Physical Modeling of Flotilla Wave Reducer System for Mitigation of Erosive Beach Profile

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Abstract

Beach profile evolution is an energetic natural phenomenon which directly affects the coastal community, sometimes in an unfortunate form of shorefront erosion and shoreline retreat. For prevention of such miserable outcomes, a revolutionary patented Flotilla wave reducer system was developed and its physical model was tested here in a laboratory wave flume. Unprotected beach profiles evolving under various wave conditions were first recorded over the time and, more importantly, at their equilibrium states. The Flotilla model was later positioned in the flume before the tests were repeated for finding a new set of beach profiles under its protection. The two sets of resulting profiles were then compared to evaluate the effectiveness of the Flotilla system. As per the results, the following significant features were found in the presence of the structure: 1) reduced overall shorefront erosion due to smaller wave run-up, 2) much flatter sandbar troughs due to less intensive wave breaking, and 3) less pronounced sandbar crests located closer to the shoreline, due to smaller pre-breaking waves. The morphodynamics underlying these features could be very complex, yet the Flotilla structure introduces a straightforward principal alteration in the process. It functions to attenuate incident waves thus allowing milder wave conditions to impose on the beach profiles which, therefore, evolve to an unsurprisingly less erosive pattern at the equilibrium states.

Keywords: Flotilla, shore protection, coastal erosion, floating breakwater, beach profile evolution, equilibrium beach profile, wave flume experiment.

1. Introduction

Coastal area, undoubtedly one of the most valuable parts of our planet, has never ceased to see destructive shorefront erosion since the beginning of the history (Pranzini, 2018). More recent investigations also point out the fact that such an unwanted phenomenon only becomes more threatening as the world develops (Mentaschi et al., 2018). In general, coastal protection can be attempted using hard structures including breakwater, seawall, and groin, or applying soft solutions such as beach nourishment and artificial reef (e.g. Srisuwan & Rattanamanee, 2015; Karasu et al., 2016). The former do not permit flow of water nor sediment, while the latter always employ a more eco-friendly process. It is unfortunate that these options often cannot offer an ideal combination of maximizing protection and minimizing environmental impact, as well as an ease of construction and operation.

Floating breakwaters have long been developed since World War II, originally reported to serve as a shelter for marine troops (Lochner et al., 1948). They are widely applied nowadays for shore protection according to some advantages over fixed or bottom-mounted structures, for example, their applicability to various seabed conditions and tidal ranges. They also feature a low profile with minimal visual impact on the horizon, and are more environmentally friendly than other hard structures such as seawalls or jetties. This characteristic is primarily due to their much lower interference with the coastal circulation, especially in the long term (Dai et al., 2018). The nearshore hydrodynamics also favors the use of such a wave attenuation system which is located at the water surface where most of the wave energy is confined. Despite the pros, conventional floating breakwaters are susceptible to low capability under long waves as well as in a harsh weather condition during which the rigidity of the structure is reduced (Tsinker, 2012).

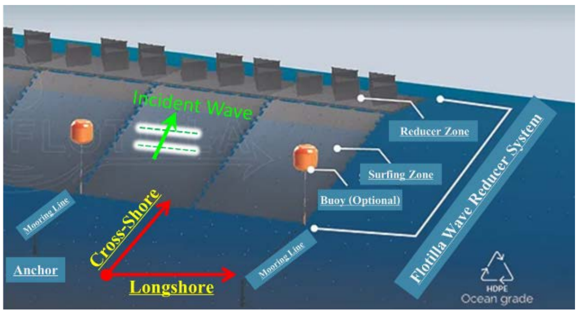


Fig. 1 An overview of Flotilla floating wave reducer system.

Through a standard technique in physical modeling, a newly-developed wave reducer system was evaluated in the present research study. This innovative system is referred to as “Flotilla” and has exclusively been granted for patents in many countries around the world (e.g. Boonlikitcheva, 2020a, 2020b, 2022a, 2022b, 2022c). Even though similar in appearance, Flotilla is not a classic floating breakwater as it consists of a surfing zone and a reducer zone which work to accumulate and dissipate the incident wave energy in consequence (Fig. 1). This uniqueness is the principal key which allows Flotilla to reduce the intensity on sediment transport and erosive beach profile. In the sections that follow, detailed design and underlying principles of Flotilla are first discussed. Physical modeling and laboratory setup are then illustrated before the experimental data are presented and analyzed. Conclusions are finally made summarizing the capability and sensitivity of Flotilla for protecting beach profile evolution which is the underlying process of coastal erosion.

