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# Experimental Study of Wave Impact Forces on Pervious Pipe Breakwaters

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## ABSTRACT

In this study, the wave impact on highly- pervious pipe breakwaters is investigated by a physical experiment conducted in a 21-m wave flume, with a combination of pre positively placed pervious pipe obstacles and an impermeable embankment. The wave impact force on the protected coastal structures were effectively mitigated and attenuated. The process of wave impact is very complicated; involving strongly nonlinearity and transient effects, and the effect of wave impact is one of the important factors on the safety and/or destructions of coastal structures. This study addresses highly pervious dense pipe with small apertures, which can be beneficial for convection and interchange of seawater within the harbor district, and furthermore, perform effectively in wave absorption. The problems of random wave impact on the highly pervious perpendicular pipe obstacles were also investigated. Physical experiments were carried out with regular and irregular waves under various conditions. The results showed that, a pervious pipe obstacles placed vertically in the front of an impermeable embankment can effectively mitigate and attenuated the wave impact.

KEY WORDS: Irregular waves; pervious pipe breakwater; wave reflection; wave transmission; wave impact force.

## INTRODUCTION

Increasing attenuation on the preservation of nature landscapes has led to the recent emphasis on hydrophilic facilities. Amenity-oriented policy was subsequently enforced to promote the comprehensive development of port and harbor facilities, and many constructions are underway, using the ecological engineering method. Offshore structures, such as breakwaters and seawalls, reduced huge wave forces and have been designed and constructed to produce hindrances for the waves and ensure urban safety. Many submerged breakwaters called "sub-dikes," which include square, trapezoid, and triangular forms, are being extensively investigated and analyzed as impermeable embankments to provide protection. In recent years, many scholars have studied various offshore-submerged breakwaters, including the varying external forms and/or shapes, permeability, quantity of submerged obstacles, and the interval between two obstacles, and changes in wave conditions.

Regarding the studies of wave impact forces acting on different wave-structures, many scholars believe that: in addition to enhancing the efficiency of energy dissipation structures, they also expect to reduce the impact of waves on the structures, either by forcing the incoming waves to break before approaching or by implanting so-called screen breakwaters. Losada (1997) study experimentally the effects between permeable submerged breakwaters conducted by different gravel sizes with harmonic evolution of monochromatic waves as they propagate over the porous breakwaters, and shown that the porous breakwater increases the effective relative depth and decreases the relative wave height. Bai and Eatock Taylor (2009) studied the interactions of fully nonlinear wave with fixed and floating vertical cylinders and flared structures by higher-order boundary element model with domain decomposition technique. The horizontal hydrodynamic force on a floating truncated cylinder is reduced significantly compared with the wave force on a comparable fixed truncated cylinder. Moreover, with increase in cylinder radius, the dimensionless vertical force at the same frequency is smaller. Kisacik, Troch and Van Bogaert (2010) studied experimentally the breaking wave impact on a vertical wall with horizontal cantilevering slab. They indicated that the highest impact pressure and forces were measured in breaking waves with a small air trap, and the horizontal part of the scaled model is more exposed to impact waves than the vertical part. Also, the variation of wave period (*T*) has a rather limited effect. Li and Lin (2012) studied the fully nonlinear wave-body interactions for a stationary floating structure under regular and irregular waves; they discussed and compared the effects of water depth, wave height and period on the variation of forces and moment. They indicated that the maximum forces and moment by irregular waves increase rapidly with relative wave height and the average values are less than those induced by regular waves. Akoz et al. (2011) investigated the prediction of geometrical properties of perfect breaking waves on composite-type breakwaters by artificial neural networks.

A variety of laboratory tests have been performed by Bea et al. (1999) to study the wave force on decks of offshore platforms, and applied the results from laboratory testing and associated analyzing to the study the hazard of hurricane wave impacts. Ren and Wang (2003) investigated experimentally the irregular wave impact on structures and expressed the characteristic peak impact pressure as well as the spectral moment of the impact pressure on the structures. They revealed that the peak impact pressure, the negative impact pressure and the pressure spectral moment increased with the increasing of incident wave height and the decreasing of $L_m/L$. Ren and Wang (2004) then investigated the impact pressure on both regular and irregular waves on open-plied structures. Furthermore, the effect of the wave direction on the wave impact forces on structure was also determined in Ding et al. (2008) by experimental tests of unidirectional irregular wave slamming on the 3D structure to discuss over the relation between the impact forces and the parameters such as significant wave height, structure width and the clearance of the structures.

Wave impacts on the wall mostly involve air entrapment by water, air-pocket entrapment influence the peak pressure at the wall, whereas the air content in water and the distance between the wave breaking and the wall varied. Air-pocket can produce large impact pressures, and the magnitude of peak pressure increases with the entrapped air amount. Plumerault et al. (2012) studied numerically the influence of air on the impact of plunging breaking wave on vertical wall using a multifluid Navier-Stokes model. They indicated that the volume of air pocket is independent from air content but the energy of air pocket decreases with the air content. However, the volume of air pocket slightly increases with the breaking distance. Huang and Yuan (2010) suggested that slotted barriers significantly reduce the drag forces on the protected structures, with a maximum reduction of 60% when the spacing-to-diameter ratio $S/D = 1.2$, and the reduction of the tsunami wave height by slotted barrier can reduced the draft force on the structures.

