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Rehabilitation of Submerged Breakwaters by Using Wave Screens

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ABSTRACT

Submerged breakwaters are widely used because of their economic, environmental, and aesthetic advantages. However, sea level rise and excessive settlement cause a reduction in wave attenuation and breakwater efficiency. So, the rehabilitation of submerged breakwaters efficiency is considered one of the important issues in the field of harbor engineering and shore protection. Wave screens can be used for this purpose due to their considerable advantages, as their construction is inexpensive, easy and requires less material, time, and space. Also, they are considered an environmental friend solution as they do not obstruct water flow or fish passage. An experimental investigation was executed to determine the impact of the settlement of submerged breakwaters on their efficiency and investigate the influence of placing the wave screens above the breakwater to enhance its efficiency. The results showed that the reduction of the relative height of the breakwater by 10 % and 20 % decreases the efficiency by 10 % and 37.5% respectively. Also, the used single wave screen improved the efficiency by 19.3% and the screen porosity had a significant impact on the breakwater efficiency. However, the screen position had an insignificant influence on rehabilitation. In addition, the double wave screens increased the breakwater efficiency by 16.40%. Finally, placing the wave screen above the tested breakwater was better than using it in front of the breakwater and more economic.

Keywords: *submerged breakwaters, wave screens, rehabilitation, settlement.*

1. Introduction

Coastal zones are reasonable locations for recreational, commercial, and industrial activities and urbanization, so, they accommodate more than 50 % of the world's population, and they are considered one of the most valuable regions in any country. Also, the shoreline is defined as the interface between land and sea and represents one of the major natural boundaries for many countries(Ezzeldin et al., 2020). So, shoreline erosion due to different parameters such as hydrodynamic processes and human interventions is one of the main crucial issues for many coastal countries.

Submerged breakwaters are considered one of the soft methods and the most suitable solutions for shore protection. Submerged breakwaters are relatively inexpensive and allow wave overtopping that enhances the water quality at the lee side. Also, they have aesthetic value as the ocean view doesn't be blocked (Saad, 2014). Also, they are preferred in areas which are prone to bacterial reproduction as it is a danger to beach users health and can be used for coral restoration (Izzat et al., 2018). In addition, submerged breakwaters have minimum reflected waves and a minor impact on the adjacent shorelines(Cheng et al., 2003), and can afford effective protection against tsunamis (Irtem et al., 2011), so the use of submerged breakwaters in the coastal protection become more popular around the world. Iskander et. al 2008 proposed the submerged breakwaters as the best solution to protect the shoreline and create a reasonably sloping beach at El- Alamein, Egypt (Iskander et al., 2008). Also, a submerged breakwater was used to protect Al-Ahlam resort on the Northwest coast of Egypt (Zahra, 2018). In addition, the implemented submerged breakwaters at Miami, east of Alexandria, Egypt, showed a good performance during the December 2010 storm as the height of the generating waves reached 7.50 meters for the first time in the last century (El-Sharnouby & Soliman, 2011).

The submergence depth of submerged breakwater crest has a significant impact on wave attenuation and breakwater efficiency (Ahmed & Anwar, 2011; Dattatri et al., 1978; Heikal et al., 2002; Rageh, 2009; Shirlal & Rao, 2007; Yuliastuti & Hashim, 2011). So, the excessive settlement of the breakwater increases the submergence depth and decreases the breakwater efficiency.

For instance, the narrow low crested breakwaters that used to protect Cleopatra beach, Alexandria, Egypt, had a complete failure due to excessive settlement (El-Sharnouby & Soliman, 2011). Also, the settlement of the used submerged breakwater on the southeast coast of Florida, USA, reduced the efficiency of the breakwater significantly. The settlement ranged from 33% to 46 % of the total height of the breakwater and most of the settlement occurred a few months after the construction (Browder et al., 1996). In addition, many submerged breakwaters were constructed in the Marche region with a typical cross-section with a crest level 0.90 m below MSL. Due to the poor performance of the implemented breakwaters, the crest level was raised to 0.50 m below MSL(Ranasinghe & Turner, 2006). Also, the constructed submerged breakwaters at Vero beach, Florida, USA, had low wave attenuation due to the excessive settlement that reached 1.02 m (Ranasinghe & Turner, 2006). In addition, due to seabed erosion in the vicinity of the breakwaters, the proposed breakwater at the Gold Coast, Australia, suffered a significant settlement that required another construction phase to restore the crest level consequently (Ranasinghe & Turner, 2006). Also, In July 1993, a submerged reef was constructed in the Atlantic Ocean at Avon, New Jersey, USA, and the entire breakwater had a significant settlement that reached 1.52 m at the southern end. The monitoring program showed that the most of settlement occurred within nine months after the installation (Stauble & Tabar, 2003). So, it is obvious that the breakwater settlement has a significant impact on its performance and decreases its efficiency. On the other hand, as sea level rise is characterized as one of the most crucial issues threatening the worldwide coastal areas(Sharaan et al., 2022), it also increases the submergence depth and affects wave attenuation and breakwater performance.

