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Investigation on bragg reflection of surface water waves induced by a train of fixed floating pontoon breakwaters

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ABSTRACT: *The water wave characteristics of Bragg reflections from a train of fixed floating pontoon breakwaters was studied numerically. A numerical model of boundary discretization type was developed to calculate the wave field. The model was verified by comparing to analytical data in literature and good agreements were achieved. Series of parametric studies were conducted systematically to investigate the dependence of the reflected coefficients by the Bragg scattering on the design variables, including the spacing between the breakwaters, the total number of installed breakwaters, the draft and width do the breakwater, and wave length. Certain wave characteristics of the Bragg reflections were observed and discussed in details which might be of help for practical engineering applications in shoreline protection from incident waves.*

***KEY WORDS*:** Wave characteristics; Bragg reflection; Floating breakwaters; Surface water waves.

INTRODUCTION

It has been reported that a phenomenon namely ‘Bragg reflection’ would emerge as incident water waves impinge on a series of fixed structures with certain formations (Davies and Heathershaw, 1984; Mei, 1985; Cho and Lee, 2000; among many others). The incident waves and the waves reflected by the structures would be resonating which raising up the wave reflections in front of the structures. This phenomenon was first discovered by Bragg and Bragg (1913) when studied X-ray waves passing through two parallel reflective crystals. They found that the highest reflection of the X-ray emerges as the spacing between the crystals is precisely multiple of the half wave-length of the X-ray and named the reflection condition ‘Bragg Law’.

The phenomenon of Bragg reflection was observed in water waves as well and has been a topical subject investigated by many researchers. Davies and Heathershaw (1984) studied water waves passing over a wavy bed by utilizing the perturbation method as an analysis tool. They showed theoretically that standing waves occur on the wavy bed when the wave-length of the bed is multiples of half of the water wave-length. They also conducted physical model experiments to verify the results. Mei (1985) showed that the sediment transport in the boundary layer of the seabed originates the dynamical mechanism for the formation of sandbars. He also showed that the sediment transport mechanism must be combined with certain standing waves in order for a sandbar to form, and Bragg reflection along the coast provides the mean to generate these standing waves. Chen (1991) solved the flow potential for water waves over a cosine-shaped bed to the second order by utilizing the perturbation method. His results showed that the strength of the wave field and the stiffness of the wave form are proportional to the ampli-

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tude of the wavy bed. He also showed that Bragg reflection emerges when the wave-length of the wavy bed is half of the incident wave-length. Miles (1981) derived a formula for the reflection coefficient caused by a small elevation change of the bed by adopting the linear water wave theorem. His results were then extended by Kirby and Anton (1990) to reproduce the shape of a sandbar by using Fourier Series Expansion. They also improved Miles' results by deriving a close form formula for the reflection coefficient. Hsu et al. (2002) conducted flume experiments to investigate wave reflections for three types of fictitious sandbars in shapes of rectangular, cosined, and triangular. Their results show that the rectangular sandbars produce the highest reflections among the three types of sandbars. They also found that near-full reflections could be achieved with more than 8 sandbars. Karmakar et al. (2013) studied the scattering of gravity waves by single and multiple surface-piercing floating membranes by using eigen-function expansion method to solve the wave potential. In their results, the resonating pattern in the reflection coefficient resembling the Bragg reflection was observed for multiple floating membranes.

In reviews of the above literatures on Bragg reflections of water waves, most of the focuses were on bottom structures and less has been studied on fixed floating structures. The aim of this paper is to address the focuses on this aspect. In the following, the governing equation and boundary conditions of the wave reflection problem were first introduced. A numerical model of boundary discretization type was developed and verified by comparing the results to analytical data in literature. Systematic simulations by means of the developed numerical model on the wave fields induced by various formations of fixed floating breakwater trains were performed to investigate the influence of various design variables on Bragg reflections. Notions with regards to practical applications in shoreline protection were addressed based on the results.

PROBLEM FORMULATION

A train of rigid and impermeable floating pontoon breakwters fixed on the water surface is considered, as depicted in Fig. 1. The geometric shape of the pontoon is rectangular and has a width and draft of w_f and d_f, respectively. The spacing of the breakwaters S is defined as the dsitance between the centers of two adjacent pontoons. The x-axis is along the mean sea level and the y-axis is on the vertical upward direction. Wave trains with wave height of H and frequency of σ traveling along the x-direction in water of arbitrary depth h impinge on the structures. The fluid is assumed to be invisicid, incompressible and irrotational, and the wave amplitude is small such that the linear water wave theory is applicable.

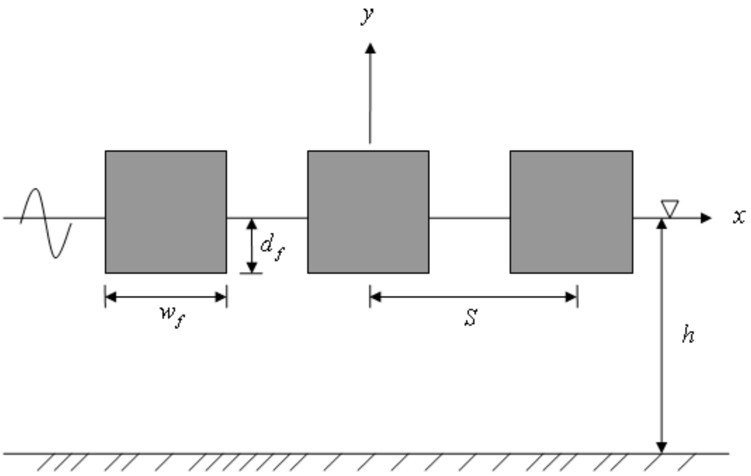

Fig. 1 Definition sketch of the floating pontoon breakwaters.

The governing equation of the wave field reads (Dean and Dalrymple, 1991)

$$\nabla^2\phi(x,y) = 0 \tag{1}$$

where $\phi(x,y)$ describes the fluctuation of the potential on the x-y plane, and is related to the velocity potential of water waves as $\Phi(x,y,t) = \phi(x,y)e^{i\sigma t}$, based on the periodicity in time.