Kirkgöz and Aköz (2005) investigated experimentally the geometrical properties of wave breaking perfectly on the vertical wall of composite breakwaters, where the greatest impact forces produced. They indicated that the deep-water wave steepness and the base slopes of the breakwaters did not have distinct effect on the properties of the wave breaking on the wall. However, Chakrabarti et al. (1997) observed the effect of breaking and steep non-breaking wave on a vertical single pile caisson; their experiment results indicated that the forces due to breaking waves were no higher in general than those in nonbreaking steep waves. Kyte and Tørum (1996) have conducted an experimental test to study the forces from plunging breakwater on vertical cylinders upon shoals, and they derived formulae for the estimation of horizontal forces and overturning moments.

Suh et al. (2001) studied the energy loss and reflection of irregular waves from a perforated-wall caisson breakwaters, they pointed out that a perforated-wall caisson breakwater reduces not only the reflection and transmission, but also the impulsive wave force that acted on the caisson. Sahoo et al. (2000) investigated the scattering of obliquely incident waves by permeable vertical barriers, they showed that the porous effect of the barriers reduced the reflection of incident waves, the wave amplitude and the hydrodynamic pressure on the barriers. Raman-Nair and Chin (2012) estimated the impact forces between small bodies by colliding in a regular wave using an elastoplastic model. However, in their model, they assumed that the dimensions of the bodies are small relative to the wavelength, and the motion of the bodies normal to the wave surface is small and negligible. Lu et al. (2011) discussed over the fluid forces on multi-floating bodies by a two-dimensional numerical model, they suggested that the horizontal wave force is highly dependent on the water level difference between the opposite sides of an individual body, and is generally smaller than the summation of wave force on each body due to the phase-lag. They also suggest that the dimensionless amplitude of horizontal wave forces on the floating bodies are generally smaller than 2.0.

Process coastal structures under the impact of the waves are extremely complex. As Laju (2005) indicated, in addition to the strong nonlinearity of the issues involved, how to reduce the tension on the tether are also the research priorities and main purposes on porous breakwater. Transient shock wave effect of random waves is an important factor related to the stability of the structures. Lorenzoni et al. (2010) demonstrated that the total horizontal force on 45° inclined blades was approximately 50% larger than the force on vertical blades and the drag forces were stronger than the inertial forces. Their results confirmed results described by Nobuoka et al. (1996), who showed that a structure with multiple blades inclined at 45° caused the strongest onshore currents on the side of a structure.

This article presents a discussion on the properties of the wave impact forces of various pervious pipe obstacles performed as a screen breakwater with coastal structures under various combinations.

## EXPERIMENTAL SETUP

Physical model tests were conducted in a 21-m wave flume located at the Fluid Mechanics Laboratory of Tungnan University (Fig. 1) to investigate the wave impact by regular and irregular waves. The wave flume was 80 cm wide and 50 cm high, and the constant water depth was 25cm. The layout of test model was divided into three modes. An obstacle with perpendicular impermeable surface was primarily adopted for the measurement of wave impact on impermeable vertical wall. Secondly, a highly- pervious pipe breakwater is in substitution for the impermeable obstacle. Finally, a series of pore pipe breakwater was set in front of the impervious dike to test the attenuation reduction and wave impact under the case of complex configuration of both pervious and impervious surfaces. The test models were placed longitudinally and parallel to the direction of incoming waves. As shown in Figs. 2 and 3, the pipe breakwaters were modeled using 12-mm-thick plywood and fixed into a rigid 80 cm × 60 cm frame. Frames were filled with polypropylene (PP) pipes of various diameters $D$ ranging from 6, 8, 10, 12 to 16 mm ($D/h$ = 0.024, 0.032, 0.04, 0.048 and 0.064). The length $w$ of the longitudinal pipes is $w$ = 5 and 10 cm ($w/h$ = 0.2 and 0.4). Pipes were placed parallel to each other, packed tightly and fastened. Base on a pipe thickness of approximately 0.17 to 0.18 mm, it was possible to determine the area of the model and assess the shielding rate and porosity per unit area. The present shielding rate $SR$ is defined as the percentage of pipe wall cross-sectional area over the pipe region area.

$$SR = \frac{\text{Pipe wall cross-sectional area}}{\text{Breakwater pipe region area}}$$

According to the pipe diameter and thickness, the shielding rate is 3.4% to 8.95%, with a porosity of 91% to 96.6%, as shown in Table 1. The results confirmed that the model was a highly pervious structure. Table 1 also listed the weights (kg) of the pipe breakwater model.

Table 1. The shielding rate and the porosity of breakwater surface according to pipe diameter.

| Diameter (mm) | shielding rate, $SR$ | porosity | weights (kg) $w/h$ = 0.2 / 0.4 ( 0.6/ 0.8) |
|---|---|---|---|
| 6 | 8.95% | 91.05% | 4 / 6 ( 9 / 11 ) |
| 8 | 6.6 % | 93.4 % | 3.2 / 6 |
| 10 | 5.34 % | 94.66 % | 3.5 / 5.1 |
| 12 | 4.5 % | 95.5 % | 2.8 / 5 |
| 16 | 3.4 % | 96.6 % | 2.8 / 5 |

