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Do wooden pile breakwaters work for community-based coastal protection?

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Abstract

In developing countries, coastal protection with wooden piles may be a low-cost and eco-friendly countermeasure option that can be readily implemented by local communities or even individuals. However, the effectiveness of these piles in a realistic environment has yet to be scientifically proven, and there have been no established design guidelines for this type of improvised coastal protection to date. This study focuses on Phan Thiet City, Vietnam, where local people are resorting to wooden piles to mitigate severe coastal erosion immediately in front of their houses. A 3D hydrodynamic modelling with irregular waves is applied to evaluate complex wave mechanisms and hydrodynamics around and between wooden piles. The complicated interaction mechanisms between incident and reflected waves cannot be adequately evaluated using a common 2D numerical model or mathematical analysis, demonstrating the benefit of using a 3D hydrodynamic model. The performance of wooden piles are simply assessed using two criteria: wave run-up and bending stress. The result shows that wooden piles installed at a severely eroded beach in Vietnam can reduce wave run-up on the beach slope to some extent. The reduction in wave run-up occurs because of the creation of turbulence and oscillation triggered by the partial reflection of waves on the piles, diverting water flows into various directions. A case study shows that wave pressure in the seaward direction is about a half of that in the shoreward direction. However, the pressure in the negative direction can be instantaneously increased due to a significant reflection from a steep shore. This paper discusses whether such a state-of-the art computational fluid dynamics model can contribute to the assessment of wooden pile breakwaters.

Keywords Wooden pile breakwaters · Community-based coastal protection · Coastal erosion · 3D hydrodynamic modelling · Wave run-up · Stability of wooden piles · Supercomputer · Phan Thiet · Vietnam · SDGs

Introduction

Particularly in developing countries, many coastal areas have suffered from sinking land due to severe coastal erosion or land subsidence caused by rapid coastal development; this will be further accelerated by climate change (World Bank 2010; IPCC 2014; Esteban et al. 2015; Takagi et al. 2017; Esteban et al. 2019a). As population increases and takes up residence in coastal areas, exposure to hazards also increase (Valenzuela et al. 2020). People in low-lying areas have traditionally lived with floods, and thus there is certain resilience among residents in coping with small floods (Takagi et al. 2016). However, coastal inhabitants may need to choose between leaving their homes for safer ground and remaining where generations of their communities have lived. Some people need to remain in their present locations at high risk because they simply do not have anywhere else to go owing to lack of financial means or alternative land (Takagi et al. 2012; Esteban et al. 2014). The cost of adaptation measures will be lower than thecost of inaction (Hoshino et al. 2016). Hence, many adaptation studies suggest that a sea-level rise will lead to relocation as coastal flooding worsens. However, there isno strong evidence that any major coastal settlements will surrender a significant portion of its land area to the sea, given the range of adaptation options available (Esteban et al. 2020). A recent survey also showed that some Pilipino islanders prefer

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in situ adaptation strategies through constructing stilted housing or raising their floors using coral stones rather than relocation to the mainland (Jamero et al. 2017; Esteban et al. 2019b).

A low-cost countermeasure, such as the use of wood piles, small stones, and portable blocks, can be used to protect coasts as short-term countermeasures. Portable and cheap materials are also preferable because they may be used for construction by local communities (Takagi 2019). Community-based coastal protection systems with wooden piles are often seen on beaches suffering coastal erosion, particularly in developing countries such as Thailand (Rasmeemasmuang and Sasaki, 2015) and Vietnam (Schmitt and Albers 2014) among many others. Apart from their cheap and easy installation, wooden piles aligned with opening gaps may not significantly hinder sediment transport and seawater exchange; thus, they are expected to harmonise with the coastal environment as an eco-friendly breakwater. A wooden pile with a circular cross-section has a structural advantage because the effect of wave forces is less on a circular cylinder than on other shapes. For instance, Morison et al. (1953) experimentally demonstrated that the moment of wave force on an H-shape pile is 1.42 to 3.5 times larger than the moment on a circular pile with the same projected area.

Several previous studies examined wave transmission or wave pressures on a breakwater composed of cylinders or columns (e.g. Hayashi et al. 1966; Spring and Monkmeyer 1974; Dalrymple et al. 1988; Kriebel 1992; Kakuno and Liu 1993; Takagi et al. 2020). These studies were mostly based on mathematically oriented approaches, often disregarding complex mechanisms such as wave breaking, varying topography, and returning flow from a steep shore. In addition, because the fluid was assumed to be non-cohesive, non-linear energy dissipation around piles was not taken into account (i.e., the water behaves as an ideal fluid). In this sense, the effectiveness of such piles has not yet been scientifically proven under a realistic nearshore environment.

Phan Thiet is a coastal city in southern Vietnam suffering from erosion problems that might have been triggered and exacerbated by the installation of jetties for the purpose of beach conservation for private hotels and landfills for fishing industries (Takagi et al. 2015). Duc Long is one of the coastal communities in Phan Thiet located near a beach that has been severely eroded in recent years. Some of the residents have tried to stop the erosion by installing wooden piles and protecting the edges of the cliffs in front of the houses with sand bags and waterproof sheets, as shown in Fig. 1. Although such improvised measures appear to be effective, they have not to been successful in stopping the process in the long run (Takagi et al. 2012; Takagi et al. 2014a; Nguyen et al. 2014). Despite such efforts, the shoreline appears to have retreated by up to 40 m between 2001 and 2010. A structured survey of local residents also revealed that, out of 17 respondents, 35% (6 people) had to elevate their houses and 24% (4 people) had to move because of coastal erosion over the last decade (Takagi et al. 2014a). However, the reason for failing to eliminate erosion are still not clearly understood, which has motivated us to investigate the performance of wooden piles.

