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SOUTHERN INSTITUTE OF WATER RESOURCES RESEARCH

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STUDYING AND PROPOSING A SOLUTION AS WELL AS ASSESSING THE FUNCTION OF WAVE ENERGY REDUCTION OF HOLLOW COMPLEX DIKE FOR COASTAL PROTECTION FROM CA MAU CAPE TO HA TIEN

Specialization: Technical constructions of hydraulic works

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SUMMARY OF TECHNICAL DISSERTATION

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FOREWORD

1. The necessity of the dissertation

In recent years, the Mekong River Delta (Mekong Delta) of Vietnam has been struggling to face many harsh challenges due to brutal interventions in the upstream of the Mekong River as well as unsustainable domestic economic development in the Mekong Delta, climate change (CC) and sea level rise (SLR). Many issues of science and technology need to focus on research to sustainably develop the Mekong Delta in accordance with nature, respect for nature, avoiding violent intervention in the nature *(Resolution No. 120 / NQ-CP dated 17/11/2017 of the Government on the sustainable development of the Mekong Delta in response to climate change)*. Therefore, the research content of the dissertation proposes the solution of an innovative, non-traditional structure and the scientific basis to evaluate the wave attenuating function of the works to be able to apply this structural solution effectively for the purpose of reducing waves protecting the eroded mangrove mud coast from the Ca Mau cape to Ha Tien with scientific significance and current urgency.

2. Research objectives

Studying and proposing the solution for a wave-attenuating breakwater with a flexible assembly structure by precast fixative concrete structures, appropriate applications to reduce wave energy for protecting the eroded mangrove-mud coast from Ca Mau cape to Ha Tien and developing a semi-experimental formula to calculate and determine the wave transmission coefficient of the construction suitable for the natural conditions in the West Sea of the Mekong Delta.

3. Subjects and scope of research

The object of the study: The wave-attenuating dike has an innovative structured shape and the mechanism of the wave energy consumption when passing through the construction.

The scope of the research: Hollow submerged breakwater with additional piles system on the top of submerged dike (complex hollow dike called in the dissertation), dike built in muddy beaches in front of the eroded mangrove belt from Ca Mau cape to Ha Tien in the Mekong Delta.

4. Approach and research method

The approach: The dissertation selects an integrated approach including: (1) Approach of ecosystem or based on ecosystem; (2) Approach from practical application of tested wave attenuating works at case study; (3) The selectively inherited approach from the international and domestic research achievements related to the wave transmission coefficients of the breakwater and the wave attenuating pile system (pile breakwater).

Research methodology: (1) General research method; (2) Experimental research method on physical modelling combining wave energy theory; (3) Method of experts; (4) Method of applied research.

5. Scientific and practical signification

Studying and proposing a solution for a complex hollow dike with an innovative, non-traditional structure and developing a scientific basis to evaluate the function of wave-attenuating for this type of construction associated with the typical nature condition of the eroded mangrove-mud coast in the case study. The technical characteristic of the complex hollow dike construction is the combination of a low-crest wave-attenuating dike with a cylinder piles system on the top of the dike, the construction with flexible wave attenuating features with the a wave-attenuating mechanism suitable for the nature action as coastal mangroves, decreasing negative impact on the coastal mangroves ecosystem.

The research results ensure the reliability and the clearly defined scope of application as well as meeting the urgent practical requirements of coastal erosion and degraded mangroves in the case study.

6. New contributions of the Dissertation

1- The study proposes a solution for a complex hollow dike, which is flexibly assembled by precast concreted structures (see Figure 2.2a). In which, the base block is a hollow submerged dike, the dissipation of wave energy through the wave breaking, the friction and currents in the dike (see Figure 2.2b), the piles system on top of the submerged dike dissipating wave energy based on the drag friction (see Figure 2.2c). The novelty and creative level of this structural solution is to propose flexible disposition of the piles system on top of the submerged dike to increase the efficiency of dissipating wave energy from this submerged dike, but incompletely prevent the flow circulation through into the submerged dike. It helps maintain the processes of exchanging water and material inside and outside the dike system. Also, it minimizes negative impacts on the adjacent natural environment, while it is also capable of sedimentation, supporting the conservation or the restoration of the mangrove ecosystem in the West Sea of the Mekong Delta. The dike structure is suitable for the soft mud geology with the capacity of poor weight load, the fast construction and installation, a reasonable cost, the ability of reuse (see Figure 2.2).

2- The general semi-experimental formula to calculate and determine the wave transmission coefficient of a complex hollow dike has been developed as follows:

$$K_t = \sqrt{K_t^{0^2} - 0{,}94.D_{pr}}$$

K_t^0 is the wave transmission coefficient of the hollow submerged dike without piles:

$$K_t^0 = 0{,}18\left(\frac{R_c}{H_{m0,i}}\right) + 0{,}58\left(\frac{B}{H_{m0,i}}\right)^{-0{,}19}.\left(1 - e^{-1/\sqrt{s_m}}\right)$$

D_{pr} is the relative wave energy dissipated by the top piles system:

$$D_{pr} = 0{,}153 \tanh\left[20{,}6\frac{(R_c + H_{m0,i})}{H_{m0,i}}.\frac{X_b}{L_m}\right]$$

when using the value of T_p instead of $T_{m-1,0}$ (ie L_p instead of L_m), D_{pr} is determined by the semi-experimental formula with the following form:

$$D_{pr} = 0{,}152 \tanh\left[16{,}3\frac{(R_c + H_{m0,i})}{H_{m0,i}}.\frac{X_b}{L_p}\right]$$

The limitation of the application scope according to the experimental conditions: $0 \le R_c/H_{m0,i} \le 2{,}459$; $0{,}713 \le B/H_{m0,i} \le 3{,}803$; $0{,}020 \le s_m \le 0{,}047$; $1{,}0 \le (R_c+H_{m0,i})/H_{m0,i} \le 3{,}459$; $0{,}010 \le X_b/L_m \le 0{,}087$; $0{,}012 \le X_b/L_p \le 0{,}118$; $0 \le R_c < H_{m0,i}$.