2. Basic Principles and Theory

2.1 Nearshore Hydrodynamics and Sediment Transport

The nearshore zone is generally defined as a transect from the shoreline over which the seabed feels an effect of the surface wave, leading to sediment transport and beach profile evolution. A widely-accepted concept of beach profile shape and natural slope was suggested in a very early day, referred to as "equilibrium beach profile" (Dean, 1991). It suggests that a beach profile is unique to a specific sediment size and wave forcing, and will remain as such if these two factors are unchanged. This classic theory, though very simple, is able to provide insight into most basic patterns of beach profile evolution. An erosive-type beach profile, showing a deep sandbar trough and a more pronounced sandbar crest (see Fig. 2), always occurs with strong waves and fine sand since the undertow can carry more sediment further seaward. If the waves become milder, like in the summer, the sandbar may deform as the onshore-directed sand transport is dominant.

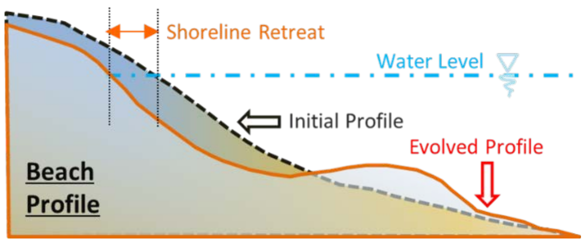


Fig. 2 Common beach profile shape and natural evolution.

Other complex processes such as wave breaking and wave run-up are also influential and the degree of beach profile change should be directly related to their intensities (Dean & Dalrymple, 2002). This wave-sediment transport relationship not only reveals the natural process but also helps to promote a simple, active, and effective solution for beach profile protection. That is, any strong incident waves need to be mitigated into a non-destructive level before they propagate and break onto the beach. The threshold at which an erosive can shift to an accretive wave condition may be anticipated following the semi-empirical equation (Dalrymple, 1992), following

$$\frac{H^2}{T.W_f} \leq 26{,}500 \quad (1)$$

where H is the wave height, T is the wave period and W_f is the sediment fall velocity. The relationship in this threshold implies that a non-erosive condition would favor a smaller but longer period wave, and larger-size sand with higher terminal velocity. Considering the fact, at any specific site, reducing the magnitude erosive wave appears to be the only reasonable solution for mitigating the erosion. The Flotilla wave reducer system here is designed for the purpose. A number of laboratory tests, in a separate occasion, were conducted to quantify the performance of the structure as per the percentage of wave height reduction following

$$SPF = \left[1 - \frac{H_T}{H_I}\right] \times 100\% \quad (2)$$

in which SPF refers to the structure performance index; H_T and H_I are the transmitted and the incident wave heights, respectively. Generally, the functionality of the Flotilla allows wave height attenuation with values of SPF ranging from 20% to 55%. These percentages can definitely be expected as the key to the erosion mitigation investigated in the present study.

2.2 Design and Operation of Flotilla

Unlike common floating breakwaters, the Flotilla system is invented with multiple parts and it serves to work as a more robust coastal protection structure. A different assemble of the structure is also possible for some other purposes such as harbor platform or ocean energy harvesting module. Fig. 3 shows an outline of the prototype structure with its uniqueness in having the surfing zone for wave energy accumulation and the reducer unit which acts to dissipate wave energy. This novel design allows the structure to not only focus near the water surface with highest wave energy but also let the wave energy dissipation occur at a superior chance as the wave shoals and its energy becomes concentrated.

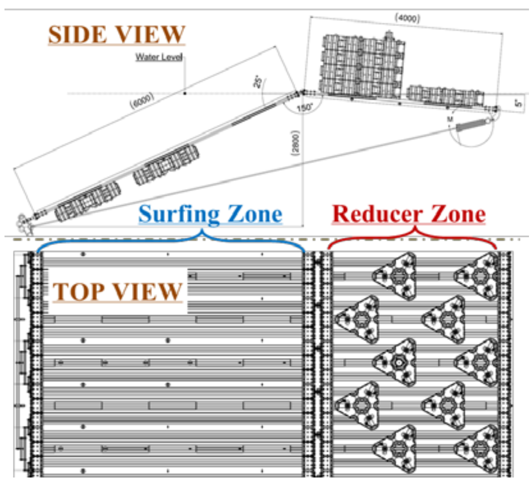


Fig. 3 Schematic and alignment of the Flotilla system at prototype.

