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Experimental and numerical investigation on the damping effect of net cages in waves

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ABSTRACT

A series of laboratory experiments were conducted to investigate the damping effect of net cages in waves. The wave transmission coefficient of the net cage was investigated with different wave periods, wave heights, numbers of net cages, net solidities, measurement positions, geometrical shapes of the net cage and Reynolds numbers. The experimental results show that the net cage has noticeable influence on wave propagation and the damping effect of net cages has a close relationship with many parameters. For multiple net cages, the transmission coefficient tends to increase as the wave period increases. The transmission coefficient of net cages decreases with increasing wave height. As the number of net cages increases, the wave transmission coefficient will decrease gradually. The damping effect of net cages on wave propagation tends to increase with increasing net solidity. The measurement position has an effect on the value of wave transmission coefficient. For net cages with different geometrical shapes, the circular net cage has more noticeable damping effect than the square net cage. A numerical model is introduced to simulate the interaction between waves and net cages with the fishing net treated as the porous media fluid model. The wave transmission coefficient downstream from net cages shows good agreement between experimental and numerical results. The study will contribute to understanding of the damping effect of a large fish farm on wave propagation.

1. Introduction

To satisfy the global need for seafood, the net cage is becoming prevalent in the aquaculture industry around the world. However, the development of aquaculture in net cages in the coastal zone is being severely constrained due to coastal multi-use issues and environmental impact concerns. Therefore, developing aquaculture in net cages located offshore and seeking superior environments for high-quality products are becoming inevitable trends. When presented in offshore locations, net cages can attenuate incident waves by a combined action of blockage and dissipation. This attenuation in waves may alter the wave field around the fish farm, and thus needs to be taken into account in the design of the net cage. Moreover, a set of net cages can be used as floating breakwater around the stocked fish farm, which is an ideal choice in protecting the fish

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Nomenclature

S_n	net solidity, the ratio between the projected area of a fishing net and the total area enclosed by the net
d	twine diameter of a fishing net
l	mesh bar length of a fishing net
D	net cage diameter
E_H	hanging ratio in horizontal direction
E_V	hanging ratio in vertical direction
W_{net}	circumference of a net chamber
H_{net}	height a net chamber
n_H	mesh number in circumferential direction
n_V	mesh number in height
T	wave period
H	wave height
L	wave length
k	wave number
h	water depth
ω	wave circular frequency
C_T	wave transmission coefficient
H_t	wave height downstream from the net cage
H_i	wave height upstream of the net cage
ξ	displacement of the wavemaker
η	wave surface profile
n	number of net cages
F	wave force acting on a unit length of mesh bar
F_I	inertia force acting on a unit length of mesh bar
F_D	drag force acting on a unit length of mesh bar
F_d	drag force acting on a plane net
F_l	lift force acting on a plane net
C_m	inertia force coefficient
C_d	drag force coefficient
C_l	lift force coefficient
C_n	normal inertial resistance coefficient
C_t	tangential inertial resistance coefficient
Re	Reynolds number
U	maximum velocity of the water particle in waves
u	velocity of water particles
$\partial u/\partial t$	acceleration of water particles
t	time
p	pressure
ρ	density of water
υ	kinematic viscosity of the fluid
μ	viscosity of water
μ_t	eddy viscosity
k_t	turbulent kinetic energy
g_i	acceleration due to gravity
S_i	source term for the momentum equation
α	attack angle of the plane net
λ	thickness of the porous media
A	area of the porous media

from fierce waves while preserving the necessary water exchange. Thus, investigation on the damping effect of the net cage in waves has become important.

To better understand the hydrodynamic characteristics of a net cage, extensive investigations have been conducted by both numerical simulations and laboratory experiments in recent decades. Colbourne and Allen (2001) surveyed the motion and wave loading on gravity cages by both in-situ measurement and physical model test. Tsukrov et al. (2003) modeled the hydrodynamic response of net panels to environmental loading by using finite element method with consistent net element concepts. Lader and Fredheim (2006) investigated the dynamic properties of a flexible net sheet exposed to waves by dividing the fishing net into super elements. Lee et al. (2008) analyzed the performance of a fish cage system with a floating collar influenced by waves using a mass-spring model. Balash et al. (2009) measured the hydrodynamic loads on plane nets of differing mesh geometry in oscillating flows. Shainee et al. (2013) investigated the submergence characteristics of a single-point-mooring fish cage in regular waves with a following current. Cui et al. (2013) investigated the motion behavior of a flatfish cage in waves using a simulation model based on the finite element method. Zhao et al. (2013a) studied the motion and wave forces of a square net cage in pure waves based on the lumped-mass method. Xu et al. (2013) analyzed the hydrodynamic response of multiple net cages exposed to waves and current.

To date, though many previous studies have been carried out and much progress has been made, there are but a few published works focusing on the damping effect of the fishing net on wave propagation. Chan and Lee (2001) analytically investigated the scattering of waves by a flexible fishnet. The fishnet was modeled as a porous-flexible barrier displaced solely by hydrodynamic force like a catenary. The solutions were obtained using the eigenfunction expansion method based on potential flow and linear wave theory. Lader et al. (2007a, b) carried out experiments to investigate on the interaction between waves and net structures. Several different regular wave cases were run through fishing nets with different net solidities. Both the wave geometry and the wave height were measured on each side of the fishing net to determine how the wave changed as it propagated through the net. In particular, the damping effect of the net on the passing wave was analyzed. Dong et al. (2008) developed a board-net floating breakwater to protect net cages and the fish from critical waves. The experimental results showed that the wave transmission coefficient of this breakwater could be affected by the width and the number of fishing nets.

The above review of the literature shows that laboratory experimentation is the main method used to study the interaction between net structure and waves. Although much progress has been made, to our knowledge, there has not been an experiment focusing on the damping effect of net cages on wave propagation.

To investigate the damping effect of net cages, a series of experiments were conducted with different wave periods, wave heights, numbers of net cages, net solidities, measurement positions, geometrical shapes of the net cage and Reynolds