Fig. 1 Photo taken at Duc Long village in Phan Thiet, January 2012

Fig. 2 Low-cost bamboo breakwaters, which have lost most of inner-grass fences. Photo taken at Soc Trang province in the Mekong Delta, March 2014

The use of low-cost bamboo and Melaleua fences has been attempted in the Mekong Delta (Schmitt et al. 2013, 2014, Cuong et al. 2015, TU Delft and GIZ 2015) (Fig. 2). Mangrove restoration in high erosion areas has been successfully facilitated by the use of these fences. Fine sediment influx from major rivers of the delta forms extensive shallow tidal flats, and contribute greatly to attenuation of wind waves. Offshore wave height measured in the Kien Giang province was only 0.64 m in the normal monsoon condition (Cuong et al. 2015). However, coastal environments in the delta fundamentally differ from those in Phan Thiet, which is a typical sandy beach subject to relatively high waves. The frequency of typhoon in Phan Thiet is also greater than the Mekong Delta (Takagi et al. 2014b). Hence, coastal conservation measures that use local materials must also take into consideration environmental conditions. However, no design guidelines have been established for this type of improvised coastal protection to date.

The present study applies a 3D hydrodynamic model with irregular waves to investigate wave mechanisms and hydraulics around and between wooden piles and discusses whether

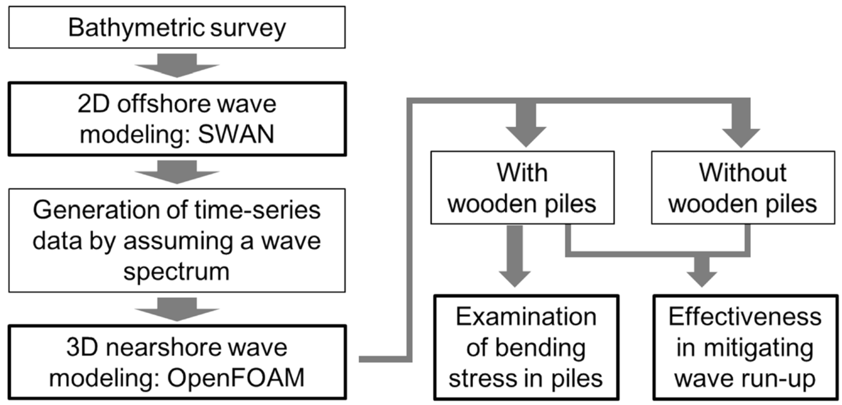


Fig. 3 Procedures of numerical modelling and examination of wooden pile breakwaters

the state-of-the art computational fluid dynamics (CFD) model can effectively work in assessing wooden pile breakwaters. This paper addresses the need for establishing design guidelines for this type of simple coastal protection for local communities to quickly determine how to install the piles effectively.

Methodologies

Figure 3 outlines the procedure for numerical simulation using two simulations: large offshore and small nearshore domains. A computation with irregular waves was performed to examine the performance of wooden piles under a realistic sea state. Particularly, we focused on Phan Thiet City, Vietnam, where local people are resorting to wooden piles to mitigate severe coastal erosion immediately in front of their houses.

Offshore wave propagation

Bathymetry within the extent of the computational domain was measured by the authors themselves by hiring a survey boat equipped with an echo-sounder and a GPS system. Because the boat was not able to approach a shallow-water

