CIVIL ENGINEERING | RESEARCH ARTICLE

On the placement of a wave manipulator suitable for energy harnessing in the Nearshore

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Abstract: The effectiveness of a wave manipulator which is used for enhancing the nearshore wave energy density is described in this paper. The manipulator is formed by cascading a converging, uniform, and a diverging channel section for concentrating, stabilizing, and dispersing the waves, respectively. The linear wave theory, mode theory for open channel wave propagation, and some semi-empirical formulations are used for estimating the wave parameters at various points of interest and the location of wave breaking. Further, a regression formula is presented to estimate the phase velocity in the inner surf zone. The energy density and flux are quantified before and after wave breaking inside the manipulator. It is shown that the procedure is most effective if the entrance of the manipulator is placed at the shoaling region but closest to the shore. If the waves are not broken, the relative increase in the energy flux is equal to the level of concentration but that of broken waves is still high enough for energy harnessing. It is also shown that either wave

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PUBLIC INTEREST STATEMENT

The total power of ocean waves reaching all the coasts in the world is estimated to be around 2000 GWs. One of the main problems in utilizing this power for generating electricity is that it is limited to about 5–50 kW/m of crest length. In solution, a converging channel section could be used to intercept wide wave crests and concentrate into a narrow channel increasing the wave energy density in the nearshore. A considerable amount of power could be harnessed by mounting wave energy converters inside the channel section because the waves inside the channel could be nearly as energetic as those in the offshore. After energy harnessing, the remaining power of the waves could be dispersed by cascading a diverging channel section to avoid coastal erosion. The main topics of the research described in this paper are the dependence of the expected behavior of the manipulator on its dimensions and on its placement in the nearshore. The other advantages of a wave manipulating structure constructed in the nearshore are the protection of energy converters from oblique waves and boat movements, simplified mooring, easy accessibility for maintenance and the safety provided for research and experimental developments of energy converters.
energy converters or hydro turbines could be used for energy harnessing by setting the dimensions of the manipulator appropriately. Finally, the other advantages of the manipulator are discussed.

**Subjects:** Mathematics & Statistics for Engineers; Fluid Mechanics; Power & Energy; Civil, Environmental and Geotechnical Engineering

**Keywords:** Wave energy conversion; Nearshore wave concentration; Open channel waves; Wave filtering; Wave breaking; Energy flux

1. Introduction

The potential of sea waves as an energy source is enormous and the total available power in all the coastlines in the world is estimated to be around 2000 GW. A good advantage of sea waves is that they are normally predictable a few days ahead (Coe et al., 2021). In addition, seasonal variations are well known except for some unusual storm events or tsunamis. For example, the annual average power available at most coastlines in the world varies from 5 to 50 kW/m of crest width of the wave. The monthly average available wave power in the Southern and Western coasts of Sri Lanka varies from 30 to 40 kW/m in July. In January, the monthly average in the same coasts is only about 10–15 kW/m (Barstow et al., 2009). Normally, such predictions are made using theoretical models of wave characteristics both nearshore and offshore. Before making any predictions, the models are validated by comparing with time series of wave data stored in various databases containing decades of sea wave statistics (Barstow et al., 2009; Kaselimi & Delikaraoglou, 2018). These databases keep records of wave data obtained using satellite altimetry, measuring instruments mounted in the sea and visual observations. Therefore, it is beneficial to develop efficient and reliable methodologies to utilize ocean wave energy.

One of the fundamental problems associated with harnessing wave energy is that the waves carry only a limited amount of energy flux in the longshore direction, which is typically less than some tens of kW/m. This implies that if one needs to harness some hundreds of kWs or a few MWs of power, the dimensions of the wave energy converter (WEC) must be very large. To solve this problem, the author has previously suggested to concentrate waves into a narrow channel in order to enhance the energy density and the energy flux (Jagath-Kumara & Dias, 2015; Jagath-Kumara et al., 2018; Maliyadda et al., 2014). According to mostly experimental results presented in those publications, the relative increase in energy flux is almost equal to the funneling ratio, if a funnel shaped structure is used for the concentration. However, for a given channel width, too small or too large a funneling ratio would be ineffective due to too small an intake in the first case and due to reflections and increased turbulence in the latter case. Further, rectangular open channels allow multiple-wave modes to propagate with the corresponding wavelengths, depending on the wave period. There is a critical channel width below which waves become evanescent. Ideally, the channel width is to be set such that there is only one propagating wave mode (Akylas & Mei, 2001-2014; Chong et al., 1979; Robert, “Ch. 233”) so that the WEC functions smoothly. Additionally, in the case of wave breaking, the break point and the remaining energy flux in the resulting surf zone must be found (I. A. Svendsen, 1983; Basco & Yamashita, 1987; Hansen, 1990; Ib. A. Svendsen, 2006; I. A. Svendsen et al, A. Svendsen) for mounting the WECs appropriately.

A wave power station known as TapChan (Mehlum, 1986) has some similarity to the wave manipulator described in this paper. That was one of the first wave power stations installed in Norway in the 1980s, which guided waves to a reservoir located on the top of a seaside cliff using a tapered channel. This tapered channel, which is similar to the funnel section of the wave manipulator, was, however, built along the face of the cliff. The concentrated energy of the oncoming waves was adequate to reach the reservoir. A normal hydro turbine, placed at the sea level, generated power using the head of the sea water in the reservoir. It provided some useful power to the grid for a few years before being abandoned. However, the novelty of the wave energy manipulator described in this paper is that it has a channel section in which concentrated
waves become stabilized and propagate and a diffuser section in which wave dispersion takes place. The channel section suits a number of different types of WECs such as point absorbers (Erikkson et al., 2005, 2007; Lejerskog et al., 2015; Sjokvist et al., 2014), oscillating water column devices (Allsop et al., 2014; Halder et al., 2017), oscillating wave surge converters (Wotabe, 2008), wave over topping devices (Mehlum, 1986; Parmeggiani et al., 2013; Peter Kofoed et al., 2006) and Pelamis devices (Camilla Thomson et al., 2018). They would produce high enough energy as the level of energy inside the channel is much higher than in the free sea. Further, by setting the channel width so that the waves break, a suitable type of a hydro turbine (Ibrahim et al., 2021) could be used to gain the advantage of the forward momentum of broken waves. In addition, all these WECs could be moored strongly to the walls of the manipulator. Because there is no hazard from oblique waves or boat movements, most types of WECs would be safer inside the manipulator and function as expected.