Many studies used additional structures placed seaward or leeward side to improve the stability and performance of submerged breakwaters. A fixed horizontal plate was placed on the seaward side of the submerged breakwater with different relative distances and different submergence depths. It was found that breakwater efficiency increased when the relative distance increased (Hsu & Wu, 1998). Also, floating breakwaters were used to enhance the efficiency of the submerged breakwater. Results showed that the proposed addition improved submerged breakwater efficiency. Also, the floating breakwater above the submerged breakwater showed better performance than placing it on the seaward or leeward side (Cho et al., 2003).

Wave screens are defined as vertical permeable walls with horizontal or vertical slots, and they are categorized as environmental friend breakwater. Also, they have many advantages such as easy construction, inexpensive, allow water exchange and sediment transport. So, wave screens are a suitable solution to rehabilitate the existing breakwaters. Single and double wave screens with horizontal slots were used to improve the submerged breakwater efficiency. The proposed alternatives were placed on the seaward side and they improved the efficiency by about 22 % (Rageh et al., 2013). However, using the wave screen above the submerged breakwaters seems to be more effective and economic. Hence, this paper aims to investigate the impact of breakwater settlement and study the influence of using wave screens in the rehabilitation of submerged breakwaters.

2. Experimental Work

Physical modeling is usually used to illustrate the performance of coastal structures and the interaction between the various structures and hydrodynamic processes such as waves, currents, and sediment transport. Also, it is considered a significant tool to have the optimum design of the coastal structures (Romya et al., 2021). So, a set of experiments were carried out to study the influence of submerged breakwater settlement on its performance. Also, the experimental study investigates the rehabilitation of submerged breakwaters after the settlement by using wave screens above the breakwater crest.

2.1 Wave flume

The experimental work was carried out in the Irrigation and Hydraulics Lab, Faculty of Engineering, Mansoura University, Egypt. The used wave flume was 15.10 m long, 1.00 m in width, and 1.00 m deep. The wave flume has a flap-type wave generator and an artificial beach with a slope of 1:3 at the end of the flume acted as a wave absorber, Fig. 1. The experiments were carried out in water depth (d) of 50 cm and variable speed motor to generate seven different wave conditions.