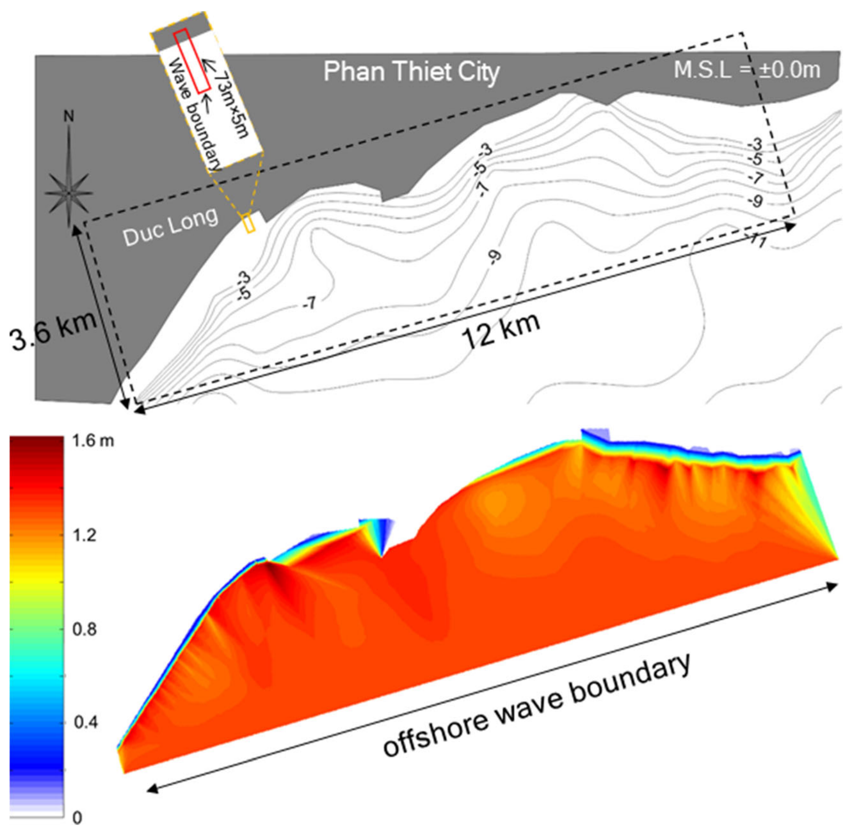


Fig. 4 [Top] Computational domain for SWAN encompassing the severely eroded coast of Duc Long, Phan Thiet City protected by wooden piles. The innermost rectangle in red indicates the computational area, to which 3D hydrodynamic modelling was applied. [Bottom] The distribution of significant wave height. Wave computation was performed in the stationary mode with the spatial resolution of 10 m in both alongshore and cross-shore directions

areas, bathymetry near the beach was measured by professional surveyors using theodolites. The two bathymetric data were combined and interpolated to obtain grid-spacing data for every 10 m (Fig. 4). The water level of the bathymetry data was referenced to mean tide level of Phan Thiet Bay. The mean sea level condition was chosen in correspondence with the annual mean wave condition assumed in the case study. In actual design, however, analysis under a high-tidal condition should also be conducted. As shown in Fig. 4, wave propagation over the large domain of Phan Thiet Bay was performed with the SWAN (Simulating WAves Nearshore) third-generation wave model to determine the nearshore wave condition in front of Duc Long beach. Using the database of Windguru (adopted from the predictions of NOAA wave watch III), the annual-mean offshore wave height and period imposed in the SWAN model as boundary conditions were estimated to be H_s = 1.32 m and T_s = 6.25 s, respectively. The offshore wave was imposed normal to the boundary (Fig. 4) with the directional spreading expressed with the Cosine power m of 4 (Phillips 1985). JONSWAP spectrum was assumed with the peak enhancement factor γ of 1.0.

Offshore wave data can rarely be obtained, particularly in developing countries. Thus, hindcasting data may be the only available source. Although offshore waves vary depending on the location, a uniform wave height and period was applied all along the offshore boundary. This can be made more realistic by considering varying wave condition. A detailed boundary could also be assigned if the nearshore model is coupled with a global wave model such as WAVEWATCH III using operational NCEP products as input. However, it may be too complicated for the design of improvised countermeasures.

Depth-limited wave-breaking and wave setup were also simulated in the SWAN model. However, as the incident wave is relatively small, it did not substantially break until it reached the offshore boundary of the small domain; consequently, the setup ratio was negligibly small. On the other hand, the wave was slightly amplified because of the wave shoaling, eventually resulting in H_s = 1.50 m and T_s = 5.54 s at the boundary (the left corner in Fig. 5). The highest wave condition should also be examined when assessing design loads on a pile breakwater. In this study, the annual maximum height off the coast of Phan Thiet was estimated to be approximately 3 m, which is 2.3 times as large as the mean wave. However, by the time the waves approach the nearshore region, they will be substantially attenuated owing to wave breaking, becoming almost of the same height with the annual-mean wave (i.e. depth-limited wave condition). Therefore, to reduce computational loads, we conducted the study only for the annual wave condition.

Nearshore wave propagation

The wave propagation over the shallow water of the Duc Long Beach (Fig. 4) was simulated with 3D hydrodynamic modelling using OpenFOAM®. The pile is reproduced using a computational mesh as small as 3 cm. A time series of irregular waves following the Bretschneider-Mitsuyasu spectrum modified by Goda (2000) (hereinafter BMG spectrum) was generated from the boundary allocated 60 m from the wooden pile, as shown in Fig. 5. We developed a program for this signal generation. It should be noted that the BMG spectrum is not adopted in the SWAN model. However, we use this model because it enables the reproduction of a time-series wave only based on a significant wave height and period without requiring additional parameters such as the peak enhancement factor γ in JONSWAP spectrum. This will contribute to simplifying the assessment procedure of improvised countermeasures. Further, the representation of the JONSWAP spectrum