The other advantages of a nearshore installation of such a wave concentrator are easy accessibility, visibility from the shore and the safety of the crew. These factors effectively result in lower initial costs and running costs. After harnessing the energy, the diffuser would disperse the remaining wave energy so that this process does not cause considerable erosion to the shoreline. The presence of a large structure nearshore may change the normal erosion patterns and the local geomorphology in the area but it is unlikely to be problematic to the livelihoods (Jagath-Kumara et al., 2018).

The objectives of this paper, which also provides a good theoretical basis for the work presented in (Jagath-Kumara & Dias, 2015; Jagath-Kumara et al., 2018; Maliyadda et al., 2014), are to describe a possible approach for estimating the best placement and the dimensions of such a wave manipulating structure in the nearshore. Section 2 lists the equations extracted from the linear wave theory for describing free propagation of a certain wave in the offshore and in the nearshore (Ib. A. Svendsen, 2006). Section 3 lists a set of equations for open channel wave propagation based on the mode theory (Akylas & Mei, 2001-2014; Robert, “Ch. 233; Chang et al., 1979). Then, this section adapts those equations to the open channel sections of a wave manipulator placed in the nearshore. Section 4 uses a semi-empirical approach to describe wave breaking and continued propagation towards the shoreline (I. A. Svendsen, 1983; Basco & Yamashita, 1987; Hansen, 1990; Ib. A. Svendsen, 2006; I. A. Svendsen et al., A. Svendsen). For a selected set of offshore waves, Section 5 quantifies the variation of wave parameters as they propagate from offshore to the nearshore and then through the manipulator, for different channel widths. Essentially, it shows how the wave parameters are affected when the manipulator placement is shifted in the cross-shore direction. Section 6 discusses the significance of the results in Section 5 and various options for energy conversion.

2. Free propagation of waves in the offshore and in the nearshore
Waves develop due to the winds exerting power on the surface of a large area of the ocean known as the fetch. These waves start moving away while gaining height and energy. Once they are no longer under the effect of winds, they continue to propagate with a stable height and a period resulting in little dissipation. Such a fully developed and a stable wave which propagates towards the shore with a constant period of \( T \) and a constant wavelength of \( \lambda_0 \) (Ib. A. Svendsen, 2006) is referred to as an offshore wave in this paper. The water depth, \( h \), is considered to be so large that it has no effect on the parameters of the propagating wave. Then, from the linear wave theory (Ib. A. Svendsen, 2006), the phase velocity and the group velocity of the wave are given by

\[
c_p = \frac{\lambda_0}{T}
\]
\[ c_{g0} = \frac{c_0}{2} \]  

(2)

If the wave energy density is \( e_0 \) in \( J/m^2 \) of surface area, the wave height must be such that

\[ H_0 = \sqrt{\frac{8e_0}{\rho g}} \]  

(3)

Therefore, the energy flux in the direction of propagation (shorewards in this case) in kW/m of crest length is given by

\[ E_{f0} = c_{g0}e_0 \]  

(4)

These parameters remain constant if there are no more winds and no other obstructions while approaching the nearshore.

The wave propagation in the nearshore is governed by several processes such as refraction, breaking, scattering, diffraction, reflection, and dissipation. Out of these, the refraction caused by the bottom topography and the reflection from submerged objects and the shoreline are more predominant. Normally, waves start shoaling for \( h < \lambda/2 \) where their wavelengths become smaller and the heights become larger as illustrated in Figure 1. On approaching the shore further, waves break at a location mainly determined by the bottom slope and the offshore wave steepness. After breaking, the waves undergo many changes including mainly the shape transformation, height loss, and dissipation. Note that the submarine topographic profile, as shown in Figure 1, may not be a straight line in reality but the foregoing analysis relies on the straight-line assumption.

Consider a nearshore region with a small, constant slope of \( h_x \) such that the depth is slowly varying and the linear theory is applicable locally (Ib. A. Svendson, 2006). Then, at a distance \( D \) from the shore in the cross-shore direction where the water depth is \( h_D \), let \( T, \lambda_D, c_D, c_{gD}, H_D, e_D \) and \( E_{fD} \) be the corresponding nearshore wave parameters of unbroken waves.

Therefore, if the wave number is \( k_D \), from (Ib. A. Svendson, 2006),

\[ \lambda_D = \lambda_0 \text{Tanh}(k_D h_D) \]  

(5)

\[ c_D = \frac{\lambda_D}{T} \]  

(6)
\[ c_{g0} = \frac{c_0}{Z} \left( 1 + \frac{2k_0 h_0}{\sinh(2k_0 h_0)} \right) \]  

(7)

\[ H_0 = H_0 \sqrt{\frac{c_{g0}}{c_{g0}}} \]  

(8)

\[ e_0 = \frac{1}{8} \rho g h_0^2 \]  

(9)

\[ E_{g0} = c_{g0} e_0 \]  

(10)

Over a crest width of \( w_0 \), the total energy flux,

\[ P_{g0} = w_0 E_{g0} \]  

(11)

3. Open channel wave propagation in the nearshore

In a rectangular channel, only some wave modes with the corresponding wavelengths can propagate according to (Akylas and Mei, 2001-2014; Robert, “Ch. 233). In this case, the wave dispersion formula takes the form

\[ \omega^2 = g \Lambda_0 \tanh(\Lambda_0 h_0) \]  

(12)

where the frequency \( \omega = 2\pi/T \). The wave number in the direction of propagation,

\[ k_0 = \sqrt{\Lambda_0^2 - k_{y0}^2} \]  

(13)

where the Eigen values,

\[ k_{y0} = \frac{\pi}{2b_0} \pm \frac{\pi}{h_0}; \quad n = 0, 1, 2, \ldots \]  

or

\[ k_{y0} = \frac{m\pi}{h_0}; \quad m = 1, 2, \ldots \]  

(14)

and \( 2b_0 \) is the width of the channel. Therefore,

\[ \lambda_0 = \frac{2\pi}{k_0} \]  

(15)

\[ c_0 = \frac{\lambda_0}{T} \]  

(16)

Then, it can be shown that

\[ c_{g0} = \frac{k_0 \omega}{2\lambda_0^3} \left( 1 + \frac{2\Lambda_0 h_0}{\sinh(2\Lambda_0 h_0)} \right) \]  

(17)
In this way, the mass flux is expressed as

\[ M_0 = \frac{1}{8 \rho g} \frac{H_0^2}{c_0} \]  

(18)

According to this formulation, there is a critical channel width below which \( k_0 \) becomes imaginary and waves become evanescent. When increasing the width beyond this value, the number of propagating wave modes increases with \( m \) and \( n \), starting from the first-order mode for \( n = 0 \). When applying Eq. (12)—(18) for an open channel in the nearshore, it is again required that \( h_x \) is small and hence \( h \) is locally constant at a distance \( D \) from the shore.