CHAPTER 1. RESEARCH OVERVIEW FOR WAVE ATTENUATING FUNCTION IN COASTAL PROTECTION OF A BREAKWATER

1.1. General introduction

The breakwater is applied in many countries with marine developed science and technology such as the US, Japan, Australia, Brazil, Canada, France, UK, Italy, Spain, …to protect the coast. In particular, US is the country that built the earliest breakwater system since 1905, with a project called Venice with 183 meters in the state of California, as of 1993, there were 23 projects with a total length of more than 17,2km. The breakwater was built for the coast protection and the embellishment of beaches in the states of California, Florida, Hawaii, ... (*John B. Herbich, 1999*). In Europe, according to the study of the DELOS project (1998-2002), it is confirmed that the breakwater provides outperform effectiveness compared to traditional construction solutions such as sea embankments, groins or jetties, which proves that the number of the breakwaters were built accounting for a very high rate, up to 66% (≈ 1,245 breakwaters). In Asia, Japan is the country building the most breakwaters in the world, as of 1996, 7.371 breakwaters were built with a total length of up to 837km (*John B. Herbich, 1999; John RC Hsu et al., 1999*). Some other countries in Asia such as China, India, ... also use the breakwater system to protect the coast, but still very limited in number and scale (*Luong Phuong Hau, 2016*). Vietnam is also testing some types of wave-attenuating structures to protect sea dykes, coastlines, and mangroves, such as: (i) the breakwater with blocks structure of Tetrapod in Nam Dinh and Hai Phong (*Luong Phuong Hau et al., 2016*); (ii) The breakwater of centrifugal concrete piles with core of cavity stone in Ca Mau and Bac Lieu (*Nguyen Huu Nhan, 2014; Luong Van Thanh et al, 2012*); (iii) Semi-circle (hollow caisson breakwater) in Ca Mau; (iv) The breakwater with non-metallic reinforced concrete in Ca Mau (*Department of Agriculture and Rural Development of Ca Mau, 2018; General Department of Disaster Prevention, 2018*); (v) The breakwater with geotube bag at Binh Thuan, Ba Ria –Vung Tau, Tien Giang, Tra Vinh, Bac Lieu, Ca Mau (*Pham Van Long, 2104*); (vi) Wave attenuating embankments to reduce cavity stone gabion, plastic sheet piles, and cajuput piles in Ca Mau (*Ca Mau Department of Agriculture and Rural Development, 2018*); (vii) Wave reduction with bamboo fences in Soc Trang, Bac Lieu, Ca Mau, Kien Giang (*Trinh Van Hanh, 2014; Schmitt et al., 2013; Von Lieberman, 2011*). However, the field experiment works are usually quite small in scale, mainly for emergency situation at locations of critical local erosion, but in some cases, the structure is unsustainable after construction, the wave attenuating effectiveness is not clear, the replication of the model is still limited (*Le Thanh Chuong et al, 2018; General Department of Disaster Prevention, 2018*). Because in the design step, there is a lack of clear scientific basis and design theory to evaluate the wave attenuating function of the works, or when applying scientific and technical solutions to protect the coast and embellish the beach in the world, although there is enough scientific basis and design theory, the limits of the application of research are paid a little attention.

1.2. Wave attenuating function of breakwaters

Incoming waves propagate perpendicular to the shore through the breakwater, the wave height is diminished due to the dissipation of the wave energy. Factors that dominate the wave energy dissipation are the incoming wave properties, water depth, geometrical parameters and material structure of the breakwaters.

The wave attenuating function of the breakwater structure is evaluated by the transmission coefficient (K_t), which is the ratio of the wave height transmitted behind the breakwater ($H_{s,t}$) to the wave height in front of the breakwater ($H_{s,i}$) with the following form:

$$K_t = \frac{H_{s,t}}{H_{s,i}} \quad (1\text{-}1)$$

Or the wave energy transmission coefficient (K_E) as follows:

$$K_E = \frac{E_t}{E_i} = \frac{H_{s,t}^2}{H_{s,i}^2} = K_t^2 \ (\text{với } E = \frac{1}{8}\rho g H_s^2) \quad (1\text{-}2)$$

where: H_s wave height in general, depending on the analysis method H_s with $H_{1/3}$ (statistical analysis) or H_{m0} (spectrum analysis).

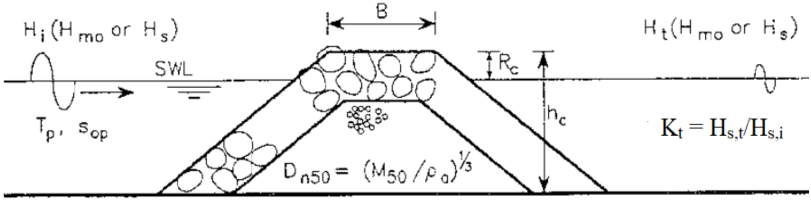


Figure 1-1. The basic parameters affect K_t.

Each different breakwater type will have wave attenuating effectiveness depending on different design function (especially for the breakwater with a new non-traditional structure), in other words, Kt will not the same for each type of the breakwater in the coastal protection function. The dissertation will review some relevant case studies on the assessment of wave attenuating function of the breakwater, with the main focus on the studies of K_t coefficient of the breakwater with the cross sections of trapezoid, rectangular and vertical walls (called breakwater) and the wave attenuating pile system with circular cross-section (called the piled breakwater).

1.2. The literature review in the world

1.2.1. The research of the breakwaters

The earliest research on K_t was done by the American and Japanese scientists such as *Johnson et al, 1951; Goda and Ippen, 1963; Goda et al, 1969; Iwasaki and Numata, 1969; Cross and Sollitt, 1972; Numata, 1975; Tanaka, 1976, Tomasichio and D'Alessandro, 2013*. However, until 1980, it started to be studied in depth, most notably the DELOS project (1998-2002) (*http://www.delos.unibo.it/*).

In general, before 1980, the studies were often implemented the experiments with regular waves transmitted through the breakwaters with quite simple geometric structure (thin wall, rectangular vertical wall, trapezoid shape with smooth roof), the number of experiments is limited, the results of the research are mainly scientifically significant, the practical applicability is little, because basic parameters that influence the wave propagation have not fully considered. From 1980 to present, especially after DELOS project (1998-2002), many studies have been carried out very elaborately, they based on experimental data synthesized from a plenty of different studies. They implemented experiments on many wave flutes with various model scales, experimental parameters including random waves, structure and shape of the breakwaters in the experiment so that they are close to the practical conditions in the archetype. The study through the experimental data set of physical modeling to analyze, evaluate and determine the parameters influencing to the process of wave transmission (non-dimensional parameters such as $R_c/H_{s,i:}$; $B/H_{s.i}$; B/L_p; ξ_{op}; $H_{s,i}/D_{n50}$; $H_{s,i}/h$; s_{op}) to give assessments, develop experimental charts or experimental, semi-experimental formulas of K_t for each type of the breakwaters with the limit of specific application for each study. The most typical two studies are *d'Angremond et al, 1996; Van der Meer et al, 2005,* which were based on the experimental data of the physical modelling synthesized and standardized by many studies as well as fully reviewed main influencing parameters to wave propagation such as relative water depth (R_c/H_s), relative width (B/H_s) and wave break parameter (ξ_{0p}) characterizing the interaction between incident waves and the slope of the works, basically reflecting the physical process of the wave energy dissipation transmitted through the breakwaters, the calculation result of K_t has accuracy and high practical applicability *Tomasicchio and D'Alessandro, 2013*. This is the scientific basis for the reference of the dissertation to build the experimental formula calculating K_t for the vacuous submerged breakwaters without piles (the wave energy dissipation due to the vacuous submerged breakwater without piles).

1.2.2. Research for the pile breakwaters.

The pile breakwater is considered as a variant of the breakwaters described in the above content "***1.2.1. Research for the breakwater***". The study and the evaluation of the wave reduction function for pile breakwater is also interested and implemented simultaneously with the breakwater, such as the study of *Costello, 1951; Wiegel, (1960, 1961); Hayashi and Kano, 1966; Hayashi et al, 1968; Truitt and Herbich, 1987; Herbich and Douglas, 1988; Koftis et al, 2012; Sonia et al, 2015,* *etc*. The purpose of the research and application of the pile breakwater is to overcome the scarcity of natural rock resources in many countries (to replace the spilled stone structure of the breakwater). In addition, the pile breakwater is also considered as a technical solution to well minimize negative impacts caused by reflecting waves in front of the works, supporting to maintain the water quality behind the works (*Norzana and Faridah, 2012*). Research on pile breakwater usually carry out to analyze, evaluate and determine the correlation between the oceanographic flow parameters (incoming wave characteristics, inundation depth) and geometrical characteristics of the pile system (the cross section of pile, the gap between the piles in the row, the distance between the rows of piles, the number of pile rows, the layout of the pile system) affecting the coefficient of K_t. The dissertation refer to the research of *Herbich and Douglas, 1988; Koftis et al., 2012; Sonia et al., 2015* to orientate the solution proposal of a complex hollow breakwaters and the method of a lateral pile arrangement.