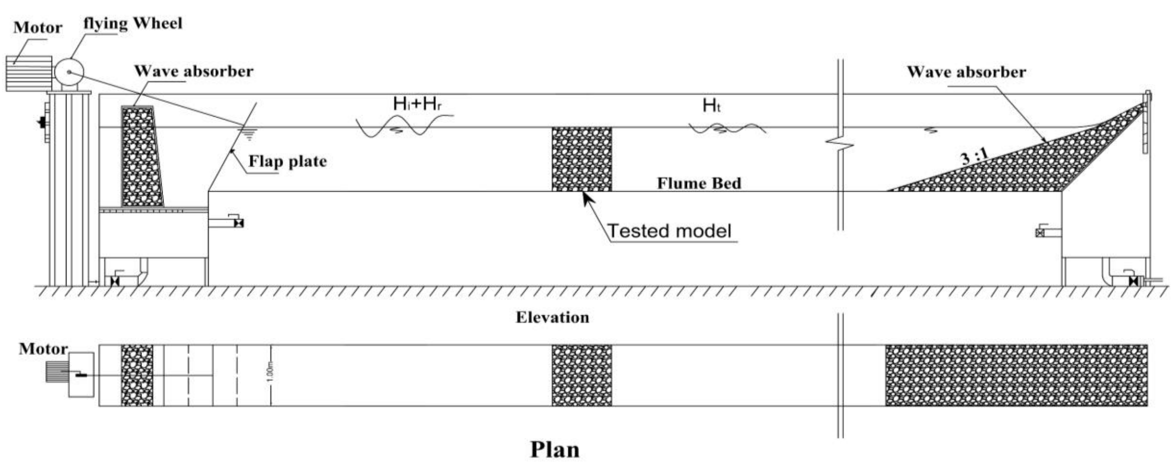

Fig. 1: Schematic diagram of the wave flume

2.2 Tested models

The main tested model is a submerged breakwater model (S.B.), that consists of a steel box made from a steel screen filled with gravel. The model was 40 cm in width and the tested heights (h) were 50, 45, and 40 cm, to simulate the excessive settlement after the construction, Fig. 2. The submerged breakwater models were placed in the middle of the wave flume.

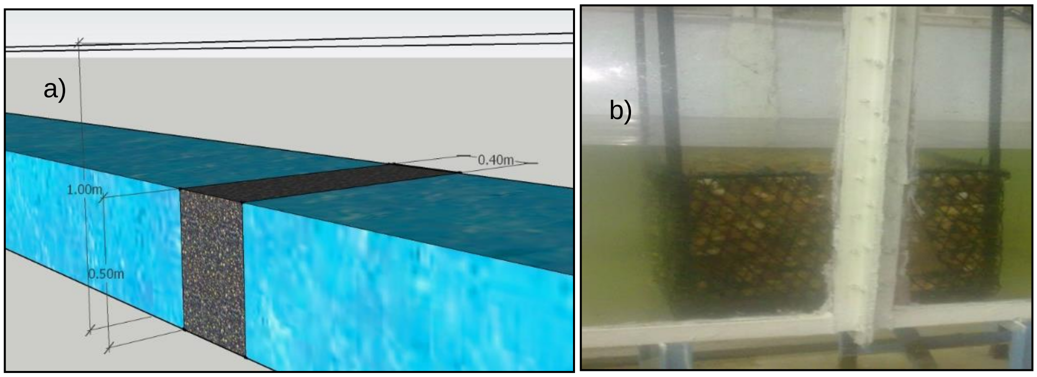

Fig. 2: a) Isometric view of tested model b) Submerged breakwater model with 40 cm height.

In the case of S.B. with 40 cm height, the wave screens were used with different configurations above the S.B. crest, Fig.3. The wave screens were made from treated wood with three different porosities of 33%, 40%, and 50%.

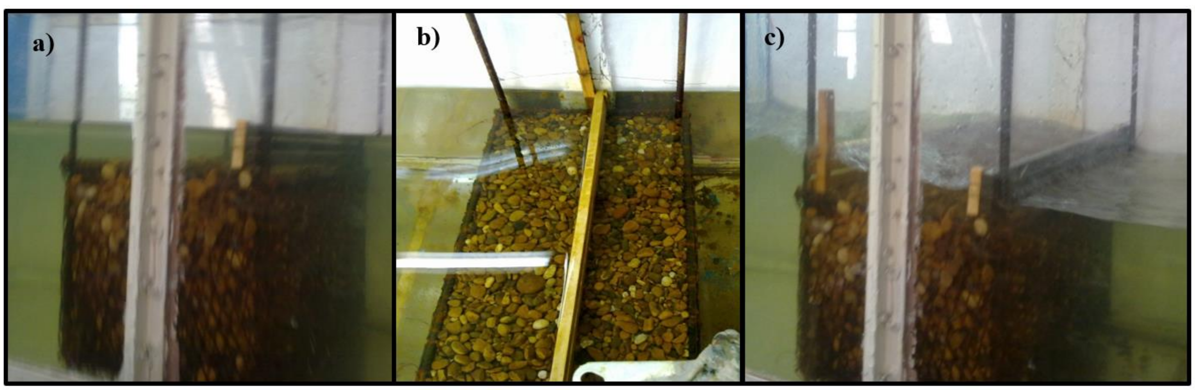

Fig. 3: a) Single wave screen on the seaward side, b) Single wave screen in the middle, c) Double wave screens.

2.3 Experimental Procedures and Tested Conditions

To study the impact of submerged breakwater settlement and the influence of wave screens in the rehabilitation of its efficiency, the experimental work had the following procedures:

1. Wave calibration was performed to measure the incident wave heights and wave periods for seven conditions without any model, the following table illustrates the tested wave conditions in the experimental work.

