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Wave attenuation and flow kinematics of an inclined thin plate acting as an alternative coastal protection structure

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ABSTRACT

This paper presents the results of a 2D experimental model application of an alternative environment-friendly coastal structure, an inclined thin plate (ITP). The primary objectives of this study were to understand (a) wave energy dissipation mechanism of ITP, (b) wave attenuation performance of ITP, and (c) the influence of ITP on water particle (orbital) velocity characteristics. In order to achieve these objectives, flume experiments were conducted for different inclination angles of ITP (i.e. 0, 5, 10, and 15°). During the experiments, water surface elevations were measured and instantaneous velocity profiles were recorded by a new generation acoustic Doppler velocimeter (ADV-Vectrino II). The experimental data revealed the fundamental physical facts regarding the dissipation mechanism and performance of ITP, which may be a base for the effective design of such coastal protection structures in the future. A tentative method based on multi-parameter regression of experimental data is proposed to determine the wave transmission performance of ITP. Finally, the practical application of an ITP structure is discussed in the light of the achieved results.

1. Introduction

In some coastal areas because of technical limitations, the conventional coastal structures may not be applicable in the coastal defense. In these cases, alternative structures such as submerged plates on pile supports may be utilized. These structures have been investigated and used in many coastal engineering applications since 1970s. Yu [26] gives a thorough review of the studies involving horizontal (or slightly inclined) submerged plates. Yu [25] studied the effect of slight inclination of submerged plates on wave attenuation. Parsons and Martin [14] developed a numerical model to study the reflection from fully submerged vertical, horizontal, and inclined plates, which was later extended for obliquely incident waves by Midya et al. [12]. Murakami et al. [13], in their experimental study, argued that a seaward steady streaming flow occurs beneath an inclined submerged plate and they measured the reflection, transmission, and energy dissipation coefficients. Rao et al. [17] are another group of researchers who conducted experiments to investigate the wave reflection and transmission from a submerged inclined plate.

Likewise, submerged permeable structures, pile-supported emerged (surface-piercing) structures, and floating structures are also widely studied as a means of coastal protection [9–11,16–18,20,21]. Surface piercing inclined plates were studied numerically first by Parsons and Martin [15] and then pursued by Parsons and McIvor [16] who tried to develop a model for the emerged inclined plates with the assumption that inclination angle is very small. Recently, Chao and Kim [4] experimentally studied a perforated inclined plate protecting a vertical seawall and developed a calculation methodology that focuses on the wave reflection.

The most commonly applied coastal defense structures are rubble mound breakwaters (RMB), conventionally practiced in nearshore zone. Armor units on RMBs resist against incoming wave energy with their weight. However, in some specific cases, elevated transportation cost of natural armor units, technical difficulties in transport, and also their unavailability may make their utilization infeasible. In these circumstances, artificial armor units such as tetrapod, accropode^{TM} and antifer may emerge as alternative solutions.

For instance, when the design wave height is particularly high, oversized artificial armor units may be required for the armor layer of the RMB's. But there are several significant disadvantages of oversized armor units. Durability of over-weighted armor units is unpredictable since oversized artificial blocks may lose their function in the long run earlier than expected due to quick hydration of the concrete, which may arise during the construction of the units [8]. Moreover, in some specific circumstances high foundation instability restricts the application of oversized RMBs. In such a case, pile-mounted inclined thin plates (ITP) applied in tandem