Possessing a superior wave energy reduction capability means a more direct and greater net wave force imposed on the Flotilla structure and the mooring system. To cope with this challenge, the structural design was focused on sharing the load through various rigid and flexible parts. Anchored piles are to be utilized mandatorily with appropriate sizes and longshore spacings depending upon the seabed property. The flexible spring and cable systems are equipped within the system which allow the structure to absorb the wave force while dissipating the wave energy. These stability factors may not directly be related to its capability in mitigating beach profile erosion, but they are so crucial that a successful practical application would not be achieved without a careful consideration on them.

3. Experiment Design

3.1 Wave Flume Facility

The proposed experimental study was achieved at the wave flume facility of Prince of Songkla University, Hatyai, Thailand. The flume features a length of 28.0 m and a width of 1.2 m with a maximum operational water depth of 1.0 m. Its offshore side is equipped with a paddle-type monochromatic wavemaker, while the other end allows an establishment of a beach profile as illustrated in Fig. 4. The definitive goal was to obtain new sets of data regarding beach profile evolution in the scenarios with and without using the Flotilla system, which had never been tested before.

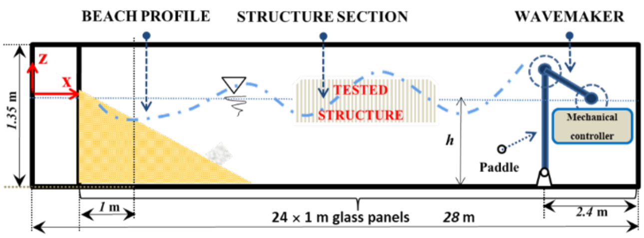


Fig. 4 Wave flume facility employed in the experimental study.

The sand used in the experiment was collected from an adjacent natural beach and its physical properties are listed in Table 1, which imply that the sand was a rather well-sorted, intermediate-size mixture. A planar slope of 1:6 obtained from geometric scaling based on equilibrium profile was set as an initial condition for every test. This required a total volume of up to 10 m^3 of the sand. Following the geometric scale, the kinematic and dynamic similitudes at prototype and in the laboratory were investigated via a dimensional analysis which showed a few distorted numbers as the sand could not be scaled down in the experiment. This limitation, however, did not obstruct the focus in evaluating the Flotilla which was based on comparing scenarios with/without the structure, as opposed to a sole study on the natural beach evolution.

Table 1 Physical properties of sand utilized in the study.

Parameter	Value	Parameter	Value
D10 (mm)	0.18	D90 (mm)	0.62
D16 (mm)	0.24	STD. (mm)	0.16
D50 (mm)	0.33	Sorting Index [-]	3.44
D84 (mm)	0.56		

3.2 Physical Model of Flotilla

The wave flume experiment was aimed at allowing the most precise evaluation of the Flotilla system. According to the flume dimension and the selected beach profile slope, it was mandatory that the prototype Flotilla be scaled down around 8:1 to 11:1, depending on the water depth. The ratio of 10:1 was thus selected for scaling down the structure. The physical model was then recreated according to the prototype in every detail as shown in Fig. 5.

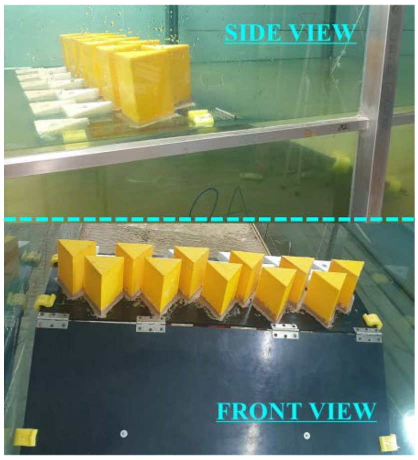


Fig. 5 Physical model of Flotilla recreated for the experiment.

To satisfy the actual conditions at prototype, the physical model of Flotilla needed to be installed into the wave flume under a very careful consideration. A major challenge arose here since some of the parts and materials of the prototype Flotilla could not be perfectly altered in the physical model. Buoyancy force per body weight, for example, was almost definitely an important ratio which could not be met. Hence, some further modifications were made on the physical model, including adding light-impermeable material around its edge and adjusting the anchor cable tensions. Such an attempt successfully allowed the preservation of 1) the submergence depth of Flotilla, 2) the incident angle of waves on the front surfing deck, and 3) the inclination of the rear reducer zone (see also Fig. 3). This alignment was believed to be the most paramount specification on the capability of the structure.