1.3. The situation of the study in Vietnam

The number of study on the breakwaters in general is still limited, the research subjects have little differences compared to the world, only the difference in the scope of the study associated with specific regional conditions and research results, in general, is quite good, but the practical application is still limited. However, the dissertation can completely refer to current studies to research and propose the solution of the breakwater suitable for the case study, for example, refer to the research of *Schmitt et al, 2013* on wave reducing efficiency and the limitations that need to be fixed for the bamboo fence, or the study of *Nguyen Tuan Anh, 2019* to study and propose the type of construction with wave reducing properties similar to mangroves, or refer to experimental research on the wave flume of the physical modelling as of *Nguyen Khac Nghia et al, 2013; Nguyen Thanh Trung, 2014; Nguyen Viet Tien, 2015; Doan Tien Ha, 2015; Thieu Quang Tuan et al, 2018 or AFD and the Institute of Forestry Science and Technology (2016-2018).*

In summary: Currently, there is the limitation of the study on the evaluation of wave reducing function for the type of submerged breakwaters combined with the above pile system. Therefore, the dissertation proposing a solution for a complex hollow breakwater and developing a scientific basis to evaluate the wave attenuating function for this type of works associated with the typical natural conditions of the western coastal area of the Mekong Delta is suitable and necessary.

CHAPTER 2. SCIENTIFIC BASIS OF STUDY ON SOLUTIONS FOR COMPLEX HOLLOW BREAKWATER

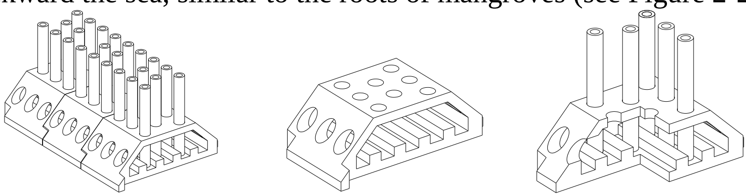
2.1. The overview of the study zone

The coastline of case study area is more than 350km from Ca Mau Cape to Ha Tien. The coastal topography is quite low compared to the sea level, the intertidal sediments surrounding the mangrove and extending into the sea, including the intertidal zone (or the alluvial area) and the sub-tidal zone (or the underground mudflats). Geomorphology of this area origin from marine and the sediment accumulates due to the impact of longshore currents. The geology is mainly soft silt-clay with poor load capacity, it leads to subsidence or erosion due to the wave impact on the South West Monsoon. Mangrove ecosystem along the coastal area is very rich and diverse. The hydrodynamic regime is directly influenced by the monsoon regime and coastal bathymetry. Currents are controlled by river flow and tidal currents. The mixed tidal regime tends to be irregular diurnal tidal, the maximum tidal amplitude is only (1,10 ± 0,1) m.

Figure 2-1: The location of case study

2.2. Studying and proposing a solution for a complex hollow breakwater

Based on the results of research overview and practical summation, the research orientation proposing the solution of applied works appropriate to the purpose of attenuating wave energy to protect mangrove mud coast in the case study, meeting the following criteria: (i) Structures with flexible wave-damping features, not completely blocking the flow of water through the dyke, should help maintain metabolic processes, exchanging water inside and outside the breakwater, minimizing negative impacts on the ecological environment of the breakwater system, at the same time, being capable of causing sedimentation, creating mudflat, restoring mangrove areas behind the breakwater; (ii) The project is suitable for the natural conditions of the hydrological regime of the case study, appropriate to the soft mud geology, easy for manufacturing the structure, the construction and installation in the field, the fast execution time, high durability in marine environment, convenient maintenance, reasonable construction cost, capable of recycling and reuse. The dissertation proposes the solution of the breakwater in the form of assembly by prefabricated concrete components, which is the hollow submerged breakwater, with additional piles on the top of the breakwater to increase the wave attenuating efficiency of the construction in the mud mangrove coastal protection function (called the complex hollow dike works in the dissertation). Wave attenuating function of the works is considered semi-natural, simulating the wave reduction principle of coastal mangroves. In particular, the pile system is flexibly assembled on the top of the breakwater, in addition to its main function to increase the wave reduction efficiency of the breakwater, and simultaneously create a system of vertical slit to allow all incoming waves and tides which can be transmitted, the pile system has a wave-blocking role similar to the coastal mangrove trunks, the process of dissipating wave energy through the pile system is based on the resistance force. The base block is a hollow breakwater, besides the main role of dissipating wave energy through wave breaking, friction and currents of the breakwater body, it also plays a role in preventing and keeping the silt and sand moving backward the sea, similar to the roots of mangroves (see Figure 2-2).



a) Complex hollow breakwater (general) | *b) The hollow submerged breakwater* | *c) Upper circular pillar assembled system*

Figure 2.2. Complex hollow breakwater (the case of 3 rows of piles)

The structure of a complete complex hollow breakwater section has three assembled components (see Figure 2-2a). In each independent component, there are the hollow submerged breakwaters (see Figure 2-2b) and the circular pillar piles assembled on the top of the submerged breakwater (see Figure 2-2c). The technical issue of the complex hollow breakwater solution is the flexible assembly of the circular pillar pile system into the hollow submerged breakwater. Flexible assembled pile system can be 1, 2, 3 or more rows of piles, arranged according to the apricot pattern. Depending on the requirement for reducing wave height, the height of the pile rows is also completely flexible that can be equal or not equal, for example, the pile rows facing the waves may be higher than the rear piles to save materials. The special feature of the arrangement of holes on the top of the hollow breakwater will allow flexibility to add or decrease the pile rows when the wave height is needed to reduce or increase, or when the height adjustment of piles is required, they can be completely replaced with new pile system with appropriate height, or when it is necessary to move the project further to encroach the sea or to another location that it is possible to reuse this old pile system. The novelty and innovative level of this solution is its flexible wave attenuating function and the ability to assist in maintaining the quality of the water environment behind the works, to nourish and regenerate mangrove ecosystems through the system of the vertical slit of the upper pile system. In other words, the components of the water quality nourishing mangroves are almost not affected by the works, minimizing negative impact on the natural ecological environment. In this study, it will focus on developing a scientific basis for the wave attenuating function of a complex hollow breakwater with the following structural features: The hollow breakwater has a trapezoidal cross-section, the roof smooth, roof coefficient m = 1 and the porosity on the breakwater roof accounting for 14% of the roof area. The pile system on top of the breakwater is arranged in the form of apricot and the rule of distance between the piles in a row is equal to the distance of the pile rows and the size of the pile diameter 30cm. The study with 4 cases of the above pile system is B = 1,68m ~ 2 rows of piles; B = 2,28m ~ 3 rows of piles; B = 2,88 m ~ 4 rows of piles; B = 3,48m ~ 5 rows of piles. The study does not consider the case that the elevation of the breakwater crest is higher than the calculated water level and the elevation of the pile system is lower than the calculated water level.

2.3. Research method based on physical modelling

2.3.1. Comparable theory and model scale

With the shortwave model, the model needs to be orthodox, i.e. when the length ratio λ_L is equal to the height ratio λ_h, in order to have similar wave dynamics and dynamics. The ratios of the model should comply with Froude's similar law. In this dissertation, the model scale selected to study is $\lambda_L = \lambda_h = 15$, proportional correlation of some basic physical parameters according to Froude's law (see Table 2-1).

