Ocean Engineering 88 (2014) 588–597

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Optimum design of a sloping-wall-type wave absorber placed in a sinusoidal propagating wave

Hee-Chang Lim*

School of Mechanical Engineering, Pusan National University, San 30, Jangjeon-Dong, Geumjeong-Gu, Busan 609-735, South Korea

ARTICLE INFO

Article history:
Received 19 October 2013
Accepted 16 March 2014
Available online 1 May 2014

Keywords:
Wave flume
Wave maker
Wave absorber
Reflectance
Incident wave
Reflected wave

ABSTRACT

We simulated coastal waves and wave absorbers in a lab-scale wave flume. The goal of this study was to observe and optimize a typical ocean environment and to reduce the wall reflection in the wave flume. In order to generate ocean waves in the wave flume, a combination of a flat-type wave generator and wave absorbers was installed in the channel. Two probes for measuring the wave heights, i.e., level gauges, were used to observe the temporal variation of the wave surface as well as the phase difference and maximum (crest) and minimum (trough) points between the propagating waves. In order to optimize the shape and size of the propagating waves, several absorption methods were proposed. Apart from an active wave absorption method, we used methods that involved vertical, porous plates; horizontal, punching plates; and sloping-wall-type wave absorbers. For obtaining the best propagating waves, the sloping-wall-type wave absorbers were chosen and tested in terms of the constitutive filling materials and the location and shape of the plate. This study also focused on the theoretical prediction of the wave surface, separating them into incident and reflective components. From the results, it is evident that the wave absorber comprised a hard filling material exhibits a better performance than the absorber comprised soft material; i.e., the wave absorber can be a strong sink to control the energy of the oncoming wave. In addition, larger wave absorbers corresponded to lower reflectance because the larger volume can remove the oncoming wave energy better. Therefore, with constant absorber conditions, the reflectance increases as the wave period increases. Finally, the reflectance of the wave was controlled to be less than 0.1 in this study so that the wave flume could be applied to simulate the offshore environment.

1. Introduction

The world population is estimated to exceed 7 billion and continues to rise while energy resources are being rapidly depleted. In this regard, the world's nations are competing to search for energy resources in the ocean and nearby offshore areas. Although the offshore ocean environment has great potential, the primary obstacles to developing these resources are the lack of simple, accessible, and mature technology grounded in extensive research. As the offshore energy harvesting of ocean resources has gradually moved out of shallow waters and advanced into deep waters, recent technology has focused on the development of floating- or fixed-type offshore structures. The accurate design of wave propagation has been a key issue because a structure floating in the ocean would continuously interact with oncoming waves. The design is highly dependent on the temporal distribution of regular and irregular waves in the offshore ocean environment. Therefore, to ensure the proper and sound prediction of the motion of floating and/or fixed bodies, it is important to first generate and analyse the behaviour of the oncoming waves and to precisely design its structure using a mechanical and hydrodynamic approach. There has been limited research in the ocean environment because full-scale field experiments are costly and time-consuming. Therefore, by installing a wave generation and absorption device in a short-distance water channel, we have developed a wave generator to simulate the offshore ocean environment.

In order to generate proper waves in a wave flume, wave absorbers are used to break the oncoming waves into smaller waves to yield the smallest wave reflection. Regarding the wave absorbers, a number of numerical approaches on the interaction between the wave and the structure have been addressed in the literature. Berkhoff (1972) presented a mathematical theory for producing a proper wave using the mild slope equation. Losada et al. (1993) calculated the distribution of the wave-induced pressure along the base of the breakwater crown and showed that the linear pressure gradient assumption, which is usually applied for uplift forces on the crown, was inaccurate. They also tried to

---

* Tel.: +82 515 102 302; fax: +82 515 125 236.
E-mail address: hclim@pusan.ac.kr

http://dx.doi.org/10.1016/j.oceaneng.2014.03.029
0029-8018/© 2014 Elsevier Ltd. All rights reserved.

use the eigenfunction expansion method to analyse the potential flow around and inside porous breakwater placed in regular waves. Berenger (1994) dealt with the suppression of wave reflection from the truncated finite flow boundary; in particular, he solved unbounded electromagnetic problems with the finite-difference time-domain method, which specifically uses the absorbing layer to absorb the electromagnetic waves without reflection. For a permeable structure with a wall shape, it was determined that the reflection and dissipation strongly depend on the wave steepness and relative width because these two parameters determine the location of the reflection (Losada et al., 1972). The effects of porosity, breakwater geometry, and relative wavelength were also studied on the basis of an eigenfunction expansion (Isaacson, 2000) and Green's function (Linton and McIver, 1964). More recently, Sulisz (2003) derived a 3D numerical solution to determine the wave field. The results showed that a reasonable wave reflection level was achieved for fairly short absorbers, which encouraged us to conduct this study.