3.3 Selection of Wave Conditions

Wave characteristics are the utmost influential factors on beach profile change and shoreline erosion in particular. A wide variety of waves were selected to be in the experiment here to represent the actual variation in the nature. The selection relied on two considerations One was the wave magnitude alone which, though simple, is always certain to be most impactful to the change. The other was the Dean's number described in Eq. (1) as it would indicate the scenario of an evolution. With these specifications, all of the wave conditions exercised in the experiment are listed in the order of test cases in Table 2.

In overall, two major test sets, A and B, were conducted with two different water depths. There were eight tests in each set, consisting of two wave periods and four different wave heights ranking from the calmest to the most severe condition. The Dean's number, of which a value of 26,500 indicates an evolution threshold, was estimated for each test as a rough guideline. Note that all of the 16 tests were performed twice with or without the Flotilla as per the ultimate goal to determine the effectiveness of the system.

Table 2 Wave conditions specified and tested in the experiment.

Test Set	No.	Water Depth(m)	Wave Height(m)	Wave Period(s)	Dean's Number
A	1	0.6	0.15	2.4	≈12,000
	2	0.6	0.15	2.8	
	3	0.6	0.18	2.4	≈18,000
	4	0.6	0.18	2.8	
	5	0.6	0.21	2.4	≈25,000
	6	0.6	0.21	2.8	
	7	0.6	0.27	2.4	≈40,000
	8	0.6	0.27	2.8	
B	1	0.7	0.18	2.4	≈18,000
	2	0.7	0.18	2.8	
	3	0.7	0.21	2.4	≈25,000
	4	0.7	0.21	2.8	
	5	0.7	0.25	2.4	≈40,000
	6	0.7	0.25	2.8	
	7	0.7	0.32	2.4	≈55,000
	8	0.7	0.32	2.8	

4. Laboratory Test and Results

4.1 Implementation and Data Collection

With the chosen initial profile and water depth, each set of the tests listed in Table 2 were implemented in a series. The wavemaker was operated continuously for a particular wave condition during which the beach profile was recorded repeatedly every five minutes via a direct reading on the scale tabs as shown in Fig. 6. Besides the profile change, the incident wave and the structure motion were also recorded as reference and for analyzing purpose.

Since the evolving profile was clearly visible on the flume glass panel, it was also hand-marked over the times. This marking line helped to track the instantaneously profile change thus allowing identification of an equilibrium profile. Once identified, the profile was to be measured once again and the incremental change would be compared. If the change was negligible, the equilibrium profile could be confirmed; otherwise, the test and the data collection would be continued. It is worth reminding that the test cases listed in Table 2 were carried out twice, independently, for simulating natural unprotected beach profile and for the scenario of protected beach in which the Flotilla system was installed.

Fig. 6 Recording and tracking of evolving beach profile in the experiment.

4.2 Beach Profile Evolution

Starting from the initial condition, Fig. 7 shows the beach profile that changed over the time in the first test (A1). The initially-plane slope evolved rather rapidly in the first 20 mins with significant erosion at the shoreline and formation of a sandbar further offshore. Thereafter, the experiment was set to continue but the instantaneous beach profile seemed to approach an equilibrium state. Note that the sand transport did not completely stop in this circumstance but the local onshore-offshore transport fluxes would tend to balance out. These spatial and temporal variations on the beach profile are one of the most common features in the nearshore zone. If snapshots of the profile evolution from every other test were illustrated, their patterns would all have been very similar only with somewhat different magnitudes of the changes.

According to the focus on equilibrium profiles, the final record of the beach evolution in every test case was passed on to the main analysis. Fig. 8 shows an example of the natural equilibrium profiles found in multiple tests (B3, B5, and B8). In Test B3, with the smallest wave condition, the evolution led to a typical equilibrium beach profile just described per Fig. 7. The more severe wave condition in Test B5, meanwhile, brought an additional erosion and sandbar migration on the equilibrium profile as if the Test B3 were continued. For the strongest wave in Test B8, a much more severe erosion was observed in its equilibrium state, and likewise the sandbar accumulation became enormous with a highly-concave bar trough and a very prominent bar crest. To reach the objective in evaluating the Flotilla capability, these equilibrium beach profiles are compared next based primarily on the net profile changes occurred differently between the two scenarios, with or without using the Flotilla system.