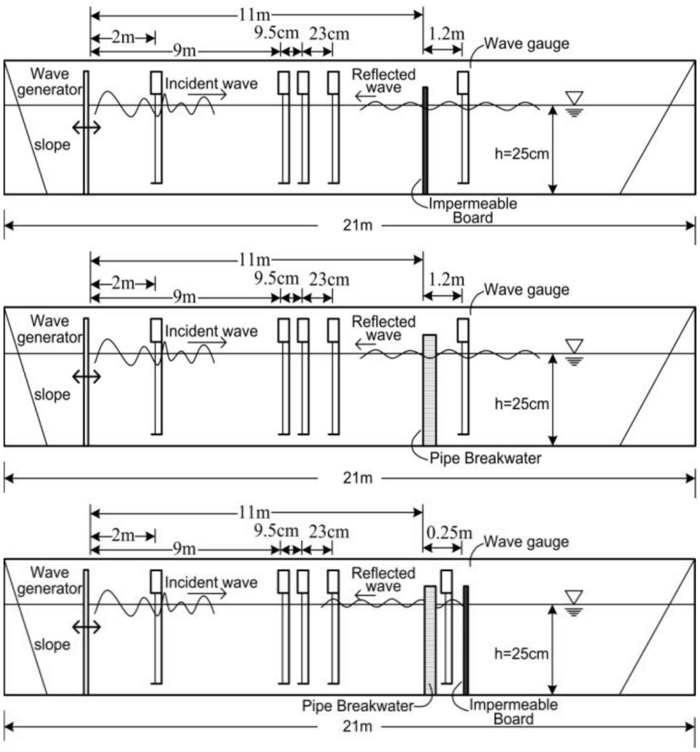


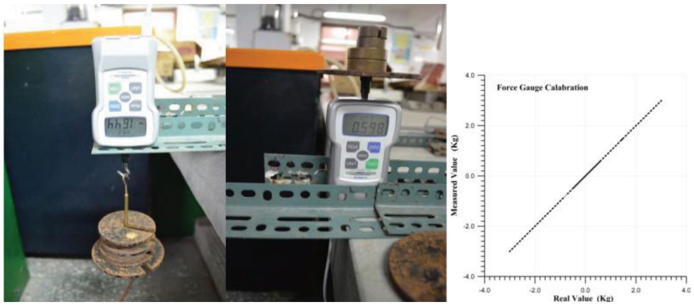
Fig.1 Schematic layout of wave flume and experimental setup.

Fig.2 Photograph of experimental setup and impact force measurement.

Fig. 3 shows the calibration process and results of the digital force gauge, where Fig. 3(a) is the calibration of pulling force by suspending various weights, while Fig. 3(b) denotes that of pushing (thrust) force by uploading weights. A linear relationship occurred between actual weights and force measurements as shown Fig 3(c). The forces acted on the breakwater is determined by averaging method (average wave force, $F$) for regular wave cases and by zero-up-cross method (significant wave force, $F_s$) for irregular wave cases.

Wave conditions of both regular and irregular waves were adopted for the experiment. Wave impact of the breakwater was first tested by applying regular waves with incident wave heights of 2, 3, and 4 cm ($H/h$ = 0.08, 0.12, and 0.16) with a wave period $T$ ranging from 0.5 to 1.5 sec (i.e. $\sigma^2 h/g = 3.2 \sim 0.36$). For irregular wave tests, the significant incident wave height $H_{1/3}$ is 2 - 4cm with significant wave period of $T_{1/3}$ = 0.5 - 1.5 sec, and the Brestschneider- Mitsuyasu spectrum were adopted for random wave generation. The conditions of the incident waves are listed in Table 2, which illustrated and compared the relevant physical characteristics of these conditions, including wavelengths and $h/L$ parameters, where $h/L$ varied from 0.641 to 0.051.

The breakwaters were located in the middle of the wave flume. A charge-couple device camera (digital video camera) recorded the deformation of the waveform and wave-breaking effect to confirm the results measured by wave gauges.



(a) (b) (c)

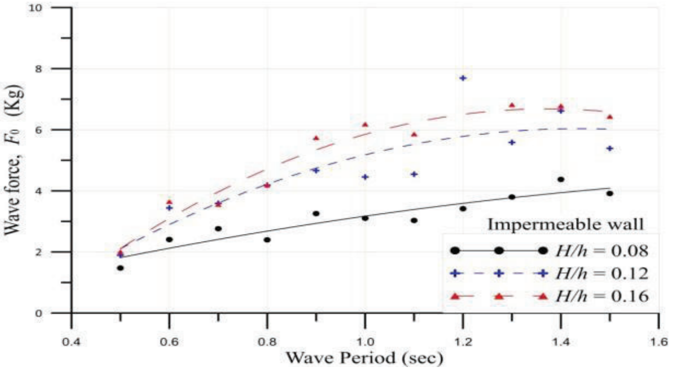
Fig.3 Photograph of force gauge calibration.

## RESULTS AND DISCUSSIONS

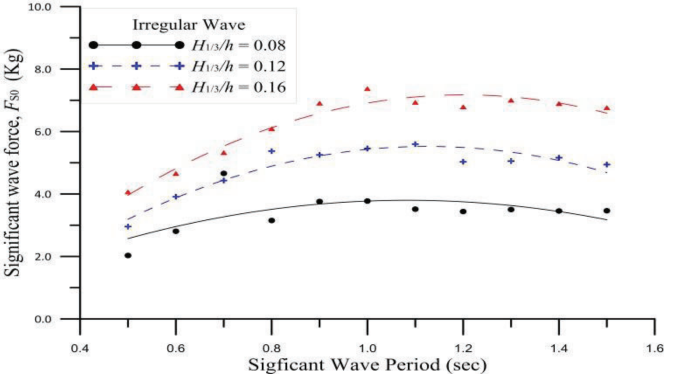
### Comparison of wave impact on the structures

Fig. 4 shows the variation of wave impact on an impervious breakwater. The results of regular wave test in Fig. 4(a) meets the expectations, that is, the wave impact increased with the increasing in wave period (wave length) and relative incident wave height $H/h$, and varied along with $H/gT^2$. When $H/h$ = 0.16, the maximum wave force exceeds 6 kg, and the minimum is about 2 kg. Moreover, Fig. 4(b) shows the results of irregular (random) wave test. The significant incident wave heights $H_{1/3}$ of irregular wave are 2, 3, and 4 cm ($H_{1/3}/h$ = 0.08, 0.12 and 0.16), respectively. It is conjectured that may lead some spurious peak values in results due to resonance effects under regular wave condition. The results also showed that the wave impact force $F_{S0}$ and the overall tendency cause by random wave is slightly larger than that by regular wave. When $H/h$ = 0.16, the results display a minimum impact force of approximately 4 kg, and a maximum of more than 7 kg. The figure also shows that, the impact wave force vary considerably with varied incident waves, which also comply with the basic characteristics of wave, i.e., wave impact force $F_0$ increases with the increasing of incident wave height $H_{1/3}/h$ and wave steepness $H_{1/3}/gT^2$.