### 3.1. Wave propagation in a wave manipulator placed in the nearshore

Figure 2 illustrates a wave manipulator, which concentrates and disperses wave energy. It consists of a funnel, channel, and a diffuser of lengths \( l_1, l_2, \) and \( l_3 \), respectively. The funnel aperture, channel width, and the diffuser aperture are \( w_1, w_2, \) and \( w_3 \), respectively. In this case, the suffix “D” in the wave equations are “en”, “ex”, “mid”, “den” or “dex” representing the funnel entrance, funnel exit, mid-channel, diffuser entrance, and the diffuser exit, respectively. It also implies the distance to these locations in the manipulator from the shore. In order to evaluate the wave energy density and the energy flux at these locations, it is first required to determine the corresponding wave parameters and the wave heights. Then, it would be possible to estimate the best placement for the manipulator by evaluating those sets of wave parameters by varying the distance \( D \) to each location.

The foregoing analysis considers the funnel entrance first and proceeds to the rest of the locations of interest in the manipulator. Note that in order to use open channel wave equations along the funnel section, the funnel width too must slowly vary over the length of \( l_1 \). This additional assumption implies that the width is almost constant locally at a certain location in the funnel. Then, at the funnel entrance which is located at a distance of \( D_1 \) from the shore where the water depth is \( h_1 \), Eq. (12)—(17) result in \( \lambda_{en}, k_{en}, \lambda_{en}, c_{en} \) and \( c_{gen} \) for \( 2b_2 = w_1 \). Here, multiple propagating modes may exist, which, however, vanish somewhere inside the funnel when the width becomes smaller, leaving only the first-order mode for \( n = 0 \). On the other hand, \( w_1 \) must be large enough to make \( k_0 \) real so that at least the first order wave mode propagates in the manipulator.

Further, for reasonably large apertures, the free mass flux just before the funnel entrance at \( (D_1, h_1) \),

\[ M_{1-} \approx M_{en} \]  

(19)

neglecting any inconsistencies at the face of the walls due to spilling, eddies, or frictional effects. Note that the suffix “1-” indicates a point just seawards of the funnel entrance. Therefore, using Eq. (18),

![Figure 2. A schematic of a wave manipulator in the nearshore.](https://example.com/image.png)
\[ H_{en} = H_1 \sqrt{\frac{c_{en}}{c_1}} \]  

which leads to \( e_{en} \) and \( E_{pen} \) with Eq. (9) and (10).

Next, the funnel exit, which is the same as the inlet to the channel, is located at a distance of \( D_2 \) from the shore where the water depth is \( h_2 \). First, the critical channel width, \( w_{2c} \), below which propagating modes cease to exit can be found from Eq. (12)—(14). Then, for \( w_2 > w_{2c} \), Eq. (12)—(17) result in the wave parameters \( \Lambda_{ex} \), \( k_{ex} \), \( \lambda_{ex} \), \( c_{ex} \) and \( c_{gex} \) at the funnel exit.

According to (Chang et al., 1979) the wave height in a converging channel corresponds to the square root of the width. Further, according to (Ib. A. Svenson, 2006), the wave height due to wave refraction in the nearshore corresponds to the square root of the group velocity. Therefore, if the waves do not break inside the funnel,

\[ H_{ex} = H_{en} \left( \frac{w_1 \ c_{gen}}{w_2 \ c_{gex}} \right) \]  

Note that \( w_1/w_2 \) in Eq. (21) is referred to as the funneling ratio.

The mid-channel position is located halfway through the channel at a distance of \( D_3 \) from the shore where the water depth is \( h_3 \). Again, for \( w_2 > w_{2c} \), Eq. (12)—(17) result in \( \Lambda_{mid} \), \( k_{mid} \), \( \lambda_{mid} \), \( c_{mid} \) and \( c_{gmid} \). For the waves which do not break before the mid-channel position, considering only the nearshore wave refraction (Ib. A. Svenson, 2006),

\[ H_{mid} = H_{ex} \sqrt{\frac{c_{gex}}{c_{gmid}}} \]  

as the channel width is constant.

The diffuser entrance, which is the same as the channel exit, is located at a distance of \( D_4 \) from the shore where the water depth is \( h_4 \). The wave parameters \( \Lambda_{den} \), \( k_{den} \), \( \lambda_{den} \), \( c_{den} \), \( c_{gden} \), \( e_{den} \) and \( E_{iden} \) can be found in the same manner. If the waves do not break in the funnel or the channel,

\[ H_{den} = H_{mid} \sqrt{\frac{c_{gmid}}{c_{gden}}} \]  

Finally, the diffuser exit, which is also the exit of the manipulator, is located at a distance of \( D_5 \) from the shore where the water depth is \( h_5 \). Again, if it is assumed that the width of the diffuser section varies slowly over the length of \( l_5 \), Eq. (12)—(17) is applicable. This results in \( \Lambda_{dex} \), \( k_{dex} \), \( \lambda_{dex} \), \( c_{dex} \), \( c_{gdex} \) for a width of \( w_3 \).

In this case, according to (Chang et al., 1979), the wave height in a diverging channel corresponds to the two-thirds power of the width while that due to nearshore refraction corresponds to the square root of the group velocity (Ib. A. Svenson, 2006). Then, for those waves which do not break inside the funnel, channel, and the diffuser,

\[ H_{dex} = H_{den} \left( \frac{w_2}{w_3} \right)^{\frac{1}{3}} \left( \frac{c_{gden}}{c_{gdex}} \right)^{\frac{1}{2}} \]
Note that once \( H_0 \) are found using Eq. (21) to (24) at the corresponding places, \( e_0 \) and \( E_{i0} \) could be found by using Eq. (9) and (10).

### 3.2. Higher order modes for large widths

If the entrance of the manipulator has an aperture of \( w_1 = 100 \) m and the water depth is 8 m, two higher order modes are excited when \( k_{y0} = 2\pi/w_1 \) and \( 3\pi/w_1 \) for \( m = 1 \) and \( n = 1 \) respectively, for example. This is in addition to the first-order mode resulting from \( k_{y0} = \pi/w_1 \) for \( n = 0 \). However, these higher order modes cease to propagate even the full length of the funnel section. Similarly, at the exit of the manipulator, one higher order mode exists when \( k_{y0} = 2\pi/w_1 \) for \( m = 1 \), if the aperture \( w_3 = 75 \) m and the water depth is 5 m.