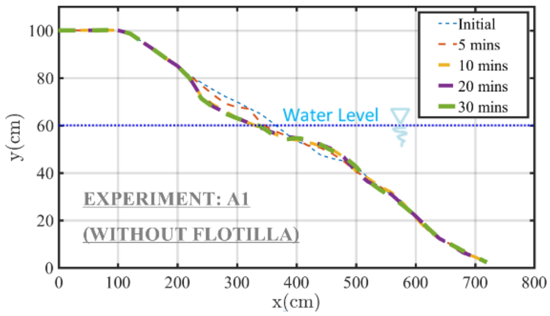


Fig. 7 Examples of evolving beach profiles in the first test (A1).

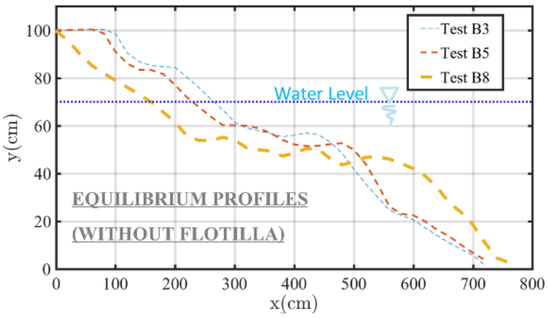


Fig. 8 Examples of equilibrium beach profiles observed in the experiment.

4.3 Result Comparison

The resulting equilibrium beach profiles allow the effectiveness of the Flotilla system to be evaluated based on the experiments operated with and without using the structure. Note that each pair of the tests in comparison were conducted under an identical experiment condition and therefore any difference on the two final beach profiles was contributed entirely by the presence of the structure.

Fig. 9 shows two pairs of the equilibrium profiles for the first and the last cases of Test Set A. It can be observed that the use of the Flotilla system led to the equilibrium beach profiles with shorter shoreline retreats and smaller sandbars in shallower depths. These evidences indicated that the incident waves were breaking much closer to the shoreline in a shallower water, agreeing with the fact that the waves would be smaller as they were attenuated once propagating through the Flotilla. All of these features are especially clear in the second comparison in Fig. 9 (Test A8) since the more severe wave condition was applied. In this case, the wave attenuation definitely became more significant, so did the difference between the final impacts on the two beach profiles in the protected/unprotected scenarios

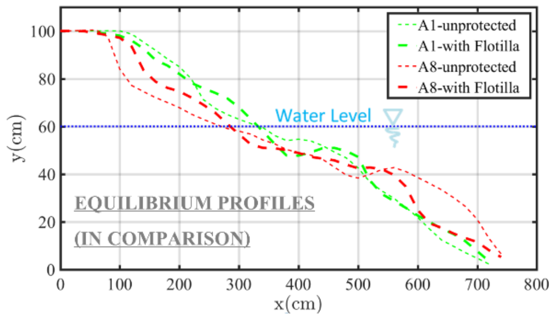


Fig. 9 Comparison of the profiles with/without Flotilla in Test Set A.

Fig. 10 illustrates the same type of results for Test Set B with the deeper water setup in the flume. The first comparison shows that using the Flotilla system still resulted in the profile that featured a smaller shoreline retreat. A flatter bar formation was also observed but the erosion in the swash zone appears to be greater than the case with an open wave forcing. The second comparison for Test B8 should better be more representative for the analysis as it was the most erosive test case. At a first glance, the difference between the two profiles may appear to be substantial compared to that of the first case (B1). A closer consideration can, however, reveal that only the magnitude of the profile evolution is somewhat larger but the temporal variation still follows the same trends. A smaller sandbar and shorter shoreline retreat were still clear if the Flotilla system was employed for the protection. A higher erosion further inland was still true despite exposing to somewhat attenuated waves. It is rather certain that this feature occurred since the breaking waves were propagating on a less erosive, milder foreshore slope thus promoting the runup to be higher. Subsequently, the sand further inland was back-washed and caused an erosion in such a wetting-drying zone.

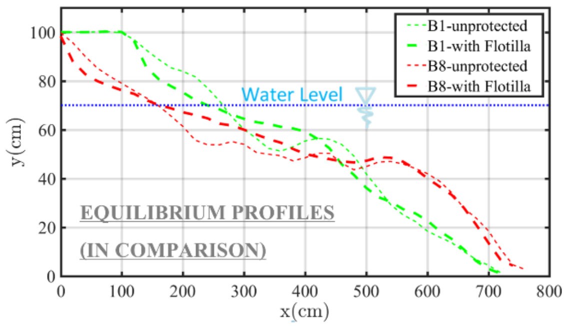


Fig. 10 Comparison of the profiles with/without Flotilla in Test Set B.

