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Review

Review of recent research and developments on floating breakwaters

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ABSTRACT

Floating breakwaters are an effective solution for protecting fragile beaches from being washed away, coastlines from erosion, floating structures, marinas and ports from strong wave action. This paper presents a literature review on the research and developments of floating breakwaters. Floating breakwaters may be categorized into seven main types, namely, the box-type, the pontoon-type, the frame-type, the mat-type, the tethered float type, the horizontal plate type and other types. The research and developments as well as the performance of these different types of floating breakwaters and wave attenuating devices are reviewed and discussed.

1. Introduction

Oceans and seas cover more than 70% of the earth surface and they continue to expand with the rising sea level due to global warming. They possess a huge amount of valuable natural resources including water, aquaculture, oil & gas, and minerals that are crucial to the economic development of mankind. Over the past few decades, the urbanization of modern metropolises and advancement of human society have led to an increasingly growing demand for more resources and space. With limited resources and usable space on land, mankind has embarked on the colonisation of the ocean for energy, food, water, resources and space creation.

Coastlines are the frontiers of land facing the seas. Marinas, ports, dockyards and floating structures along the shoreline play an important role in supporting human activities on the sea. In addition, ocean exploration relies heavily on marine engineering structures and facilities. The protection of both coastal and offshore structures against strong wave action is of utmost significance. Breakwaters, also known as wave attenuators, are commonly seen as coastal structures that reduce the wave action in inshore waters and thereby diminish coastal erosion and provide safe harbourage. They may be built from quarried rocks (see Fig. 1a) or massive concrete caissons resting on a rock mound foundation (see Fig. 1b) (Integrated Publishing, 2017).

There is no doubt that the growing offshore and maritime activities have led to the demand for larger ports with a deeper fairway depth. This definitely increases the difficulty and costs in constructing conventional bottom founded breakwaters to protect harbours that are exposed to rough seas. Moreover, the classical wave theory estimates that most wave energy is concentrated at the free surface. In fact, more than 90% of the total wave energy is distributed within a depth of three times the wave height below the free surface (Gao, 2017). Conventional bottom-founded breakwaters are rectangular or trapezoidal in shape to resist the overturning moment at the bottom. Clearly, the variation in the section (and thus the construction materials) is not compatible with the wave energy distribution along the water depth. In addition, these bottom founded breakwaters strongly block the natural water circulation, leading to aggravated pollution and sediment issues within the protected area.

Floating breakwaters represent an appealing alternative to their bottom founded counterparts. Their construction is hardly affected by the water depth and seabed conditions. Tidal variation and water surface elevation induced by global warming have a little effect on these floating structures. They have a low profile and thus they have little visual impact on the horizon, particularly for areas with high tidal variations. Furthermore, they are environmentally friendly as they present minimal interference with the water circulation. More importantly, they can be easily rearranged, relocated and removed with minimum effort. However, floating breakwaters are often criticized for their ineffectiveness in resisting long waves. Their mooring systems are more prone to damage under severe environmental conditions, leading to drift away of the floating breakwaters that jeopardise the surrounding structures.

The application of floating breakwaters at least dates back to 1811 when a wooden breakwater was proposed to the Admiralty to protect the

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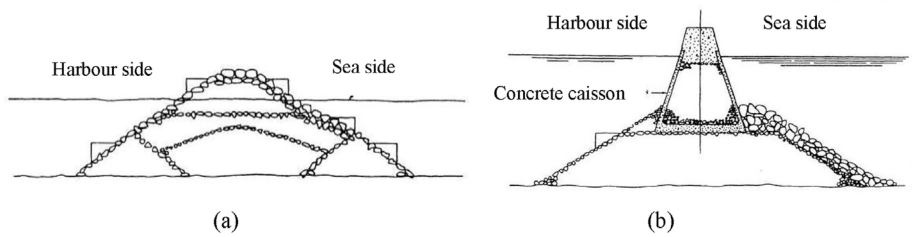

Fig. 1. Conventional bottom founded breakwaters: (a) rock mound breakwater, and (b) caisson breakwater (Integrated Publishing, 2017).

Plymouth Sound. The wooden breakwater consisted of 117 floats of wood in a triangular or prismatic form. Each float spans 9 m in width and depth, 12 m in length, and they are to be moored by iron chains (Stuart, 1842). Although the Admiralty finally settled on a stone breakwater, the accumulation of mud and silt and the consequent diminution of water depth within the harbor after years of constructing revealed the problems due to the installation of a fixed breakwater. Since then, researchers and coastal engineers have paid greater attention to floating breakwaters.