Section 3.1 considers the parameters of only the first-order mode because the energy coupled into the higher order modes are usually small (Robert, “Ch. 233).

### 4. Wave breaking in the nearshore

On approaching the shore further, wavelengths become too short while wave heights become too large and the waves break collapsing their crests. The position of breakin a plane beach is mostly governed by the offshore wave steepness, nearshore wavelength, and the water depth. According to the empirical formulations suggested in (Hansen, 1990; Ib. A. Svendson, 2006), a wave will break if

\[
\left( \frac{\lambda}{h} \right)_b = 2.3 \left( \frac{H_0}{\lambda_0} \right)^{\frac{1}{3}} = p
\]

(25)

where the suffix “b” indicates the values at the breaking point. Further, small, medium, or high relative bottom slope, which is given by \( 2.3h_0/\sqrt{(H_0/\lambda_0)} \), indicates the type of breaking known as spilling, plunging, and surging.

The empirical normalized crest elevation at breaking (Ib. A. Svendson, 2006; A. Svendson)

\[
\left( \frac{H_c}{H} \right)_b = 1 - 0.5 \tanh \left( \frac{4.85}{\sqrt{U_b}} \right)
\]

(26)

where

\[
U_b = \left( \frac{10.1h_0^{0.2}}{H_0/\lambda_0} \right)
\]

(27)

Immediately after breaking, the waves undergo rapid changes in their shape and height. This region is known as the outer region where the shape of the waves transforms into those of bores. The bores then continue to propagate towards the shore in the next region known as the inner region. Over this region, bores lose height due to the dissipation of energy but gains some height due to refraction (Ib. A. Svendson, 2006). Thereafter, in the swash zone, which is closest to the shore, some or all of the remaining wave energy is absorbed or reflected back depending on the local slope and the type of the beach, rocky or sandy. These three regions are collectively known as the surf zone. The surf zone is longer and changes are more gradual with a spilling breaker which results from shorter waves in a smaller slope. In case of surging, which occurs due to longer waves in a steeper slope, waves collapse abruptly and the surf zone is shorter.

### 4.1. Wave breaking inside the manipulator

The entrance of the manipulator, which is the same as the entrance of the funnel, is to be placed somewhere in the shoaling region before the waves start breaking. However, longer waves may
break in the funnel section because of the increasing wavelength caused by the decreasing width. To estimate the position of breaking, the funnel section is again considered to be a slowly converging open channel with a reasonably large average width. Hence, assuming that the empirical formulae for wave breaking is still valid, \( \lambda_b = h_b, \rho \) in Eq. (25) must also satisfy Eq. (12)—(14) at the breaking point such that

\[ \omega^2 = g\Lambda_b \tanh(\Lambda_b h_b) \]  \hspace{1cm} (28)

where

\[ \Lambda_b^2 = \left( \frac{2\pi}{h_b \rho} \right)^2 + \left( \frac{\pi}{w_b} \right)^2 \]  \hspace{1cm} (29)

If \( l \) = distance to breaking point from the funnel exit (towards the entrance), using the geometry of the funnel,

\[ w_b = \frac{l(w_1 - w_2)}{l_1} + w_2 \]  \hspace{1cm} (30)

\[ h_b = h_{ox} + lh_x \]  \hspace{1cm} (31)

Then, for a given offshore wave \( (\lambda_0, H_0) \), the parameters at the breaking position \( h_b, \Lambda_b \) and \( \lambda_b \) can be found by varying \( l \) until Eq. (28)—(31) are valid (at \( l_b \) and \( w_b \)). If these set of equations are not satisfied even for \( l = 0 \), the wave is unlikely to break in the funnel section.

The same set of equations could be used to find out if the waves break inside the channel by substituting \( w_b = w_2 \) (constant) in Eq. (29)—(30). Using a similar approach, it is possible to check if the waves break inside the diffuser. Based on the break point parameters, the parameters at a certain location in the outer region (osz) or the inner region (isz) of the surf zone (sz) can be found using some more semi-empirical formulations given in (I. A. Svendsen, 1983; Basco & Yamashita, 1987; Hansen, 1990; Ib. A. Svendson, 2006; I. A. Svendsen et al., A. Svendsen).

### 4.2. Location of the transition point

After breaking, waves normally lose about one-third of the height over the outer region. However, the loss of wave height does not directly correspond to the dissipation loss because some of the potential energy transforms into horizontal momentum flux. Importantly, the mean water level \( (\eta) \) stays constant over this region which starts increasing in the inner region due to set-up. Hence, the boundary between the outer region and the inner region, which is known as the transition point, could be found by locating the point at which \( \frac{\partial \eta}{\partial x} \) becomes nonzero, where \( x \) is the distance in the direction of propagation (I. A. Svendsen, 1983; Basco & Yamashita, 1987). Using the empirical curves for some spilling and plunging breakers given in (Basco & Yamashita, 1987), \( h/h_b \) at the transition point could be estimated approximately with the help of the surf similarity parameter,

\[ \xi = h_x/\sqrt{(H_0/\lambda_0)} \]  \hspace{1cm} (32)

This implies that if the depth ratio, \( h_x/h_b \), at a certain point in the surf zone is greater than (or less than) \( h_b/h_b \), that point is in the outer region (or in the inner region), respectively.

### 4.3. Wave parameters in the outer region

Although the waves undergo rapid transformations with respect to the energy flux, momentum flux and the shape in the outer region, I. A. Svendsen, 1983 suggests that the energy flux is approximately proportional to the wave height and the depth as
\[ E_{\text{froz}} \propto \sqrt{H_{\text{froz}}^2} \]  

(33)

Therefore, taking the break point parameters as those of the first point in the outer region,

\[ \frac{E_{\text{froz}}}{E_b} = \left( \frac{h_{\text{froz}}}{h_b} \right) \left( \frac{H_{\text{froz}}}{H_b} \right)^2 \]  

(34)

Further, I. A. Svendsen, 1983 illustrates another empirical curve for the variation of \( H_{\text{froz}}/H_b \) with \( h_{\text{froz}}/h_b \), making it possible to estimate \( E_{\text{froz}} \) using Eq. (34).

