

# Hybrid floating breakwater-WEC system: A review

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## Abstract:

Ocean wave energy is attractive for its large reserves, exploitability and low emissions. Although many Wave Energy Converter (WEC) concepts have been proposed, high construction cost hinders the engineering application of WECs. Similar challenges arise in the applications of floating breakwaters. The construction cost can be reduced by combining different structures as one integrated system which has the advantage of cost-sharing, space-sharing and multi-functionality. This integrated design approach has stimulated the rapid development of the hybrid system combining floating breakwaters and WECs in recent years. The novel floating breakwater-WEC system is often classified as a wave-energy-utilizing type floating breakwater. The different approaches for integrating floating breakwaters and WECs are summarized in this review. The hydrodynamic performance and power take-off performance of these hybrid floating breakwater-WEC systems are the focus of this review. The insights gained from previous studies of this system and the potential challenges for further developments of this technology are also provided. The cost-sharing and multi-function of the breakwater-WEC system can help facilitate the engineering application of the floating breakwaters and WECs.

**Keywords:** Breakwater; Wave energy converter; Hybrid system; Hydrodynamic performance; Power take-off.

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# 1 **1. Introduction**

2 With the depletion of the traditional energy resources and low carbon requirement, ocean  
3 renewable energy is attractive for its large reserves and exploitability in many sea areas  
4 (Clément et al., 2002; Wang et al., 2011; Lehmann et al., 2017; Guerra, 2018; Hemer et al., 2018;  
5 Neill et al., 2018). Even though the technical solutions of the wave energy utilization are mature  
6 to some extent and some devices are in the pre-commercial stage, the present research and  
7 developments indicate that wave energy devices are still far from reaching the stage of real  
8 engineering application (Cruz, 2007; Drew et al., 2009). The High construction cost of the  
9 WECs may directly lead to uneconomic price of the electricity converted from ocean wave  
10 power by WECs. Therefore, these high construction costs of WECs is one of the major obstacles  
11 that limits the past and future development of the wave energy utilization device (Ferro, 2006;  
12 Allan et al., 2011; Jeffrey et al., 2013; Astariz et al., 2015; Mustapa et al., 2017). The  
13 competitiveness of wave power extraction in the energy market can be enhanced by reducing the  
14 construction cost.

15 The cost-sharing strategy may be one of the solutions to reduce the construction cost. This  
16 can be achieved by combining two or more kinds of marine structures into one installation. It is  
17 worth noting that the marine structures to be combined would be producing the synergistic effect  
18 and operating in similar environmental conditions. Such similarities may pave the way for the  
19 integration of the different functional aspects. In addition, the multi-purpose objective of the  
20 marine structures can be achieved simultaneously.

21 The hybrid systems include breakwater-WEC integrations (Mustapa et al. 2017), offshore  
22 wind turbine-WEC integrations (Pérez-Collazo et al., 2015; Chen et al., 2016; Elginos et al.,  
23 2017), offshore platform-WEC integrations (Zhang et al., 2017; Lee et al., 2018) and aquaculture  
24 cage-WEC integrations (Toner et al., 2002; Vassiliou et al., 2015; Lopes De Almeida, 2017).  
25 Examples of these integrations include: floating power plant P80 (Floating Power Plant Products  
26 & Services, 2019), Spar-Torus Combination (STC) concept (Muliawan et al., 2013),  
27 WindWaveFloat concept (Peiffer et al., 2011), Berkeley Wedge concept (Madhi et al., 2014), etc.  
28 Through the integration strategy, the cost-sharing, space-sharing and multi-functionality of the  
29 hybrid structures can be achieved. Consequently, the cost per structure can be effectively

1 reduced and the engineering application of wave energy harvesting devices becomes more  
2 feasible.

3 WECs are used to convert wave energy to other useful forms. Theoretically, a capture width  
4 ratio (CWR) of 100% can be achieved by using a device with special design, such as a capturing  
5 buoy oscillating in multiple degree of freedoms (DOFs) (Evans, 1976) or an asymmetrical  
6 capturing buoy (Mynett et al., 1979). However, it is difficult to install a device with a CWR of  
7 100% in the field conditions (Salter, 1974). When incident waves encounter a WEC array, part  
8 of the incident wave energy is absorbed and the remained unabsorbed part is transmitted across  
9 the WEC array. As a result, the wave height at the lee side of the WEC (array) is reduced  
10 significantly. The purpose of breakwaters is to attenuate wave energy and provide sheltering for  
11 coastal communities and infrastructure. The wave height at the leeside of breakwaters is smaller  
12 than that at the weather side. This is the common characteristic for the WECs (array) and  
13 breakwaters in terms of the wave transmission through wave barriers, which aids the argument  
14 for the integretated design of breakwater-WEC integrations. Besides, there are some  
15 investigations on the performance of WEC farms with the affiliated function of coastal  
16 protection (Abanades et al., 2015; Abanades et al., 2018).

17 Many design concepts of breakwater-WEC integrations have been proposed during the past  
18 several decades. In the earlier stages, the pilot breakwater-WEC integrated systems focused on  
19 the bottom-mounted breakwaters, such as caisson breakwaters (Takahashi, 1988), rubble-mound  
20 breakwaters (Margheritini et al., 2009; Vicinanza et al., 2014; Di Lauro et al., 2019), and  
21 composite sea walls (Buccino et al., 2015). Examples of the bottom-mounted breakwater-WEC  
22 integrated system include: the Sea Slot-cone Generator (SSG) device (Margheritini et al., 2009)  
23 and the Overtopping Breakwater for Energy Conversion (OBREC) device (Musa et al., 2017),  
24 etc. Mustapa et al. (2017) give a comprehensive review of the bottom-mounted hybrid  
25 breakwater-WEC system. By introducing those concepts, wave energy utilization in coastal areas  
26 becomes more attractive due to the sharing of the cost and space between the WECs and the  
27 breakwaters. It is known that the bottom-mounted breakwater becomes uneconomical in the  
28 relatively deep-water area. Floating breakwaters are favored for their lower construction cost and  
29 the added advantages of being flexible and environmentally-friendly (McCartney, 1985). Most  
30 of the floating breakwaters are of the form of floating surface-piercing structures. Similarly,

1 some wave energy devices are often located at the free surface; for example, raft type devices,  
2 point absorbers and floating Oscillating Water Column (OWC) type devices. Besides the  
3 similarity in the configurations, the working environment conditions are similar for the WECs  
4 and the floating breakwaters. They are both employed in sea areas with abundant wave energy  
5 resources. The similarity in environmental conditions and structural configurations may provide  
6 the natural advantages for combining the floating breakwaters and WECs as hybrid systems.

7 In recent years, there has been a rapid development of floating breakwater-WEC  
8 integrations. Comprehensive reviews on floating breakwater-WEC integrations are absent in the  
9 literature. The objective of the present paper is to present a literature review on the research and  
10 development of different types of hybrid floating breakwater-WEC system. Furthermore, the  
11 technical issues and the challenges associated with these hybrid systems are discussed in a  
12 detailed manner. The advantages and disadvantages of different types of floating  
13 breakwater-WEC systems are also outlined in this review.

14 This paper is organized as follows. In Section 2, the classification of the floating  
15 breakwaters and WECs based on their working principles are introduced. Various approaches to  
16 integrate floating breakwaters with wave energy harvesting devices are classified and their  
17 characteristics, efficiency and survivability are reviewed in Section 3. The technology  
18 development issues and challenges of the hybrid system are discussed in Section 4. Finally,  
19 conclusions are drawn in Section 5.

## 20 **2. Classifications of floating breakwaters and wave energy converters**

### 21 2.1 Floating breakwaters

22 Floating breakwaters are favored for the advantageous reasons of relatively low construction  
23 costs, reduced dependencies on marine geological conditions, low environmental impact,  
24 aesthetic considerations and flexibility (McCartney, 1985). McCartney (1985), Sawaragi (1995)  
25 and Dai et al. (2018) presented comprehensive reviews of the research and development of  
26 floating breakwaters. According to the configurations, traditional floating breakwaters are  
27 categorized as follows: box-type, pontoon-type, frame-type, mat-type, tethered-floating type and  
28 horizontal-plate type. It is understood that the wave attenuation function of the floating

1 breakwaters is achieved by dissipating incident wave energy or hindering the incident wave  
 2 propagation. Hence, the wave attenuation principles of the floating breakwaters mainly include:  
 3 reflecting type, disturbing type, and friction type (Sawaragi, 1995; Dai et al. 2018). Reflecting  
 4 type breakwaters hinder the wave propagation by partially reflecting incident wave to the  
 5 weather side of the breakwater, which leads directly to the reduction of wave height on the lee  
 6 side of the structure. For the disturbing type breakwater, the original wave-particle orbit velocity  
 7 can be disturbed by breakwaters with specific shapes and the resulting induced phenomenon of  
 8 wave breaking or wave fission may dissipate the incident wave energy. Consequently, the aim of  
 9 wave attenuation may be achieved. In contrast, the wave energy is dissipated by producing  
 10 vortices caused by a particular media (such as tires) for the friction type breakwaters. The  
 11 classification and wave attenuation principles of each type of floating breakwaters are shown in  
 12 Table 1(Dai et al. 2018).

13

14 Table 1 Classification of the traditional floating breakwaters and the corresponding operational  
 15 principles

| Structural type       | Wave attenuation principle |
|-----------------------|----------------------------|
| Box-type              | Reflecting type            |
| Pontoon-type          | Reflecting type            |
| Frame-type,           | Disturbing type            |
| Mat-type              | Friction type              |
| Tethered float type   | Friction type              |
| Horizontal plate type | Disturbing type            |

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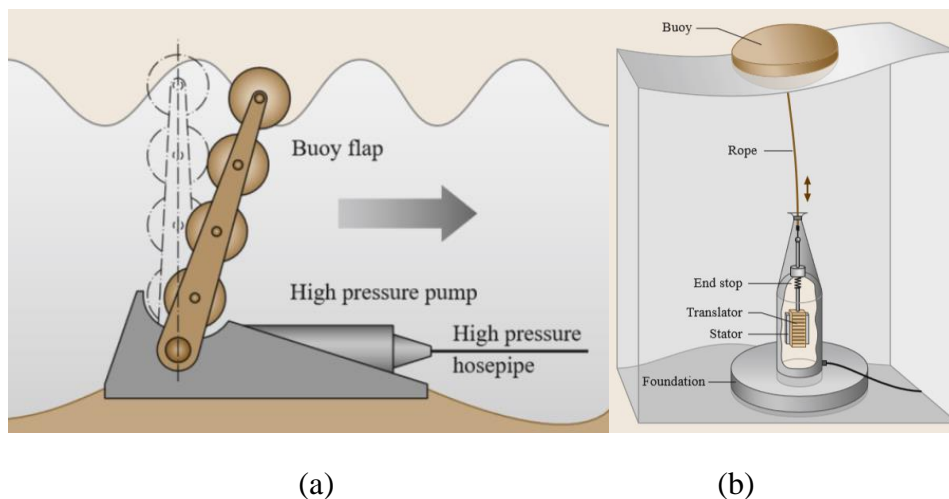
## 17 2.2 Wave energy converters

18 WECs are used to convert wave energy into a useful form (e.g., electricity). Based on the  
 19 principle of capturing wave energy, WECs can be categorized as Oscillating Body (OB) type,  
 20 OWC type, and overtopping type (Falnes, 2007; Drew et al., 2009; Falcão, 2010; Borthwick,  
 21 2016; Babarit, 2017). The sketches of each kind of WECs are shown in Figure 1-3.