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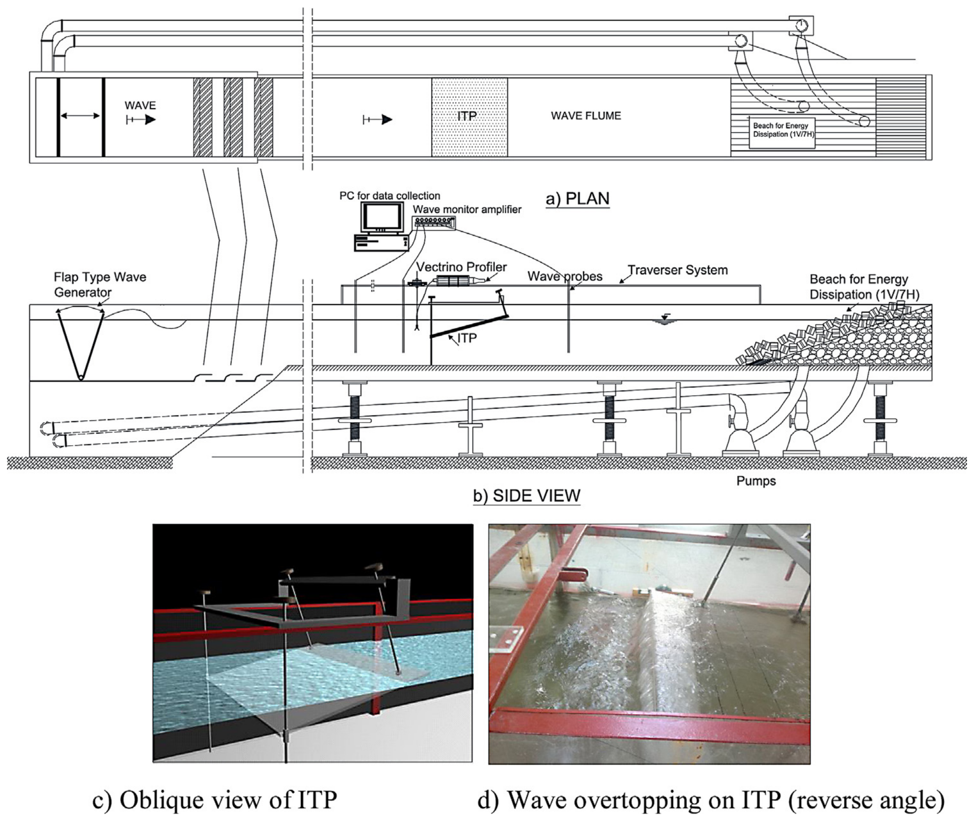

Fig. 1. A sketch of the glass-sided wave flume: (a) plan, (b) side view, (c) oblique view of ITP, and (d) wave overtopping on ITP (reverse angle).

arise as useful alternative structures in terms of diminishing the wave height at the seaward side of RMBs. As a result of reduced wave height owing to ITP, the necessary weight (i.e. size) of the armor units and the volume of RMB dramatically decreases. The study by Acanal et al. [1] pointed out that the size (i.e. nominal diameter) of required armor unit can be decreased up to 3.5 times when ITP is applied in tandem at the seaward of an RMB. Furthermore, when it is applied in a standalone manner (without RMB), ITP does not totally eliminate the current or wave action and thus does not entirely interrupt the longshore and cross-shore sediment transport that are vital processes for sustainable coastal management. However, it should be mentioned that due to the structure–wave interaction, the bottom around these piles are exposed to local scour in addition to global scour. ITP can also be a useful solution for the mitigation of wave agitation in a harbor when applied at the seaward of the harbor entrance as a detached breakwater. In the past, based on the experimental results by Yagci et al. [24] the entrance of a naval harbor in Aqaba (Jordan) has been effectively protected against North-Westerly waves by a pile-supported emerged (surface-piercing) structure, a wavescreen, that has quite similar anatomy to ITP [7]. In this perspective, these reasons make ITP a viable alternative solution to RMBs in some specific cases.

In this study, differing from the aforementioned studies above, wave dissipation process of relatively steeper angles (i.e. 10 and 15°) of surface-piercing ITPs were examined in addition to inclination angles of 0 and 5°. The principal objectives of this study can be summarized under three main captions:

(1) Gaining insight about the dissipation mechanism of ITP would help a better understanding of required design conditions. In the light of this fact, understanding the dissipation mechanism of ITP was the major objective of this study.
(2) As stated above, when ITP is positioned at the seaward of the RMBs, the required armor unit weights and overall RMB weights are expected to be diminished. In this context, investigating the wave attenuation and dissipation performance of the ITP was another objective of the study.
(3) Last but not least, describing the role of ITP on sediment transport and similar processes in coastal waters was necessary. From this motivation, it was aimed to understand the influence of ITP on wave orbital velocities and general flow structure by measurements.

So as to achieve the objectives presented above, a two dimensional physical model study was conducted. Once the model results were analyzed, a tentative method based on multi-parameter regression for determination of the wave transmission behind the ITP is presented. Finally, remarks on practical application are stated along with a numerical case example.

2. Experimental set-up and procedure

All the experiments were performed in the Hydraulics Laboratory of Istanbul Technical University. A sketch of the glass-sided wave flume is presented in Fig. 1. The wave flume is 26 m long, 0.98 m wide and 0.85 m deep and it has a capability of generating regular waves with a flap-type wave maker. Water depth in the flume was kept constant at $d = 0.50$ m throughout the experiments. In order to prevent the accumulation of reflected waves in the wave flume, an artificial gravel beach (1V:7H) that is covered by two layers of “antifer armor units” was built at the landward end of the flume. In the placement of the antifer units, the irregular placement method which is introduced by Yagci and Kapdasli [22] and Yagci et al. [23] was implemented in order to maintain higher surface roughness and enhanced wave absorbing functionality.