4.4 Qualitative Analysis

The extent to which the sand transport occurred along a beach profile may vary from case to case. The main objective here is to quantify a degree of the total change on an equilibrium profile, to allow a clear qualitative comparison among the evolved profiles. This quantification was achieved by defining a new parameter "β" of which the estimation is illustrated in Fig. 11. For a particular profile evolution, this parameter straightforwardly represents the total change incurred by the shorefront sand transport and the sandbar formation. For beach profile erosion, these changing patterns are so typical that they may be referred to as "undesirable changes".

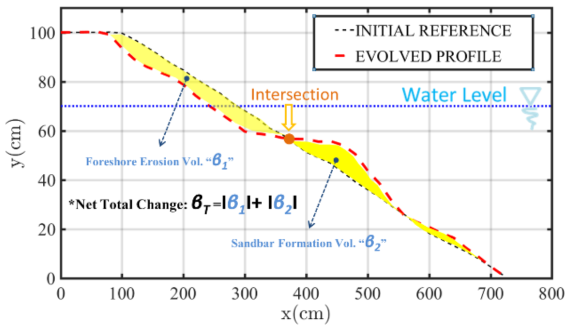
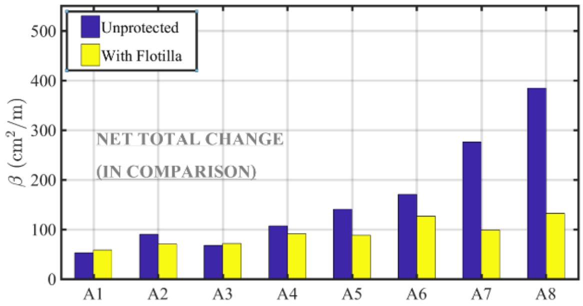


Fig. 11. Quantification of the net total change in beach profile evolution.

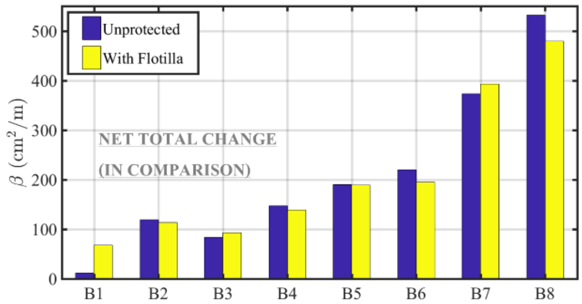
Fig. 12 shows the values of "β" computed and passed on to the inter-comparison for every pair of the equilibrium profiles with and without the installation of Flotilla. In Fig. 12(a), the resulting values from Test Set A show that the total changes tended to reduce with the use of Flotilla. The reduction is especially clear for some later cases with larger wave conditions. This favorable outcome is definitely achieved due to the degree of wave attenuation described earlier, e.g. for Fig. 9. An exception is, however, found for the first few tests in which the total changes seem to be very comparable. In such cases, the experiment was not operated in a clear erosive mode, according to the Dean's number. Therefore, the protection by Flotilla did not provide much superior result as the beach erosion was not modest even in the intrinsic condition.

In Fig. 12(b), the comparison is shown based on the results from Test Set B in which the margins of the total changes between the two scenarios are now not as obvious as those in the first test set. As per the alignment of the Flotilla system (see also Fig. 3), a greater water depth could cause a decrease in the wave attenuation as the surfing deck is located higher up in the water column. This shifting is believed to have a first-order effect as it implies more wave energy passing through and hence a smaller portion of wave energy dissipation.

Such smaller margins on the net profile changes, indicated by the values of "β", were also due to different local erosion/deposition along the equilibrium profiles. In the case of using Flotilla, it was clear that the sandbar would be closer to the shore with a flatter bar trough, which would accrue less to the total change (see Fig. 11). Meanwhile, the other portion on the inland side would include the furthest extra erosion into the total change due to the possibility of higher wave runup described earlier. Note that this does not necessarily mean that using Flotilla lifted up the swash zone erosion, but it just led to a slightly different evolution pattern associated with some sand transport further inland. The shoreline retreat, which was always more minor, should account for the fact that the use of the structure still resulted in a more desirable change of the beach profile.