1 For the OB type WECs, the movable bodies (floating or submerged) are selected as the  
2 “absorber” to capture wave energy. Wave energy is converted to kinetic energy of the body in the  
3 first step. Generally, the movable bodies are connected to the PTO system by a transmission  
4 mechanism (e.g., mooring line or rigid driving link). In this way, the body drives the PTO system  
5 directly and wave energy can be converted to electricity. Examples of the OB type WECs  
6 include Oyster (Renzi et al., 2014), PowerBuoy (Hart et al., 2012) and Seabased AB WEC  
7 (Chatzigiannakou et al., 2017), etc.

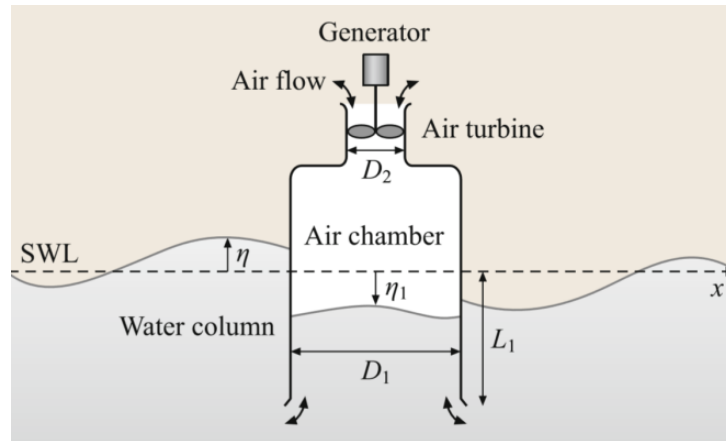
8 The OWC type WECs comprise a partially submerged structure with an opening below the  
9 water surface. Distinct components termed the air chamber and the water column are formed  
10 inside the structure (Falcão et al., 2016). The incident wave excites the motion of the water  
11 column, which may lead to the fluctuation of the air pressure in the chamber. The conversion of  
12 wave energy can be realized through an air turbine, which is driven by fluctuating air pressure.  
13 Examples of the OWC type WECs include LIMPET (Heath, 2000) and Mighty Whale (Hotta et  
14 al., 1996), etc.

15 Distinct from the above two devices, the overtopping type WECs involve a specific structure  
16 named a water reservoir. The overspilling of water waves fills the reservoir and, in this way, the  
17 wave kinetic energy is transformed into the potential energy of the stored water mass in the  
18 reservoir. The potential energy of the stored water can be converted to the electrical energy by  
19 using low-head hydraulic turbines. Examples of the overtopping type WECs include the Wave  
20 Dragon device (Kofoed et al., 2006) and the SSG device (Margheritini et al., 2009), etc.

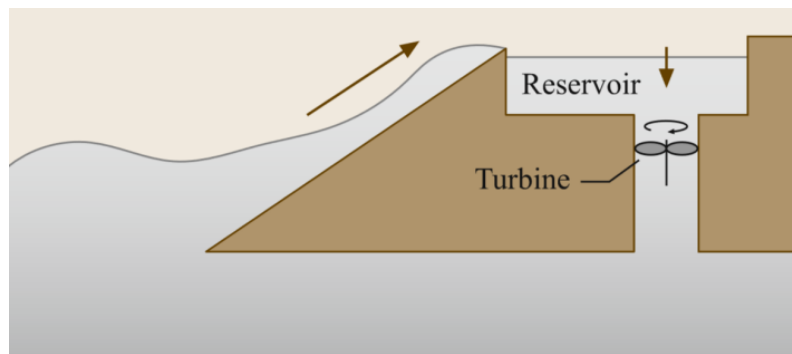


21  
22  
23 Figure 1 Sketch of the OB type WEC. a) Oscillating Wave Surge Convertors, Oyster device; b)

1 point absorber, Uppsala Seabased AB device. Adapted from Xiros et al. (2016)



3  
4 Figure 2 Sketch of the OWC type WEC. Adapted from Xiros and Dhanak (2016)



6  
7 Figure 3 Sketch of the overtopping type WEC. Adapted from Xiros and Dhanak (2016)

### 9 **3. Floating hybrid breakwater-WEC system**

10 As described in Section 2, the working principles of conventional floating breakwaters include  
11 reflecting type, disturbing type, and friction type, etc. That is to say, the conventional floating  
12 breakwaters work by dissipating or reflecting the wave energy to achieve the aim of attenuating  
13 incident waves. In this way, part of the incident wave energy is transformed into the wasted  
14 energy. Coincidentally, WECs work on the principle of converting wave energy into other forms.  
15 The synergetic effect will be augmented if the floating breakwaters can be designed as  
16 wave-energy-utilizing type structures, in which the function of wave energy utilization and wave  
17 attenuation can be achieved simultaneously. In this section, we will present a comprehensive  
18 review of floating wave-energy-utilizing type breakwaters, i.e., hybrid floating breakwater-WEC

1 systems. The hybrid systems are categorized as floating breakwater-OB type WEC systems,  
2 floating breakwater-OWC type WEC systems and floating breakwater-overtopping type WEC  
3 systems. In contrast to the conventional WECs or breakwaters, both conversion efficiency and  
4 transmission coefficients shall be examined while evaluating a hybrid system.

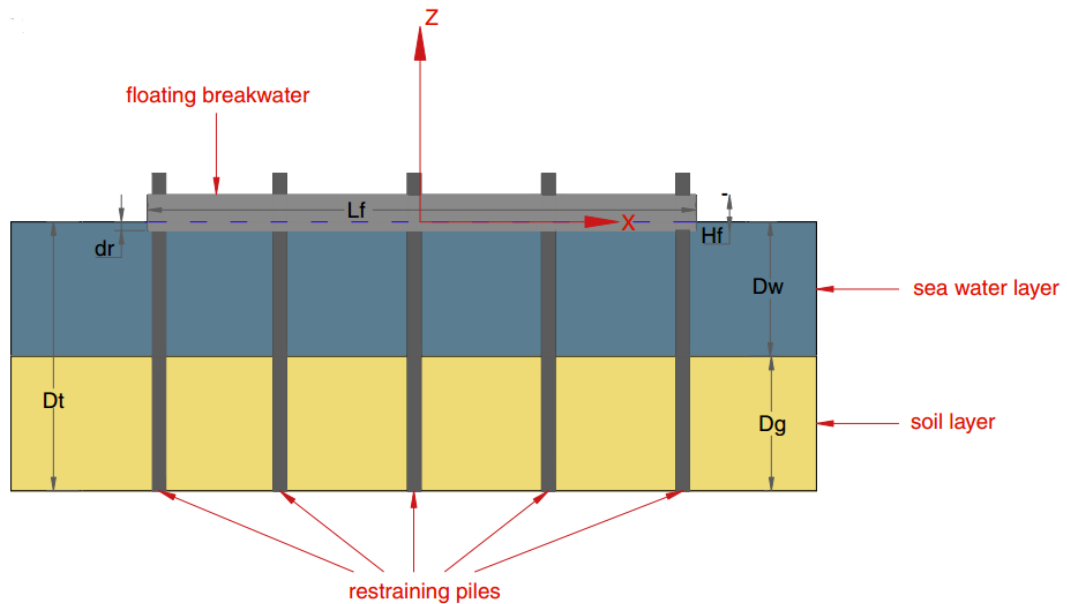
### 5 3.1 Floating breakwater-OB type WEC system

6 The floating breakwater-OB type WEC system combines the OB type WEC and the  
7 conventional floating breakwater. Generally, the breakwater acts as the base structure. Box-type  
8 breakwaters and pontoon-type breakwaters are common in this category. The hybrid system can  
9 be formed in 2 ways, i.e., 1) adding a PTO system on the original breakwater; 2) the additional  
10 attachment of a complete WEC (array) on the original breakwater. The main body of the  
11 breakwater is similar to that of the conventional floating breakwater (retaining its pontoon shape  
12 or box shape).

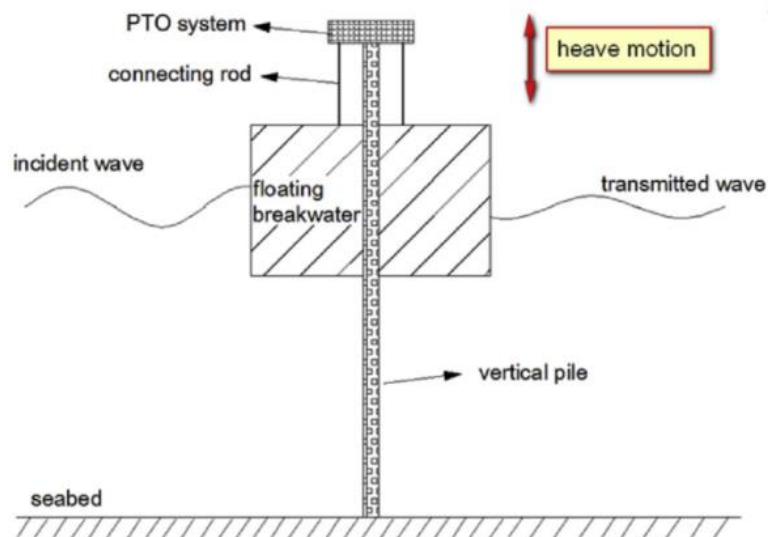
13 Box type breakwaters are attractive for their advantages of durability, simplicity and  
14 easy-to-construct, etc. Some floating box-type breakwaters have reached the stage of  
15 engineering application (Kusaka et al., 2015; Com, 2017). Due to the simplicity and ease of  
16 modification, Pile-restrained Floating Breakwaters (PRFBs) are often adapted to form a hybrid  
17 system with the dual functions of coastal protection and wave energy utilization. Previous  
18 investigations verified that such kind of breakwater operates effectively in terms of the wave  
19 attenuation performance (Isaacson et al., 1998; Koutandos et al., 2004; Koutandos et al., 2005;  
20 Diamantoulaki et al., 2008; Wang et al., 2010).

21





1  
 2 Figure 4 Section view of the pile-restrained floating breakwater. The rectangular breakwater  
 3 moves in heave mode under the restriction of the vertical piles. Adapted from Diamantoulaki et  
 4 al. (2008)

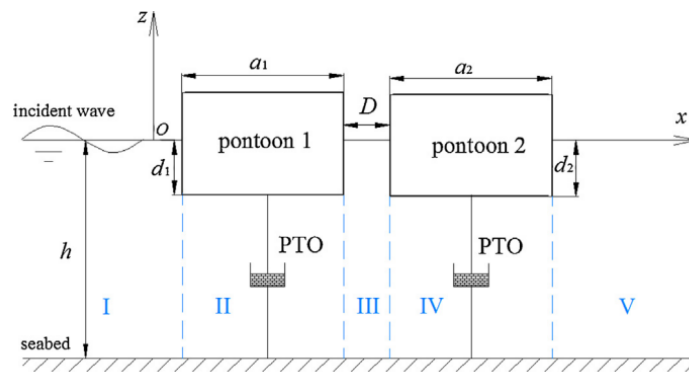


6  
 7 Figure 5 Sketch of the hybrid system. The pile-restrained floating pontoon moves in heave mode  
 8 and a PTO system driven by the floating pontoon achieves the wave power absorption. Adapted  
 9 from Ning et al. (2016)

11 The floating pontoon of the PRFB moves in heave mode under the restriction of the vertical  
 12 pile (as is shown in Figure 4). Similarly, the energy-capturing body of the heaving OB type

1 WEC moves in heave mode (Zang et al., 2018). The similarity in motion characteristics may  
 2 pave a way to integrate the two aspects as one. Ning et al. (2016) proposed a hybrid system (as  
 3 shown in Figure 5) by matching a PTO system to the PRFB. Similar to the conventional PRFB  
 4 (Koutandos et al., 2004; Diamantoulaki et al., 2008), the shape of the floating body remains as  
 5 a rectangular box. Zhao et al. (2017) investigated the performance of such kind of hybrid system  
 6 based on linear potential flow theory. The condition of CWR  $\eta > 20\%$  and transmission  
 7 coefficient  $K_T < 0.5$  can be achieved at a certain frequency range. A corresponding experimental  
 8 investigation was conducted by considering the nonlinearity of the PTO damping force (Ning et  
 9 al. 2016). Experimental results reveal that the qualified CWR and the effective wave attenuation  
 10 performance can be achieved simultaneously. The disadvantage of this hybrid system is the poor  
 11 wave attenuation performance when the device is operational in long waves. This shortcoming  
 12 results from the box type breakwater. The PTO system slightly modifies the transmission  
 13 coefficient of the hybrid system in long waves. In addition, the theoretical maximum value of the  
 14 CWR for the heaving two-dimensional pontoon (moving in single mode) is 50%. Due to the  
 15 fluid viscous effect and friction losses, the optimal CWR is smaller than 50% in the laboratory  
 16 test. Consequently, the frequency range satisfying the condition of  $\eta > 20\%$  and  $K_T < 0.5$   
 17 (hereinafter called effective frequency range) is narrow.

