International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 28, No. 2, June 2018, pp. 135–142; https://doi.org/10.17736/ijope.2018.ak24

http://www.isope.org/publications/publications.htm

Bragg Reflection of Water Waves by Multiple Composite Flexible Membranes

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The interaction of water waves with multiple composite flexible membranes is studied based on the assumption of linear wave theory and small membrane response. The eigenfunction expansion method and the wide spacing approximation are used to obtain the reflection and transmission coefficients. The characteristics of Bragg reflection are investigated by changing various factors including the relative group spacing, the end condition, the number, the tension, the draft, and the protrusion of membranes. It is found that the multiple composite flexible membranes can enlarge the bandwidth of Bragg reflection. This study can provide guidance on the design of multiple composite flexible membranes as effective floating breakwaters by taking advantage of Bragg reflection.

INTRODUCTION

Floating breakwaters offer an option to protect harbors and shorelines from wave attack when conventional fixed breakwaters are inappropriate because of large costs. Floating breakwaters often consist of all kinds of structures, such as boxes, pontoons, mats, tires, and flexible membranes. Among them, flexible membranes, generally made of synthetic fiber, rubber, or polymeric materials, have been thought as prospective floating breakwaters because of the advantage of lightness, cheapness, and rapid deployment. Early typical studies on the wave interaction with flexible membranes can be found in Williams (1996), Kim and Kee (1996), and Cho and Kim (1998). They only considered the single flexible membrane. Lee and Lo (2002) analyzed the efficiency of wave attenuation of single and double surface-penetrating flexible membranes of finite draft. Hsiao et al. (2007) proposed a composite breakwater consisting of a flexible membrane and a submerged breakwater, and they found that it had better reflection characteristics than a single submerged breakwater for long period waves. More recently, Karmakar et al. (2012) investigated the interaction between water waves and multiple vertically moored surface-piercing membranes with the spacing between adjacent membranes keeping all the same in finite water depth.

Multiple structures usually consist of a number of isolated structures. When the spacing between adjacent isolated structures stays the same, the multiple structures can be defined as periodical structures, and the periodical length is equal to the spacing. In the field of water wave interaction with periodical structures, Bragg reflection is a phenomenon in which the peak reflection coefficient is achieved when the wavelength of the normally incident wave is approximately twice that of the periodical length of the structures. The earliest experimental results on the Bragg reflection of submerged sand bars were obtained by Heathershaw (1982). Since that time, the phenomenon of Bragg reflection in the wave interaction with submerged structures has been widely studied using experimental, theoretical, and numerical methods (Davies and Heathershaw, 1984; Mei, 1985; Hsu et al., 2007). The phenomenon of Bragg reflection of floating structures with periodicity has also been investigated. For example, Linton (2011) analyzed the phenomenon of Bragg reflection of water waves propagating over arrays of horizontal cylinders floating in the water. When multiple flexible membranes with equal spacing serve as floating breakwaters, their periodicity can definitely induce the phenomenon of Bragg reflection and attenuate the incident wave with corresponding wavelength. The multiple flexible membranes are usually arranged vertically in the water and fixed or moored through buoys, cables, or springs. The phenomenon of Bragg reflection of the multiple flexible membranes was simply indicated by Karmakar et al. (2012), and no more details were provided. Moreover, the bandwidth of Bragg reflection by the traditional multiple flexible membranes is often narrow because they have only one periodical length, corresponding to one primary Bragg reflection.

Hsu et al. (2003) and Tsai et al. (2011) proposed the multiply composite artificial bars and investigated the Bragg reflection of water waves induced by these bars. Inspired by their ideas, this paper presents a model of multiple composite flexible membranes to increase the bandwidth of Bragg reflection to effectively attenuate incident waves in a wide range of wavelength. Lee and Lo (2002) used the full linear wave theory to analyze the wave interaction with flexible membranes, which considered the influences of both wave propagation mode and wave evanescent modes. In the present paper, the influences of wave evanescent modes on the adjacent flexible membrane are ignored to simplify the problem

Received July 17, 2017; updated and further revised manuscript received by the editors September 13, 2017. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-seventh International Ocean and Polar Engineering Conference (ISOPE-2017), San Francisco, California, June 25–30, 2017.
KEY WORDS: Floating breakwaters, multiple structures, composite flexible membranes, Bragg reflection.