Table 2-1. Scale correlation of some basic physical parameters

Parameters	**Dimension unit**	**Correlation**	**Value**
Lenght	[L]	λ_L	15
Height	[L]	$\lambda_h = \lambda_L$	15
Time	[T]	$\lambda_t = \sqrt{\lambda_l}$	3,873

2.3.2. Application of dimensional analysis method to establish general equations (PI-BUCKINGHAM theory)

The dissertation uses the PI-BUCKINGHAM theory (PI-Theorem) to establish general equations that show the relationship between the basic dominant parameters in the form of non-dimensional quantities and wave transmission coefficient Kt. This is the basis for the design of experimental series to carry out the analysis of results, leading to experimental and semi-experimental formulas about K_t.

a. General function of the wave transmission coefficient through the hollow breakwater without piles:

$$K_t^0 = f_1\left(\frac{R_c}{H_{m0,i}}, \frac{B}{H_{m0,i}}, \frac{H_{m0,i}}{L_m}\right) \quad \text{2-1}$$

b. The general function describes the dissipation of wave energy across the pile system:

$$D_{pr} = f_2\left(\frac{R_c}{H_{m0,i}}, \frac{X_b}{L}, \frac{H_{m0,i}}{L}\right) \quad \text{2-2}$$

The expressions Eq.(2-1) and Eq.(2-2) showing between the parameters that dominant the wave propagation through the works will be concretized in Chapter 3 based on the results of the physical experiment.

2.3.3. Hydrodynamic factors in protoplast and model

Table 2-2. Hydrodynamic factors in prototypes and models.

TT	**Protoplast**			**Model**			**Note**
	$H_{m0,i}$	**$T_{m-1,0}$**	**R_c**	**$H_{m0,i}$**	**$T_{m-1,0}$**	**R_c**	
1	1,05m	4,38s	0m 0,75m 1,50m 2,25m	0,07m	1,13s	0m 0,05m 0,10m 0,15m	λ_L =15 The criteria of Froude. 4 inundation depth R_c
2	1,05m	5,19s		0,07m	1,34s		
3	1,50m	5,23s		0,10m	1,35s		
4	1,50m	6,20s		0,10m	1,60s		
5	1,80m	5,73s		0,12m	1,48s		
6	1,80m	6,78s		0,12m	1,75s		
7	2,10m	6,20s		0,14m	1,60s		
8	2,10m	7,32s		0,14m	1,89s		
9	2,40m	6,62s		0,16m	1,71s		
10	2,40m	7,86s		0,16m	2,03s		

2.4. The design of the experiment

To develop a semi-experimental formula for calculating K_t of a complex hollow breakwater (see Content 2.3.2). A matrix of 300 test scenarios of physical experiment is implemented - see Table 2-3 below.

Table 2-3. Synthesis of physical experiment scenarios

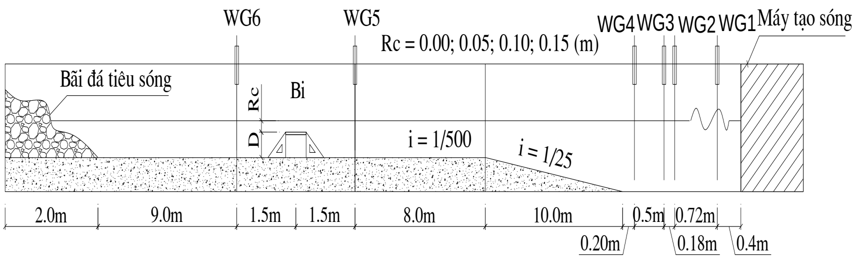
Experiment scenarios	HT	Hollow breakwater without piles and complex hollow breakwater								Inundation R_c
	B=0	B=0,112m		B=0,152m		B=0,192m		B=0,232m		
	n_c	n_c		n_c		n_c		n_c		
	= 0	= 0	= 2	= 0	= 3	= 0	= 4	= 0	= 5	
H07T113	x	x	x	x	x	x	x	x	x	0m 0,05m 0,10m 0,15m
H07T134	x		x	x	x		x		x	
H10T135	x	x	x	x	x	x	x	x	x	
H10T160	x		x	x	x		x		x	
H12T148	x	x	x	x	x	x	x	x	x	
H12T175	x		x	x	x		x		x	
H14T160	x	x	x	x	x	x	x	x	x	
H14T189	x		x	x	x		x		x	
H16T171	x	x	x	x	x	x	x	x	x	
H16T203	x		x	x	x		x		x	
Tổng số	**40**	**20**	**40**	**40**	**40**	**20**	**40**	**20**	**40**	**300**

2.5. Experimental diagram of physical model

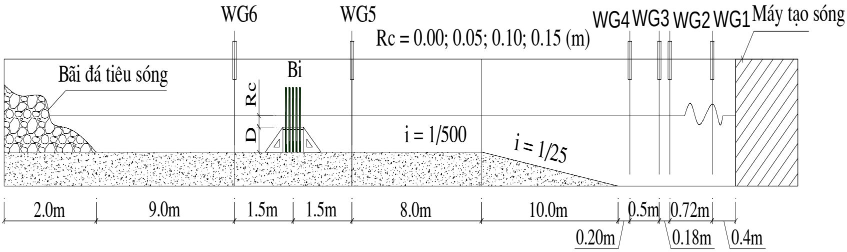
To measure the wave parameters, 5 front detectors (WG1, 2, 3, 4, 5) and 1 detectors behind the building are arranged (WG6) (see Figure 2-3).

The experiment was conducted with JONSWAP spectral random wave in standard form, ensuring suitable for wave characteristics at case study and experimental equipment.

The time of experiment implementation t = 500 x T_p + 300s = (865 ÷ 1.315) s, ensuring > 500 waves to ensure the basic frequency range of the required wave spectrum is created completely.



a) Experiments of hollow breakwater without piles



b) Experiments of complex hollow breakwater

Figure 2-3. Experimental diagram of physical experiments

2.6. Scientific basis to evaluate wave reduction functions for complex hollow breakwater

The average wave energy balance written for a wave that travels to the shore can be written in the following form:

$$\frac{\partial(\mathrm{E.c_g.cos\phi})}{\partial \mathrm{x}} = -\sum_{i=1}^{i=n} \mathrm{D_i} \qquad \text{2-3}$$

where: ϕ is the wave propagation angle (compared to the linear method of the shoreline x, x has the direction towards the sea).

Considering the case where the wave propagates perpendicular to the shore ($\phi = 0^o$), Eq.(2-3) can be written in the following form:

$$\frac{\partial(\mathrm{E.c_g})}{\partial \mathrm{x}} = -\sum_{i=1}^{i=n} \mathrm{D_i} \qquad \text{2-4}$$

$$\text{với } \mathrm{E} = \frac{1}{8}\rho g H_s^2 \qquad \text{và } c_g = \frac{c}{2}\left(1 + \frac{2kh}{\sinh(2kh)}\right)$$

Applying Eq.(2-4) to establish energy balance equations of random waves traveling perpendicular to the shoreline across the structure (the case of hollow breakwater without piles and complex hollow breakwater). In which, the right side of Eq.(2-4) is the wave energy dissipated by the hollow underground dyke breakwater system, then we will develop the semi-empirical formula calculating and determining of K_t for the complex hollow breakwater (see Chapter 3).

CHAPTER 3. STUDY ON DEVELOPING FORMULA OF CALCULATING WAVE TRANSMISSION FOR COMPLEX HOLLOW BREAKWATER

3.1. Problem

A complex hollow breakwater consists of a hollow breakwater dissipating wave energy through breaking wave, reflection, friction and currents through the breakwater, while the upper pile system dissipates wave energy by means of resistance force.