Fig. 5 shows the comparison and variation of wave impact force on the pervious pipe breakwaters, whereas Fig. 5(a) shows the results of regular wave test, revealing that wave impact force varied considerably regular with various incident wave heights. Fig. 5(b) displayed the results of irregular wave test; the overall impact is slightly smaller than that of regular wave test. Compared with the results of impervious surface, and the variations of wave impact force versus wave period of both the regular and irregular waves were unapparent. That is, when $w/h$ = 0.2, the length of the pipe (relative to structure width) $w/h$ is small relative to the wavelength, therefore, the wave impact force on the structure is relatively smaller. As shown in Fig.6, the wave impact force measured by force gain was compared with that acting on impermeable breakwater, revealing that, under the same incident wave conditions, the impact force on the pervious breakwater is much smaller than that on impermeable embankment. The proportion was similar with regular wave, and obviously exist great relationship with the shielding rate and porosity of the pervious structures.

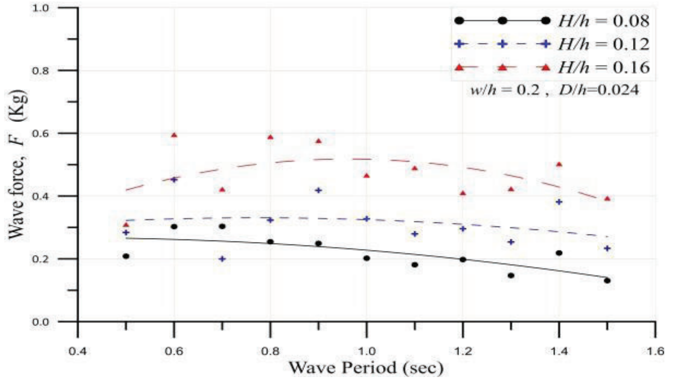


(a) Regular wave

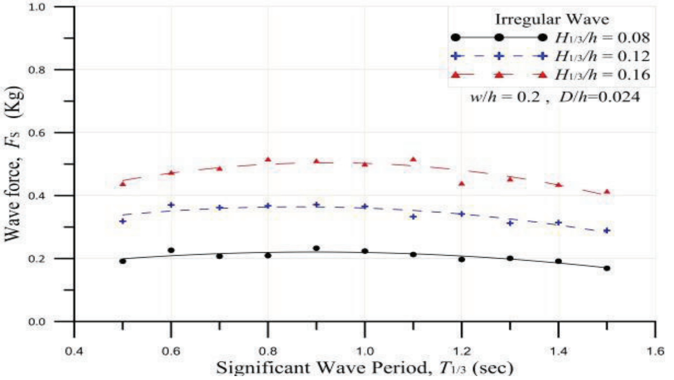


(b) Irregular wave

Fig. 4 Comparison and variation of wave impact on an impervious breakwater wall.



(a) Regular wave



(b) Irregular wave

Fig. 5 Comparison and variation of wave impact force on the pervious pipe breakwaters.

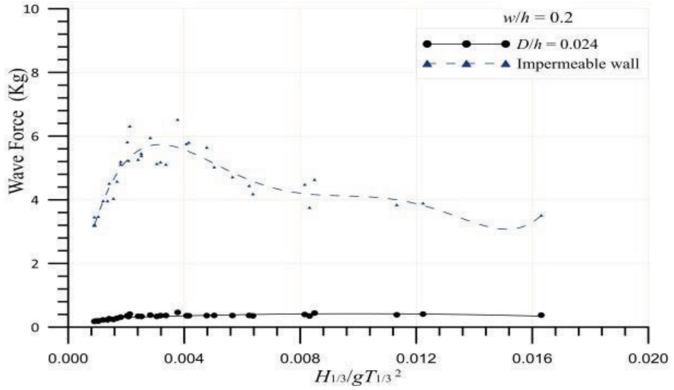


Fig. 6 Comparison of wave impact forces on impermeable wall and pervious pipe breakwater with $w/h = 0.2$ and $D/h = 0.024$.

## Analysis of wave impact attenuation

Figure 7 shows the variation in relative wave impact force $F/F_0$ on the impervious surface when $w/h = 0.2$, under various apertures $D/h$ conditions. $F/F_0$ increased versus with the increasing of $H/gT^2$, and minimal value exists when $H/gT^2 < 0.002$ for shorter waves, the wave impact power are less than 5% of that on impervious surfaces. With the reduction of wavelength (wave period), a maximum value of $F/F_0$ increased up to 18%. Wherein, in addition to $D/h = 0.32$ with maximum relative wave impact forces, the overall tendency of $F/F_0$ decreased with the increasing of pipe apertures. When $D/h = 0.064$, the maximum impact wave force is only approximately 5% of that on impermeable surface, the structure is almost unaffected by vertical component wave forces. Fig. 8 shows the variation of $F/F_0$ when $w/h = 0.4$, and was significantly increased compared with $w/h = 0.2$, the maximal values increased to 40%. Similarly, $F/F_0$ decreases with increasing wavelength, but when $D/h > 0.04$, the influence of diameter on $F/F_0$ tends to be unapparent. That is, when $D/h = 0.04$, 0.048 and 0.064, $F/F_0$ has smaller values and variation discrepancies.