As described in Section 4.2, if the funnel exit is found to be in the outer region, the energy flux \( (E_{\text{froz}})_{\text{osz}} \) could be estimated by substituting the corresponding depth ratio and the height ratio in Eq. (34). Then, the loss of wave energy up to the funnel exit since breaking is given by

\[ L_{\text{osz}} = w_1 E_{\text{fen}} - w_2 (E_{\text{froz}})_{\text{osz}} \]  

(35)

However, Eq. (33) and hence Eq. (34)—(35) are approximate which depend on empirical results (I. A. Svendsen, 1983). Note that after breaking, Eq. (21) can no longer be used for evaluating the wave height and the energy flux at the funnel exit. Similarly, it is possible to check if the mid-channel, diffuser entrance, and the diffuser exit are in the outer region and use Eq. (34) to estimate the energy flux.

4.4. Wave parameters in the inner region

The shoreward side of the transition point found in Section 4.2 is the inner region where bore-like waves propagate with decaying heights. The theory and empirical results presented in (I. A. Svendsen, 1983; Ib. A. Svendsen, 2006 and A. Svendson) relate the parameters of interest such as the phase velocity \( c_{\text{isz}} \), wave height-to-depth ratio \( (H/h)_{\text{isz}} \), and the normalized crest elevation \( (\eta_c/H)_{\text{isz}} \) in the inner region. For example,

\[ c_{\text{isz}} = a \sqrt{gh_{\text{isz}}} \]  

(36)

where the constant \( a \) is given by

\[ a^2 = 1 + \left( \frac{3}{2} + 3 \left( \frac{\eta_c}{H} \right)_{\text{isz}} \right) \left( \frac{H}{h} \right)_{\text{isz}}^2 \]  

\[ + \left( \frac{1}{2} - 3 \left( \frac{\eta_c}{H} \right)_{\text{isz}} + 3 \left( \frac{\eta_c}{H} \right)_{\text{isz}}^2 \right) \left( \frac{H}{h} \right)_{\text{isz}}^2 \]  

\[ + \left( \frac{1}{2} \left( \frac{\eta_c}{H} \right)_{\text{isz}} - \frac{3}{2} \left( \frac{\eta_c}{H} \right)_{\text{isz}}^2 \right)^2 + \left( \frac{\eta_c}{H} \right)_{\text{isz}}^3 \left( \frac{H}{h} \right)_{\text{isz}}^3 \]  

(37)

and

\[ \left( \frac{\eta_c}{H} \right)_{\text{isz}} = 0.5 + \left[ \frac{\eta_c}{H} - 0.5 \right] \left( \frac{h_{\text{isz}}}{h_b} \right) \]  

(38)

However, \( (H/h)_{\text{isz}} \) is not known initially to use Eq. (37) to evaluate \( a \) and then \( c_{\text{isz}} \). Therefore, it is necessary to begin with an approximate value, based on empirical results (I. A. Svendsen, 1983), such as \( (H/h)_{\text{isz}} = 0.8 \) and use an iterative procedure to increase the accuracy. In nearshore estimations, it is rather common to assume that the wave height at a certain depth in the surf
zone is the corresponding breaking height, \((H/h)_b\), which is given by another empirical formula (Ib. A. Svendsen, 2006),

\[
\left( \frac{H}{h} \right)_b = \left( \frac{H}{h} \right)_{laz} = 1.9 \sqrt{\frac{S_{laz}}{1 + 2.5S_{laz}}} \quad (39)
\]

where the relative bottom slope,

\[
S = h_s \left( \frac{z}{h} \right)_{laz}
\]

and from the first estimate of \(c_{laz}\) found using Eq. (36)—(38), the wavelength at this depth

\[
\lambda_{laz} = c_{laz}T
\]

By substituting \((H/h)_{laz}\) just found from Eq. (39) in Eq. (37), \(c_{laz}\) could be further refined. In this way, \((H/h)_{laz}\) could be made accurate enough by iterating on the parameters \(a, c_{laz}, \lambda_{laz}\) and \(S_{laz}\) again and again. Normally, \((H/h)_{laz}\) converges to a value with a high precision (two or more decimal places) in two to three iterations.

Then, the energy dissipation rate in the inner region of the surf zone, (I. A. Svendsen, 1983; Ib. A. Svendsen, 2006),

\[
d_{laz} = D_{u_3} \rho g H_{laz}^3
\]

where

\[
D_{u_3} = \frac{1}{\left( 1 + \left( \frac{H}{h} \right)_{laz} \left( \frac{h}{h_{laz}} \right) \right) \left( 1 + \left( \frac{H}{h} \right)_{laz} - 1 \right) \left( \frac{h}{h_{laz}} \right)}
\]

Note that \(d_{laz}\) varies continuously over the inner region along the cross-shore direction. In order to estimate the remaining energy flux at a certain point in the inner region, the total dissipation loss \((L_{laz})\) from the transition point to this point must be found using \(d_{laz}\). If this distance is high, the variation of \(h_{laz}/h_{laz}(H/h)_{laz}\) and \(H_{laz}\) could be considerable and the variation of \(d_{laz}\) would not be negligible. Therefore, in order to estimate \(L_{laz}\), \(d_{laz}\) has to be found by iterating Eq. (36)—(43) at every point and the corresponding loss must be integrated from the transition point to the point of concern. This would be a rigorous approach but the result would still be approximate. Optionally, for example, the loss at each meter could be found by assuming \(d_{laz}\) is nearly constant over that meter. Then, \(L_{laz}\) could be found by summing the individual losses.

5. Results
A set of six offshore waves described in Table 1 were selected for studying the variations of wave parameters as they travel towards nearshore, through the manipulator and towards the shoreline.

The aperture of the funnel entrance and the diffuser exit were set to \(w_1 = 100\) m and \(w_3 = 75\) m respectively. The aperture of the diffuser exit was made smaller than that of the funnel entrance so that more waves would break just before the diffuser exit making wave energy dispersion more effective. The lengths of the funnel, channel, and the diffuser sections of the manipulator were set to \(l_1 = l_2 = l_3 = 60\) m which is around one wavelength of these waves by the time they reach the nearshore. Note that this is an arbitrary selection but it should accommodate more or less one
wave crest somewhere in the funnel or the channel. In practice, different lengths should be considered for the study, which may or may not result in better efficiencies. However, too short lengths would make the assumptions of slowly varying water depth and the funnel width incorrect and the calculation and estimation procedures in Sections 3 and 4 inapplicable.