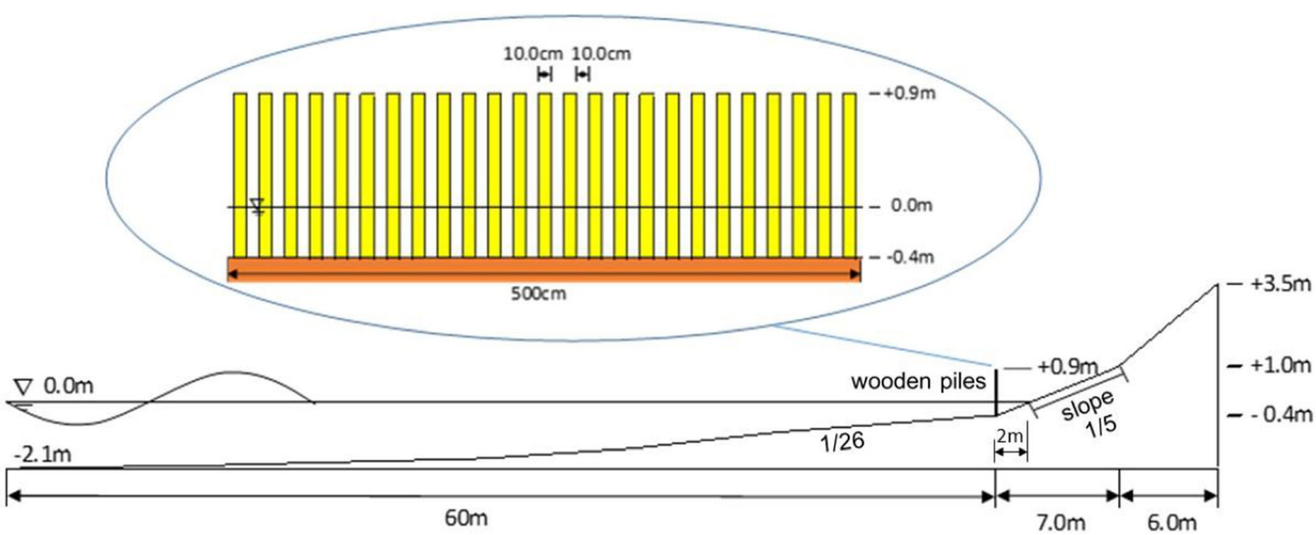


Fig. 5 Geometry of the Phan Thiet coast and the arrangement of wooden piles installed at the toe of the steep beach slope

becomes identical with BMG spectrum if γ is taken as unity, as we assume in this study.

Because the computational domain (Fig.5) is obviously narrow (only 5 m), we assume the bathymetry to be constant in the alongshore direction. As shown in Fig. 4, the offshore boundary for the OpenFOAM domain is allocated nearly in parallel with the coastline so that incident waves can be imposed perpendicular to the boundary. Instead of using the default solver of interFoam, which is a solver for two incompressible fluids, IHFoam was used to more correctly deal with incident and reflected wind waves (Higuera et al. 2013). This model solves the 3D Reynolds-averaged Navier-Stokes (RANS) equations for two incompressible phases using finite volume discretization and the volume of fluid (VOF) method. The LES-Smagorinsky model was selected in this study to carefully reproduce the turbulence caused by wave breaking and/or interactions with wood piles. As shown in Fig. 5, wooden piles 1.3 m tall were installed along the shore with a spacing of 10 cm in the model. As shown in Fig. 1, patterns and dimensions of installed piles are very random. From the site investigation, however, the present study assumed that this particular alignment is typical for pile installation implemented by local inhabitants.

Part of the numerical code was compiled on the supercomputer TSUBAME2.5 (peak performance: 17 Pflops, single precision) to drastically reduce computational time: the performance of an ordinary personal computer would be insufficient to run such a 3D fluid simulation with detailed grid geometries around the row of wooden piles within a reasonable time. Nevertheless, it took about 20 days to complete one test case, even when using the supercomputer; fine computational grids, particularly around the piles, required a very small time step to satisfy the CFL condition.

Investigation of a detailed flow pattern around the piles is only possible by using the 3D hydrodynamic model. However, it should be noted that, in this study, we neglected many factors that also influence the 3D flow pattern such as longshore variation of bathymetry, obliquity of waves, wave spreading, and variation of beach profile along the shore. Although it is hard to consider all these elements in the present study alone, a more realistic condition will be taken into consideration in our future study.

Evaluation criteria and scope of the present study

The specification of steel pile breakwaters or jetties is determined by considering various design factors in terms of hydrodynamic response (e.g. wave transmission, reflection, and wave setup), pile durability (e.g., wave force, share stress, punching resistance, pull-out resistance, and scouring). However, the design consideration of all of such design parameters appears not to be realistic particularly in the case of community-based countermeasures. In this study, the performance of wooden piles were simply assessed using two criteria: *wave run-up* and *bending stress*. These criteria were chosen from among many others because (1) reduction in wave run-up is considered to be the most important performance metric of wooden piles, and (2) bending stress is the most critical load metric that determines the occurrence of a fracture in the piles.

Pile geometries such as diameter and protruding lengths change the hydrodynamic characteristics, which influence the durability of the piles in turn. In addition, run-up and bending stress are both highly sensitive to wave and tidal conditions. It should be noted that precise assessment can only be achieved by considering many more possible pairs of these conditions, though seeking a critical design condition is out of the scope of the present study.

The wave run-up distance was statistically examined to verify whether the presence of wooden piles could effectively mitigate wave impacts as compared to cases without piles. The bending stresses developed in piles were calculated by integrating pressures over the entire surface area of the wooden pile, and statistical characteristics were also examined. Stochastic characteristics of run-up and bending stress can be taken into account in designing wooden pile structures if irregular wave data over sufficiently long period are available. In the present 3D simulation, irregular waves were generated for 10 min containing 126 individual waves. In field wave observations, a standard procedure is to take records of about 100 consecutive waves (Goda 2000). Therefore, this number is considered to be sufficient to discuss wave characteristics in a statistical manner. It should be noted that the data of the beginning of the computation (up to 20 s) were eliminated, as this could be considered as a warm-up period premature for analysis.