Figs. 7 and 8 determined that the reduction of force is more effective for long-period waves. However, due to the experimental investigation by Shih (2012), the performance characteristics of porous perpendicular pipe breakwaters is greatly influenced by increased incident wave heights for shorter waves, but comparatively long waves seem to have less influence. The superiority of the structure can be determined by considering the pros and cons simultaneously. In addition to the reduction of wave impact force, a necessity of significant wave absorption and energy dissipation must also be taken into consideration, to be able to identify the best design.

Fig. 9(a) shows variation and distribution of relative wave force $F/F_0$ versus $H/gT^2$ when the diameter $D = 6$ mm ($D/h = 0.024$) with various pipe length $w$. As can be seen in the Figure when $w/h = 0.2$, because the structure is comparatively thinner, according to the principle of inertia, the percentage of measured wave impact forces on pervious pipe surface ranged from 5% (long wave) to 16% (short wave) of those on impermeable surface. When $w/h$ increased to 0.4, the wave impact forces was contrarily the largest, and increased to approximately 40% for long-wave. With the increasing of $w/h$ to 0.6 and 0.8, $F/F_0$ has a relative downward trend. The critical reason may because of the increasing structure weight and inertia with increasing $w/h$ when they exceed a certain value, which caused the reduction of the measured impact force contrarily. Fig. 9(b) shows the comparison and variation of irregular wave impact forces on perpendicular pipe breakwaters with aperture of $D/h = 0.024$ and various length $w/h$. In addition to minimum $F_S/F_{S0}$ at $w/h = 0.2$, relative impact force decreased with increasing $w/h$, revealing the wave impact force is related with the 8.95 % shielding rate of the pipe structure. Pipe breakwaters mainly dissipate wave energy, and partly reflect and transmit, wave energy is dissipated by destroying customary particle trajectory and the flow of water through the hole, thus, the performance was gradually affected by the lengths of the pipes when $w/h \geqq 0.4$, including the impact of the drag force within the pipes and the weight of the structures. Thus, the relative impact force $F/F_0$ decreases with increasing $w/h$, wherein the experiment when $D/h$ = 0.024, the body weights of the structures in $w/h$ = 0.2, 0.4, 0.6 and 0.8 were 4, 6, 9 and 11 Kg, respectively.

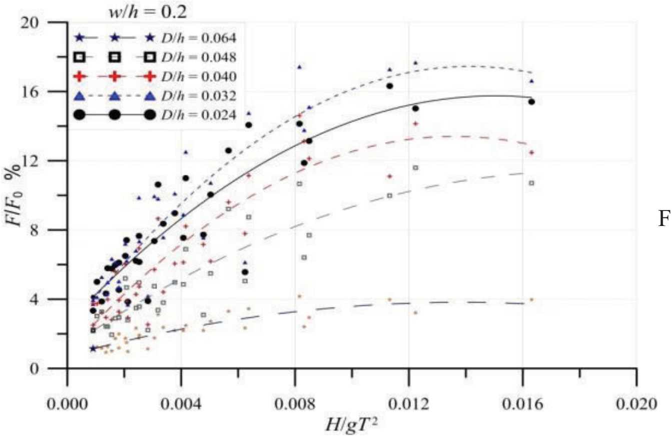


Fig.

Fig. 7 Variation in relative wave impact force $F/F_0$ on the impervious surface when $w/h$ = 0.2.

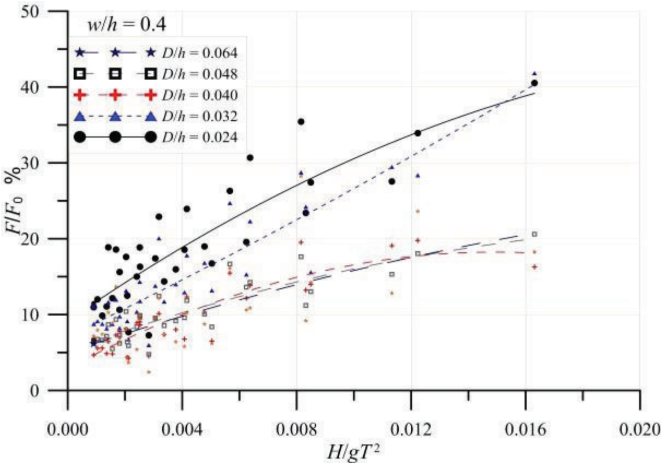
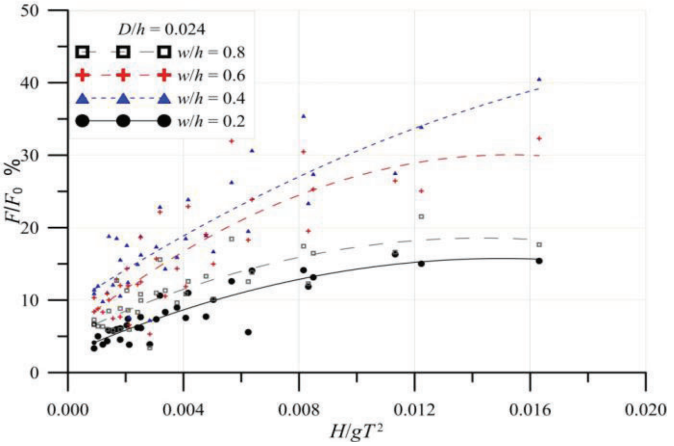