18



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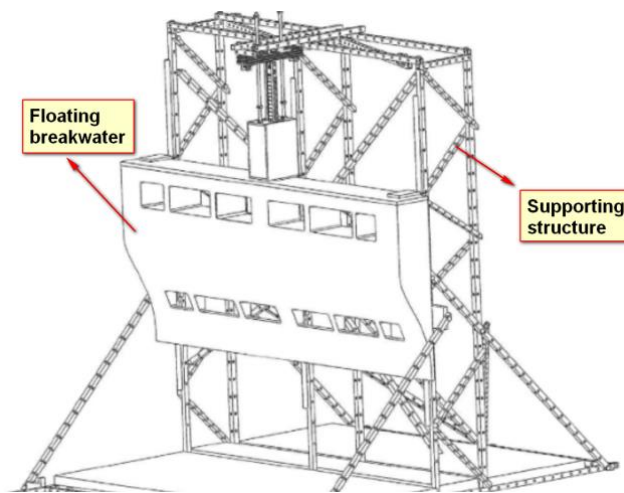
20 Figure 6 Sketch of the dual pontoon-PTO system. The two pontoons and their matching the PTO  
 21 system (arranged in tandem) work independently. Adapted from Ning et al. (2017)

22

23 Comparing with the single pontoon system, the dual pontoon type breakwater gives better  
 24 breakwater performance (Koutandos et al., 2005). The energy conversion performance of WECs

1 consisting of several small buoys is shown to be better than that of a single buoy system with  
2 equal total volume (Garnaud et al., 2009). To broaden the effective frequency range of the  
3 breakwater-WEC system proposed in Ning et al. (2016), Ning et al. (2017) put forward a dual  
4 pontoon-PTO system consisting of two pontoons and two PTOs as shown in Figure 6.  
5 Preliminary analytical investigation revealed that the effective frequency bandwidth (i.e., the  
6 width of the effective frequency range) of the dual pontoon-PTO system is broader than that of  
7 the single pontoon system with equal total pontoon volume. The efficiency of the former case is  
8 obviously greater than that of the latter one (Ning et al., 2017). Even though the friction losses  
9 and viscous effect play an important role in experiments, conclusions obtained from  
10 experimental research data verifies the advantages of the dual pontoon, dual PTO system (Ning  
11 et al., 2018). Note that two PTO systems are needed for the dual pontoon-PTO system, and only  
12 one PTO system is needed for the single pontoon system. This may lead to the increase of  
13 installation cost.

14



15

16 Figure 7 Sketch of the TBW. The working principle of this system is similar to that of the system  
17 described in Fig. 5. The floating buoy is designed as a wedge-shaped structure. Adapted from  
18 Madhi et al. (2018)

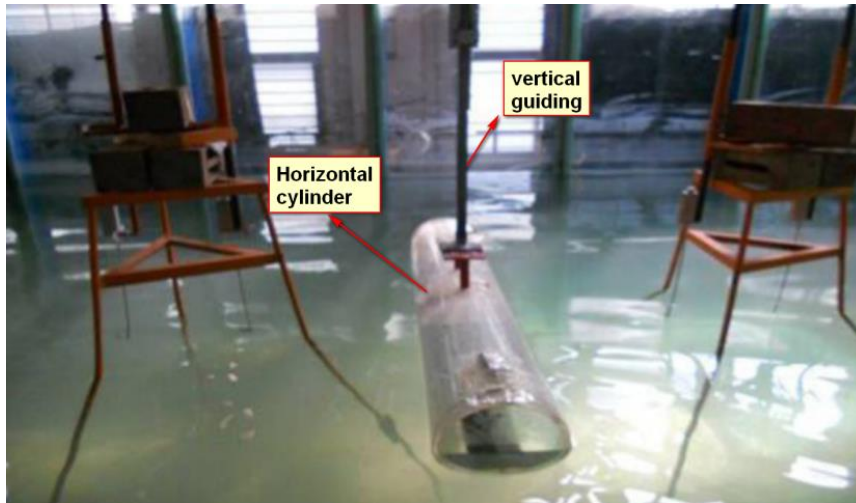
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20 Madhi et al. (2015) proposed a concept called ‘The Berkeley Wedge’ (TBW), which consists  
21 of a floating wedge-shaped box and a PTO system installed above the floating body as shown in  
22 Figure 7. The floating body moves in heave mode and drives the PTO system to produce power.  
23 The shape of the floating body described in Madhi et al. (2015) is different from that in Ning et

1 al. (2016). Specifically, the floating wedge-shaped box is designed such that the draft of the rear  
2 wall is larger than that of the front wall. This asymmetrical characteristic is similar to the Salter  
3 Duck device (Salter, 1974; Wu et al., 2018). Comparing the TBW with the conventional  
4 symmetrical device, the devices with the asymmetrical wedge-shaped body is beneficial to the  
5 improvement of the energy conversion efficiency (Madhi et al., 2014). This is due to the fact that  
6 the radiated waves at the leeside of the device are very small. Similar mechanisms can also be  
7 used to illustrate the high efficiency of the Salter Duck device (Mei, 1976; Evans, 1976).  
8 Consequently, the transmitted wave energy at the lee side of the breakwater will be reduced  
9 effectively (Madhi et al., 2014). This suggests that the effective coastal protection function can  
10 be realized if it acts as a breakwater. However, for the pontoon-type breakwater, a tough  
11 challenge is to make the transmission coefficient acceptable in longer waves.

12 To further improve the competitiveness of the TBW, some investigations were conducted from  
13 the point view of safety and survivability in both operational and extreme conditions (Tom et al.,  
14 2017; Madhi and Yeung, 2018). Tom et al. (2017) proposed a power-to-load balancing strategy  
15 to maximize power capture while minimizing structural and actuator loads. The survivability of  
16 the Berkeley wedge device in extreme waves was examined using Computational Fluid  
17 Dynamics (CFD) method (Madhi and Yeung, 2018). The modification of a pressure-relief  
18 channel (PRC) is introduced to improve the survivability of the device (Madhi and Yeung, 2018).  
19 The PRC design can be realized by removing part of the device that may experience the large  
20 wave pressures due to the slamming phenomenon.

21



1

2 Figure 8 Wave flume test of the cylindrical device. The energy capturing bouy (i.e., the cylinder)  
3 moves in heave mode and is configuraged horizontally. Adapted from Chen et al. (2016).

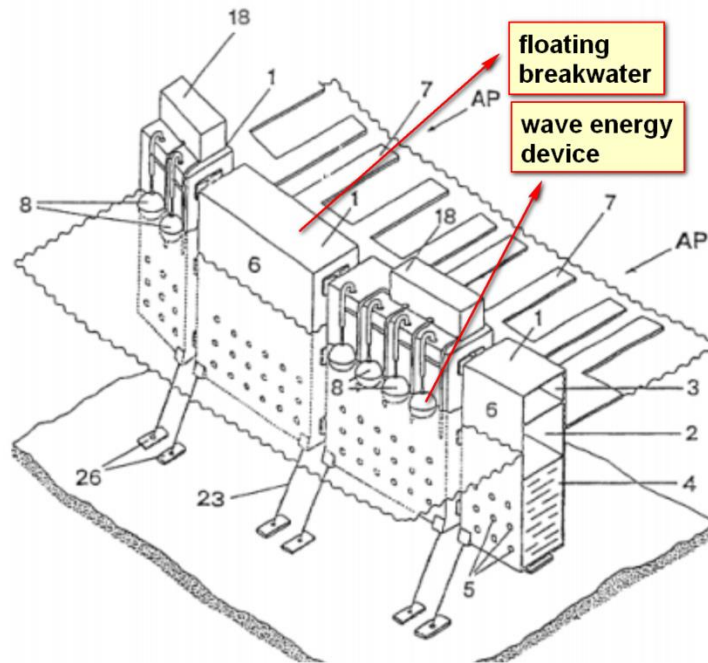
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5 Chen et al. (2015) proposed a wave energy system consisting of several floating horizontal  
6 cylinders. Each cylinder moves in heave mode and works independently as shown in Figure 8.  
7 The size of the cylinders is obviously smaller than that of the floating body in Ning et al. (2016)  
8 and Madhi and Yeung (2018). Chen et al. (2016) thoroughly investigated the performance of the  
9 system proposed in Chen et al. (2015) using a numerical wave flume technique. The wave  
10 attenuation performance of a single device in Chen et al. (2015) is not comparable to that in  
11 Ning et al., (2016) and Madhi and Yeung (2018). They pointed out that the qualified energy  
12 conversion performance and breakwater performance can be anticipated by deploying multiple  
13 devices.

14 Waves formed at the front of the breakwater are characterized as the superposition of the  
15 incident waves and the reflected waves, which may amplify the wave height at the weather side.  
16 This characteristic may be useful to improve the efficiency of WECs. There have been many  
17 attempts to combine WECs and floating breakwaters by attaching WECs at the weather side of  
18 the breakwaters (Zingale, 2002; Martinelli et al., 2016; Favaretto et al., 2017; Zhao et al., 2017;  
19 Ning et al., 2018; Zhao et al., 2019). Zingale (2002) proposed a modular floating breakwater  
20 with the additional function of wave energy utilization. As shown in Figure 9, an array of  
21 spherical OB type WECs were arranged at the weather side of the floating breakwater. The PTO  
22 system was arranged at the top of the breakwater, which acted as the base structure. As described

1 in Figure 9, the size of the breakwater is obviously greater than that of many wave energy  
2 devices. The relative motion of the WEC devices and the breakwater drives the PTO system to  
3 produce power. Specific data on the efficiency and transmission coefficient of the integrated  
4 system are absent from the published results.

5



6

7 Figure 9 Sketch of modular floating breakwater-WEC system. Several oscillating buoy type  
8 wave energy devices were arranged at the weather side of the moored floating breakwater.