In this study, the examination was only carried out for the average wave condition because wave height should be limited by a shallow water depth, as already mentioned. In actual design, however, the maximum waves within a lifecycle of the structure are commonly applied for the structural durability test. The expected lifetime of wooden piles should be much shorter compared to general breakwaters with a typical design period of over 50 years (Goda and Takagi 2000). Therefore, for example, maximum waves over the past several years will be sufficient for use as the design wave of wooden piles.

Results

Amplification of water surface elevations was observed between piles owing to multiple mechanisms including characteristics of irregular waves, partial reflection of waves on the piles, returning flow from the beach, and intensified flow into

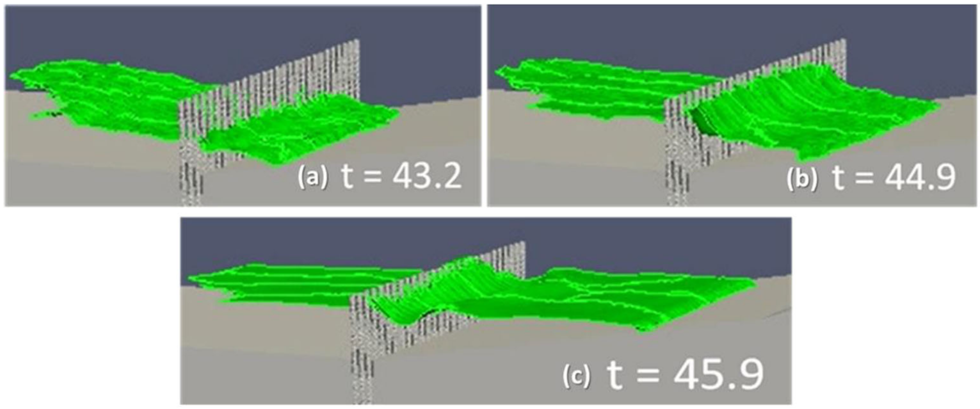


Fig. 6 Snapshots of the 3D hydrodynamic model around the wooden piles at (**a**) t = 43.2 s (before a wave arrives), (**b**) 44.9 s (as the wave passes through the gaps), and (**c**) 45.9 s (during wave run-up on the beach slope)

the gaps between piles. It is obvious that these complicated mechanisms cannot be adequately evaluated by a common 2D numerical model or mathematical analysis, demonstrating the benefit of using a 3D hydrodynamic model with irregular waves.

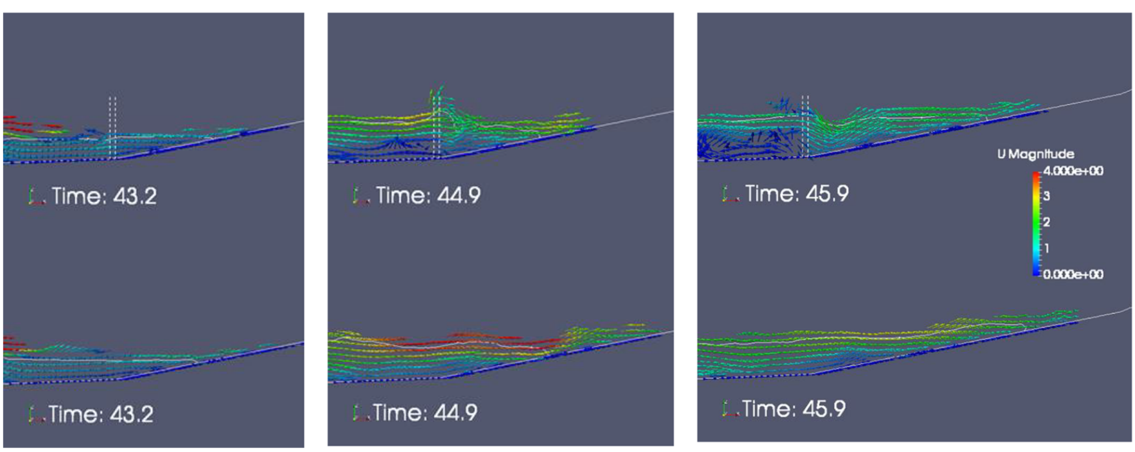
Wave–pile interaction and wave transmission

As shown in Fig. 6, the process involves multiple phases such as (a) where a wave reaches the piles, (b) when the crest of the wave passes the piles, and (c) when the wave runs up to the highest point on the beach slope. Water surface elevation appears to instantaneously rise around the piles.

The potential flow theory of classical fluid dynamics suggests that a concentration of flow into contracted gaps causes an intensified flow, reducing the water levels. However, the vector plot in Fig. 7(b) indicates that the water surface instantaneously rises within the pile gap. Figure 8 (a) and Fig. 9 also demonstrate that water surface elevations between the piles were substantially larger than those without piles. The increase in water surface elevation caused by piles is estimated as 0.134 m on average and 0.35 m at most. We consider that this amplification is particularly caused by wave reflection on the surface of the piles. However, water surface rapidly drops behind the piles, and this creates an oscillating flow, which is not observed in the case of those without pile.

Table 1 shows the estimated water surface elevations 1 m behind the pile position. Contrary to the general perception that water surface elevations should be reduced by installing wooden piles, the highest water surface elevations as well as the mean and lowest water surface elevations do not seem to be remarkably different between cases with and without piles. On the other hand, the reduction ratio of wave heights reaches about 24%, which is more remarkable than water level.