The results of research are coded in MATLAB language to perform data analysis, developing correlation charts, regression analysis, developing experimental and semi-experimental formulas to evaluate wave attenuating functions for general complex hollow breakwater.

3.2. Transmitting waves through the hollow breakwater without piles

- In general, $R_c/H_{m0,i}$ have dominantly influence on K_t^0, the relationship is co-variable similar to other submerged breakwater (see Figure 3-1). However, due to the structure of the hollow breakwater, it only shows a significant wave attenuating effect with a small inundation depth $R_c/H_{m0,i}$ <1,0. When $R_c/H_{m0,i}$ > 1,0 then K_t^0 increases very slightly or almost unchanged. When R_c = 0, the breakwater has the best wave attenuating efficiency with K_t^0 = 0,50 (average).
- The influence of the relative width of B/L_m or B/L_p is generally weaker than $R_c/H_{m0,i}$ (see Figures 3-2, 3-3 and 3-1). The effect of B/L_m or B/L_p becomes weaker as R_c increases, when R_c = 0,10 and 0,15m then B/L_m or B/L_p has insignificant. The relationship is inverse. The use of $B/H_{m0,i}$ instead of B/L_m or B/L_p leads to similar results with weaker level (see Figure 3-4).

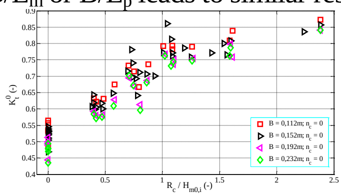


Figure 3-1. The effect of relative inundation depth ($R_c/H_{m0,i}$) on K_t^0.

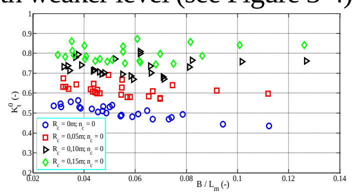


Figure 3-2. The effect of relative width B/L_m to K_t^0.

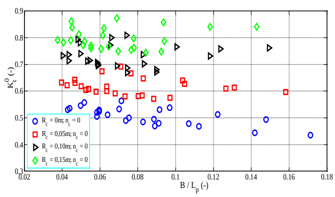


Figure 3-3. The effect of relative width B/L_m to K_t^0

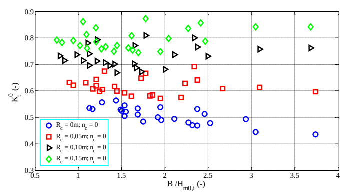


Figure 3-4. The effect of relative width $B/H_{m0,i}$ to K_t^0

Normally, the wave interaction with the slope is showed in the value of Iribarren's number ξ_{m0}. However, the coefficient of the breakwater roof is a constant ($\tan\alpha = 1$), hence this property of interaction can be considered through the value of the wave slope at the breakwater position s_m.

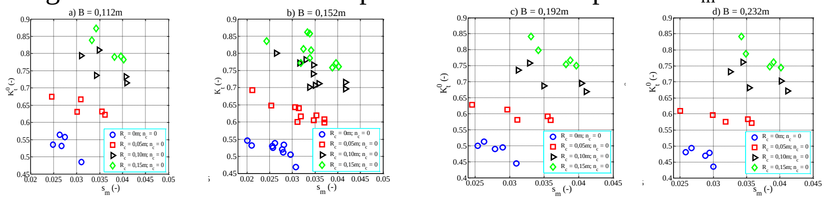


Figure 3-5. The correlation $s_m \sim K_t^0$

From the above-mentioned analysis, it can be seen that the wave transmission through the hollow submerged breakwater without piles is mainly dominated by three parameters that are: $R_c/H_{m0,i}$, $B/H_{m0,i}$, s_m. Similar to other types of the breakwaters, (*see Angremond et al., 1996; Van der Meer et al., 2005 are presented in Chapter 1*). Thus, we have the coefficient of the wave transmission through the hollow hollow submerged breakwater without piles of the form:

$$K_t^0 = a.\left(\frac{R_c}{H_{m0,i}}\right) + b.\left(\frac{B}{H_{m0,i}}\right)^{c_1}.\left(1 - e^{c_2/\sqrt{s_m}}\right) \qquad (3\text{-}1)$$

where: the coefficients of a, b (positive values) and the exponents of c_1, c_2 (negative values) are determined by regression method with experimental data for the case of the hollow submerged breakwater without piles (100 experiments - see Table 2-3).

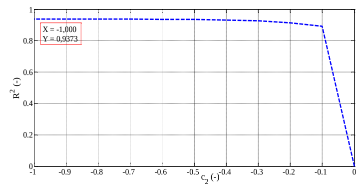


Figure 3-6: The relationship of $c_2 \sim R^2$

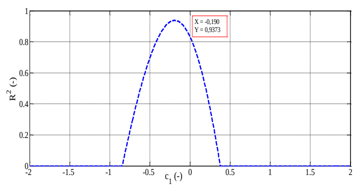


Figure 3-6: The relationship of $c_1 \sim R^2$ (with $c_2 = -1{,}0$).

Using the detection method according to the combinations for the two exponents c_1 and c_2 stars so that Eq.(3-1) is the most suitable for the experimental data, i.e. the largest regression coefficient R^2. For each value of c_2, there will be a series of c_1 values which are assumed to analyze regression and select the parameters of c_1 and c_2 for the largest R^2. Relationship results between c_2 and R^2 in Figure 3-6 show that the sensitivity R^2 is not significant when $c_2 < 0$. When $c_2 \leq -1{,}0$, then R^2 reaches the maximum value, so choose $c_2 = -1{,}0$ to analyze the regression. For c_2 determined, Figure 3-7 shows the relationship between c_1 and R^2 for the value c2

= -1,0. The result of c1 = -0,19 gives the largest value of R^2, approximately 0.94. Using the exponents of c_1 = -0,19 and c_2 = -1,0 determined the experimental constants of a = 0,18 and b = 0,58, respectively. Thus, Eq.(3-3) above has been rewritten as the following form:

$$K_t^0 = 0{,}18.\left(\frac{R_c}{H_{m0,i}}\right) + 0{,}58.\left(\frac{B}{H_{m0,i}}\right)^{-0{,}19}.\left(1 - e^{-1/\sqrt{s_m}}\right) \quad (3\text{-}2)$$

The results of comparing the wave transmission coefficients through the submerged breakwater without piles between the calculation based on the experimental formula Eq.(3-2) and the experimental data shown in Figure 3-8 with high correlation (R^2 = 0,94). In cases $T_{m-1,0}$ cannot be determined correctly, it is still possible to use Eq.(3-2) with s_p instead of s_m with slightly lower confidence.

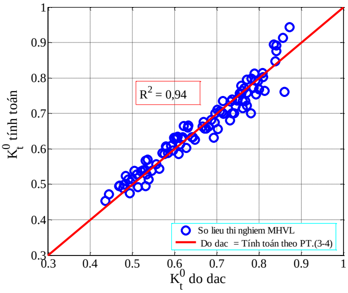


Figure 3-8. Comparing K_t^0 calculated by formula and experimental data.

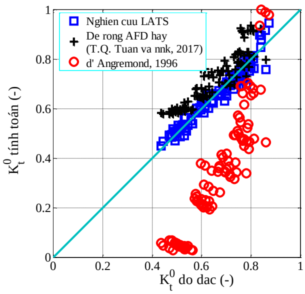


Figure 3-9. Compare K_t^0 calculated by formula and previous studies.