As floating breakwaters became popular as a viable alternative solution to shoreline and harbourage protection, they were proposed, designed and constructed in various forms. In the 1970s, Jones (1971) and Richey and Nece (1974) recognized more than 60 different floating breakwater configurations. Based on their geometric and functional similarities, Hales (1981) classified these floating breakwaters into 11 categories according to their fundamental features. Later, McCartney (1985) separated them into 4 general categories (box, pontoon, mat, and tethered floats) based on the shape, and reviewed their performance in reducing wave height and evaluated their construction costs. According to the wave attenuation mechanisms, Sawaragi (1995) classified the floating breakwaters into 3 groups (reflection type, reflection and wave breaking type and friction type). To date, more floating breakwaters with distinct shapes and wave attenuation mechanisms have been proposed, tested and built. Modern designs often enable multiple wave attenuation mechanisms to achieve a low transmission coefficient. Note that transmission coefficient is defined as the ratio of transmitted wave height to the incoming wave height and it is a key indicator of the effectiveness of floating breakwaters. Thus, there is certainly an imperative need to review the recent research and developments as well as the performance of various floating breakwaters. This review should be beneficial to not only researchers but also practicing engineers working in the area of coastal and offshore engineering.

The objective of this paper is to present a literature review on the research and developments of different types of floating breakwaters. We shall categorize them according to their shapes, somewhat similar to that of McCartney (1985). They are: (1) box-type, (2) pontoon-type, (3) frame-type, (4) mat-type, (5) tethered float type, (6) horizontal plate type, and (7) other types. Section 2 presents the research and developments on box-type breakwaters and also some real examples of such breakwaters that have been constructed. Section 3 is devoted to the review on pontoon-type breakwaters. Section 4 discusses the research on frame-type breakwaters. The mat-type breakwaters, tethered float type and horizontal plate type are discussed in Section 5, Section 6 and Section 7, respectively. Recent research and developments of other types of floating breakwaters are presented in Section 8. The effectiveness of wave attenuating devices that can be coupled with different types of breakwaters is discussed in Section 9. Finally, Section 10 summarizes the conclusions and recommendations for future studies on floating breakwaters.

2. Box-type breakwaters

The prismatic, rectangular box-type floating breakwater (see Fig. 2) may be the simplest type and it has been investigated extensively (Bottin and Turner, 1980; Carr, 1950; Carver, 1979; Hay, 1966; Ofuya, 1968) in the last century. This type of breakwater attenuates ocean/sea waves mainly through reflecting incoming waves. Owing to its simple geometry, theoretical formulae have been derived to predict the wave transmission coefficient. This includes the following classic formula obtained by Macagno (1953) based on the linear wave theory and assuming zero motion of breakwater, no green water on top deck and constant water depth conditions:

$$K_t = \frac{1}{\sqrt{1 + \left[\frac{k_i B \sinh(k_i h)}{2 \cosh(k_i h - k_i d)}\right]^2}} \tag{1}$$

where K_t is the transmission coefficient defined as the ratio of transmitted wave height over the incident wave height; k_i ($= 2\pi/L$) the incident wave number; L the incident wave length; B the width of the breakwater; d the draft; and h the water depth.

Floating breakwaters are laterally held in position by mooring lines, piles or dolphins, and they are bound to take some motions under wave actions. Their complex performance and the corresponding mooring forces were analysed using theoretical models based on two-dimensional potential theory by Adee (1976, 1975, 1974), Adee and Martin (1974), Adee et al. (1976), and Drimer et al. (1992). These analytical models furnish reasonable predictions when compared to physical model tests by Davidson (1971) at Oak Harbor in Washington. For the analysis of more

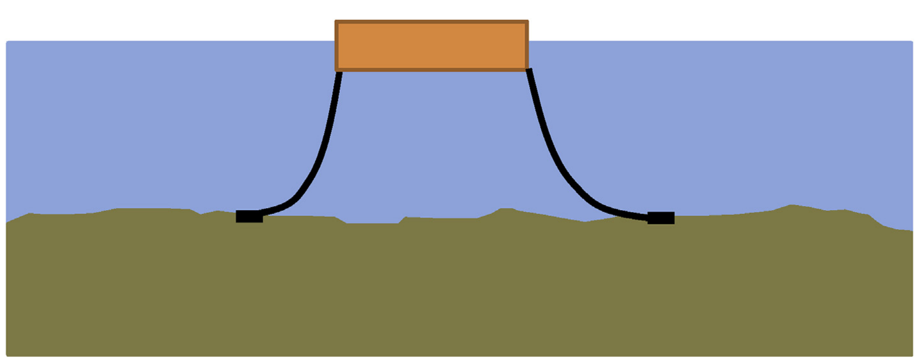

Fig. 2. Sketch of box-type floating breakwater.