Figure 8 (a) also shows that mean water levels increased at an average of approximately 30 cm, which is equivalent to 20% of the incident wave height ($H_s = 1.50$ m). The change in mean water level caused by breaking wave is denoted by $\overline{\eta}$



(a) t = 43.2 s (before a wave arrives)

(b) 44.9 s (as the wave passes through the gaps)

(c) 45.9 s (during wave run-up on the beach slope)

Fig. 7 Velocity-vector plots on the vertical plane crossing in the middle of two piles (top: with pile, bottom: without pile). (**a**) t = 43.2 s (before a wave arrives) (**b**) 44.9 s (as the wave passes through the gaps) (**c**) 45.9 s (during wave run-up on the beach slope)

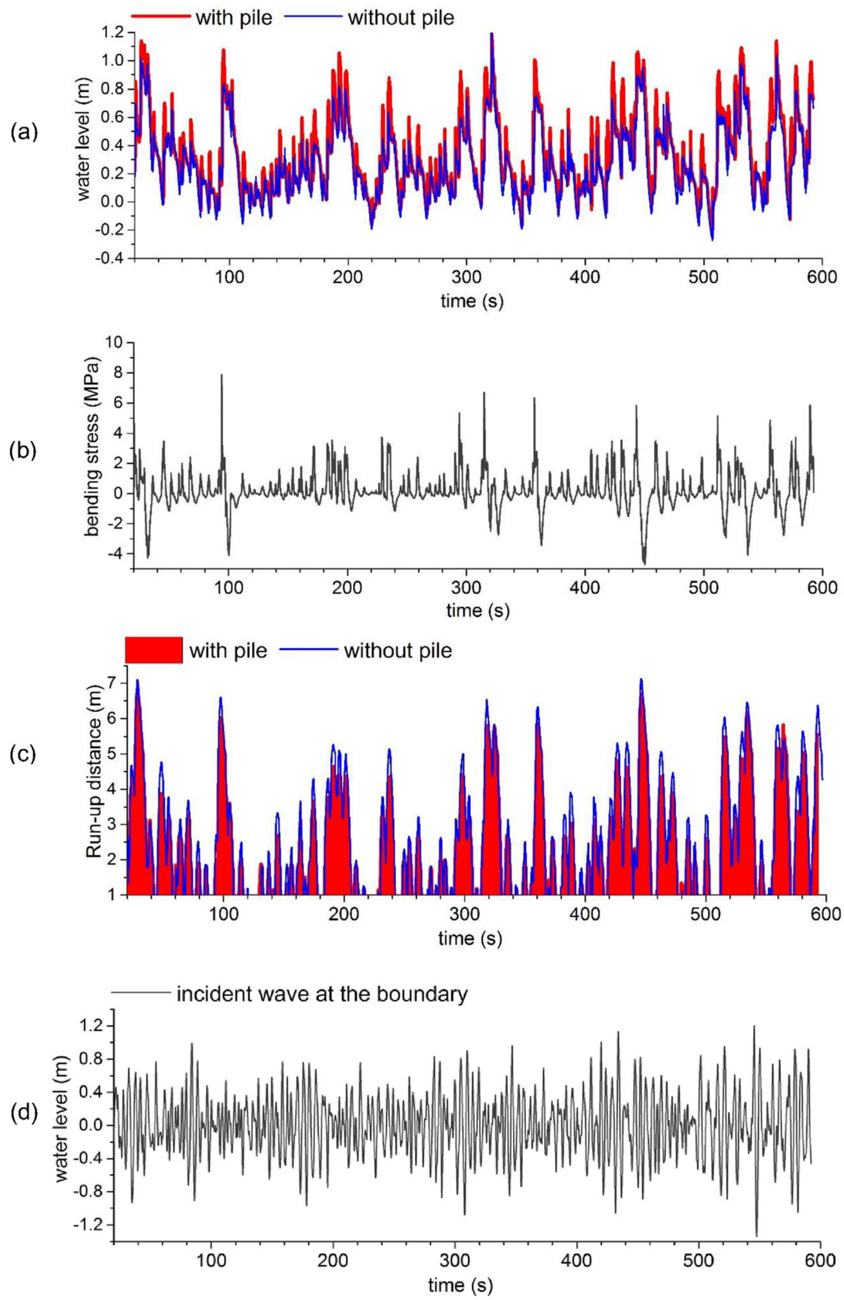


Fig. 8 **a** Water-level variations monitored between two piles. The water surface elevation without piles was measured at the same location as that with piles. **b** Time history of bending stresses under irregular waves over 10 min (positive value: pushing towards the shore; negative value: pulling towards the sea). **c** Run-up distance in the horizontal direction from the shoreline in the still-water condition. **d** Water surface elevation, which was imposed along the offshore boundary

and can be evaluated by numerically integrating the following differential equation from deep water toward the shoreline (Longuet-Higgins and Stewart 1962; Goda 2000).

$$\frac{d\overline{\eta}}{dx} = -\frac{1}{\left(h+\overline{\eta}\right)}\frac{d}{dx}\left[\frac{1}{8}H^2\left(\frac{1}{2}+\frac{(4\pi h/L)}{\sinh 4\pi h/L}\right)\right] \quad (1)$$

where H denotes the wave heights, h is the water depth, and L is the wave length. The wave setup was calculated, for simplicity, by assuming that the boundary waves (H_s = 1.50 m and T_s = 5.54) propagate normal to the shorelines over a uniform slope with 1/30. As the water depth becomes shallower, wave setup becomes larger and reaches up to approximately 22 cm at a water depth of 50 cm. Therefore, this significant water-level rise could be mostly explained by the breaking-wave-induced set-up. In addition, other mechanisms such as return flow from the steep beach face and nonlinear interaction between incoming and reflected waves seem to add an increase of the setup.