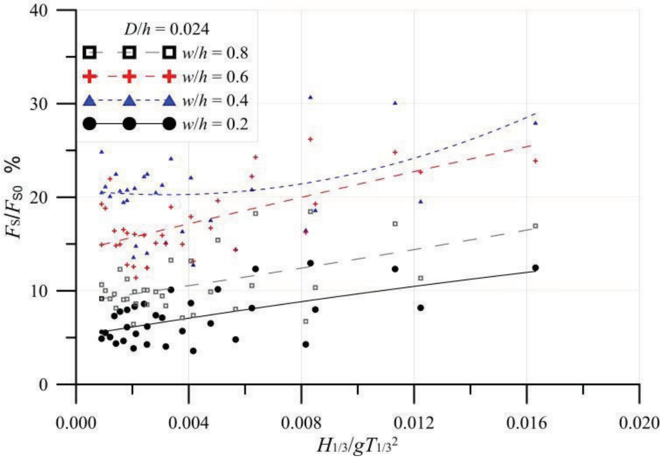
Fig.8 Variation in relative wave impact force $F/F_0$ on the impervious surface when $w/h$ = 0.4.

Fig. 10 shows the results of irregular wave impact on the pipe breakwaters when $w/h$ = 0.2 and 0.4. Compare the figures, it was found that the impact forces of $w/h$ = 0.2 case were smaller than those when $w/h$ = 0.4, with a ratio about 1:2.5, and was about 1:2 for regular waves (Figs. 7-8), the attenuation magnitude is larger than the results of regular waves. Similar to the results of regular waves, when $D/h > 0.04$, the affection of pipe diameter to impact force $F/F_0$ tends to be obscured and unnoticeable.

Figs. 11 and 12 revealed the percentage of force reductions in both regular and irregular wave tests. The wave impact force on the perpendicular impermeable surface was set as the reference value, and compared the impact force after replacement of permeable pipe structures. Fig. 11 shows the experimental results under the condition of $w/h$ = 0.2, the maximum attenuation rate of wave impact forces was found to reach more than 95% when $w/h$ = 0.2 and $D/h$ =0.64. Moreover, even the percentage force reductions of long-waves are over 85%, which generally have largest wave power and worst effects of energy dissipation. With the same results as regular wave tests, as shown in Fig. 12, the maximum attenuation rate is over 90% when $w/h$ = 0.4, the percentage force reductions of long-waves are reduced from a distribution range of 85-97% ($w/h$ = 0.2) to 70-90%.



(a) Regular wave



(b) Irregular wave

Fig.9 Variation and distribution of relative wave force $F/F_0$ versus $H/gT^2$ when the diameter $D$ = 6 mm ($D/h$ = 0.024).

## Impact force of composite breakwater with permeable screen structure

As shown in Fig. 1(c), a composite breakwater with combination of an impermeable breakwater and a series of pervious screen structures were conducted to investigate the characteristic of wave impact force. Wave passing through the pre- positively placed pervious pipe breakwater reaches the impermeable wall; and a digital force gauge, as shown in Fig. 13 then measured the impact forces on the impermeable vertical wall. When a pipe breakwater of $w/h$ = 0.2 was place pre-positively, the wave impact force on the impermeable wall was significantly affected and reduced, and is most significant in long waves, which was reduced from 7 to 4 kg, moreover, it was reduced from 2 to 1 kg for short-period waves. When the pipe length increased to $w/h$ = 0.4, the impact force attenuation efficiency of short-period wave slightly decreased, but was slightly increased for long-period wave, which the impact force $F$

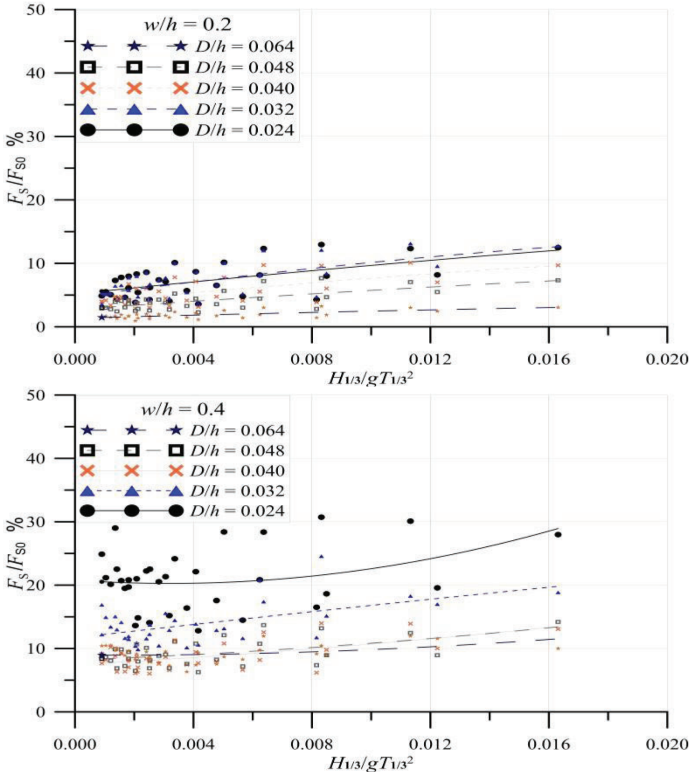
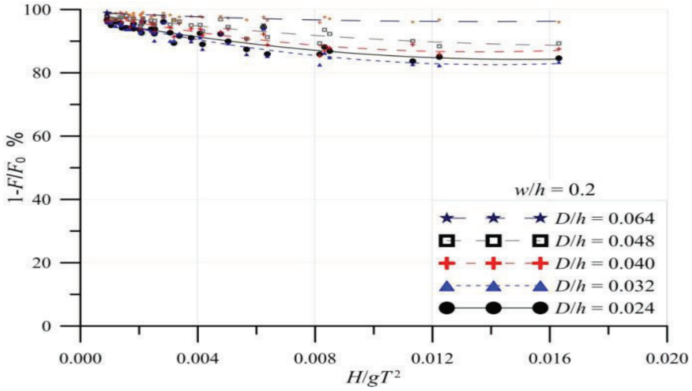
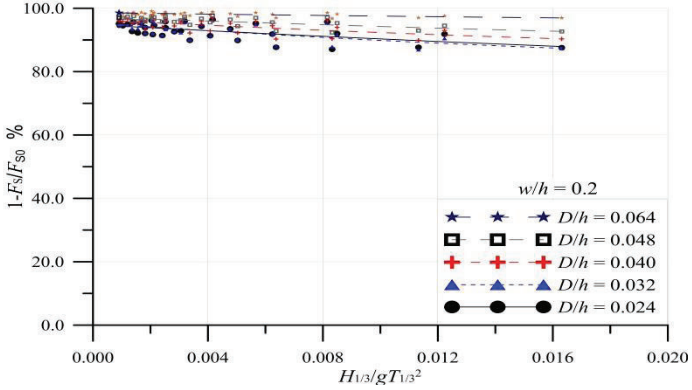


