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An empirical evaluation of the sea depth effects for various wave characteristics on the performance of a point absorber wave energy converter

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ABSTRACT

In this paper, the effects of sea depth on the performance of a modified point absorber wave energy converter (WEC) are examined using an experimental study. For experimental evaluation of WEC, the general cubic shape is used. For obtaining the final shape of this novel WEC, 3 stages are considered including, still water depth optimization, optimization of geometrical specifications and shape optimization. The focus of this article is on the first stage. In this context, by creating waves with different amplitudes and periods, evaluation is conducted in three different still water depths. WEC oscillation in the directions of heave, surge and pitch are measured and compared. Furthermore, an appropriate scale for building a full scale WEC for operating in the Caspian Sea environment is studied and proposed. Experimental test results show that increasing the water depth causes an increment on the WEC oscillation on the directions of heave and pitch. However, this process is different in the case of surge oscillations; increasing the depth leads to a reduction in WEC oscillation. The analysis of these results shows that the use of point absorber WEC with the dominant motion of pitch in deep water can provide better conditions for energy extraction.

1. Introduction

Energies extracted from the ocean waves around the world are acknowledged as clean, natural, abundant and renewable. These renewable resources do not have any environmental pollution and will not lead to increase in the rate of global warming. Ocean waves have several advantages for using as a renewable energy production method; they are frequent, periodic, and predictable. The possibility of converting wave energy into usable energy has been an inspiration to many inventors and researchers. By 1980, more than a thousand patents were registered in this area and since then the number has increased considerably (McCormick, 1981).

In the leading countries, with respect to wave energy technologies, preliminary studies were developed for the purpose of exploring wave energy resources. According to the literature, the majority of works are done with respect to the characteristic of a specified sea or region; on this basis in recent years, many seas around the world have been studied by researchers (Kamranzad et al., 2013; Mota and Pinto, 2014; Soomere and Eelsalu, 2014; Zheng et al., 2013). However, the Caspian Sea with having suitable energy level did not gain a lot of attentions. In the current article, the Caspian Sea is introduced briefly and wave energy potential near the coast of northern Iran is investigated.

In 2014, a comprehensive study was done by Alamian et al. (Alamian et al., 2014) on the proper wave energy converters (WECs) for extracting energy from the Caspian Sea waves. Their results indicated that a point absorber WEC with dominant oscillations in the pitch direction is the most suitable type of WEC for operating in the Caspian Sea. McCabe et al. in 2006 explored the development of PS Frog Mk 5 WEC made at Lancaster University (McCabe et al., 2006). This WEC consists of a large buoyant paddle with an integral ballasted 'handle' hanging below it. The waves act on the blade of the paddle and the ballast beneath provides the necessary reaction. When the WEC is pitching, power is extracted by partially resisting the sliding of a power-take-off mass, which moves in guides above sea level. It totally enclosed in a steel hull, with no external moving parts.

In the same year, Babarit et al. presented a new point absorber

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Fig. 1. : Left: left side view of the wave tank, right: right side view of the wave tank.

WEC, known as SEAREV (Babarit et al., 2006). SEAREV is a floating device enclosing a heavy horizontal axis wheel serving as an internal gravity reference. The centre of gravity of the wheel being off-centred, this component behaves mechanically like a pendulum. Two major advantages of this arrangement are firstly that first: all the moving parts are sheltered from the action of the sea inside a closed, water-proof shell; and secondly that the choice of a wheel working as a pendulum involves neither end stop nor any security system limiting the stroke. Later, Bracco et al. designed a 1:45 scaled WEC device, so called ISWEC, with a rated power of 2.2 W and performed several tank tests with a simplified plain float to verify the actual prototype power capabilities (Bracco et al., 2011). ISWEC is a system using the gyroscopic reactions provided from a spinning flywheel to extract power. The flywheel works inside a sealed floating body in order to be protected from the outer environment and grant a reliable and durable operation.