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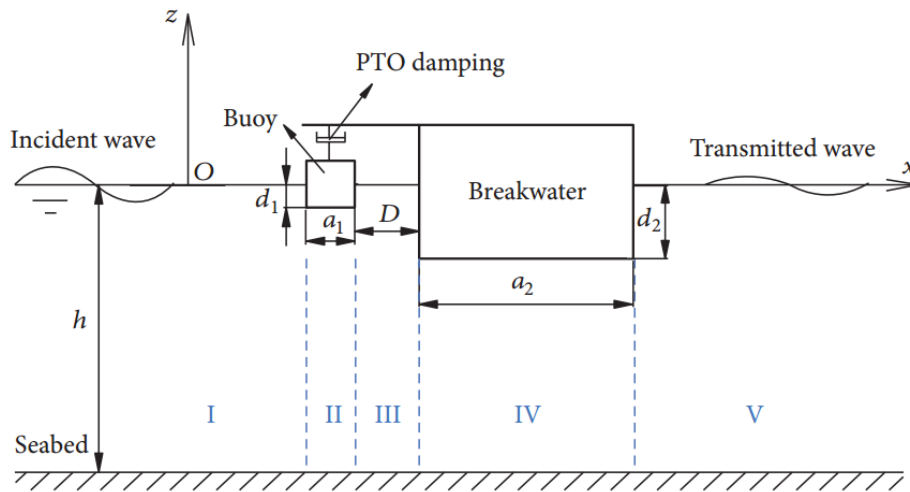
Adapted from Zingale (2002)

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11 Zhao et al. (2017) proposed a hybrid system comprising of an OB type WEC arranged in front  
12 of a floating pontoon-type breakwater. The efficiency of the OB type WEC arranged in front of  
13 the breakwater is greater than that of the isolated case in a wide frequency range. The  
14 superposition of the incident waves and reflected waves amplify the efficiency of the WECs. The  
15 corresponding experimental results revealed that the efficiency of the OB type WEC arranged in  
16 front of the breakwater is obviously greater than that of the isolated case, especially for shorter  
17 waves (Zhao et al., 2018). As a general extension, Ning et al. (2018) investigated the effect of  
18 the breakwater on the performance of a WEC array located at the weather side. A significant  
19 increment in the efficiency of the WEC array can be observed due to the existence of the rear

1 breakwater. Corresponding experimental results show that the wave forces and heave response  
 2 of the WECs can be amplified (Zhao et al., 2019). Such kind of integrations with significant  
 3 improvement of the efficiency may pave the way to improve the energy conversion performance  
 4 of WECs in areas experiencing medium wave conditions. It is important to note that zero  
 5 efficiency occurs at certain frequencies for the devices located at the weather side of a  
 6 breakwater. This is due to the fact that Bragg resonance with strong reflections may be triggered  
 7 for such kind of multi-body system (Ouyang et al., 2015). When Bragg resonance occurs, wave  
 8 forces acting on the front buoy are almost negligible. This may directly lead to the zero  
 9 efficiency of the device. Due to the constructive effect on the energy conversion efficiency,  
 10 Bragg resonance should be avoided while designing the integrations characterized by the  
 11 multi-body system.

12



13

14 Figure 10 Sketch of the floating breakwater-WEC system. One PTO system is used to link the  
 15 front buoy and the floating breakwater in fixed type configuration. Adapted from Zhao et al.

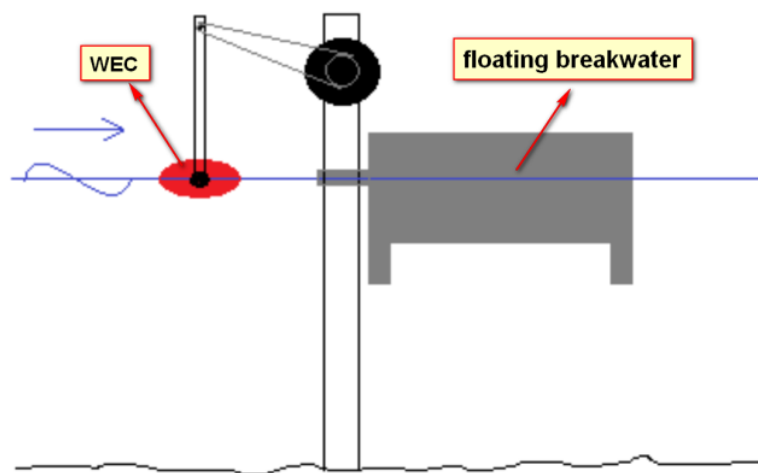
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(2017)

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18 Martinelli et al., (2016) proposed a multi-functional structure combining a breakwater and an  
 19 OB type WEC (namely ShoWED). The breakwater moves vertically along an upright pile as  
 20 shown in Figure 11. ShoWED is situated at the weather side of the breakwater. Experimental  
 21 results reveal that the energy conversion efficiency can reach 26%. This efficiency of 26% is  
 22 smaller than that presented in Zhao and Ning (2018). Since the two contrasting configurations in

1 Martinelli et al. (2016) and Zhao and Ning (2018) are not the same, the direct comparison of  
2 efficiencies between the two systems is inapplicable. The relatively low efficiency indicated that  
3 further optimization of the system proposed by Martinelli et al. (2016) may be necessary to  
4 improve its energy conversion efficiency. As an extension, Favaretto et al. (2017) proposed a  
5 novel integrated system consisting of a catamaran floating breakwater and an OB type WEC.  
6 The aim of generating electrical energy whilst also providing a coastal protection function can be  
7 achieved for both of the systems proposed in Refs. (Martinelli et al., 2016; Favaretto et al.,  
8 2017).



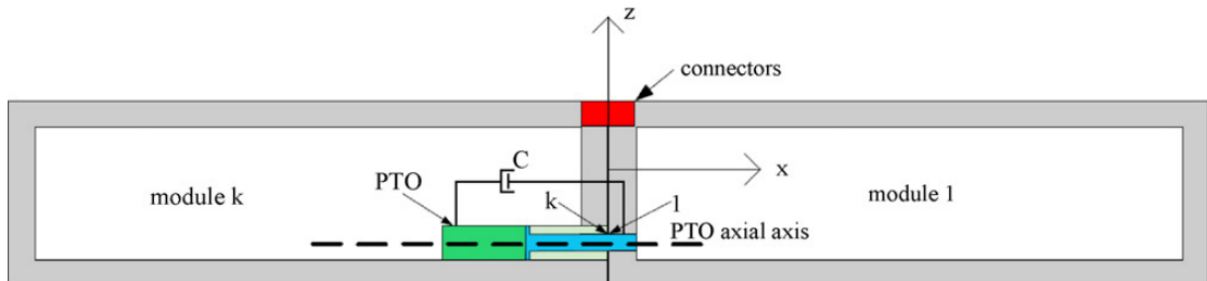
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11 Figure 11 Sketch of the hybrid floating breakwater-WEC system proposed by Martinelli et al.  
12 (2016). A WEC (ShoWED) was attached at the weather side of the breakwater, which moves in  
13 heave mode along the vertical pile. Adapted from Martinelli et al. (2016).

14  
15 For the above mechanisms described in this subsection, the energy capture body of the  
16 device moves in heave mode. In contrast, the devices described below belong to the category of  
17 multi-mode WEC. The energy-capturing body moves in multiple degrees of freedom.  
18 Michailides et al. (2011) proposed a flexible floating breakwater consisting of several modules  
19 as shown in Figure 12. The neighboring modules are connected by the PTO system, which is  
20 driven by the relative motion of the modules. This is similar to the raft-type WEC, as mentioned  
21 in Zheng et al. (2017). The energy conversion performance and wave attenuation performance of  
22 such a system were investigated theoretically (Michailides and Angelides, 2012; Michailides et  
23 al., 2013; Michailides et al., 2015; Michailides, 2017). Results revealed that the system can



1 simultaneously satisfy the effective energy conversion efficiency and qualified wave attenuation  
2 performance. So far, there are no corresponding experimental investigations reported. The  
3 flexible floating breakwater can be fixed by a mooring system and deployed in the deep-water  
4 area. Comparatively, it is uneconomic to deploy the pile-supported system in deep water. A sea  
5 location with medium depth may be favorable for the pile-supported system.

6



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8 Figure 12 Sketch of the multiple module flexible floating breakwater-WEC system proposed by  
9 Michailides and Angelides (2011). The two neighboring modules were connected by the PTO  
10 system. Adapted from Michailides and Angelides (2011)

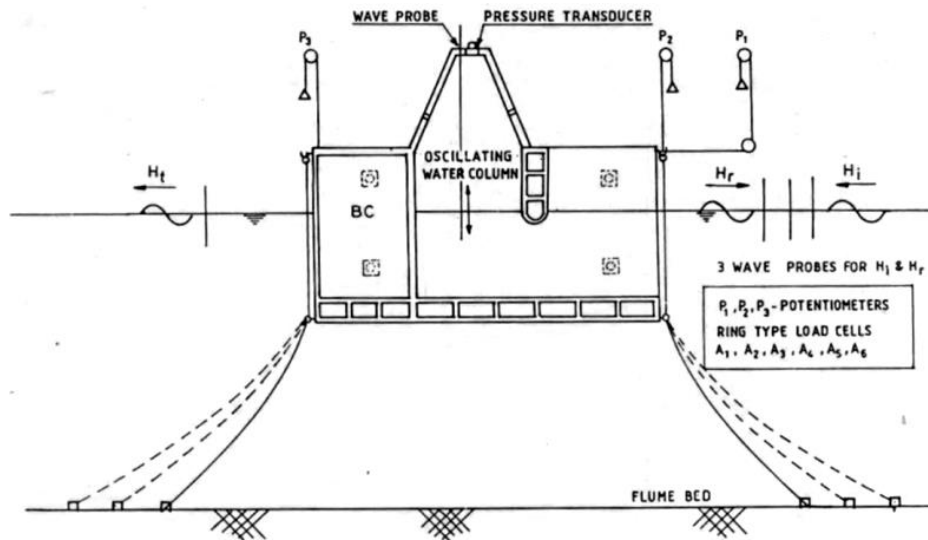
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### 12 3.2 Floating breakwater-OWC type WEC system

13 The floating OWC type device is a hollow-shaped structure (Luo et al., 2014; Elhanafi et al.,  
14 2017). The hollow-shaped structure can be formed by removing the bottom of the conventional  
15 floating box/pontoon type breakwater. Generally, the displacement of the OWC type breakwater  
16 is smaller than that of the OB type breakwater. This may result in a relatively lower construction  
17 cost of the OWC type breakwater. Neelamani et al. (2006) proposed a floating OWC caisson  
18 structure with an air chamber as shown in Figure 13. The anchor chain mooring system is  
19 adapted to fix the system in location. From the experimental data on the pneumatic efficiency of  
20 the system, it can be deduced that the system can be effectively used as breakwaters and as  
21 WECs. Koo (2009) investigated the wave attenuation performance of a pneumatic-type floating  
22 breakwater as shown in Figure 14; this structure possesses the characteristics of the OWC type  
23 wave energy device. The imposed pneumatic damping is helpful to dissipate wave energy and  
24 improve the wave attenuation performance. Hence, the wave attenuation performance of the

1 pneumatic-type floating breakwater is better than that of the conventional box type breakwater.

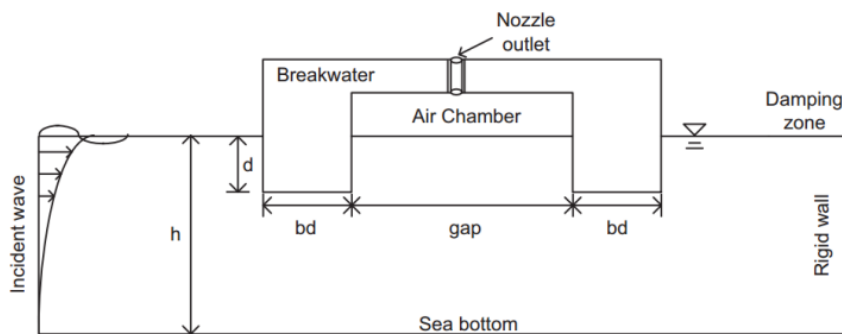
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4 Figure 13 Sketch of the floating OWC type breakwater. The moored breakwater is a hollow type  
5 structure. In the middle section of the breakwater, an OWC and an associated air chamber are  
6 formed. Adapted from Neelamani et al. (2006).