Fig.10 Irregular wave impact on the pipe breakwaters when $w/h = 0.2$ and 0.4.

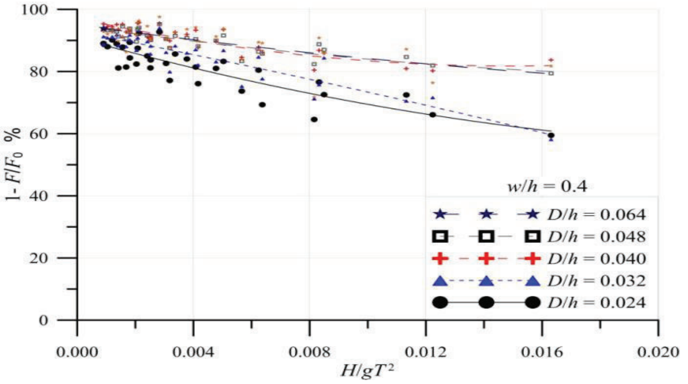


(a) Regular wave

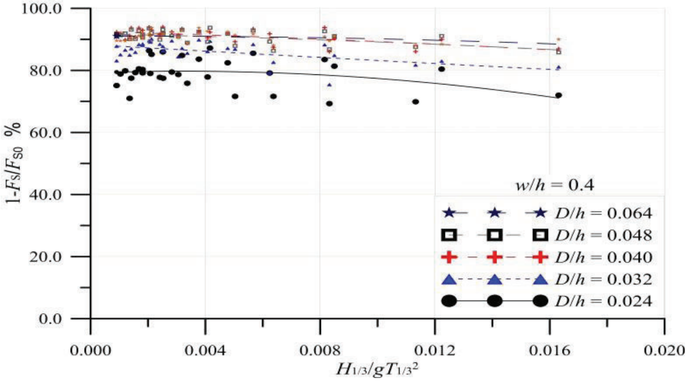


(b) Irregular wave

Fig.11 Percentage of force reductions when $w/h = 0.2$.

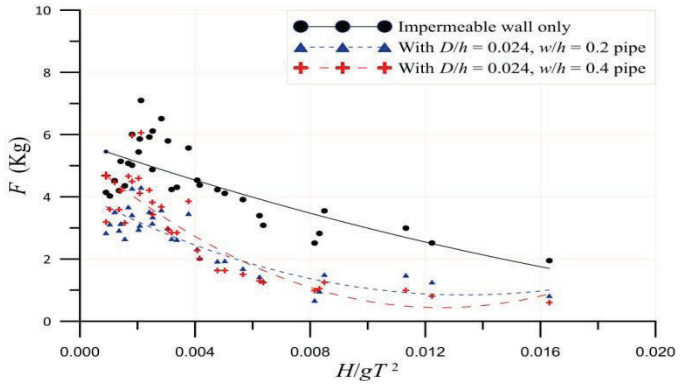


(a) Regular wave

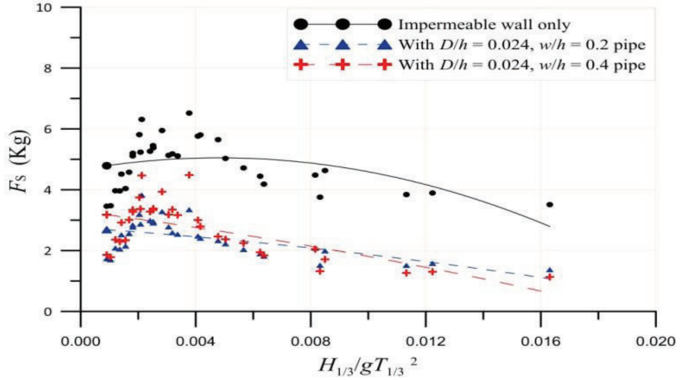


(b) Irregular wave

Fig.12 Percentage of force reductions when $w/h = 0.4$.



