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The performance characteristics of inclined highly pervious pipe breakwaters

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ABSTRACT

This study investigates highly pervious dense pipes with small apertures, which benefit convection and the interchange of seawater within harbor districts and provide effective wave absorption. Additionally, this study explored the problems of wave impacts on the inclined state of highly pervious pipe obstacle, the energy dissipation characteristics for a series of inclined pipe breakwaters, and the relationship between the inclination angle and the dissipation effect. Pipe breakwaters were arranged in diverse angles of inclination. Forward inclination replicated the effects of a concave embankment, and backward inclination replicated the inclined plane of a sloping revetment. Physical experiments were conducted to investigate the influence that various apertures and inclined angles have on reflection coefficient, transmission coefficient, and loss coefficient. The results show that the influence of highly pervious inclined permeable breakwaters varies according to the effect of minimum reflectivity. The attenuation of long waves is ineffective compared to the efficacy for short waves. Lengthening the pipe enhances the effects of attenuation more compared to shifting the inclination angle, and shifting the inclination angle enhances the effects more than enlarging the aperture.

1. Introduction

Coastal protection structures, such as dense embankments and armor units, are employed to protect ports, docks, waterfronts, ecological environments, and coastal facilities from the destructive force of waves and the shore erosion. Although these structures may be effective, they may destroy the landscape and render the waterfront inaccessible. These structures are regarded as the final method for coastline protection and vary according to changes in social patterns and space requirements, thereby enhancing people's leisure activities. Because of the saturation of land leisure, the land-based leisure industry has gradually moved toward the coast. Therefore, it is necessary to consider cost effective, easy installation, environmentally friendly, and efficient landscape preserving.

Taiwan is surrounded by the ocean and has numerous large and small ports. Recently, the development of coastal leisure activities, recreation, and tourism has flourished. The geographic environments of the eastern, western, southern, and northern coasts of Taiwan are distinct. The annual seasonal winds and frequent typhoons in the summer and fall contribute to the erosion of coastal land. Walruses of many variation and considerable quantities of armor units and breakwaters have been established in coastal areas to reduce the impact that ocean waves have on land. However, these structures generally do not generally provide effective wave attenuation. Instead, they commonly cause coastal erosion and destroy the ecological environment and landscape. Numerous structures have been constructed along the coast to control wave disturbances. This has prompted extensive research of breakwaters that are comparatively inexpensive, convenient to construct and configure, environmentally friendly, and capable of providing both temporary and long term protection depending on the used type of breakwater.

In previous decades, coastal engineering researchers have investigated the physical properties and absorption of maritime structures to develop coastal defense solutions. This objective may be realized by either reflecting or dissipating approaching wave energy through induced turbulence. Safety factors, the ecological effect of the solution, effects on the landscape, and the reduction of carbon emissions generated by the leisure industry must be considered when planning coastal spaces. New types of energy dissipation structures have been extensively investigated and discussed to achieve coastal protection, prevent damage to the natural landscape, and improve the use of coastal spaces. Mani and Jayakumar (1995) designed a suspended pipe breakwater consisting of a row of closely spaced pipes mounted on a frame. The wave transmission characteristics indicate that reductions of 50% in incident wave height and 40% in investment costs can be achieved. Neelamani and Sandhya (2005) proposed dentated and serrated seawalls that reduce wave reflections by

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Nomenclature

a_i	incident amplitude
a_r	reflected amplitude
D	diameter of pipes
D/h	relative pipe diameter
f	wave frequency
g	gravitational acceleration
h	water depth
h/L	water-depth wave-length ratio
H_i	incident wave height
H_r	reflected wave height
H_t	transmitted wave height
H_i/h	relative wave height
k	wave number
K_r	coefficient of reflection
K_t	coefficient of transmission
K_L	coefficient of dissipation
L	wave length
T	wave period
w	length of pipe
w/h	relative pipe length
w/L	relative ratio of pipe length to wave length
σ	angular frequency
ε	phase angle
θ	inclination angle
Δl	spacing between two probes

approximately 20–40%; thus, they are more effective for reducing wave reflections compared with plane seawalls.