(a) for experiment Set A.



(b) for experiment Set B.

Fig. 12 Summary of different degree of profile changes with/without Flotilla.

4.5 Sensitivity Analysis

Given the feasibility of Flotilla for mitigating beach erosion, the next objective would be to correlate such a capability with some influential factors to provide an initial guideline for practical application. Certainly, these factors would be those of the incident waves and the water depth. The structure performance is therefore investigated here for its sensitivity to the following non-dimensional parameters.

4.5.1 Relative Wave Height (H/h)

This parameter represents the ratio between the wave height to water depth. Not only does it imply the wave magnitude, but it also indicates stability and linearity of the wave. For example, a ratio closer to 0.5 to 0.6 would infer to a wave that is becoming more non-linear and closer to breaking. Fig. 13 shows the correlation between this ratio and the capability of Flotilla in reducing the beach erosion. Note that the latter fraction, referred to as *"α"*, was represented by normalizing the margin of the net change *"β"* between the scenarios of Flotilla on or off. Therefore, a value of unity infers to the best test result found in the experiment. Meanwhile, a value of zero is intentionally given for the case where the Flotilla cannot be proven to provide any reduction in the erosion.

The correlations are shown separately for Test Sets A and B since the results were so different that the value of the water depth alone could be taken as one of the most important recommendations for the application. Nevertheless, the relationship between the capability factor "α" and the relative wave height shows a similar trend in both test sets. The erosion mitigation could be achieved better for the cases with larger values of *H/h*, supporting by two interrelated reasons. One is on the more energetic waves and the other is on the more erosive condition in the tests, both of which imply greater wave height reduction and relatively higher protection degree on the beach profiles.

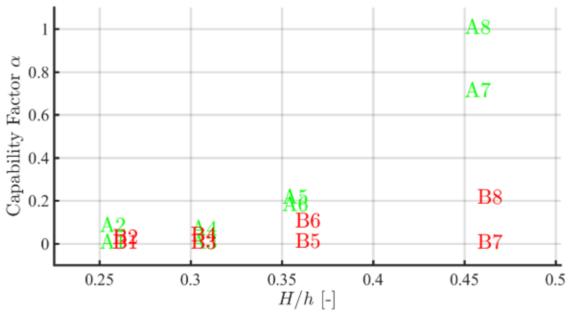


Fig. 13 Reduction of beach profile change offered by Flotilla as function of relative wave height (*H/h*).

4.5.2 Wave Steepness (H/L)

This parameter straightforwardly provides information about physical profile of the wave. As per linear wave theory, the wave length is fixed for a given wave period and water depth. The wave steepness therefore increases proportionally to the wave height, so does the slope of the oscillating water surface. Typical non-breaking linear waves would have a steepness lower than 0.05 and it should be very realistic that the variation of this factor affects the effectiveness of a floating wave reduction structure.

Fig. 14 shows the relationship between the wave steepness and the capability of Flotilla, in terms of normalized values "α". Again, the magnitudes of "α" found in Test Sets A and B are so different but their variations are similar for both sets. In overall, the structure performance appears to enhance for the cases with higher wave steepness, or the more severe wave conditions. Now consider any two consecutive odd- and even-numbered tests, for example, A7 vs. A8 or B5 vs. B6. If the capability factors are intercompared between them, the superior values will be found in almost all of the even-numbered tests which featured smaller wave steepness. This secondary finding could be contradictory to the overall trend of "α" rising with *H/L*, but such an occurrence might also be due to another possible factor, and it is to be analyzed next.

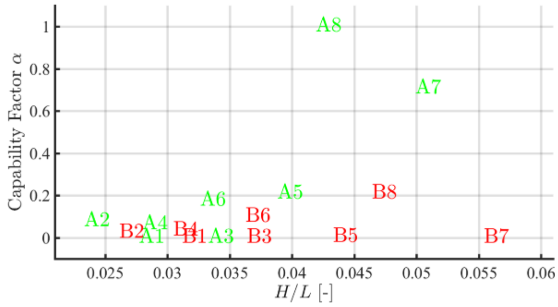


Fig. 14 Reduction of beach profile change offered by Flotilla as function of wave steepness (*H/L*).