The bottom slope of the nearshore was set to $h_b = 1/60$ causing the surf similarity parameter $\xi$ to be around 0.11–0.15 for the set of waves in Table 1. Within these limits of $\xi$, those waves would undergo spilling-type breaking. Next, three different placements of the manipulator, as described in Table 2, were selected for comparing the manipulation efficiencies. Without a wave manipulator, those free propagating waves would break at a depth of about 3 m and at a distance of less than 180 m from the shore. Therefore, the diffuser exit was placed seawards from this normal breaking area starting from 180 m ($P_1$). At the same time, the funnel entrance must not be too far away from the shoreline in order to realize nearshore advantages. With these placements, whenever the set of waves break, they would break before the mid-channel and the mid-channel would be in the outer region so that the energy fluxes are still high enough to be useful. The wave parameters at all the points of concern, starting from offshore to the manipulator exit in the nearshore, were evaluated as described in the sections 2, 3 and 4 using MS Excel. However, $\lambda_1$ and $\lambda_0$ were found by trial and error using Eq. (5) and (12) respectively while some of the surf zone parameters such as $h_b$, $H_b$ and $H/H_b$ were read from the empirical curves (I. A. Svendsen, 1983; Ib. A. Svendsen, 2006 and Basco & Yamashita, 1987). Note again that all the results presented in this section is approximate because they rely on certain assumptions and empirical results.

## 5.1. The critical channel width ($w_{2c}$) and the maximum breaking channel width ($w_{2m}$)

For each offshore wave in Table 1 and for each placement in Table 2, $w_{2c}$ below which no wave propagation occurs in the channel were found as described in Section 3. However, more than one propagating wave modes were found to exist in the first half of the funnel. Next, in each section of the manipulator, the semi-empirical procedure described in Sections 4 and 4.1 with Eq. (25)—(31) was used to find $w_{2m}$ ($> w_{2c}$) below which each wave breaks. This implies that a wave would not break as long as $w_2 > w_{2m}$. For all the waves and for all the placements considered, it was found that wave breaking occurs inside the funnel section close to the exit. None of the unbroken waves, however, broke in the channel section or in the diffuser. Note in this case that $w_2$ was varied in steps of 2 m.

### Table 1. Tested waves

| Wave | Wave Period, $T$ (s) | Wave Length, $\lambda_0$ (m) | Wave Height, $H_0$ (m) | Energy Density, $e_{0}$ (kJ/m$^2$) | Energy Flux, $E_{p0}$ (kW/m) |
|------|---------------------|----------------------------|-----------------------|-----------------------------------|-------------------------------|
| Wave 1 | 8                   | 100                         | 2                     | 5                                 | 31                            |
| Wave 2 | 8                   | 100                         | 2.3                   | 6.5                               | 40                            |
| Wave 3 | 9                   | 126                         | 1.9                   | 4.5                               | 31                            |
| Wave 4 | 9                   | 126                         | 2.1                   | 5.75                              | 40                            |
| Wave 5 | 10                  | 156                         | 1.8                   | 4                                 | 31                            |
| Wave 6 | 10                  | 156                         | 2                     | 5.25                              | 41                            |

### Table 2. Manipulator placements $P_1$, $P_2$, and $P_3$ (Distances are from the shoreline.)

|        | Funnel Entrance (m) | Funnel Exit (m) | Mid Channel (m) | Diffuser Entrance (m) | Diffuser Exit (m) |
|--------|---------------------|----------------|-----------------|-----------------------|-------------------|
| $P_1$  | 360                 | 300            | 270             | 240                   | 180               |
| $P_2$  | 420                 | 360            | 330             | 300                   | 240               |
| $P_3$  | 480                 | 420            | 390             | 360                   | 300               |
Figure 3. Critical channel widths below which no wave propagation occurs for P3.

Figure 4. Maximum breaking channel widths below which waves undergo breaking for P3.

Figure 3 illustrates the critical channel widths ($w_{2c}$) below which waves cease to propagate for P3. Figure 4 illustrates the maximum channel width at which waves break in the funnel section for the same placement. It is evident that $w_{2c}$ is lower for waves 1 and 2 but higher for waves 5 and 6. In other words, the wave manipulation by funnelling passes short wavelengths with short periods through the channel but stops long wavelengths with long periods unless the channel width is high enough. This implies that the manipulator acts as a filter which limits long wavelengths. Further, $w_{2m}$ too is higher for long waves but lower for short waves implying that the long waves are attenuated by breaking unless the channel width is even higher. For example, with wave 1 and 2, propagation begins at a width of 31 m but that continues without breaking beyond a width of 36 m only. However, with wave 5 and 6, these limiting values are 39.5 m and 46 m respectively.

5.2. The transition point and the energy flux of broken waves inside the manipulator

For $w_{2c} < w_2 < w_{2m}$, over which waves break, the empirical approach described in Section 4.2 was used to locate the transition point between the outer region and the inner region of the surf zone. For the range of $\xi$ values of these waves, it was found that $h_x/h_b$ is around 0.66. It was further found that, for all three placements,

$$\frac{h_x}{h_b} > 0.66 \text{ and } \frac{h_{mid}}{h_b} > 0.66$$

(44)

and hence, both the funnel exit and the mid-channel were considered to be in the outer region of the surf zone. Then, for those waves which break in the funnel, energy fluxes were estimated at the funnel exit, ($E_{fex}$)$_{asw}$ and at the mid-channel, ($E_{fmid}$)$_{asw}$, using Eq. (34) with the other empirical
results described in Sections 4.3. The unshaded data points in Figure 5 shows \((E_{\text{flux}})_{\text{az}}\) at the funnel exit for each broken wave for the placement P3.

### 5.3. Wave parameters of unbroken waves

For each unbroken wave where \(w_2 > w_{2m}\), Eq. (12)—(24) leads to the wave parameters of interest. The shaded data points in Figure 5 shows the energy flux at the funnel exit, \(E_{\text{flux}}\) when \(w_2\) is increasing in steps of 2 m. It indicates that even though the waves break, a high percentage of energy is available at a width which is not very smaller than \(w_{2m}\). For example, in the case of wave 2, the energy flux is 107 kW/m at a width of 38 m which is just higher than the breaking width but it is not less than 100 kW/m for all the lower widths even though the wave breaks. Generally, the energy flux increases when the width increases from \(w_{2c}\). It reaches a peak at a width of \(w_{2p}\) which is just higher than \(w_{2m}\). Then, any further increase in the width causes the energy flux to decrease.