Figure 3-9 showing the comparison with the research of *T.Q. Tuan et al, 2017* for the case of the hollow submerged breakwaters provide the results quite close to the study of the dissertation. In contrast, according to the study of *d 'Angremond et al., 1996*, results evaluated a rather underestimating of the experimental data from the study, this difference can be explained by the rocky inclined submerged breakwater is the structure of porous body with much higher wave energy dissipation compared to the structure of surface porosity. Thus, with the two types of submerged breakwater of the hollow surface structure, the results are similar, however the reliability level and application scope of the formula Eq.(3-2) is more significant due to fully considering the main dominant parameters to wave propagation.

3.3. Dissipating wave energy through the upper pile system

Applying Eq.(2-4), we have energy balance equation of random waves traveling perpendicular to the shore through the complex hollow breakwater:

$$\frac{\partial(\mathrm{E.c_g})}{\partial \mathrm{x}} = -\mathrm{D_d} - \mathrm{D_f} - \mathrm{D_p} \tag{3-3}$$

$$\mathrm{E} = \frac{1}{8}\rho \mathrm{g} \mathrm{H}_{\mathrm{rms}}^2 \; ; \; \mathrm{c_g} = \frac{\mathrm{c}}{2}\left(1 + \frac{2\mathrm{kh}}{\sinh(2\mathrm{kh})}\right) \tag{3-4}$$

where: x is a typical length according to the wave direction; E is the sum of the energy of the wave; H_{rms} is the mean squared wave height in the case of a hollow complex breakwater; h is the water depth; c is the velocity of the peak wave; c_g is the wave group velocity; D_d is the wave energy dissipation rate due to the hollow submerged breakwater without piles; D_f is the wave energy dissipation due to the bottom friction; D_p is the wave energy dissipation rate due to the resistance of the pile system.
Under the same conditions, applying Eq.(2-4) for the hollow submerged breakwater without piles as follows:

$$\frac{\partial(\mathrm{E}^{(0)}.\mathrm{c_g})}{\partial \mathrm{x}} = -\mathrm{D_d^{(0)}} - \mathrm{D_f^{(0)}} \qquad \text{3-5)}$$

where: $E^{(0)}$ is wave energy in case of hollow submerged breakwater without piles; $D_d^{(0)}$ is the wave energy dissipation rate due to the hollow breakwater; $D_f^{(0)}$ is the wave energy dissipation due to the bottom friction.
From Eq.(3-3), Eq.(3-4) and Eq.(3-5), we have:

$$\frac{\partial[(\mathrm{E} - \mathrm{E}^{(0)}).\mathrm{c_g}]}{\partial \mathrm{x}} = \left[\left(\mathrm{D_d^{(0)}} - \mathrm{D_d}\right) + \left(\mathrm{D_f^{(0)}} - \mathrm{D_f}\right)\right] - \mathrm{D_p} \; = \Delta_\mathrm{p} - \mathrm{D_p} \tag{3-6}$$

where: Δ_P is the total difference of the wave energy dissipation rate due to the hollow submerged breakwater and the bottom friction in cases of pile system and without pile system.
Assuming that the wave energy dissipated by friction and reflected waves are the same between the two cases of a complex hollow breakwater and hollow submerged breakwater without a pile (according to the experimental data, the reflectivity coefficient is not significantly different). In addition, this difference is also taken into account by taking the wave height in front of the dyke as the average of wave heights between the two cases of works and latter it is also considered through coefficients of the model correction and the existence of the pile system does not change the energy consumption rate of the hollow submerged breakwater compared with the breakwater without a pile system. Therefore, the value of Δ_P is very small, insignificant ($\Delta_P \approx 0$). Thus, Eq. (3-6) was summarized and rewritten as follows:

$$D_p = \frac{\partial\left[\frac{1}{8}\rho g\left(H^2_{rms,(0)} - H^2_{rms}\right).c_g\right]}{\partial x} = \frac{\partial\left(\frac{1}{8}\rho g H^2_{rms,p}.c_g\right)}{\partial x} \tag{3-7}$$

Where: $H_{rms,p}$ is the component of wave height attenuated by the pile system.
If the incoming waves are the same, then Eq. (3-7) can simply interpret that the wave energy dissipated by the pile system is the difference in the wave energy behind the dyke between the two cases of pile system and without pile system.

$$D_p = \frac{1}{8}\rho g c_g \frac{\left(H^2_{rms,t}\right)_0 - \left(H^2_{rms,t}\right)_p}{X_b} = \frac{1}{8}\rho g c_g \frac{\Delta H^2_{rms,p}}{X_b} \tag{3-8}$$

where: $H_{rms,t}$ is the wave height behind the breakwater, the corresponding indexes "0" and "p" are used to indicate the case of the hollow submerged breakwater without piles and piles; X_b is the width of the influence of the upper pile system (X_b is the center distance of the two rows of piles in the boundary).
Here, we introduce the concept of relative wave energy dissipated by the pile system D_{pr}, which is a dimensionless unit defined as follows:

$$D_{pr} = \frac{\Delta H^2_{rms,p}}{H^2_{rms,i}} = \frac{\left(H^2_{rms,t}\right)_0 - \left(H^2_{rms,t}\right)_p}{H^2_{rms,i}} \tag{3-9}$$

From Eq.(3.10) and Eq. (3.11), the relationship as follow:

$$D_p = \frac{1}{8}\rho g c_g \frac{D_{pr}.H^2_{rms,i}}{X_b} = \frac{D_{pr}.E.c_g}{X_b} \tag{3-10}$$

The results of the calculation D_{pr} according to Eq.(3-8) and Eq.(3-9) corresponding to 100 experimental pairs (see Table 2-3) with the same wave and water level boundary conditions and implemented with comparing each other shows that D_{pr} value is quite small, only around (10 ÷ 20)% of the total incident wave energy. Similar to the case of the hollow submerged breakwater without piles, relative inundation depth $R_c/H_{m0,i}$ (the length of the submerged section of the pile) also has a critical influence on D_{pr} - see Figure 3-10. In general, it can be seen that this relation is clearly co-variable with the nonlinear trend. D_{pr} increased strongly with $R_c/H_{m0,i}$ < 1,20 then hardly increased any more. D_{pr} also increases the ratio with the number of rows of piles (the width of pile system).

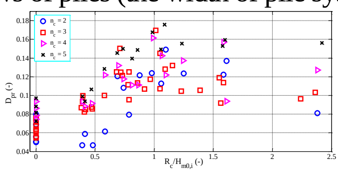


Figure 3-10: The influence of $R_c/H_{m0,i}$ to D_{pr}

Figure 3-11: The influence of (X_b/L_p) and ($X_b/H_{m0,i}$) to D_{pr}

The influence of the relative width of the pile system (X_b/L_p) and (X_b / $H_{m0,i}$) on D_{pr} is shown in Figure 3-11, respectively, showing a significant dependence with the positive relationship of the width of the pile system to D_{pr}. The most pronounced effect was on low levels of inundation. The D_{pr} tending to increase slowly with large depths of inundation is explained that when the water depth is large enough, the most of the wave energy in the short frequency range is dissipated by the pile system, only the wave energy at low frequency range remains. As analysed above, waves in the long frequency range have little energy dissipation when passing through the pile system, therefore when the water depth continues to increase or the number of pile rows increases, D_{pr} will not continue to increase.