In order to verify the numerical and theoretical methods, it is necessary to compare the theoretical and numerical results with the experimental results. However, there has been little work dealing with the comparison of theoretical and experimental results. It is still rare to find the designs for producing wave absorbers in the wave flume. Sollitt and Cross (1972) reported that for a series of breakwater, both the theory and the experiment generally agree that (1) The transmission coefficient decreases with decreasing wavelength, breakwater porosity, and permeability, as well as increasing wave height and breakwater width. (2) The reflection coefficient decreases with decreasing breakwater width and wavelength as well as increasing porosity and permeability.

Therefore, in this study, we conducted a series of experiments to obtain the proper characteristics of a wave absorber. In addition, suitable methods were suggested to analyse the experimental data. Several researchers have proposed effective absorption methods. For example, using the principle of conservation of energy, Sollitt and Cross (1972) proposed using the linear friction coefficient to describe the wave energy dissipation of a porous structure by analysing the reflection and transmission characteristics when an incident wave travels through a porous vertical wall. Madsen (1983) researched the reflection characteristics of various porous structures by using mathematical and physical analytic methods. He concluded that the reflection coefficient was not only determined by the porosity and width of the absorber but also by the water depth, wave period, and incoming wave height. Tatavarti et al. (1988) used collocated current and elevation/pressure sensors. Here, the current provides information on the slope of the sea surface from which the propagating direction can be estimated. This method overcomes the variability in bathymetry; however, the reflection coefficients obtained are larger owing to different types of noise. Huntley et al. (1999) developed two methods of using collocated measurements of elevations and horizontal current to estimate the frequency-dependent reflection coefficients for irregular waves.

The goal of this study is to determine the energy dissipation characteristics of a wave absorber, i.e., nylon fabric mesh. This paper observed the behaviour of propagating waves, which was intentionally separated into the incident and reflected waves. Healy (1952) developed a method for estimating the reflection of regular waves by measuring the maximum and the minimum value of the standing wave envelope, which requires a slow moving wave gauge in the wave flume along a line parallel to the direction of the wave propagation. Although this method was simple and convenient to analyse, the error of the reflected wave in a continuous system was substantially large. There are alternative methods to separate the incident and reflected waves. They include using two fixed wave gauges to measure two wave heights and one wave phase (Goda and Suzuki, 1976), and three fixed wave gauges to measure three wave heights and two wave phases (Masard and Funke, 1980). Previous studies on the optimization methods for wave absorption were rarely addressed because they were highly dependent on the wavelength and period. Because of the limitation of the wave flume, the method suggested by Goda and Suzuki (1976) appears to be appropriate for our test conditions.

In this study, we also intend to determine a suitable wave absorption method inside a short distance wave flume. In particular, this work would be appropriate in the planning stage of fixed/floating platform development in the ocean environment in order to produce an optimized engineering design of an absorber. Previous studies on optimisation methods for wave absorption were rarely helpful because their findings were highly dependent on both the wavelength and the period. Svendsen and Jonsson (1976), Dalrymple (1985), and Ouellet and Datta (1986) delved into this aspect of wave absorption and provided useful descriptions. Svendsen and Jonsson (1976) suggested a condition for small wave reflection in terms of the absorber wall's slope, wavelength, and water depth. Dalrymple (1985) also suggested that the most efficient way to dissipate wave energy is to install a parabola-shaped wave absorber. Furthermore, Ouellet and Datta (1986) summarised the efficiencies for different types of wave absorbers and reported that the parabolic profile also appears to be the most efficient for absorbing the incident waves. However, as their work indicated, absorbers with this parabolic profile seem to be limited to a narrow range of wave parameters and water depths. Therefore, it could be argued that a wave absorbers optimal shape depends on different wave environments and requires a long operational life, must be applicable to a wide range of water depths, and is constrained to a minimum length.

Therefore, this paper focuses on a laboratory experiment designed to observe the reflectance characteristics of oncoming waves and also to evaluate the reflectance characteristics of a wave absorber under different conditions: material variation, alignment of absorber plates, and variation in water depth. The effect of wave absorption was experimentally observed and compared with the theoretical results using the wave envelope and the propagating wave. The first procedure to optimise the wave absorber involves varying the material inside the wave absorber, such as hard or soft nylon fabric mesh. Additionally, to determine the proper alignment and optimum size/shape for absorbing the oncoming waves, we observed the volume effects of nylon fabric mesh on wave absorption. Finally, to test the practical applications for the wave absorber, water depth was varied to investigate the effect of water depth on the reflection from the wave absorber and thereby determine that the dissipation of wave energy is sufficiently high, even under different conditions.

2. Design of laboratory experiments

2.1. Design of wave maker

There are two common methods to generate waves in the laboratory: one involves a piston-type motion, in which there is no vertical variation of paddle displacement over the depth, and the other involves flap motion, in which the paddle is hinged at the bottom. The motion of the paddle induces horizontal or vertical velocities of the water particles, thereby yielding a propagating wave. In shallow waters, the piston-type wave maker generates a propagating wave more effectively than the flap-type because the horizontal water particle velocities of the wave and paddle are nearly constant over the water column. In deep waters, the reverse is true: the wave motions are confined near the surface in a