Table 1. Different wave conditions

Motor frequency	Wave characteristics			
	Wave period, T (s)	*Incident Wave Height, H_i (m)*	*Wavelength, L (m)*	*Wave Steepness Hi/L*
2.50	2.003	0.064	2.003	0.0156
2.70	1.810	0.068	1.810	0.0190
3.00	1.368	0.074	1.368	0.0290
3.50	1.180	0.088	1.180	0.0430
4.00	1.110	0.101	1.110	0.0550
4.50	1.064	0.104	1.064	0.0610
5.00	1.013	0.112	1.013	0.072

2. Then submerged breakwater models with 40, 45 and 50 cm height were placed, and the transmitted wave height (H_t) was measured for each case. The transmission coefficient (K_t) and breakwater efficiency (η) can be calculated according to the following equations:

$$K_t = H_t / H_i \quad (1)$$

$$\eta = 1 - K_t \quad (2)$$

3. Singe wave screens were placed above the seaward side of S.B. with three porosities of 33%, 40%, and 50%.
4. To study the impact of screen positions, a single wave screen with 33% porosity was placed in the middle, above the leeward side, and the seaward side of S.B..
5. In the case of double wave screens, the leeward screen had a fixed porosity of 33.0%, and the seaward screen had three different porosities of 33.0%, 40.0% and 50.0%.

3. Experimental Results and Analysis

3.1 Impact of Submerged Breakwater Settlement

Three used heights of the S.B. model represented the decrease of the relative height of S.B. (h/d) from 1.0 to 0.90 then 0.80 to simulate the effect of the excessive settlement after the construction. Results showed that the efficiency of S.B. decreased by 10% when the relative height (h/d) decreased by 10%, Fig. 4. Also, when the relative height decreased by 20% the efficiency reduced by 37.50 %. So, it is clear that excessive settlement has a significant impact on submerged breakwater efficiency.

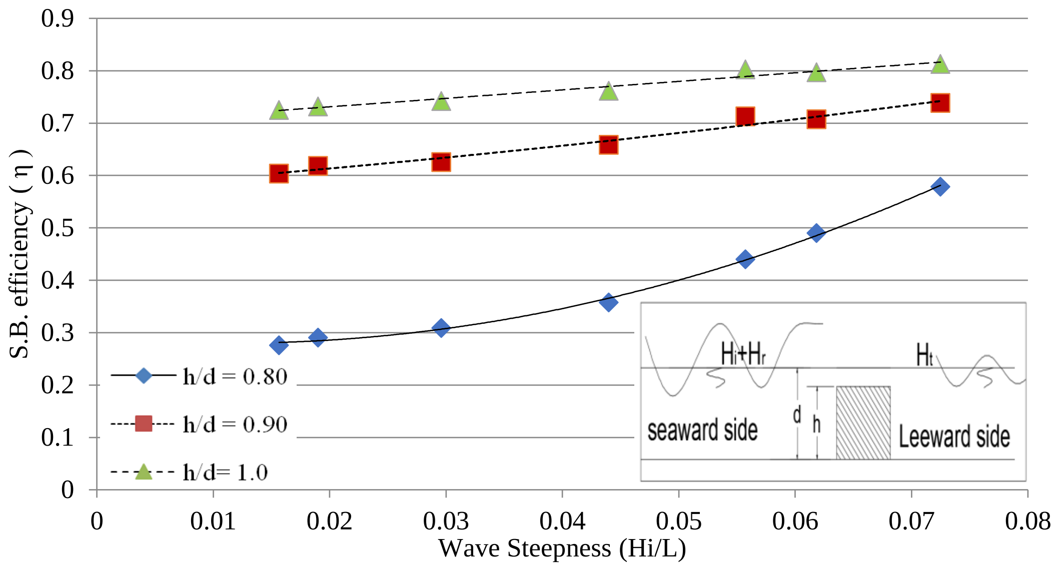

Fig. 4: The impact of excessive settlement on submerged breakwater efficiency.