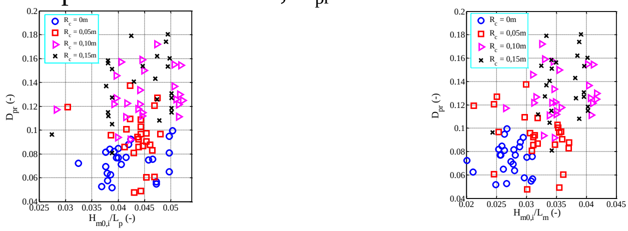


Figure 3-12: The influence of s_p (left) và s_m (right) to D_{pr}.

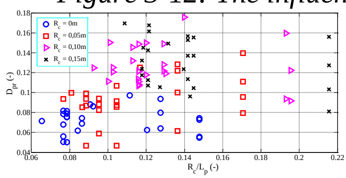


Figure 3-13. The influence of $R_c/L_p \sim D_{pr}$.

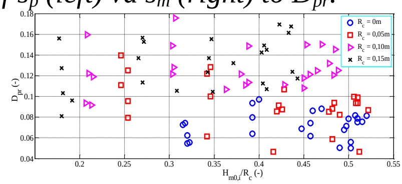


Figure 3-14. The influence of $H_{m0,i}/R_c \sim D_{pr}$.

Figure 3-12 shows the wave slope ($s_p = H_{m0,i}/L_p$ and $s_m = H_{m0,i}/L_m$) at the site of the works for D_{pr}. The general trend is positive, but quite weak compared to the case of the hollow breakwater without piles. Other effects such as relative water depth (h/L_p) and breaking wave index ($H_{m0,i}/h$) on D_{pr} are negligible (see Figure 3-13 and Figure 3-14). With the above correlation analysis, we have a general equation of the form:

$$D_{pr} = f_2\left(\frac{R_c}{H_{m0,i}}, \frac{X_b}{L_m}\right) \tag{3-11}$$

D_{pr} means that the wave energy dissipated due to the pile system energy compares to the total incoming wave energy (D_{pr} can also means the performance of the pile system $D_{pr} < 1,0$). Thus, D_{pr} depends on the total volume of the relative water resistance range of the pile system compared to the entire volume of water volume in a wave cycle. Also, when $R_c = 0$ then $D_{pr} > 0$ because a part of the wave still passes over the hollow submerged breakwater crest and is still dissipated the energy by the above pile system. From the above analysis, we have proposed parameters representing the relative resistance volume of the pile system as follows:

$$\widehat{V}_p = \frac{V_p}{V_w} = \frac{(R_c + H_{m0,i}).X_b}{H_{m0,i}.L_m} = \frac{R_c + H_{m0,i}}{H_{m0,i}}.\frac{X_b}{L_m} \tag{3-12}$$

where: $\widehat{V}_p$ is the relative wave resistance volume of the pile system; V_p and V_w are the volume of the resistance range of the pile system and the total volume of the water oscillating in a wave cycle.

Eq.(3-12) still preserves the dominant parameters of Eq.(3-11). Figure 3-15 shows the relationship between the relative resistance volume of the pile system and D_{pr}, hence it can be seen that, similar to the correlation analysis in the previous section, D_{pr} tends to increase as $\widehat{V}_p$ increases, i.e. when the relative inundation increases or the width of the pile system increases. When $\widehat{V}_p$ increases to a certain limit, D_{pr} does not increase anymore (above explained).

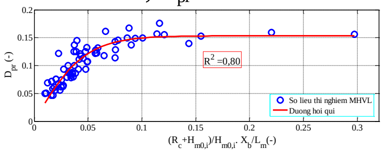


Figure 3-15. Experimental regression line $D_{pr} \sim \widehat{V}_p$ (with L_m).

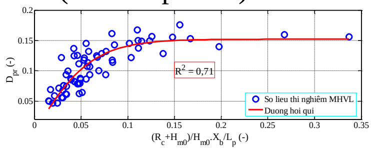


Figure 3-16. Experimental regression line $D_{pr} \sim \widehat{V}_p$ (with L_p).

Thus, this correlation exists with some boundary conditions as follows: there is the upper asymptote $D_{pr, max}$ and $D_{pr} = 0$ when there is no pile system ($X_b = 0$), and $D_{pr} > 0$ when $R_c = 0$. For these properties and a parameter describing performance ($D_{pr} < 1,0$), the function of tanh(x) (with x <1) is a suitable form of function.

Using the regression method with 100 experiments with the same wave conditions passing through the hollow submerged breakwater without pile and the complex hollow submerged breakwater (see Table 2-3), we develop the following regression line relation (see Figure 3-15), high relevance $R^2 = 0,80$.

$$D_{pr} = 0{,}153 \tanh\left[20{,}6\frac{(R_c + H_{m0,i})}{H_{m0,i}}.\frac{X_b}{L_m}\right] \qquad (3\text{-}13)$$

When using T_p instead of $T_{m-1,0}$ (L_p instead of L_m) in the calculation, the suitability with the obtained experimental data will be slightly lower with $R^2 = 0{,}71$ (see Figure 3-16).

$$D_{pr} = 0{,}152 \tanh\left[16{,}3\frac{(R_c + H_{m0,i})}{H_{m0,i}}.\frac{X_b}{L_p}\right] \qquad (3\text{-}14)$$

3.4. Wave transmission through a complex hollow breakwater (general case)

The wave energy balance equation when the works is an hollow submerged breakwater without piles:

$$E_{tot} = E_t^0 + E_d^0 + E_f^0 + E_r^0 \qquad (3\text{-}15)$$

When the works is a complex hollow breakwater:

$$E_{tot} = E_t^p + E_d^p + E_p^p + E_f^p + E_r^p \qquad (3\text{-}16)$$

where: E_t, E_d, E_p, E_f, and E_r are the energy of the waves behind the dyke, the energy dissipated by the breakwater body, by the pile system, friction and reflected wave energy, respectively. E_{tot} is the total wave energy (including the incident waves and the reflected waves from the works).

Assuming the same wave energy E_{tot}, the difference in the wave energy dissipated by the friction E_f and the breakwater body E_d is very small, i.e. $E_d^0 \sim E_d^p$ and $E_f^0 \sim E_f^p$. Then, from Eq.(3-15) and Eq.(3-16) can deduce:

$$(E_t^0 - E_t^p) + (E_r^0 - E_r^p) - E_p^p = 0 \qquad (3\text{-}17)$$

$$\frac{1}{8}\rho g(H_{rms,t}^{0^2} - H_{rms,t}^{p^2}) + \frac{1}{8}\rho g H_{rms,i}^2 (C_r^{0^2} - C_r^{p^2}) - \frac{D_p X_b}{c_g} = 0$$

where: C_r (^{0} và ^{p}) is the reflection coefficients in two cases of the works which are hollow submerged breakwater without piles and complex hollow breakwater, respectively.

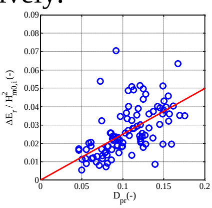


Figure 3-17. Relationship between the difference in the relative reflected wave energy and the energy dissipation due to the pile system D_{pr}.

Eq.(3-17) can be rewritten as the wave transmission coefficients ($K_t = H_{rms,t} / H_{rms,i}$) by dividing the two sides of this equation by the incoming wave energy $E = 1/8\rho g H_{rms,i}^2$ we have:

$$(K_t^{0^2} - K_t^{p^2}) + (C_r^{0^2} - C_r^{p^2}) - \frac{D_p X_b}{\frac{1}{8}\rho g H_{rms,i}^2 c_g} = 0 \tag{3-18}$$

Based on Eq.(3-18) with Eq.(3-10) we have:

$$(K_t^{0^2} - K_t^{p^2}) + (C_r^{0^2} - C_r^{p^2}) - D_{pr} = 0 \tag{3-19}$$

Note: $(E_r^0 - E_r^p)/E = (C_r^{0^2} - C_r^{p^2})$ is very small and positive proportion compared with the wave energy dissipated by the breakwater with a pile system - see Figure 3-17. Thus, differential effect in reflected wave can be considered indirectly through D_{pr} with a factor of model correction.