The wavelength, \(\lambda_{\text{mid}}\), phase velocity, \(c_{\text{mid}}\), group velocity, \(c_{\text{gmid}}\), wave height, \(H_{\text{mid}}\), and the energy density, \(e_{\text{mid}}\), of unbroken waves at the mid-channel for the placement P3 are illustrated in Figure 6(a-e) respectively. In general, the smaller the channel width, the higher the mid-channel wavelength, phase velocity, and the wave height for propagating waves. This causes the energy density to increase when the channel width decreases as expected. However, the group velocity increases with the channel width.

The mid-channel energy flux is illustrated for both broken waves, \((E_{\text{flux}})_{\text{az}}\), and unbroken waves, \((E_{\text{flux}})\), when \(w_2\) is increasing from \(w_{2c}\) in Figure 7. In this figure, the unshaded data points and the shaded data points correspond to broken waves (\(w_{2c} < w_2 < w_{2m}\)) and unbroken waves (\(w_2 > w_{2m}\)) respectively. Note that the energy flux at mid-channel shows a similar tendency to that at the funnel exit in that it is initially increasing to a peak at a width of \(w_{2p}\) which is just above \(w_{2m}\) and then decreasing for \(w_2 > w_{2p}\). For example, \(w_{2p}\) is 38 m for wave 2, which however is approximate in this case as \(w_2\) is varied in steps of 2 m. The main target of wave manipulation is increasing the energy density by converging them into a smaller surface area. Therefore, the best channel width suitable for energy harnessing is indeed \(w_{2p}\) for a given wave. Then, the optimum value of \(w_{2p}\) could be found if the probability of occurrence of each wave is known.

The energy fluxes of unbroken waves at the diffuser exit (manipulator exit), averaged over the range of channel widths considered for the sake of simplicity, are illustrated in Figure 8. They are somewhat higher than those at the funnel entrance (Table 1) because the aperture of the diffuser, being 75 m, is smaller. Anyway, the high level of energy flux in the channel, which is close to 100 kW/m, is successfully dispersed inside the diffuser. When setting \(w_3\) to 75 m (< \(w_2\)), it was expected that the remaining unbroken waves would break before leaving the diffuser. However,
none of the tested waves broke in the diffuser. Therefore, it may be more beneficial to increase \( w_3 \) further to reduce the energy flux at the diffuser exit.

5.4. The gain in wave concentration
The gain in wave concentration, which is the energy flux at mid-channel, \( E_{\text{mid}} \), expressed as a fraction of that at a point just seawards of the funnel entrance, \( E_{\text{P2}} \), is illustrated in Figure 9 for P3. Again, the unshaded and the shaded data points correspond to broken waves and unbroken waves. The concentration gain is equal to the funneling ratio for unbroken waves. However, it suddenly drops when the waves break for larger funneling ratios. For a given wave, the highest gain results at the highest funneling ratio which still does not cause wave
breaking (when $w_2 = w_{2p}$). Therefore, shorter waves result in higher gain in manipulation for a given placement but the absolute energy flux also depends on that of the incident wave.

The experimental results presented in (Jagath-Kumara & Dias, 2015; Jagath-Kumara et al., 2018; Maliyadda et al., 2014) too indicate that the wave concentration gain is more or less equal to the funneling ratio, which validates the analysis in sections 2, 3 and 4 of this paper.
5.5. The variation of wave energy flux in the cross-shore direction

Figure 10 illustrates how the maximum energy flux (when $w_2 = w_{2p}$) vary when a wave travels from offshore to the nearshore and then through the various sections of the manipulator.

5.6. Comparison of the efficiency of wave manipulation for different placements

The results of wave manipulation illustrated in Figures 3–10 are somewhat different for the placements P1 and P2. Considering the unbroken waves first, a comparison of the approximate best channel widths, $w_{2p}$, for different placements and for different waves is given in Figure 11. It can be observed that $w_{2p}$ decreases as the placement becomes closer to the shore resulting in the smallest for P1 for a given wave. A comparison of maximum energy fluxes at mid-channel, $E_{f_{mid}}$, evaluated at the corresponding $w_{2p}$ for each wave, for different placements is shown in Figure 12. The maximum energy flux is slightly higher with shorter waves for P1 and then for P2 because these cases allow higher funneling ratios due to smaller $w_{2p}$. Therefore, the corresponding maximum manipulation gains, $E_{f_{mid}}E_{f_2}$, for P1 are slightly higher than those for P2 but are considerably higher than those for P3, as illustrated in Figure 13. However, for those waves which break, the maximum energy fluxes at mid-channel is highest for P3, as illustrated in Figure 14.
According to the comparative results presented in Figure 12 and 14, if all the six waves considered are equally likely to occur, the best placement seems to be P3 as the mid-channel energy flux is highest for broken waves and is similar for unbroken waves. However, it should be
noted that \( w_{2m} \) at which this highest energy flux is available is higher for \( P3 \). Hence, at \( P3 \), the channel is broader, the concentration gain is smaller and the nearshore advantages are fewer.

6. Discussion

In this paper, a methodology for estimating the best placement for a wave concentrator in the nearshore has been described. The linear wave theory, wave modes in open channels, some empirical results, and the semi-empirical formulations presented in Akylas and Mei, 2001-2014; Robert, Ch. 233; Chang et al., 1979; Ib. A. Svendsen, 2006; I. A. Svendsen et al.; I. A. Svendsen, 1983; A. Svendsen; Hansen, 1990; Basco & Yamashita, 1987 have been treated as established knowledge and have been used to estimate the wave parameters in converging and diverging channel sections and in a uniform channel section. Further, those theories and the empirical formulations have been combined to estimate the point at which waves break in a converging channel and the energy flux in the outer surf zone after breaking. In addition, they have been used to form a regression formula for estimating the phase velocity and then the energy flux of the shallow water waves in the inner surf zone. Numerical results have been presented for a set of six different offshore waves with periods of 8, 9, and 10s and energy fluxes of 30 and 40 kW/m. This kind of waves are very probable in the southern and the western coasts of Sri Lanka during the high season and also in some other coastlines in the world (Barstow et al., 2009; Kaselimi & Delikaraoglu, 2018). In summarizing the results, the higher the period (and the wavelength) the higher the critical channel width and the maximum breaking channel width. Therefore, the funneling ratio could be increased as desired only with shorter waves. As a result, the energy flux and the manipulation gain are found to be higher for shorter waves. Further, the manipulation gain increases linearly with the funneling ratio for unbroken waves as expected but it drops for excessively high funneling ratios due to wave breaking. Hence, one of the main conclusions is that the wave manipulation is more effective in a sea where the short waves are more probable.