3.2 The influence of single wave screen

The screen porosity is a significant design parameter, as the wave attenuation usually increases when the screen porosity decreases. On the other hand, the exerted pressure and the costs of the screen increase as the porosity decreases. So, choosing the screen porosity impacts its performance and construction costs. As expected, the results showed that the wave screen improved S.B. efficiency by about 19.30% on average, Fig. 5. The figure shows that the performance of the tested model increased by 19.30%, 15.30%, and 13.25% on average in the case of using single wave screens with a porosity of 33.0%, 40.0% and 50.0% respectively.

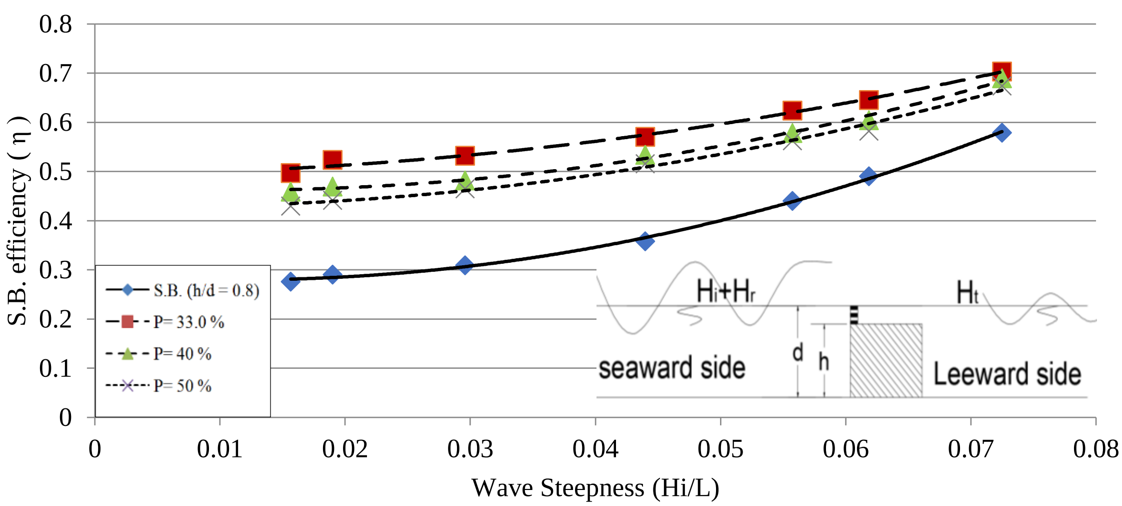

Fig. 5: The influence of screen porosity on the submerged breakwater efficiency.

On the other hand, the screen position had an insignificant impact on the breakwater efficiency Fig.6, so it is recommended that the best location is proposed to be in the middle of the breakwater crest to ensure the stability of the wave screen.

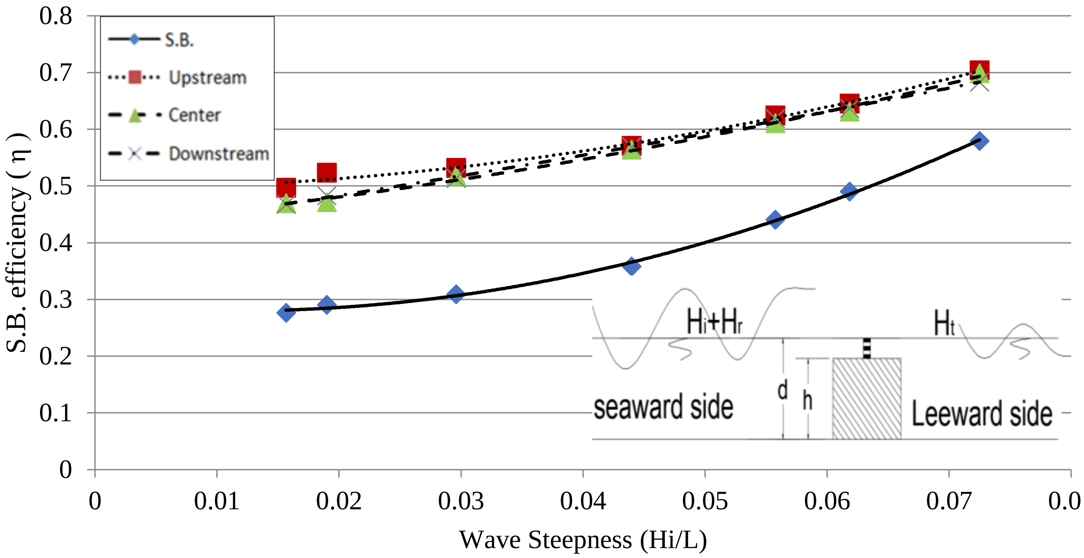

Fig. 6: The influence of screen position on the submerged breakwater efficiency.