From Eq. (3-19), we can give a semi-empirical formula to determine the wave transmission coefficient of a complex hollow breakwater (hollow breakwater with piles above):

$$K_t = \sqrt{K_t^{0^2} - m.D_{pr}} \tag{3-20}$$

where: m is the model coefficient (m <1,0) corrected with the experimental data to take into account the effect of reflected waves and the deviations due to other assumptions stated in the process developing Eq. (3-20).

Note: K_t^0 is determined by Eq.(3-2) and D_{pr} is determined by Eq.(3-13) or Eq.(3-14). When the works is the hollow submerged breakwater without piles (ie D_{pr} = 0), then Eq.(3.20) will return to Eq.(3.2).

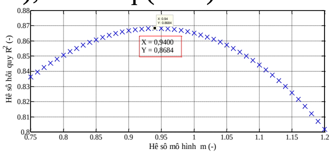


Figure 3-18. Correcting model coefficient m with experimental data.

Using Eq.(3-2), Eq.(3-13) and Eq.(3-20) with the set of experimental data for the case of the complex hollow breakwater to determine the model coefficient of m (160 experiments - see Table 2-3). The results in Figure 3-18 show that m = 0,94 gives the best match (R^2 = 0,87).

Figure 3-19 compares between K_t according to Eq. (3-20) with m = 0,94 and experimental data-set. The very good fit of the formula Eq.(3-20) with the set of experimental data confirmed the correctness of the method and assumptions made in the process developing formulation. Figure 3-20 shows the comparison of calculation results between the hollow submerged breakwater without piles and the complex hollow breakwater, a total of 260 tests (see Table 2-3).

Limitation of the application: $0 \le R_c/H_{m0,i} \le 2{,}459$; $0{,}713 \le B/H_{m0,i} \le 3{,}803$; $0{,}02 \le s_m \le 0{,}047$; $1{,}0 \le (R_c+H_{m0,i})/H_{m0,i} \le 3{,}459$; $0{,}01 \le X_b/L_m \le 0{,}087$; $0{,}012 \le X_b/L_p \le 0{,}118$; $0 \le R_c < H_{m0,i}$.

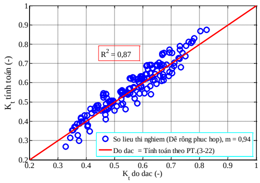


Figure 3-19. Comparing K_t with experimental data of a complex hollow breakwater (m = 0,94).

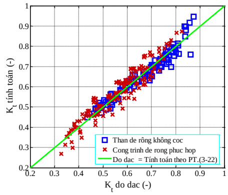


Figure 3-20. Comparing K_t with all experimental data (≈ 260 physical experiments).

3.5. Applying the results of research for designing experimental works

Application of research results to calculate and select basic technical parameters of hollow complex breakwater is used for the purpose of planting mangroves in Kenh Moi sluice gate, Khanh Hai commune, Tran Van Thoi district, Ca Mau province (National project, code ĐTĐL.CN-09/17).

Table 3-1. The summary of project design parameters

Parameters for designing works	Sign	Unit	Value
Design wave height	$H_{m0,i}$	m	1,01
Design wave period	$T_{m-1.0}$	s	5,59
Design average water level	Z_{MLS}	m	+ 0,06
The crest elevation of the breakwater	$Z_{breakwater}$	m	+ 0,06
Pile diameter	Ø	m	0,30

Replacing the design parameters in Table 3-1 into Eq.(3-2), Eq.(3-13), Eq.(3-20). We can determine the wave height ($H_{m0,t}$) as follows:

Table 3-2. Calculating the wave heights behind the works ($H_{m0,\,t}$)

The parameters	Complex hollow breakwater (B ~ n_c)			
	1,68m ~ 2	**2,28m ~ 3**	2,88m ~ 4	3,48m ~ 5
K_t (-)	0,449	**0,373**	0,316	0,273
$H_{m0,i}$ (m)	1,010	**1,010**	1,010	1,010
$H_{m0,t}$ (m)	0,453	**0,377**	0,319	0,275

According to the standards of Vietnam 10405: 2014 "Hydraulics works - Breakwater belts - Survey and Design" in Appendix E stipulates that under normal conditions, waves in mangrove planting area is lower than $H_{m0,t}$ < 0,40m. Hence, it is appropriate to choose a complex hollow breakwater with three rows of round pillars above it.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

(1) The study proposes a solution for a complex hollow breakwater with a new structure, flexibly assembled by precast concrete structures suitable for protecting

mangrove mud beaches from Ca Mau Cape to Ha Tien eroded in the Mekong Delta; (2) The study develops a semi-experimental formula of the general form to calculate and determine the wave transmission coefficient of the works associated with the natural conditions of the West Sea in order to be able to effectively apply this structural solution in the function of protecting coastal shorelines and mangrove.

2. Recommendations

(1) Adding new contributions of the dissertation to the reference documents guiding the design of the breakwaters in our country and the instruction materials for students; (2) Continuing to study and evaluate the wave attenuating function of the complex hollow breakwater using piles with non-circular cross-section (triangle, square, rectangular,...) and the arrangement of the pile system according to the other rules; (3) Studying to evaluate the sedimentation efficiency of the complex hollow breakwater.

THE LIST OF PUBLICATION

1. **Nguyen Anh Tien**, Thieu Quang Tuan (2019), "Wave damping efficiency of porous piled dikes on a mangrove foreshore", *Proceedings of the 10th International Conference on Asian and Pacific Coasts (APAC 2019), September 25-28, 2019, Hanoi, Vietnam*, pp.863-868.

2. **Nguyen Anh Tien** (2019), "To study impact level of dominate parameters and propose estimate methodology for wave transmission efficiency of unconventional complex pile submerged breakwater", *Vietnam Journal of Marine Science and Technology*, Volume 19, Issue 4 (2019), pp.611-625.

3. **Nguyen Anh Tien** (2019), "Propose semi-empirical equation to estimate wave transmission coefficient via complex submerged breakwater (A case study for Ca Mau and Ha Tien coastal zone", *Science and Technology Journal of Agriculture and Rural Development*, Vol. 3 + 4 (February 2019), pp.194-202.

4. Le Duc Vinh, **Nguyen Anh Tien**, Lieou Kien Chinh (2018), "Study on sea wave regime from Ca Mau cape to Kien Giang", *Journal of Water Resources Science and Technology*, No. 47 (9-2018), pp.72-86.

5. **Nguyen Anh Tien**, Trinh Cong Dan, Thieu Quang Tuan, To Van Thanh (2018), "Scientific basis for developing a method of calculating wave transmission through a complex pile submerged breakwater", *Journal of Water Resources Science and Technology*, No. 46 (8-2018), pp.81-87.

6. **Nguyen Anh Tien**, Trinh Cong Dan, Lai Phuoc Qui, Thieu Quang Tuan (2018), "Study on developing a method to calculate wave transmission coefficient through hollow submerged breakwater using physical models", *Journal of Water Resources Science and Technology*, No. 46 (08-2018), pp.24-34.