4.5.3 Relative Water Depth (h/L)

This ratio between the depth and the wave length is commonly adopted to classify if a wave is a deep water or a shallow water wave. Alternatively, it may be described as a short or a long wave of which the underlying mechanics can be quite different. For example, the latter features kinematic energy distributed more over the water column and thus sends greater impact to the seabed. Their wave phase speeds, group velocities, and orbital velocities are also dissimilar and these factors are influential to the wave energy transmission and dissipation.

Fig. 15 shows the correlation between the performance of Flotilla and the relative water depth. Interestingly, the capability factors "α" appear to be higher for smaller *h/L* which were from longer period waves. This trend might potentially be against a common criticism on floating breakwaters' ineffectiveness in resisting long waves (e.g. Dong et al., 2018). The finding here should however be considered with some reservations. One is due to the fact that such a criticism is about the hydrodynamics and not on the beach profile evolution. More noteworthy, the Flotilla system is certainly not a common floating breakwater so that its performance may vary differently. In the most likely scenario, it should be the wave runup that played an important role in the relationship shown in Fig. 15. With all other parameters being equal, a longer period wave will tend to result in a larger runup and a more severe erosion in the swash zone. As the Flotilla system was installed, such a local erosion could be better mitigated according to its specific intensity. It is imperative that this occurrence be noted for the description of Flotilla capability on waves with different wave lengths.

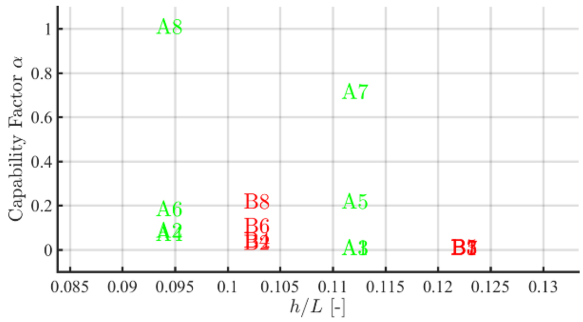


Fig. 15 Reduction of beach profile change offered by Flotilla as function of relative water depth (*h/L*).

5. Conclusion and Discussion

Coastal erosion in the nearshore zone has only become worsened in the past few decades and an immediate solution is needed for the mitigation. A newly-developed wave reducer system referred to as "Flotilla" has recently been introduced for the purpose. This innovative structure can be considered as a sophisticated floating breakwater with a surfing deck and a reducer zone for better surface wave attenuation. The experimental study carried out in this research program aims at answering two straightforward questions. One is whether the Flotilla system is feasible for mitigation of beach profile. If it is, there comes the other question as to what site and wave conditions would favor an application of the structure.

A total of 32 laboratory tests of beach profile evolution were conducted with a physical model of Flotilla to provide datasets that would help to achieve the aims. The intercomparison between the scenarios of using or not using Flotilla showed that the former option could lead to equilibrium beach profiles which appeared as if they were not fully evolved, having smaller sandbars and shorter distances of shoreline retreats. This result can be attributed to the fact that the incident waves would first be attenuated by Flotilla, thus becoming less energetic and started to break much closer to the shoreline. In overall, the erosion reduction by Flotilla can be warranted. The only part appearing to not be preserved by Flotilla was the furthest onshore at the tip of wave runup where some additional erosion could be found. This feature was a result of breaking waves propagating on a milder, less eroded slope so they could surge farther. Note that it did not lead to any higher swash zone erosion in total but only induced a slight back-washing further onshore.

The capability of Flotilla was also analyzed for its sensitivity against important parameters involving waves and water depth. First of all, the attempt into the analysis revealed that the water depth alone should be taken as one of the most crucial factors since it defines the relative submerging depth of Flotilla which is influential to the wave energy dissipation. More detailed sensitivity tests led to a final straightforward conclusion that the Flotilla's protection on beach profiles could be more clearly evident for highly erosive beach evolution with more energetic waves. Such a case simply implies the situation with a larger wave height whether for its actual magnitude, or its relativity to the water depth, and in terms of the wave steepness.

Based on the resulting equilibrium beach profiles, the Flotilla also did not show a declination of capability against long waves. It was understood that, despite such intrusive waves, an overall erosion in the foreshore zone could better be mitigated once the Flotilla was deployed. This finding could be another attribution of the system over traditional floating breakwaters; yet, as with its other advantages, subjected to further tests and affirmation. For the most conclusive result, a field experiment based on actual ocean waves and natural beach profiles will definitely be preferred. As part of the present research program, the prototype Flotilla is being tested at an erosion-prone beach area to serve for this purpose.

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