3.3 The influence of double wave screen

Using a double screen is expected to provide more stability for the screen and may enhance the performance of the breakwater. However, results show that the porosity of the seaward screen had an insignificant impact on the breakwater performance, Fig. 7. Also, figure 8 shows that using a single wave screen showed a better performance than double wave screens.

The main reason for the last finding is that the single screen allows the wave overtopping and the wave breaking above the breakwater crest, which increases the wave attenuation. Unlike the double wave screens, as water oscillations between screens reduce the impact of wave breaking.

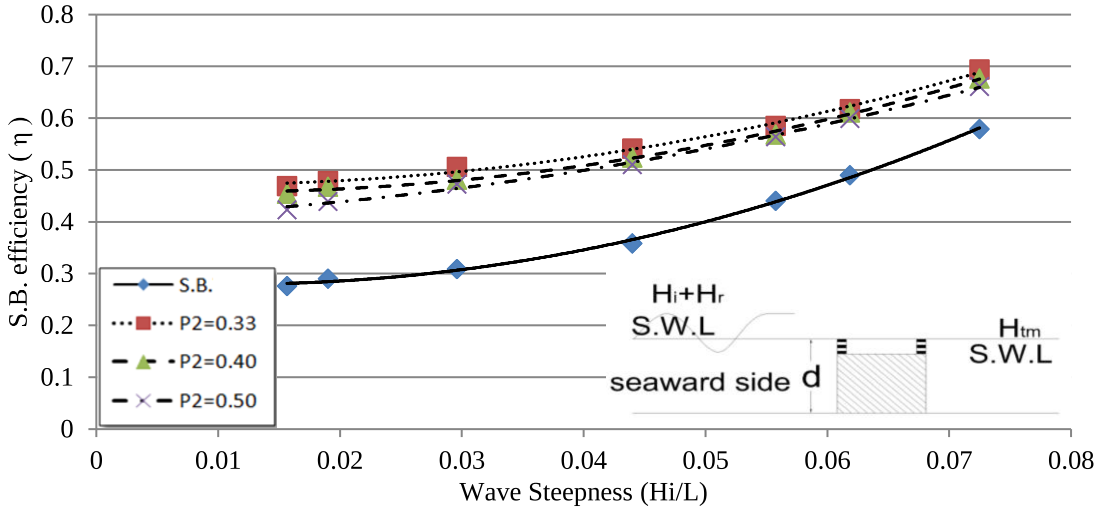

Fig. 7: The influence of seaward screen porosity on the submerged breakwater efficiency.

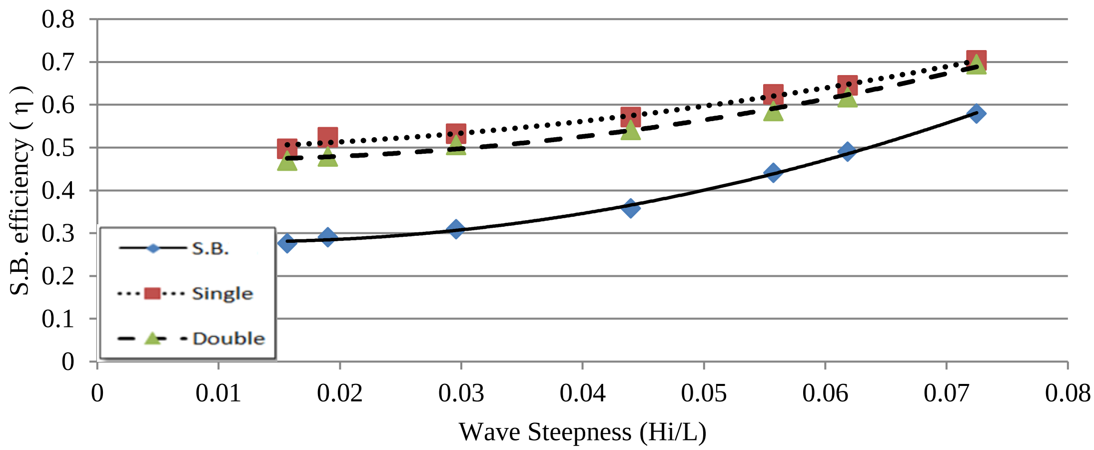

Fig. 8: The comparison between single and double wave screens.