7



8

9 Figure 14 Sketch of the pneumatic-type floating breakwater. The breakwater with  
10 finite-thickness wall and a nozzle outlet is arranged above the air chamber to provide damping  
11 effect. Adapted from Koo (2009)

12

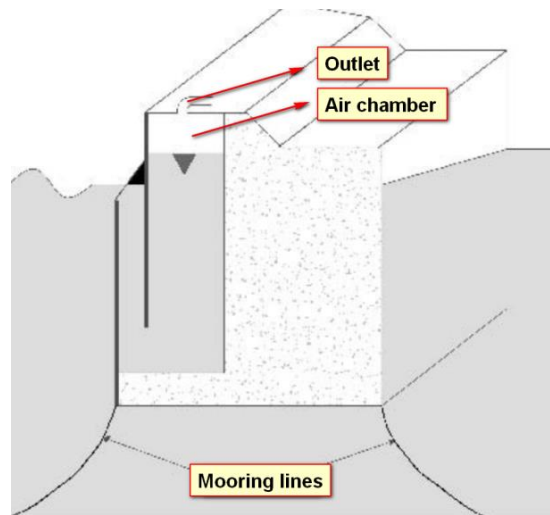
13 He and Huang (2014) proposed a pile-based breakwater with an OWC air chamber. In  
14 appearance, the new breakwater design is equivalent to a bottomless box. Compared with the  
15 conventional pile-supported box-type breakwater, the wave attenuation performance of the  
16 device is improved due to the energy absorption function of the air chamber. Furthermore, the  
17 measured fluctuations in air pressure revealed that this kind of device is suitable for wave energy

1 utilization. He et al. (2012) proposed a breakwater with double OWC air chambers. The two  
2 OWC air chambers are symmetrically located at the front and rear sides of the box. Additionally,  
3 this system has the potential to harvest wave energy. He et al. (2013) and He et al. (2017)  
4 modified the hybrid system proposed in He et al. (2012) by incorporating two asymmetric air  
5 chambers. As a result of the modifications, the pressure fluctuation inside the air chamber  
6 (arranged asymmetrically) are amplified significantly. This is beneficial to improve the wave  
7 energy conversion efficiency without compromising the coastal protection function.

8 Through integrating the air chamber into the conventional breakwater, the function of wave  
9 energy conversion can be achieved. More importantly, compared with the conventional box-type  
10 breakwater, the wave attenuation performance of the hybrid system is improved. This is  
11 attributed to the fact that wave energy is dissipated by pneumatic damping, which can be  
12 observed directly from the fluctuation of the air pressure in the chamber. In addition, the  
13 embedding of the OWC air chamber decreases the displacement of the breakwater. For floating  
14 bodies, the displacement roughly indicates the construction cost. So the reduction of the  
15 construction cost may be achieved adjunctively.

16 Sundar et al. (2010) proposed a novel floating breakwater–OWC WEC system as shown in  
17 Figure 15. The system combines the U-OWC device and the floating box-type breakwater. Many  
18 theoretical and experimental investigations verified that the U-OWC is an effective land-based  
19 OWC device (Boccotti, 2007; Strati et al., 2016; Malara et al., 2017). So far, both the theoretical  
20 and experimental investigations that evaluate the performance of this novel floating system are  
21 absent.

22



1

2 Figure 15 Sketch of the floating skirt breakwater with OWC. Contrary to the conventional OWC  
 3 devices, the front submerged wall is included to form the U-OWC concept. Adapted from  
 4 Sundar et al. (2010)

5

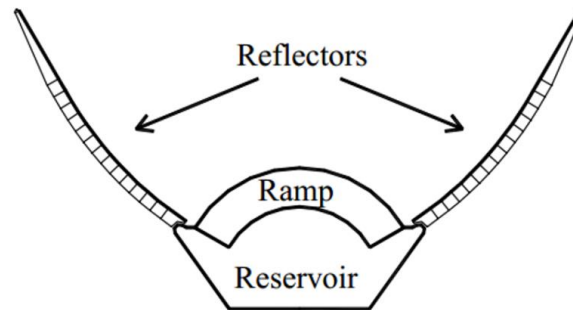
6 Since the OWC WEC has the preliminary function of absorbing wave energy; it can serve as a  
 7 sheltering structure for particular offshore engineering installations. Hong and Hong (2007) and  
 8 Hong et al. (2006) applied the concept of using floating OWC breakwaters to shelter the Very  
 9 Large Floating Structures (VLFS) by arranging the WECs at the weather side of the VLFS. Since  
 10 part of the incident wave energy is absorbed by the OWC breakwater, the response of the VLFS  
 11 can be reduced effectively.

### 12 3.3 Floating breakwater-overtopping type WEC system

13 MSc Erik Friis-Madsen proposed an overtopping type WEC called Wave Dragon, which  
 14 can also serve as a wave-damping structure (Kofoed et al., 2006). Unlike conventional WECs,  
 15 this device includes two reflection walls as shown in Figure 16, which can amplify the wave  
 16 height substantially. This typical design is beneficial to improve the wave energy conversion  
 17 efficiency of the wave energy harvesting device. The main structure of the Wave Dragon device  
 18 consists of a curved ramp and a water storage reservoir. Incident waves can be focused by the  
 19 reflectors and the overtopping water fills the reservoir. The potential energy of the water in the  
 20 reservoir is converted into electricity through low-head hydro turbines. Small-scale laboratory  
 21 test and offshore test with the scale of 1:4.5 showed that the device operates effectively in terms

1 of the PTO performance (Soerensen et al., 2000; Hansen et al., 2003; Frigaard et al., 2006).  
2 Beels et al. (2010) investigated the influence of the existence of the Wave Dragon device on the  
3 surrounding wave field. Due to its excellent wave absorbing performance, the Wave Dragon  
4 device has the potential to act as a breakwater (Nørgaard et al., 2013).

5



6

7 Figure 16 Sketch of the of the Wave Dragon device. Wave height was amplified due to the wave  
8 gathering effect produced by the two reflectors. This resulted in the reservoir filling with the  
9 overtopping water. Adapted from Kofoed et al., (2006)

10

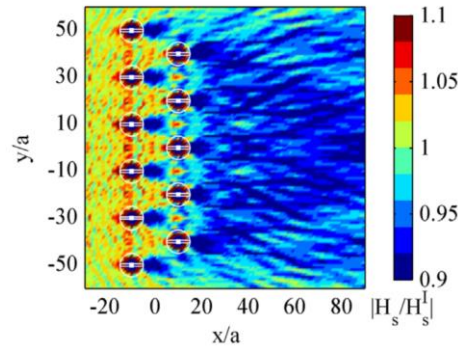
### 11 3.4 WEC array with sheltering function

12 The essential purpose of a wave farm (i.e., WEC array) is to transform wave energy into  
13 other useful forms. This means that the incident wave energy will be partially absorbed while the  
14 waves transmitted through the WEC array and, consequently, the wave height at the lee side of  
15 the WEC array is mitigated (Carballo et al., 2013; McNatt et al., 2015; Flocard et al., 2017;  
16 Abanades and Flor-Blanco et al., 2018; Rodriguez-Delgado et al., 2018). Naturally, the wave  
17 farm may possess the function of sheltering or providing coastal protection from erosion.

18 The conventional coastal protection structures are single-functional and no other benefits can  
19 be achieved. Many attempts have been made to realize multiple functionality (including wave  
20 energy utilization, wave attenuation, etc.). Wave farms with a coastal protection feature are  
21 preferable for their advantageous multiple function, cost-sharing and space-sharing. McNatt et al.  
22 (2015) presents the wave fields as shown in Figure 17 around a WEC array consisting of several  
23 point absorbers (situated by using an analytical method based on linear potential theory). It can  
24 be directly observed that wave height at the lee side of the WEC array is obviously smaller than

1 that at the weather side. This may provide intuitive evidence that a WEC farm can act as a single  
2 synergistic structure with effective wave attenuation performance.

3



4

5 Figure 17 Wave field around the WEC array.  $H_s$  and  $H_s^I$  denotes significant wave height and  
6 the incident significant wave height, respectively. For the detailed information of the WEC array  
7 see McNatt et al. (2015). Adapted from McNatt et al. (2015).

8

9 Zanutigh et al. (2010) analyzed the breakwater performance and energy conversion  
10 efficiency of a floating WEC (i.e., DEXA). The DEXA device is essentially formed by two  
11 hinged floating buoys, and the relative motion of the hinged buoys drives the PTO system. Using  
12 the DEXA device, energy conversion efficiency of 10%~35% can be achieved in laboratory  
13 conditions. The transmission coefficient for the single device and double devices with staggered  
14 configuration are 0.8 and 0.6, respectively (Zanutigh et al., 2013). From this trend, it can be  
15 deduced that more effective wave attenuation performance can be obtained for a WEC array  
16 with many DEXA devices.

17 Since a reduction in wave height is observed behind a wave farm, it can be used to protect  
18 coastal areas from erosion. The role of the wave farm from a perspective of providing coastal  
19 protection from erosion is analyzed in Refs. (Bergillos et al., 2018; Abanades et al., 2014;  
20 Abanades et al., 2015). As is expected, the wave farm induces a wave height reduction at its lee  
21 side and significant reduction in erosion of the beach can be achieved. It is worth noting that the  
22 distance between the coast and the wave farm affects the shelter pattern (Abanades et al., 2015).  
23 Mendoza et al. (2014) investigated the beach response to wave farms (consisting of classical  
24 WECs, such as DEXA, Wave Dragon, SeaBreath, Blow-Jet, etc.) acting as a coastal defense.

1 They pointed out that the farm layout with several lines of WECs is favorable for near-shore  
2 protection purpose. Nevertheless, the other coastal activities (such as aquaculture, navigations,  
3 etc.) should be taken into account while designing such kinds of wave farm with the function of  
4 coastal protection.

5 Sheltering effect is an important function of a wave farm. In addition to the function of coastal  
6 protection from erosion, wave farm can provide sheltering for other marine operations, such as  
7 offshore wind farm, aquaculture facilities, etc. (Weiss et al., 2018). Many hybrid wave-wind  
8 farm schemes have been proposed (Astariz et al., 2015; Pérez-Collazo et al., 2015). Due to the  
9 sheltering effect of the wave farm, wave conditions at the proposed areas will be more moderate  
10 (Veigas et al., 2014; Astariz et al., 2015; Astariz et al., 2015; Onea et al., 2016). Hence, longer  
11 design life periods and lower maintenance costs for the offshore wind turbines can be realized.  
12 Similarly, offshore renewable energy devices can also provide power for the offshore  
13 aquaculture facilities and stimulate the synergies between the two aspects. This may provide  
14 opportunities for co-location of offshore renewable energy devices and aquaculture farms.  
15 Making full use of the function of sheltering and power supply features of WECs may enhance  
16 the competitiveness of the ocean wave energy resource.

#### 17 **4. Issues and challenges**

18 The floating breakwater-WEC hybrid systems possess dual functions (i.e., breakwater  
19 function and wave energy utilization). The performance indexes of the hybrid systems are  
20 different from that of original breakwaters or WECs with single function. For the conventional  
21 structures, only one indicator (transmission coefficient or wave energy conversion efficiency)  
22 may be of concern. However, for the hybrid systems, both the functions of wave energy  
23 conversion and coastal protection shall be considered collectively. Hence, the design methods or  
24 the test procedures for the conventional breakwaters or WECs may not suitable for the hybrid  
25 systems.

26  
27 Table 2 Comparisons of the achievable transmission coefficient and efficiency of some hybrid  
28 systems. A, B and C represent the floating breakwater-OB type WEC system, floating

1 breakwater-OWC type-WEC system and WEC array with sheltering function, respectively.