(a) Regular wave

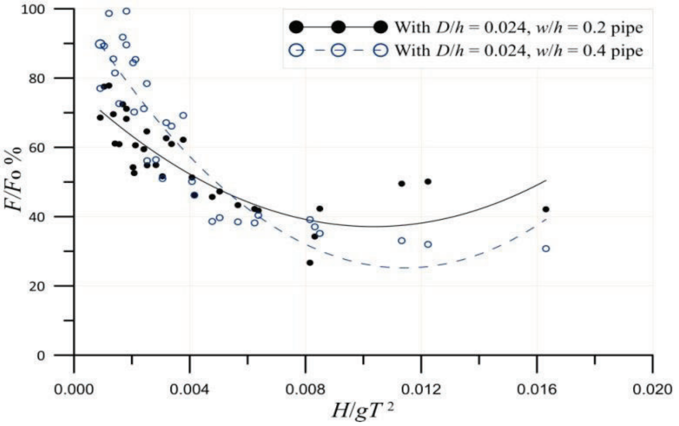


(b) Irregular wave

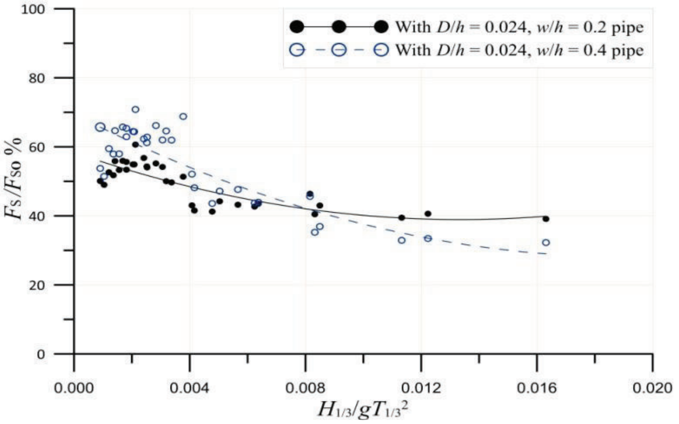
Fig.13 Impact forces on the impermeable vertical wall with a pipe breakwater of $w/h = 0.2$ placed pre positively.

was attenuated from 7 to 4.7 kg. However, Fig. 13(a) reveals that the results have no significant difference between $w/h$ = 0.2 and 0.4. Compare the results of regular wave with those of irregular waves in Fig. 13(b), revealing that when $H/gT^2 > 0.008$, the discrepancy of significant impact force $F_S$ variation between $w/h$ = 0.2 and 0.4 was small. However, the significant impact forces of irregular waves were smaller comparing with the results of regular waves.

Overall, a composite breakwater with a series of pervious screen breakwaters can effectively attenuate and mitigate the impact force on the breakwater surface. Fig. 14 shows the variation of impact force $F_S/F_{S0}$ on the impermeable wall with a pervious screen breakwaters of $w/h$ = 0.2 and 0.4 when $D/h$ = 0.024. As can be seen that the reduction of wave impact forces is most efficiency at $H/gT^2 > 0.004$, the measured wave impact forces were lower than 50 % of the original cases (impermeable perpendicular wall). Nevertheless, when $H/gT^2 <$ 0.004, the reduction of wave impact forces by pervious screen structures were less effective, especially when $H/gT^2 < 0.002$, with diameter $D/h$ = 0.024 and pipe length $w/h$ = 0.4, the reduction of wave impact forces was most inefficiency, that is, the measured wave impact forces were higher than 80 % of the original cases. Fig. 14(b) displays the experimental results of irregular waves. Similarly, the reduction of wave impact forces were less effective when $H/gT^2 < 0.004$. In a word, the reduction effect is better when compared with the results of regular waves, the relative wave force $F_S/F_{S0}$ did not exceed 70%, especially when the $H/gT^2 < 0.002$, the related wave impact force $F_S/F_{S0}$ slightly decreased, there are significant discrepancies between the results of regular waves and irregular waves tests.



(a) Regular wave



(b) Irregular wave

Fig.14 variation of impact force $F_S/F_{S0}$ on the impermeable wall with a pervious screen breakwaters of $w/h$ = 0.2 and 0.4 when $D/h$ = 0.024.

## CONCLUSIONS

The performance and effectiveness of a highly- pervious, perpendicularly arranged pipe breakwater was demonstrated. Furthermore, in this study, the experimental results indicated the reductions of wave impact forces on the breakwaters. Under various configurations of the pipe breakwaters, the destructive powers for long-period waves were mitigated. In addition, high pervious pipes decrease the force exerted by the waves on the structure, and substantial reduction in wave force contributes directly to reduction in the cost of construction of the breakwater. The present pipe breakwater can satisfy the following requirement: including cost effective, easy installation, environmentally friendly, and efficient landscape preserving. Moreover, it will achieve the effect of coastal protection. However, how to meet the existing facilities on the coast to the practical engineering applications are yet to be further in depth studies. The results obtained the following conclusion:

1. According to the experimental results of regular and regular wave tests, we obtained the magnitude and variation of wave impact force on the three different configurations. The unitary previous pipe breakwater suffered minimal impact forces, and exists a significant relationship with the shielding rate and porosity of the pressure-receiving surface.
2. Composite breakwaters with combinations of an impermeable breakwater and a series of pervious screen breakwaters can effectively mitigated and suffered the wave impact forces on the embankment surface. Overall, when $w/h$ = 0.4, the relative impact force $F/F_0$ significantly increased compared with $w/h$ = 0.2, but under the condition of $D/h > 0.04$, the influence of pipe diameter upon the variation tendency of $F/F_0$ is smaller than that in $w/h$ = 0.2.
3. When $w/h$ = 0.2, maximum percentage of impact force reductions were over 95 %, and the maximum attenuation rate is still above 90% when $w/h$ = 0.4.

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