Although conventional breakwaters are still employed extensively in most coastal areas, sea walls, jetties, and detached breakwaters are traditionally adopted as absorbing structures to reduce wave energy in near-shore regions. Unitary use of coastal protection structures is progressively becoming unacceptable. Today, people pay particular attention to ecological, environmental, and landscape problems. Ecological engineering methods that provide several substitutes have been developed to preserve the natural landscape and enforce the so-called amenity-oriented policy by considering energy dissipation technology, natural ecology, and landscape maintenance. The purpose of these methods is to develop coastal protection structures that are visually pleasant and provide efficient wave attenuation to mitigate coastal erosion. Modifications, such as submerged breakwaters, artificial submerged reefs, artificial beaches, amenity-oriented sea dikes, and permeable barriers, are currently preferred. Therefore, predicting how waves interact with such permeable barriers is of interest.

Investigating and designing floating breakwaters is also of great interest because these structures offer several advantages. Specifically, they can be constructed rapidly, are environmentally friendly, do not require silting or scouring, are inexpensive (which benefits regions that can afford only low capital expenditure), and can be applied for temporary protection in deep offshore areas.

However, before considering geometric configurations that facilitate wave attenuation, the stability of offshore structures must be investigated. Thus, the force in floating moorings was also examined. A wide variety of floating breakwaters, such as anchored porous breakwaters, have been designed to attenuate wave energy and reduce mooring forces. Hegde et al. (2008, 2011) subjected breakwater models composed of 3 layers to various degrees of wave steepness, width, and spacing to investigate the mooring forces of horizontally interlaced, multilayered, and floating pipe breakwaters. Their research showed that the force in seaward side moorings increases as the wave steepness increases, and decreases as the relative width increases.

Various types of inclined structures designed to reduce the impact of incoming waves and the effects of wave-structure interaction have been discussed. Previous studies have shown that inclined structures may not necessarily be more efficient compared with vertical structures, and some even report greater impact pressures and run-ups on inclined walls compared with vertical seawalls, and that the relative pressure exerted on sloping walls is slightly higher. Kirkgöz (1995) analyzed the results of an experiment concerning the impact pressures of waves breaking directly on vertical and sloping walls and found that the highest dimensional maximum impact pressure occurred on a 30° backward inclined wall, whereas the highest values of the bottom impact pressure occurred on a vertical wall. Neelamani and Muni Reddy (2002) investigated the wave forces on a vertical cylinder protected by perforated vertical and inclined barriers. Their results showed that a vertical perforated barrier is more effective for reducing wave force compared with a sloping (inclined) barrier of the same porosity. Sundar and Anand (2010) investigated variations in the run-up of vertical and curved seawalls, and found that the curvature of the Galveston seawall inadequately directs wave run-ups, increasing the run-up by approximately 25% compared with that of a vertical wall.

However, in several circumstances, inclined structures are preferred over vertical structures. Rao et al. (2009a, 2009b) examined the wave transmission of a submerged inclined plate breakwater oriented at varying inclinations. Their results indicated that inclined plate breakwaters are more effective than horizontal structures, and a plate oriented at an inclination of 60° is effective for the entire range of wave parameters and reduces wave height by 40%. Neelamani and Sandhya (2005) demonstrated that slope structures can effectively dissipate energy. Incident wave energies are dissipated because of the phase lag of reflected waves, which occurs when waves break on an inclined slope. Nakamura et al. (2001) presented a double-walled breakwater in which an inclined plate array served as the front wall. They confirmed that this structure is highly effective for reducing both reflected and transmitted waves. They also reported that the downslope model of the plate array front wall provides greater dissipation of long waves than of short waves. Koraim and Salem (2012) examined the hydrodynamic performance of a new type of breakwater consisting of half pipes suspended on supporting piles. The proposed breakwater (comprising horizontal half pipes, an increased pipe diameter, 45° inclination angle, and comparatively long drafts and wavelengths) yielded an improved performance compared with that of other types. Bayram (2000) evaluated the performance of an inclined pontoon breakwater and discussed the effects that incident wave height, wave steepness, and mooring cable length exert on the transmission coefficient with and without bottom clearance. The results showed that the inclined float breakwater is suited to shallow and intermediate water depths. The transmission decreased in accordance with increases in the wave period and mooring length, which marginally depend on the length of the structure. Murakami et al. (1994) discussed the feasibility of using breakwaters with a gradual upward- and downward-sloping plate for wave absorption, suggesting that upward-inclined plates are effective for controlling both wave absorption and water purification. Examining the performance of a submerged and horizontal plate for offshore wave control, Yu (2002) indicated that overtopping may occur on an inclined plate, but variations in plate inclination do not substantially affect the