2 W2W denotes wave-to-wire.

| Hybrid system                                    | Transmission coefficient | Efficiency               | Efficiency measurement            | Category | Reference                 |
|--|--------------------------|--------------------------|-----------------------------------|----------|---------------------------|
| Single pontoon system                            | 0.4-0.55                 | 0-35%                    | W2W measured value                | A        | (Ning et al., 2016)       |
| Dual pontoon-single PTO system                   | 0.42-0.55                | 42%-55%                  | W2W measured value                | A        | (Zhao and Ning, 2018)     |
| Dual pontoon- PTO system                         | 0.34-0.52                | 22%-51%                  | W2W measured value                | A        | (Ning et al., 2018)       |
| The Berkeley Wedge                               | 0.125                    | 96%                      | Theoretical value                 | A        | (Madhi et al., 2018)      |
| Double horizontal cylinder                       | 0.71-0.85                | 25%-42%                  | W2W numerical value               | A        | (Chen et al., 2016)       |
| Floating breakwater-WEC system                   | 0.5                      | 20%                      | W2W measured value                | A        | (Martinelli et al., 2016) |
| Catamaran breakwater-WEC system                  | < 0.5                    | 37% (resonant condition) | W2W measured value                | A        | (Favaretto et al., 2017)  |
| Floating wave energy caisson breakwaters         | < 0.5                    | 50% (maximum efficiency) | Experimental pneumatic efficiency | B        | (Neelamani et al., 2006)  |
| Floating breakwater with dual pneumatic chambers | -                        | 44% (maximum efficiency) | Experimental pneumatic efficiency | B        | (He et al., 2017)         |
| DEXA device                                      | 0.8 for single device,   | 10%-35%                  | W2W measured value                | C        | (Zanuttigh et al., 2013)  |



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For the hybrid breakwater-WEC systems, the ideal condition is that the incident wave energy is totally absorbed by the WECs and the scattered wave energy is canceled at a wide frequency range. Previous theoretical investigations reveal that an efficiency of 100% can be achieved for devices with multiple DOFs (Evans, 1976). However, it is challenging to achieve this ideal condition in reality. It is understood that the transmission coefficient is an important indicator while evaluating the wave attenuation performance of the floating breakwater. For a specific floating breakwater that meets the engineering application design, the transmission coefficient should be maintained below 0.5. Hence, under the premise of  $K_T < 0.5$ , hybrid systems with higher energy conversion efficiency are more competitive. Table 2 showed the achievable transmission coefficient and efficiency of some selected hybrid systems. It can be observed that the hybrid systems with OB type WECs perform better in terms of the wave energy conversion efficiency. Improvement of the energy conversion performance of the WECs can be achieved by two methods: 1) making full use of the waves reflected from the adjacent structures; 2) optimizing the energy-capturing buoy performance through methods such as the use of asymmetrical bodies (such as the TBW). In addition, the effective frequency bandwidth (with effective efficiency and a qualified transmission coefficient) is another important indicator that evaluates the performance of the hybrid system. Hybrid systems with broader effective frequency bandwidths are favorable.

For most of the floating breakwaters, poor wave attenuation performance in long wave conditions may lower their competitiveness. For hybrid systems that possess the characteristics of floating breakwater, similar issues still exist. Generally, floating breakwaters work effectively in short waves. However, wave energy devices operate ineffectively with features of low efficiency. High efficiency for WEC system in short waves is very important for the applications in the sea areas with mild wave conditions, such as the East China Sea (Wang et al., 2011). Hence, improving the energy conversion efficiency in short waves and the wave attenuation performance in long waves is necessary to broaden the effective frequency bandwidth of the floating hybrid systems.

1 Most of the existing investigations were conducted in long-crested wave conditions. However,  
2 real ocean waves are multidirectional and coexist with wave-currents. There are some  
3 investigations that evaluate the performance of the conventional WECs in multi-directional  
4 waves, such as (Götteman et al., 2018). However, considering the hybrid systems, the data  
5 indicating the performance of the integrated system in short-crested waves and coexisting  
6 wave-current fields is rare and there is a necessity for further investigations.

7 The survivability of the hybrid system in extreme waves determines its prospects in  
8 engineering applications (Tiron et al., 2015; Saincher et al., 2016). The occurrence of extreme  
9 wave events accompanies the interaction of breaking waves and structures. These are a complex  
10 phenomenon characterized by flow separation and air-entrainment (Saincher and Banerjee, 2016;  
11 Wei et al., 2016; Chen et al., 2018; Martin-Medina et al., 2018). Fundamentally, developing  
12 corresponding efficient numerical techniques (such as the CFD method) and high-quality  
13 experimental procedures may pave the way to understand this complex hydrodynamic problem  
14 (Saincher and Banerjee, 2016; Windt et al., 2018). Further exploring the mechanics of the  
15 hydrodynamic behavior of floating buoys in breaking waves and proposing advanced protection  
16 strategies are necessary to improve the survivability of the hybrid system.

17 So far, most of the concepts are in the stage of theoretical study or small-scale laboratory test.  
18 As a design stage that must be completed, large-scale experiments and sea trial tests with the  
19 implementation of the real hydraulic PTO systems are urged.

## 20 **5. Conclusions**

21 In this paper, a literature review was presented with a focus on the research and development  
22 of various types of hybrid floating breakwater-WEC systems over the past few years. The  
23 features and the advantages and disadvantages of different types of floating integrations were  
24 described. The corresponding challenges and issues were specified from the point view of  
25 fundamental hydrodynamics and technical solutions.

26 The conventional floating breakwaters and conventional wave energy devices are introduced  
27 and categorized based on their working principles. As hybrid structures with dual functionality  
28 (wave energy utilization and wave attenuation), the floating breakwater-WEC systems are

1 categorized as the wave-energy-utilizing type breakwater. The floating breakwater-WEC systems  
2 are divided into four categories: floating breakwater-OB type WEC system, floating  
3 breakwater-OWC type WEC system, floating breakwater-overtopping type WEC system, and  
4 floating WEC array with sheltering function. Since such kind of systems were characterized by  
5 the cost-sharing, space-sharing and their multiple capabilities, the concept of combining the two  
6 aspects of protection and energy generation is beneficial to reduce the construction cost of both  
7 floating breakwaters and WECs. In addition, we present some investigations on wave farms with  
8 the dual function of coastal protection from erosion and sheltering specific engineering  
9 installations (such as offshore wind farms).

10 The floating breakwaters-WEC system is an attractive solution to coastal engineering, island  
11 engineering, aquaculture engineering and other massive ocean engineering projects (e.g., VLFS)  
12 that need power supply and protection against wave action. Even though many effective  
13 concepts have been proposed, there remain many untapped research areas. The main interesting  
14 outstanding challenges include evaluating the performance of the hybrid system in realistic sea  
15 states (i.e., multi-directional waves, wave-current coexisting filed, etc.), broadening the effective  
16 frequency bandwidth of the hybrid system, examining survivability of the hybrid system in  
17 extreme waves, etc. Since the marine structures must survive severe storms, the new challenges  
18 for the hybrid system are how to improve the survivability of the devices and propose further  
19 design guidance.

20 Further studies may also include the fundamental research on wave-structure interactions  
21 (especially for breaking wave-structure interactions) and protection strategies from extreme sea  
22 states to improve the survivability of these installations. Of course, novel designs of the hybrid  
23 system with simplicity in configuration, high energy conversion efficiency, excellent wave  
24 attenuation performance and broad effective frequency bandwidth are welcomed.

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1 (Grant No. ISEE2018PY05).

## 3 **References:**

- 4 Floating Power Plant Products & Services. <http://www.floatingpowerplant.com/products/> (accessed 1 Dec  
5 2019).
- 6 Abanades, J., Flor-Blanco, G., Flor, G., Iglesias, G., 2018. Dual Wave Farms for Energy Production and  
7 Coastal Protection. *Ocean Coast Manage.* 160, 18-29.
- 8 Abanades, J., Greaves, D., Iglesias, G., 2014. Coastal Defence through Wave Farms. *Coast Eng.* 91, 299-307.
- 9 Abanades, J., Greaves, D., Iglesias, G., 2015. Coastal Defence Using Wave Farms: The Role of Farm-to-Coast  
10 Distance. *Renew Energ.* 75, 572-582.
- 11 Allan, G., Gilmartin, M., Mcgregor, P., Swales, K., 2011. Levelised Costs of Wave and Tidal Energy in the Uk:  
12 Cost Competitiveness and the Importance of “Banded” Renewables Obligation Certificates. *Energy Policy.*  
13 39(1), 23-39.
- 14 Astariz, S., Abanades, J., Perez-Collazo, C., Iglesias, G., 2015. Improving Wind Farm Accessibility for  
15 Operation & Maintenance through a Co-Located Wave Farm: Influence of Layout and Wave Climate. *Energy*  
16 *Convers Manage.* 95, 229-241.
- 17 Astariz, S., Iglesias, G., 2015. The Economics of Wave Energy: A Review. *Renewable and Sustainable Energy*  
18 *Reviews.* 45, 397-408.
- 19 Astariz, S., Perez-Collazo, C., Abanades, J., Iglesias, G., 2015. Towards the Optimal Design of a Co-Located  
20 Wind-Wave Farm. *Energy.* 84(Supplement C), 15-24.
- 21 Babarit, A., 2017. *Ocean Wave Energy Conversion: Resource, Technologies and Performance.* ISTE Press -  
22 Elsevier
- 23 Beels, C., Troch, P., De Visch, K., Kofoed, J.P., De Backer, G., 2010. Application of the Time-Dependent  
24 Mild-Slope Equations for the Simulation of Wake Effects in the Lee of a Farm of Wave Dragon Wave  
25 Energy Converters. *Renew Energ.* 35(8), 1644-1661.
- 26 Bergillos, R.J., López-Ruiz, A., Medina-López, E., Moñino, A., Ortega-Sánchez, M., 2018. The Role of Wave  
27 Energy Converter Farms On Coastal Protection in Eroding Deltas, Guadalfeo, Southern Spain. *J. Clean Prod.*  
28 171, 356-367.
- 29 Boccotti, P., 2007. Comparison Between a U-Owc and a Conventional Owc. *Ocean Eng.* 34(5-6), 799-805.
- 30 Borthwick, A.G.L., 2016. Marine Renewable Energy Seascape. *Engineering.* 2(1), 69-78.
- 31 Buccino, M., Stagonas, D., Vicinanza, D., 2015. Development of a Composite Sea Wall Wave Energy  
32 Converter System. *Renew Energ.* 81, 509-522.
- 33 Carballo, R., Iglesias, G., 2013. Wave Farm Impact Based On Realistic Wave-WEC Interaction. *Energy.* 51,  
34 216-229.
- 35 Chatzigiannakou, A.M., Dolguntseva, I., Leijon, M., 2017. Offshore Deployments of Wave Energy Converters  
36 by Seabased Industry AB. *J. Mar. Sci. Eng.* 5(2), 15
- 37 Chen, B., Liu, C., Kang, H., 2015. Performance of Floating Breakwater Double Used as Wave Energy  
38 Converter. In: *Proceedings of the 25<sup>th</sup> International Offshore and Polar Engineering Conference.*
- 39 Chen, B., Ning, D., Liu, C., Greated, C.A., Kang, H., 2016. Wave Energy Extraction by Horizontal Floating  
40 Cylinders Perpendicular to Wave Propagation. *Ocean Eng.* 121, 112-122.
- 41 Chen, Q., Zang, J., Kelly, D.M., Dimakopoulos, A.S., 2018. A 3D Parallel Particle-in-Cell Solver for Wave  
42 Interaction with Vertical Cylinders. *Ocean Eng.* 147, 165-180.
- 43 Chen, W., Gao, F., Meng, X., Chen, B., Ren, A., 2016. W2P: A High-Power Integrated Generation Unit for  
44 Offshore Wind Power and Ocean Wave Energy. *Ocean Eng.* 128, 41-47.