3.4 The comparison between the proposed alternatives

Rageh et. al 2013 proposed the use of single and double wave screens on the seaward side of the submerged breakwater to enhance its efficiency. The proposed alternatives improved the breakwater efficiency by about 14.0 : 22.0 % (Rageh et al., 2013). The suggested solution requires the construction of the wave screen with the full water depth. Also, placing the wave screen on the seaward side with higher water depth increases construction costs due to the large screen depth and the massive wave pressure on the wave screens. On the other hand, figure 9 shows that using the single wave screen above the breakwater showed a better performance than using the wave screen in front of the breakwater. Also, according to construction cost, the use of a wave screen above the breakwater is more economic. In addition, results showed an insignificant difference between using the double wave screen in front of the breakwater and the single screen above the breakwater. So, it is recommended to use a single wave screen above the submerged breakwater crest to save construction costs and has more wave attenuation.

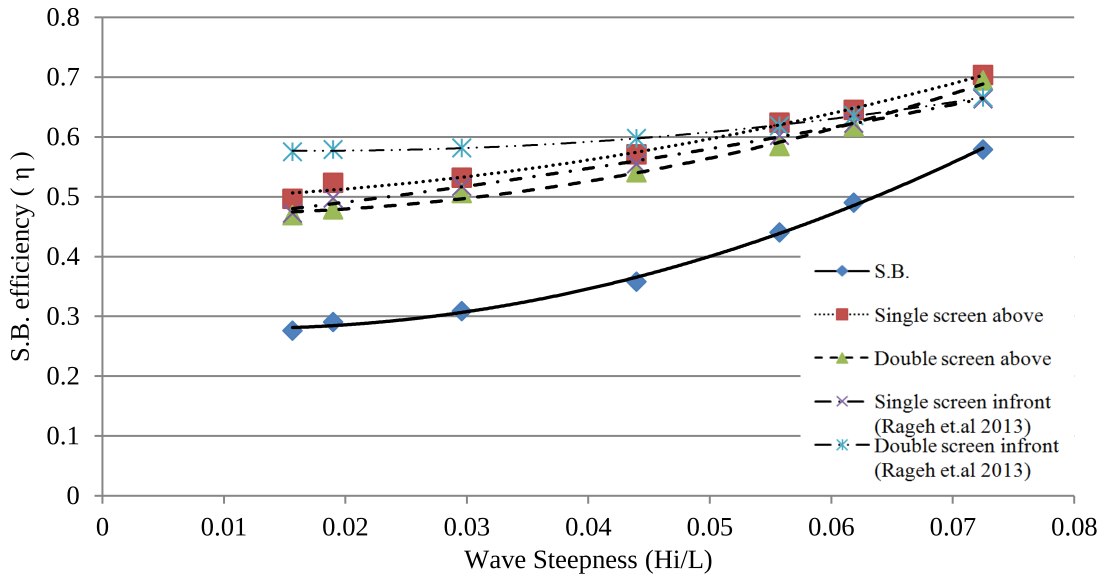

Fig. 9: The comparison between the proposed alternatives.

Conclusion

The excessive settlement of submerged breakwaters has a significant impact on wave attenuation and efficiency. Wave screens could be used in the rehabilitation of the submerged breakwaters in the case of excessive settlement. The experimental study concluded that:

1. The efficiency of S.B. decreased by 10% and 37.5 % when the relative height (h/d) decreased by 10% and 20% respectively.

2. The wave screen porosity is a significant design parameter, and the single screen increased the performance of the tested model by 19.30%, 15.30%, and 13.25% on average for wave screens with porosity of 33.0%, 40.0% and 50.0% respectively.

3. The wave screen position had an insignificant impact on the breakwater efficiency, so it is recommended to use the wave screen in the middle of the breakwater crest to ensure stability of the wave screen.

4. Single wave screen above the breakwater crest showed a better performance than the double wave screens.

5. The proposed wave screens above the breakwater crest showed a better performance than using the wave screens in front of the breakwater.

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