It may suggest that an increasingly higher amount of energy could be captured by placing the manipulator more and more seawards but it is not really possible unless \( w_2 \) is not large enough to make those long waves propagate through the manipulator. Further, a certain marginally long wave which break at \( P3 \) may not break at \( P1 \). This is because the wave concentration increases the wavelength and causes the wave to break earlier than in the free sea. Note that the wavelength just seawards of the funnel entrance is longer at \( P3 \) but shorter at \( P1 \) due to the refraction. Therefore, for a given funneling ratio, the increased wavelength due to concentration at \( P3 \) is higher than that at \( P1 \). Therefore, the advantages of the nearshore wave manipulation could be realized by placing the manipulator at \( P1 \), in which case the entrance and the mid-channel is only 360 m and 270 m away from the shore, respectively.

The accuracy of the methodology described in this paper is based on the assumptions that the funnel width and the water depth are slowly varying. Therefore, the corresponding results would not be valid for any higher funneling ratios anyway. For example, the highest possible funneling ratio for unbroken waves is about 2.8 for wave 1 in \( P1 \). The corresponding angle, a wall of the funnel makes with the center line, is about 30° which may be a limiting value. Further, based on the same assumptions, the losses due to wall friction and eddies are considered to be negligible. This set of assumptions are in addition to those used in deriving the linear wave theory such as the water being inviscid and the bottom friction being small. Anyway, the success of TapChan (Mehlum, 1986) in concentrating real ocean waves indicates that the wave manipulator would function as expected in the ocean nearshore.

When multiple waves are present at the same time in random as in the real ocean, this methodology would still be valid. The composite wave could be obtained as normal by the linear superposition of individual waves according to the Fourier analysis (Annette Kristin Brask, 2015; Elgar et al., 1985; Gabriel Rueda-Bayona et al., 2020; Ib. A Svendsen, 2006). Therefore, the contributions from each wave could be evaluated and summed appropriately to find the
required parameter of the composite wave. However, if a certain longer wave breaks, the resulting wave transformation would disturb and influence the other waves too. This is a limitation of this methodology because it relies on empirical results meant only for monochromatic waves. However, the wave manipulator is also a wave filter and it stops longer waves (lower frequencies) and passes shorter waves (high frequencies). Therefore, the channel width could be set such that those peak frequencies with higher power in the wave spectrum do not break. Then, those frequencies, which are higher than the peak frequencies, would not break either. Lower frequencies, even if they break, may not alter the characteristics of the dominant waves considerably if they carry much lower power.

6.1. Energy conversion inside the wave manipulator

The wave manipulation would be particularly suitable for WECs such as point-absorbers because the range of wavelengths are limited in the channel section simplifying the stability issues. For example, illustrated in Figure 15 is a top-mounted spring-assisted, chain-driven, point absorber type WEC which is being developed by the author. The chain connects the floater to the spring and rotates the gearwheel to which a generator is coupled. The whole power-take-off assembly could be easily supported above sea by columns erected on the walls of the manipulator. Additionally, a wave manipulator would also suit oscillating water column devices (Allsop et al., 2014; Halder et al., 2017) and oscillating wave surge converters (Watabe, 2008) as it would enhance the wave heights and wave energy. A nearshore wave overtopping device (Mehlum, 1986; Parmeggiani et al., 2013; Peter Kofoed et al., 2006) would acquire a higher volume of water into the reservoir if connected to the end of the channel section of a manipulator appropriately. Note that TopChan (Mehlum, 1986) too is a different version of overtopping devices. Further, a Pelamis type WEC (Camilla Thomson et al., 2018) would lie safely along the length of the channel section of the manipulator. Note also that some kinds of WECs do not function well if they happen to be in the surf zone after wave breaking due to the reduced level of potential energy. For this case, a hydro turbine (Ibrahim et al., 2021) suits well as the forward momentum of the waves is much higher in

![Figure 15. A schematic of a top-mounted spring-assisted, chain-driven, point absorber type WEC in a wave concentrator](https://example.com/f15.png)
the outer and inner regions of the surf zone. Such a turbine could be mounted individually somewhere close to the channel exit. This implies that the manipulator could be made suited to a hydro turbine by setting the funnel aperture and the channel width such that waves are broken before reaching the end of the channel. Optionally, another type of WEC could be mounted seawards from the turbine where the waves are not broken.

There are a number of other advantages of a wave manipulating structure constructed in the nearshore, only about a few hundreds of meters away from the shore and at a depth of about 6 to 10 m. First, it is a safe haven for WECs as it would guard them against oblique waves and long waves with excessive energy. Yet, the concentrated waves with higher wave heights and energy fluxes would make them capture a level of energy an offshore device would do. Then, it is a huge advantage for the scientists, engineers and the technical staff who are not normally sea farers or divers, as they can reach the site themselves to make visual observations and take necessary measurements for solving design and implementation problems. This also implies that such a structure would be an ideal testing ground for research and development of WECs suitable for both nearshore and offshore.

With regard to the implementation of various WEC systems in practice, Hong et al., 2014; Ringwood, 2008; Felix et al., 2019; Sandberg et al., 2016 describes the corresponding technical, environmental, and social issues in detail.

7. Conclusion
Theoretical and semi-empirical analysis presented in this paper has proved that the wave manipulator can increase the energy density and flux of the nearshore waves and then disperse them. Depending on the channel width, waves may continue to propagate, break, or cease to propagate through the manipulator. The relative increase in wave energy flux of unbroken waves is equal to the funneling ratio and that of broken waves is considerable if the channel width is high. This wave enhancement procedure is more effective if the manipulator is placed as close to the shore as possible but the entrance must be at the shoaling region of the expected waves. More seawards placements have less gain for a given set of wave periods. Although, it seems to be possible to capture longer waves with higher energy further away from the shore, the necessary increase in channel width results in decreasing the manipulation efficiency. Thus, the best placement for such a wave manipulator could be estimated if the bottom slope and the most probable wave periods are known for a given coast.

In the channel section of the manipulator, powerful waves similar to those in the offshore would make existing types of WECs generate considerable amount of power. Further, manipulator dimensions could be selected such that the forward surge of broken waves is suitable for certain types of hydro turbines. A wave manipulating structure facilitates mounting the power take off assembly of some WECs above sea level, protects them from oblique waves and boat movements and is a safe testing area for research and development of WECs.

Funding
The authors have no funding to report.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: On the placement of a wave manipulator suitable for energy harnessing in the Nearshore, K. D. R. Jagath Kumara, Cogent Engineering (2022), 9: 2124636.

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