1 Clément, A., Mccullen, P., Falcão, A., Fiorentino, A., Gardner, F., Hammarlund, K., Lemonis, G., Lewis, T.,  
2 Nielsen, K., Petroncini, S., Pontes, M.T., Schild, P., Sjöström, B., Sørensen, H.C., Thorpe, T., 2002. Wave  
3 Energy  
4 in Europe: Current Status and Perspectives. *Renewable and Sustainable Energy Reviews*. 6(5), 405-431.  
5 Com, M., 2017. Breakwater Beats the Weather at Holy Loch.  
6 <https://www.maritimejournal.com/news101/marine-civils/port,-harbour-and-marine>  
7 [construction/breakwater\\_beats\\_the\\_weather\\_at\\_holy\\_loch](https://www.maritimejournal.com/news101/marine-civils/port,-harbour-and-marine)  
8 Cruz, J., 2007. Ocean Wave Energy: Current Status and Future Perspectives.  
9 Dai, J., Wang, C.M., Utsunomiya, T., Duan, W., 2018. Review of Recent Research and Developments On  
10 Floating Breakwaters. *Ocean Eng.* 158, 132-151.  
11 Di Lauro, E., Lara, J.L., Maza, M., Losada, I.J., Contestabile, P., Vicinanza, D., 2019. Stability Analysis of a  
12 Non-Conventional Breakwater for Wave Energy Conversion. *Coast Eng.* 145, 36-52.  
13 Diamantoulaki, I., Angelides, D.C., Manolis, G.D., 2008. Performance of Pile-Restrained Flexible Floating  
14 Breakwaters. *Appl Ocean Res.* 30(4), 243-255.  
15 Drew, B., Plummer, A.R., Sahinkaya, M.N., 2009. A Review of Wave Energy Converter Technology.  
16 *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*. 223(8),  
17 887-902.  
18 Elginöz, N., Bas, B., 2017. Life Cycle Assessment of a Multi-Use Offshore Platform: Combining Wind and  
19 Wave Energy Production. *Ocean Eng.* 145, 430-443.  
20 Elhanafi, A., Macfarlane, G., Fleming, A., Leong, Z., 2017. Experimental and Numerical Investigations On the  
21 Hydrodynamic Performance of a Floating–Moored Oscillating Water Column Wave Energy Converter. *Appl*  
22 *Energ.* 205, 369-390.  
23 Evans, D.V., 1976. A Theory for Wave-Power Absorption by Oscillating Bodies. *J. Fluid Mech.* 77(1), 1-25.  
24 Falcão, A.F.D.O., 2010. Wave Energy Utilization: A Review of the Technologies. *Renewable and Sustainable*  
25 *Energy Reviews*. 14(3), 899-918.  
26 Falcão, A.F.O., Henriques, J.C.C., 2016. Oscillating-Water-Column Wave Energy Converters and Air Turbines:  
27 A Review. *Renew Energ.* 85, 1391-1424.  
28 Falnes, J., 2007. A Review of Wave-Energy Extraction. *Mar Struct.* 20(4), 185-201.  
29 Favaretto, C., Martinelli, L., Ruol, P., Cortellazzo, G., 2017. Investigation on Possible Layouts of a Catamaran  
30 Floating Breakwater Behind a Wave Energy Converter. In: *Proceedings of the 27<sup>th</sup> International Offshore*  
31 *and Polar Engineering Conference*.  
32 Ferro, B.D., 2006. Wave and Tidal Energy: Its Emergence and the Challenges It Faces. *Refocus.* 7(3), 46-48.  
33 Flocard, F., Hoeke, R.K., 2017. Coastal Protection through Wave Farms: Feasibility Assessment Using  
34 Numerical Wave Modelling and Parametric Study. *Coasts and Ports Conference*.  
35 Frigaard, P., Kofoed, J.P., Tedd, J.W., 2006. The Wave Energy Device: Wave Dragon. In: *Proceedings of the*  
36 *International Interdisciplinary Conference on Sustainable Technologies for Environmental Protection: ICSTEP*  
37 *2006*.  
38 Garnaud, X., Mei, C.C., 2009. Wave-Power Extraction by a Compact Array of Buoys. *J. Fluid Mech.* 635,  
39 389-413.  
40 Göteman, M., Mcnatt, C., Giassi, M., Engström, J., Isberg, J., 2018. Arrays of Point-Absorbing Wave Energy  
41 Converters in Short-Crested Irregular Waves. *Energies* 2018, 11(4), 964  
42 Guerra, F., 2018. Mapping Offshore Renewable Energy Governance. *Mar Policy.* 89, 21-33.  
43 Hansen, L.K., Christensen, L., Chr, H., 2003. Experiences from the Approval Process of the Wave Dragon  
44 Project. In: *Proceedings from the 5<sup>th</sup> European Wave Energy Conference, Cork, Ireland*  
45 Hart, P., Lurie, R.F., 2012. Application of Powerbuoy Wave Energy Converter Technology to Remote Power

1 Requirements in Oil and Gas Field Developments. In: Offshore Technology Conference, OTC-23135-MS:  
2 1-11

3 He, F., Huang, Z., 2014. Hydrodynamic Performance of Pile-Supported Owc-Type Structures as Breakwaters:  
4 An Experimental Study. *Ocean Eng.* 88, 618-626.

5 He, F., Huang, Z., Law, A.W.K., 2013. An Experimental Study of a Floating Breakwater with Asymmetric  
6 Pneumatic Chambers for Wave Energy Extraction. *Appl Energ.* 106, 222-231.

7 He, F., Huang, Z., Wing-Keung Law, A., 2012. Hydrodynamic Performance of a Rectangular Floating  
8 Breakwater with and without Pneumatic Chambers: An Experimental Study. *Ocean Eng.* 51, 16-27.

9 He, F., Leng, J., Zhao, X., 2017. An Experimental Investigation into the Wave Power Extraction of a Floating  
10 Box-Type Breakwater with Dual Pneumatic Chambers. *Appl Ocean Res.* 67, 21-30.

11 Heath, T.V., 2000. Chapter 334 - The Development and Installation of the Limpet Wave Energy Converter. In  
12 *Sayigh AAM (World Renewable Energy Congress VI. Oxford, Pergamon, 2000, pp 1619-1622.*

13 Hemer, M.A., Manasseh, R., McInnes, K.L., Penesis, I., Pitman, T., 2018. Perspectives On a Way Forward for  
14 Ocean Renewable Energy in Australia. *Renew Energ.* 127, 733-745.

15 Hong, D.C., Hong, S.Y., 2007. Hydroelastic Responses and Drift Forces of a Very-Long Floating Structure  
16 Equipped with a Pin-Connected Oscillating-Water-Column Breakwater System. *Ocean Eng.* 34(5), 696-708.

17 Hong, D.C., Hong, S.Y., Hong, S.W., 2006. Reduction of Hydroelastic Responses of a Very-Long Floating  
18 Structure by a Floating Oscillating-Water-Column Breakwater System. *Ocean Eng.* 33(5), 610-634.

19 Hotta, H., Washio, Y., Yokozawa, H., Miyazaki, T., 1996. R&D On Wave Power Device “Mighty Whale”.  
20 *Renew Energ.* 9(1), 1223-1226.

21 Isaacson, M., Baldwin, J., Bhat, S., 1998. Wave Propagation Past a Pile-Restrained Floating Breakwater. *Int J.*  
22 *Offshore Polar.* 8(4), 265-269.

23 Jeffrey, H., Jay, B., Winkler, M., 2013. Accelerating the Development of Marine Energy: Exploring the  
24 Prospects, Benefits and Challenges. *Technol Forecast Soc.* 80(7), 1306-1316.

25 Kofoed, J.P., Frigaard, P., Friis-Madsen, E., Sørensen, H.C., 2006. Prototype Testing of the Wave Energy  
26 Converter Wave Dragon. *Renew Energ.* 31(2), 181-189.

27 Koo, W., 2009. Nonlinear Time-Domain Analysis of Motion-Restrained Pneumatic Floating Breakwater.  
28 *Ocean Eng.* 36(9), 723-731.

29 Koutandos, E.V., Prinios, P., Gironella, X., 2005. Floating Breakwaters Under Regular and Irregular Wave  
30 Forcing: Reflection and Transmission Characteristics. *J. Hydraul Res.* 43(2), 174-188.

31 Koutandos, E.V., Karambas, T.V., Koutitas, C.G., 2004. Floating Breakwater Response to Waves Action Using  
32 a Boussinesq Model Coupled with a 2Dv Elliptic Solver. *Journal of Waterway, Port, Coastal and Ocean*  
33 *Engineering.* 130(5), 243-255.

34 Kusaka, T., Ueda, S., 2015. *Ujina Floating Ferry Pier and Kan-On Floating Breakwater*, Japan, Springer  
35 Singapore, 2015.

36 Lee, H., Poguluri, K.S., Bae, H.Y., 2018. Performance Analysis of Multiple Wave Energy Converters Placed  
37 On a Floating Platform in the Frequency Domain. *Energies*, 11(2), 406

38 Lehmann, M., Karimpour, F., Goudey, C.A., Jacobson, P.T., Alam, M., 2017. Ocean Wave Energy in the  
39 United States: Current Status and Future Perspectives. *Renewable and Sustainable Energy Reviews.* 74,  
40 1300-1313.

41 Lopes De Almeida, J.P.P.G., 2017. Reefs: An Artificial Reef for Wave Energy Harnessing and Shore Protection  
42 – a New Concept Towards Multipurpose Sustainable Solutions. *Renew Energ.* 114, 817-829.

43 Luo, Y., Wang, Z., Peng, G., Xiao, Y., Zhai, L., Liu, X., Zhang, Q., 2014. Numerical Simulation of a  
44 Heave-Only Floating OWC (Oscillating Water Column) Device. *Energy.* 76, 799-806.

45 Madhi, F., Sinclair, M.E., Yeung, R.W., 2014. The “Berkeley Wedge”: An Asymmetrical Energy-Capturing

1 Floating Breakwater of High Performance. *Mar. Syst. Ocean Technol.* 9(1): 5-16

2 Madhi, F., Yeung, R.W., 2018. On Survivability of Asymmetric Wave-Energy Converters in Extreme Waves.

3 *Renew Energ.* 119, 891-909.

4 Madhi, F., Yeung, R.W., Sinclair, M.E., 2015. Energy-Capturing Floating Breakwater.

5 Malara, G., Romolo, A., Fiamma, V., Arena, F., 2017. On the Modelling of Water Column Oscillations in

6 U-OWC Energy Harvesters. *Renew Energ.* 101, 964-972.

7 Margheritini, L., Vicinanza, D., Frigaard, P., 2009. SSG Wave Energy Converter: Design, Reliability and

8 Hydraulic Performance of an Innovative Overtopping Device. *Renew Energ.* 34(5), 1371-1380.

9 Martinelli, L., Ruol, P., Favaretto, C., 2016. Hybrid Structure Combining a Wave Energy Converter and a

10 Floating Breakwater. In: *Proceedings of the International Offshore and Polar Engineering Conference, 2016,*

11 *2016-January*, pp 622-628.

12 Martin-Medina, M., Abadie, S., Mokrani, C., Morichon, D., 2018. Numerical Simulation of Flip-through

13 Impacts of Variable Steepness On a Vertical Breakwater. *Appl Ocean Res.* 75, 117-131.

14 Mccartney, B.L., 1985. Floating Breakwater Design. *Journal of Waterway, Port, Coastal and Ocean*

15 *Engineering.* 111(2), 304-318.

16 McNatt, J.C., Venugopal, V., Forehand, D., 2015. A Novel Method for Deriving the Diffraction Transfer Matrix

17 and its Application to Multi-Body Interactions in Water Waves. *Ocean Eng.* 94, 173-185.

18 Mei, C.C., 1976. Power Extraction from Water Waves. *J. Ship Res.* 20(2), 63-66.

19 Mendoza, E., Silva, R., Zanuttigh, B., Angelelli, E., Lykke Andersen, T., Martinelli, L., Nørgaard, J.Q.H., Ruol,

20 P., 2014. Beach Response to Wave Energy Converter Farms Acting as Coastal Defence. *Coast Eng.* 87,

21 97-111.

22 Michailides, C., 2017. Power Performance and Dynamic Response of the Wlc Wave Energy Converter Based

23 On Hydroelastic Analysis. *International Journal of Marine Energy.* 19, 83-94.

24 Michailides, C., Angelides, D.C., 2011. Wave Energy Production by a Flexible Floating Breakwater. In:

25 *Proceedings of the 21<sup>th</sup> International Offshore and Polar Engineering Conference, 2011*, pp 614-621.