Bending stresses

The bending stress at a given moment can be readily calculated by integrating water pressures across the surface of the

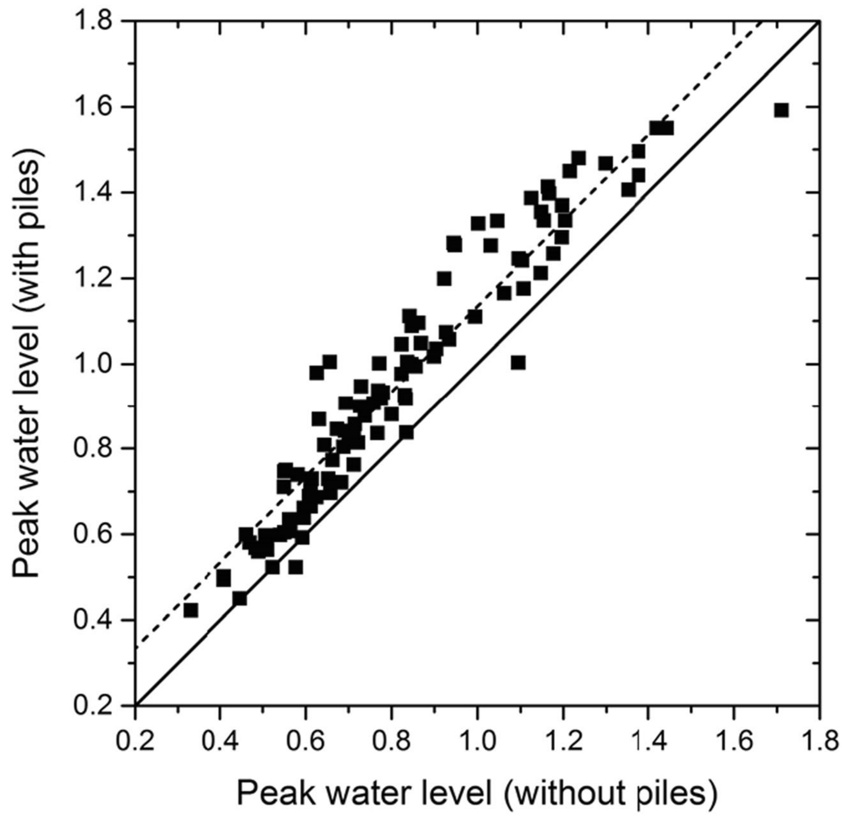


Fig. 9 Comparison between those with piles and without piles in terms of peak value within the time series of water surface elevations shown in Fig. 8 (**a**). The discontinuous line indicates that the water level increases by 0.134 m on an average

piles. Bending stresses fluctuate in both positive (shoreward) and negative (seaward) directions (Fig. 8 (b)). Larger stresses tend to appear in the positive direction, demonstrating the predominant influence of incident waves. However, negative stresses, which bend the piles towards the sea, appear not negligible. This case study shows that the pressure in the seaward direction is about a half of that in the shoreward direction. However, the pressure in the negative direction can be further amplified due to e.g. a significant reflection from a steep shore. Amplified water surface elevations would also cause adverse effects on the stability of wooden piles. Although pressures act from both sides on the piles, a slight time lag inevitably exists between the seaside and land side of the pile. The imbalance of pressures between front and rear side of the pile is anticipated to cause an adverse influence on the piles. Thus, the stability of piles should be examined in both shoreward and seaward directions during the course of the design of wooden pile breakwaters.

Table 1 Water surface elevations and significant waves 1 m behind (shore side) the pile position. Wave height is defined based on the zero-up-cross method

Without piles			With piles		
Max (m)	Min (m)	Average (m)	Max (m)	Min (m)	Average (m)
1.17	−0.20	0.29	1.21	−0.19	0.32
Hs (m)	Ts (s)		Hs (m)	Ts (s)	
0.34	6.32		0.26	6.31	

Run-up distance

The run-up caused by each wave was calculated as a horizontal distance from the still water shoreline (the intersection between the still water surface and the beach), as shown in Fig. 8 (c). Although the distance varies significantly with time, phases in water surface elevations are almost same between the with-piles and without-piles conditions. Therefore, a reduction in run-up distance could be readily calculated by taking the difference at the same moment between the with-piles and without-piles cases. It was found that wooden piles contribute to a reduction in run-up by 0.9 m at a maximum and 0.4 m on an average, with a standard deviation of 0.28 m (Fig. 10). When the distance is measured from the shoreline in the still-water condition, the reduction ratio with piles to without piles is calculated to be 12.9% on average and 37.2% at the maximum. The reduction effect seems not to be remarkably significant. Given a situation of an eroded beach approaching immediately beneath houses (Fig. 1), however, the placement of wooden piles is expected to retard coastal erosion to some extent. It is also interesting to point out an