The WEC, used in the current article, like the other three WECs mentioned above is placed in an outer shell for complete sealing. The working principles of this WEC are the same as the one explained for the SEAREV; however, the power take-off (PTO) system which will be used in this system is different (Alamian et al., 2016). However, the PTO system is not in the concept of this article and will be explored more in detail in the future.

It is noted that, one of the most prominent features of the Caspian Sea is its drastic change in depth; hence, the important point in the use of WEC is considering the depth of the sea at the WEC installation site and its interactions during the extraction of energy. Therefore, this research concentrates on obtaining the proper still water depth for achieving the best WEC performance. This is first stage for optimizing the geometry and operating conditions for the WEC before working on the PTO, control or survivability of the WEC. The others including optimization of geometrical specifications and shape optimization, which also will be discussed in the future works.

In the recent years, there are few works focusing on the effect of still water depth on the performance of WECs. Fernandes, and Fonseca in 2013, analyzed the water depth effects on the wave energy resource and on the energy absorbed by a floating device (Fernandes and Fonseca, 2013). They modelled a point absorber-type wave energy converter and used the wave climatology of Figueira da Foz (Portugal) as a case study. They identified significant reductions for both the wave energy resource and wave energy converted as the water depth decreases. In 2007, Folley et al. extensively investigated the effect of water depth on the performance of a small surging WEC using analytical, numerical as well as experimental approaches (Folley et al., 2007). Their experimental results demonstrated that both the surge wave force and power capture of a flap-type WEC increase in shallow water.

These works focused either on one direction for extracting wave energy or studied the effect of water depth on the general performance of a specific WEC; they do not discuss about the performance of the WEC in different directions with changing in still water depth. Achieving this goal, in the current study an experimental wave tank is used to examine the performance of a WEC system in variety of sea conditions. For this purpose, first, waves generated by wave maker system are calibrated. Then, the WEC is placed in the wave tank and the data from WEC oscillation in different directions is analyzed and discussed. Additionally, in order to achieve comprehensive and applicable results, the tests are repeated for three different still water depths and the water depth impact on WEC oscillations in three directions including heave, surge and pitch is reported. The ultimate goal of this study is to determine the suitable still water depth for WEC settlement in order to achieve the greatest oscillations in the desired direction. Furthermore, an appropriate scaling, according to oscillation type of the WEC, is obtained and presented in order to build a real model (full scale) for applying in the Caspian Sea. Finally, it is worth noting that although this work is done experimentally, investigating the same case using analytical and/or numerical approaches and their comparison with the current results is of great importance. This will be done in future study. Interested reader for analytical solution of simplified geometries for regular waves can be found in (Ghadimi et al., 2012).

2. Laboratory equipment

For studying the designed WEC and according to the operating conditions and model scale assessment and calculations, a wave tank with dimensions of 11 m length, 3 m width, and 3 m depth was designed and built in the Hydrodynamic, Acoustic and Marine Propulsion Laboratory of Babol Noshirvani University of Technology. The wave tank includes a flap wave maker system for generating regular waves with desirable length and amplitudes and a wave damper for simulating the seacoast. The wave damper decreases the reversing wave effects on the WEC motion. In Fig. 1, the right and left side views of the wave tank are shown. As can be seen in these views, a passageway is made for accessing the WEC and its mooring system; also windows are situated for observation and video capturing.

Fig. 2-left shows the flap wave maker system which is controlled by an inverter device located outside of the wave tank. The designed wave maker system has 15 different arm lengths. This enables 15 horizontal displacements of the wave maker plate, so called paddle, from 6 to 36 cm. Table 1 shows displacement quantity of the paddle for each arm number. This system has a 5 kW motor and a reduction gearbox; it provides revolutions variety of 10–150 rpm for the wave maker system. The motor attached to the wave maker system is displayed in Fig. 2-right.

Fig. 3 shows the damper which is used in the wave tank. This damper can be adjusted in four locations, where its position will be changed according to different depths of still water.