nets with copper alloy netting. The advantages include: reduction in biofouling, improved fish cage volumetric stability, structural strength, and protection from predators. The copper alloys suitable for this application include different types of brasses, copper-nickels, and bronzes. In the text to follow we refer to various copper alloy nets simply as “copper nets”.

Development of fouling- and predator-resistant copper net technology started in 1970s with enclosures for salmon farming in the Northeast USA. Initial trials documented that after six years of deployment, enclosures had very little biofouling and minimal losses due to predator attacks (Efird, 1975; Efird and Anderson, 1975; Huguenin and Ansuini, 1975). Biological growth on copper net chambers is minimal compared to the nylon net pens (Drach et al., 2013), allowing improved oxygen flow and fish growth rates, as well as decreased maintenance and cleaning costs. The use of copper alloy net materials has shown promising results in gravity-type and rigid-frame cages located in protected areas, such as bays and fjords (Ansuini and Huguenin, 1978; Huguenin et al., 1981; DeCew et al., 2010a). It is estimated that more than 300 cages utilizing copper alloy nets are currently installed in Australia, Chile and Japan.

However, there are several difficulties associated with wide adoption of this new technology by the marine aquaculture industry. They include:

- Increased initial costs due to high material costs of copper alloys and necessity to improve structural strength of the cage framework;
- Need for modification of design, analysis and installation procedures to integrate copper nets into the existing industry;

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- Difficulties in handling components during cage fabrication and deployment due to the substantially increased weight of the system both dry and in water.

To allow retrofitting of the existing fish farms with polymer nets, engineering procedures should be developed in such a way that existing aquacultural technologies and practices can be used with few changes to accommodate the new netting type. This approach provides a lower economical barrier to the introduction of this technology and helps to offset high initial costs of copper nets.

Design of marine aquaculture fish farms follows well established procedures, as reflected, for example, in the Norwegian Standard NS 9415.E (2009). These procedures were developed for systems with polymer nets, deployed primarily on the sea surface (non-submersible) in low energy environments characterized by significant wave heights lower than 3 m and currents lower than 1.5 m/s. In this paper, we present the revised engineering procedures for successful utilization of copper nets in fish farms deployed in both protected and exposed locations. In the sections to follow, we discuss the methodology and illustrate the proposed approach using two case studies (rigid-body and flexible gravity-type fish cages). We conclude the paper with discussion of performance of the developed systems after long-term field deployments in the exposed marine environment.

2. Design approach and major engineering steps

Fish cages can be classified into three major categories with respect to their structural design using an approach similar to the one proposed in (Loverich and Gace, 1997). Gravity type flexible cages rely on a combination of upper structure (floater) buoyancy and lower structure (ballast rim or system of sinkers) weight to maintain the shape and volume of fish containment chamber. In tension-leg systems, the forces from pre-tensioned mooring lines are used instead of weights to stabilize the fish cage volume. Rigid-frame cages retain their volume and shape due to the stiffness of frame. The examples of all three fish cage types are provided in Fig. 1. Note that all three of them can be used in both surface and submerged regimes with some design modifications and proper choice of a mooring configuration.

Incorporation of the copper netting in fish cage containment systems presents some new technological challenges as compared with utilizing polymer nets. The major issues to be addressed include: (1) strength and stability of a fish cage frame; (2) material compatibility issues; (3) design of net connections and attachments; and (4) choice of a submergence control system. Fish cage frame to be used with heavy metal net has to be able to preserve its structural integrity both during cage construction and service. In addition to the traditional stress analysis to prevent fracture or yielding of structural components, the system has to be analyzed for possible buckling. Buckling can occur in long structural elements subjected to compression (global buckling) or in thin-walled pipes under transverse loading (local buckling), see Fredriksson et al. (2007). Structural analysis of the frame can be performed utilizing engineering strength of material techniques or by employing finite element simulations.

While designing a fish farm, it is important to ensure that the structural strength is adequate and that the fish cage dynamic behavior is steady enough for a successful farming. This can be achieved through the structural strength analysis and dynamic simulations for both service and storm conditions. Recent developments of the computational techniques (Bessonneau and Marichal, 1998; Tsukrov et al., 2003; Jensen et al., 2007; Lee et al., 2008; Xu et al., 2012; Zhao et al., 2013) allow for a robust analysis of the investigated design prior to the physical testing and field deployment. The proposed engineering procedure for the development of an offshore fish cage system with copper alloy components includes the following steps:

- Obtain environmental data for the planned fish farm location;
- Select appropriate fish cage type and mooring system configuration. Evaluate the possibility of using existing fish farm designs retrofitted with copper nettings;
- Establish the design constraints, operational limits and service life requirements taking into account longer service life expectancy of copper components;
- Generate several candidate designs; for each design, analyze hydrostatic characteristics and perform sizing of major components;
- Select the best configuration and develop the first design iteration including detailed drawings of all system components;
- Analyze structural integrity and dynamic response of the individual components and system as a whole; analyze material compatibility (e.g., make sure steel components are securely isolated from any copper parts to prevent galvanic corrosion); design suitable copper net attachments, which ensure net pen integrity and limit wear of the netting;
- Perform design reviews with construction/operations personnel; address potential handling issues during assembly/construction/deployment; produce assembly/construction/deployment plans;
- If possible, perform scaled physical testing;
- Finalize the design and produce detailed documentation.

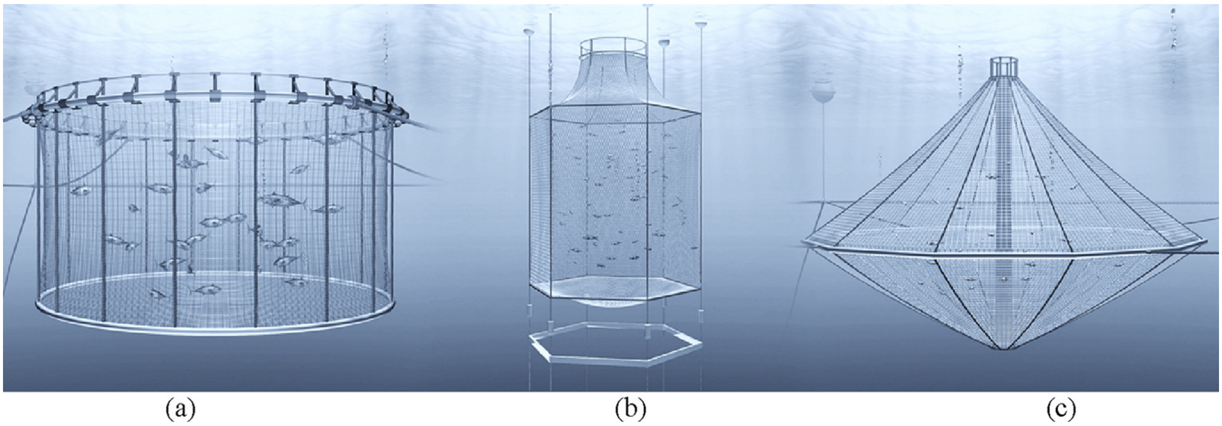

Fig. 1. Examples of fish cage types: (a) gravity-type flexible cage, PolarCircle; (b) tension-leg system, REFA; (c) rigid-frame fish cage, OceanSpar.