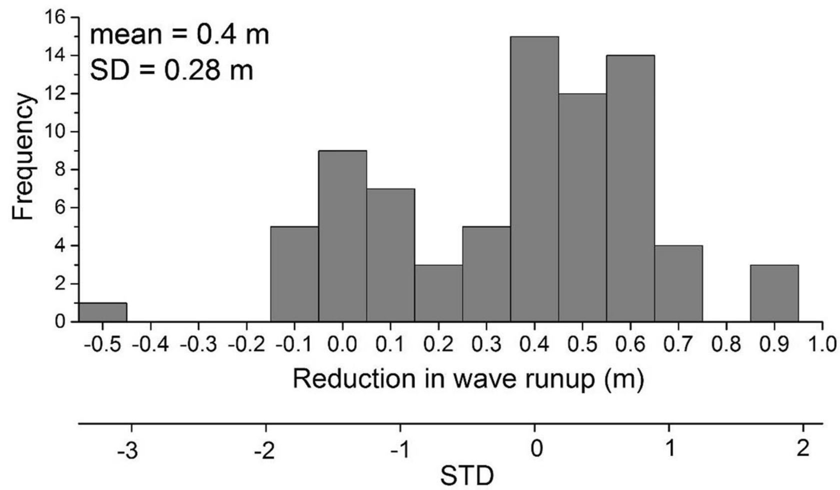


Fig. 10 Histogram of the reduction in wave run-up measured in the horizontal direction from the still water shoreline

apparently contradictory result. Despite the fact that the water surface elevation in front of the beach slope was not lowered by the installation of piles, the run-up distance was effectively reduced. We consider that the reduction in wave run-up occurred because of the creation of turbulence and oscillation triggered by the partial reflection of waves on the piles, diverting water flows into various directions, as found in Fig. 7. However, the presence of the piles does not always contribute to the reduction in run-up distance, but even sometimes causes an increase of the run-up. Although the mechanisms is still not clear, the amplification may be caused by a complicated interaction between incident and reflected waves that occurred within the foreshore between the piles and the eroded beach.

Discussion

In comparison with the without-piles case, the placement of wooden piles could cause higher water surface elevations between piles through multiple mechanisms such as the partial reflection on the piles, the collision of incoming and reflected waves, stagnant water behind piles, and flow concentration between piles. Such mechanisms could be unfavourable in terms of the stability of the structures, and thus should be taken into consideration in the design of wooden piles.

In practice, the wave force on a cylinder is often estimated using the Morison formula (Morison et al. 1950) or its extended expression, considering both drag force and inertial force. Based on a series of laboratory tests, Goda (1964) presented a diagram for the total drag force on a vertical pile that considers wave breaking as well as non-breaking waves. Hayashi et al. (1966) proposed a theory for the transmission ratio of waves past a row of closely spaced circular piles. Spring and Monkmeyer (1974) mathematically demonstrated that the inertia force on a given cylinder is affected by the presence of neighbouring cylinders.

These empirical or theoretical formulas are greatly beneficial in quickly designing wooden pile structures. However, their theory extensively simplified the treatment of waves for the sake of mathematical simplicity. The results of this study suggest that the following important factors cannot be evaluated with such commonly used formulas and should be incorporated in the design of wooden pile breakwaters.

- Statistical characteristics of wave forces and run-up owing to irregular waves
- Returning flows from the beach slope, which is particularly important in designing the stability of wooden piles
- Spatial and temporal changes in water surface elevation around and between the piles
- Wave set-up, which is the increase in mean water level above the still water level
- Turbulence or oscillation induced behind the piles, likely leading to a reduction in wave run-up

Patterns of wave forces and run-up are represented by not only the characteristics of incident waves but also by the interaction between waves and piles or beach slope. The water surface elevation in Fig. 8 (d), which was imposed from the boundary as the incident wave, appears to differ from the fluctuating pattern near the pile as shown in Fig. 8 (a). This discrepancy implies that only considering irregularity of incident waves is not sufficient in assessing the pile. Statistical characteristics in terms of parameters such as the wave force, run-up, wave transmission, and water surface elevations adjacent to piles needs to be better studied.

A 3D computation incorporating the detailed geometry of thin wooden piles takes a long time, even when using a state-of-the-art supercomputer. Given the fact that computer technologies are rapidly growing, as predicted by Moore's law, we believe that the application of 3D hydrodynamic modelling to the assessment of wooden pile breakwaters will become more realistic in the near future. However, we should emphasize that our overarching goal is not necessarily to promote the usage of such state-of-the-art CFD models in designing wooden piles, but to establish practical design methods (e.g., recommendation of pile-installation layout, simple design diagram) based on these computational assessments, particularly with the aim of facilitating community-based disaster management.

Conclusions

Improvised coastal protection systems using wooden piles are often seen on beaches suffering coastal erosion, particularly in developing countries, as they can be readily implemented by local communities or even individuals. However, the effectiveness of these piles has yet to be satisfactorily proven. The present study applied 3D hydrodynamic modelling, developed on a powerful supercomputer, to evaluate complex wave mechanisms and hydraulics around and between wooden piles. The comparison between the numerical models with and without wooden piles shows that wooden pile breakwaters can effectively reduce wave run-up on the beach slope and potentially delay the rate of coastal erosion if appropriately designed. Based on these observations, this paper suggests the need for conducting extensive research and thereby establishing design guidelines for this type of simple coastal protection system in order for local inhabitants and communities to quickly understand how to install the piles most effectively.

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