26 Michailides, C., Angelides, D.C., 2012. Modeling of Energy Extraction and Behavior of a Flexible Floating

27 Breakwater. *Appl Ocean Res.* 35, 77-94.

28 Michailides, C., Angelides, D.C., 2015. Optimization of a Flexible Floating Structure for Wave Energy

29 Production and Protection Effectiveness. *Eng Struct.* 85, 249-263.

30 Michailides, C., Loukogeorgaki, E., Angelides, D.C., 2013. Response Analysis and Optimum Configuration of

31 a Modular Floating Structure with Flexible Connectors. *Appl Ocean Res.* 43, 112-130.

32 Muliawan, M.J., Karimirad, M., Moan, T., 2013. Dynamic Response and Power Performance of a Combined

33 Spar-Type Floating Wind Turbine and Coaxial Floating Wave Energy Converter. *Renew Energ.* 50, 47-57.

34 Musa, M.A., Maliki, A.Y., Ahmad, M.F., Sani, W.N., Yaakob, O., Samo, K.B., 2017. Numerical Simulation of

35 Wave Flow Over the Overtopping Breakwater for Energy Conversion (Obrec) Device. *Procedia Engineering.*

36 194, 166-173.

37 Mustapa, M.A., Yaakob, O.B., Ahmed, Y.M., Rheem, C., Koh, K.K., Adnan, F.A., 2017. Wave Energy Device

38 and Breakwater Integration: A Review. *Renewable and Sustainable Energy Reviews.* 77, 43-58.

39 Mynett, A.E., Serman, D.D., Mei, C.C., 1979. Characteristics of Salter's Cam for Extracting Energy From

40 Ocean Waves. *Appl Ocean Res.* 1(1), 13-20.

41 Neelamani, S., Natarajan, R., Prasanna, D.L., 2006. Wave Interaction with Floating Wave Energy Caisson

42 Breakwaters. *J. Coastal Res.* 22(2), 745-749.

43 Neill, S.P., Hashemi, M.R., 2018. *Fundamentals of Ocean Renewable Energy.* Academic Press, 2018, pp 1-30.

44 Ning, D., Zhao, X., Götteman, M., Kang, H., 2016. Hydrodynamic Performance of a Pile-Restrained Wec-Type

45 Floating Breakwater: An Experimental Study. *Renew Energ.* 95, 531-541.

1 Ning, D., Zhao, X., Zhao, M., Kang, H., 2018. Experimental Investigation On Hydrodynamic Performance of  
2 a Dual Pontoon–Power Take-Off Type Wave Energy Converter Integrated with Floating Breakwaters.  
3 Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime  
4 Environment., 1475090218804677.

5 Ning, D.Z., Zhao, X.L., Zhao, M., Hann, M., Kang, H.G., 2017. Analytical Investigation of Hydrodynamic  
6 Performance of a Dual Pontoon WEC-Type Breakwater. *Appl Ocean Res.* 65, 102-111.

7 Ning, D. Z., Zhao, X. L., Chen, L. F., Zhao, M., 2018. Hydrodynamic Performance of an Array of Wave  
8 Energy Converters Integrated with a Pontoon-Type Breakwater. *Energies* 11(3), 685

9 Nørgaard, J.H., Andersen, T.L., Kofoed, J.P., 2011. Wave Dragon Wave Energy Converters Used as Coastal  
10 Protection. Coastal Structures 2011, Yokohama, Japan

11 Onea, F., Rusu, E., 2016. The Expected Efficiency and Coastal Impact of a Hybrid Energy Farm Operating in  
12 the Portuguese Nearshore. *Energy.* 97, 411-423.

13 Ouyang, H., Chen, K., Tsai, C., 2015. Investigation On Bragg Reflection of Surface Water Waves Induced by a  
14 Train of Fixed Floating Pontoon Breakwaters. *Int. J. Nav. Arch. Ocean.* 7(6), 951-963.

15 Peiffer, A., Roddier, D., Aubault, A., 2011. Design of a Point Absorber Inside the Windfloat Structure. In:  
16 Proceedings of 30th International Conference on Ocean, Offshore and Arctic Engineering, Rotterdam, The  
17 Netherlands.

18 Pérez-Collazo, C., Greaves, D., Iglesias, G., 2015. A Review of Combined Wave and Offshore Wind Energy.  
19 *Renewable and Sustainable Energy Reviews.* 42, 141-153.

20 Renzi, E., Doherty, K., Henry, A., Dias, F., 2014. How Does Oyster Work? The Simple Interpretation of Oyster  
21 Mathematics. *European Journal of Mechanics - B/Fluids.* 47, 124-131.

22 Rodriguez-Delgado, C., Bergillos, R.J., Ortega-Sánchez, M., Iglesias, G., 2018. Wave Farm Effects On the  
23 Coast: The Alongshore Position. *Sci Total Environ.* 640-641, 1176-1186.

24 Saincher, S., Banerjee, J., 2016. Influence of Wave Breaking On the Hydrodynamics of Wave Energy  
25 Converters: A Review. *Renewable and Sustainable Energy Reviews.* 58, 704-717.

26 Salter, S.H., 1974. Wave Power. *Nature.* 249, 720

27 Sawaragi, T., 1995. Coastal Engineering – Waves, Beaches, Wave-Structure Interactions.

28 Soerensen, H.C., Hansen, R., Friis-Madsen, E., Panhauser, W., Mackie, G., Frigaard, P., Hald, T., Knapp, W.,  
29 Keller, J., Holmén, E., 2000. The Wave Dragon - Now Ready for Test in Real Sea. In: Proceedings of the 4<sup>th</sup>  
30 European Wave Energy Conference, Aalborg, Denmark

31 Strati, F.M., Malara, G., Arena, F., 2016. Performance Optimization of a U-Oscillating-Water-Column Wave  
32 Energy Harvester. *Renew Energ.* 99, 1019-1028.

33 Sundar, V., Moan, T., Hals, J., 2010. Conceptual Design of Owc Wave Energy Converters Combined with  
34 Breakwater Structures. ASME 2010 29th International Conference on Ocean, Offshore and Arctic  
35 Engineering.

36 Takahashi, S., 1988. Hydrodynamic Characteristics of Wave-Power-Extracting Caisson Breakwater.  
37 Twenty-First Coastal Engineering Conference, New York, NY, United States

38 Tiron, R., Mallon, F., Dias, F., Reynaud, E.G., 2015. The Challenging Life of Wave Energy Devices at Sea: A  
39 Few Points to Consider. *Renewable and Sustainable Energy Reviews.* 43, 1263-1272.

40 Tom, N.M., Madhi, F., Yeung, R.W., 2019. Power-to-Load Balancing for Asymmetric Heave Wave Energy  
41 Converters with Nonideal Power Take-Off. *Renew Energ.* 131, 1208-1225

42 Toner, D., Mathies, M., 2002. The Potential for Renewable Energy Usage in Aquaculture. Report.

43 Vassiliou, V., Charalambides, M., Menicou, M., Chartosia, N., Tzen, E., Evagelos, B., Papadopoulos, P.,  
44 Loucaides, A., 2015. Aquaculture Feed Management System Powered by Renewable Energy Sources:  
45 Investment Justification. *Aquaculture economics & management.* 19(4), 423-443.



1 Veigas, M., Iglesias, G., 2014. Potentials of a Hybrid Offshore Farm for the Island of Fuerteventura. *Energy*  
2 *Conversion and Management*. 86, 300-308.

3 Vicinanza, D., Contestabile, P., Quvang Harck Nørgaard, J., Lykke Andersen, T., 2014. Innovative Rubble  
4 Mound Breakwaters for Overtopping Wave Energy Conversion. *Coast Eng.* 88, 154-170.

5 Wang, S., Yuan, P., Li, D., Jiao, Y., 2011. An Overview of Ocean Renewable Energy in China. *Renewable and*  
6 *Sustainable Energy Reviews*. 15(1), 91-111.

7 Wang, Y.X., Dong, H.Y., Liu, C., 2010. Experimental Study of a Pile-Restrained Floating Breakwater  
8 Constructed of Pontoon and Plates. *China Ocean Eng.* 24(1), 183-190.

9 Wei, Y., Abadie, T., Henry, A., Dias, F., 2016. Wave Interaction with an Oscillating Wave Surge Converter. Part  
10 II: Slamming ☆. *Ocean Eng.* 113, 319-334.

11 Weiss, C.V.C., Ondiviela, B., Guinda, X., Del Jesus, F., González, J., Guanche, R., Juanes, J.A., 2018.  
12 Co-Location Opportunities for Renewable Energies and Aquaculture Facilities in the Canary Archipelago.  
13 *Ocean Coast Manage.* 166, 62-71

14 Windt, C., Davidson, J., Ringwood, J.V., 2018. High-Fidelity Numerical Modelling of Ocean Wave Energy  
15 Systems: A Review of Computational Fluid Dynamics-Based Numerical Wave Tanks. *Renewable and*  
16 *Sustainable Energy Reviews*. 93, 610-630.

17 Wu, J., Yao, Y., Zhou, L., Götteman, M., 2018. Real-Time Latching Control Strategies for the Solo Duck Wave  
18 Energy Converter in Irregular Waves. *Appl Energy*. 222, 717-728.

19 Xiros, N.I., Dhanak, M.R., 2016. Ocean Wave Energy Conversion Concepts. *Springer Handbook of Ocean*  
20 *Engineering*, pp1117-1146.

21 Zang, Z., Zhang, Q., Qi, Y., Fu, X., 2018. Hydrodynamic Responses and Efficiency Analyses of a  
22 Heaving-Buoy Wave Energy Converter with PTO Damping in Regular and Irregular Waves. *Renew Energy*.  
23 116, 527-542.

24 Zanuttigh, B., Angelelli, E., 2013. Experimental Investigation of Floating Wave Energy Converters for Coastal  
25 Protection Purpose. *Coast Eng.* 80, 148-159.

26 Zanuttigh, B., Martinelli, L., Castagnetti, M., Ruol, P., Kofoed, J.P., Frigaard, P., 2010. Integration of Wave  
27 Energy Converters into Coastal Protection Schemes. In: *Proceedings of the 3rd International Conference*  
28 *and Exhibition on Ocean Energy*.

29 Zhang, H., Xu, D., Liu, C., Wu, Y., 2017. A Floating Platform with Embedded Wave Energy Harvesting Arrays  
30 in Regular and Irregular Seas. *Energies*. 10(9), 1348.

31 Zhao, X., Ning, D., 2018. Experimental Investigation of Breakwater-Type Wec Composed of Both Stationary  
32 and Floating pontoons. *Energy*. 155, 226-233.

33 Zhao, X., Ning, D., Zhang, C., Kang, H., 2017. Hydrodynamic Investigation of an Oscillating Buoy Wave  
34 Energy Converter Integrated into a Pile-Restrained Floating Breakwater. *Energies*. 10(5), 712

35 Zhao, X., Ning, D., Zhang, C., Liu, Y., Kang, H., 2017. Analytical Study On an Oscillating Buoy Wave Energy  
36 Converter Integrated into a Fixed Box-Type Breakwater. *Math Probl Eng.* 2017

37 Zhao, X.L., Ning, D.Z., Liang, D.F., 2019. Experimental Investigation On Hydrodynamic Performance of a  
38 Breakwater-Integrated Wec System. *Ocean Eng.* 171, 25-32.

39 Zheng, S., Zhang, Y., 2017. Analysis for Wave Power Capture Capacity of Two Interconnected Floats in  
40 Regular Waves. *J. Fluid Struct.* 75, 158-173.

41 Zingale, G., 2002. Modular Floating Breakwater for the Transformation of Wave Energy.