SYSTEM PERFORMANCE OF A COMPOSITE STEPPED-SLOPE FLOATING BREAKWATER

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To my friends, teachers, lecturers and professors, who patiently share their ideas, knowledge and skills with me all these years; and

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ABSTRACT

With the increasing demand for multi-purpose use of coastal sea areas in recent years, the composite stepped-slope floating breakwater system (STEPFLOAT) has been designed and developed as an alternative engineering solution, mainly for shore protection and coastal shelter to pioneer the floating breakwater technology in Malaysia. The unique stepped-slope and multiple sharp-edge features of the STEPFLOAT serve to intercept waves by dissipating (rather than reflecting) the wave energy through the formation of wave breaking, turbulence and eddies around the polyhedron as the waves impinge on the surface of the structure. Laboratory experiments were conducted to study the performance of the STEPFLOAT as a wave attenuator under unidirectional monochromatic wave only environment on various system arrangements, i.e. 2-row, 3-row, G = b and G = 2b systems. A suggested mooring method using vertical piles as a modification to the classical mooring system using chains or cables is applied to the STEPFLOAT system to overcome the problem of roll and sway motions. Additional tests on the 2-row chain-moored STEPFLOAT were also conducted to allow comparisons with the fundamental design of the SSFBW system as well as the pile-supported STEPFLOAT. Experiments on restrained case for 2-row and 3-row systems were performed to evaluate the effect of heave and limited roll motions of the floating body on wave attenuation. For the present study, a simple conventional method is applied to decompose the co-existing composite wave record in front of the model into the incident and reflected waves. Transmitted wave heights were measured at the lee side of the model. Measured transmission coefficient (C_t), reflection coefficient (C_r) and loss coefficient (C_l) were related to the non-dimensional structural geometric parameters, i.e. relative width (*B/L*), relative draft (*D/L*) and relative pontoon spacing (*G/L*), and hydraulic parameters, i.e. wave steepness (*H/L*) and relative depth (*d/L*). Two new non-dimensional composite parameters, i.e. *BD* number and *BDG* number were introduced and examined. Experimental results for C_t are presented and compared to the results of previous studies of various floating breakwater designs done by other researchers. Empirical equations for predicting the transmission coefficient are developed for each tested system using Multiple Linear Regression Analysis. The STEPFLOAT, with relatively smaller structure width, generally has excellent wave attenuation ability over most of the previous floating breakwaters. The experimental results showed that the composite pile-supported STEPFLOAT with 3-row, G = b and G = 2b arrangements are capable to attenuate waves up to 80% of the incident wave height for wave period of less than 1.33 seconds.

ABSTRAK

Berikutan dengan peningkatan permintaan terhadap penggunaan kawasan pantai sejak kebelakangan ini, sistem pemecah ombak terapung komposit bercerun tingkat (STEPFLOAT) telah direkabentuk dan dibangunkan sebagai satu penyelesaian kejuruteraan alternatif, khasnya untuk kawalan dan perlindungan pantai bagi merintis teknologi pemecah ombak terapung di Malaysia. Bentuk STEPFLOAT yang bercerun tingkat dan berbucu tajam berfungsi untuk memintas ombak dengan mengurangkan tenaganya melalui pembentukan pemecahan ombak, gelora dan eddi di sekitar struktur polihedron tersebut apabila ombak bertindak pada permukaannya. Ujikaji makmal telah dijalankan dalam keadaan ombak seragam sehala bagi pelbagai penyusunan sistem, iaitu sistem 2-baris, 3-baris, G = b dan G = 2b bagi menilai prestasi STEPFLOAT sebagai struktur pelemah ombak. Penggunaan cerucuk menegak sebagai pengubahsuaian kepada sistem tambatan secara tradisional yang menggunakan rantai atau kabel telah diaplikasikan dalam sistem STEPFLOAT bagi mengatasi masalah gerakan oleng dan huyung. Ujikaji tambahan terhadap STEPFLOAT berbaris dua yang ditambat oleh rantai juga dilakukan untuk perbandingan dengan sistem SSFBW dan STEPFLOAT yang ditambat oleh cerucuk. Eksperimen untuk kes terhalang bagi sistem 2-baris dan 3-baris telah dilaksanakan bagi menilai kesan gerakan lambung dan oleng yang terhad pada struktur terapung tersebut terhadap pelemahan ombak. Kaedah konvensional telah digunakan dalam kajian ini bagi menguraikan rekod ombak komposit kepada ombak tuju dan ombak pantulan. Tinggi ombak terhantar diukur di belakang model. Pekali penghantaran ombak (C_t), pekali pantulan (C_r) dan pekali kehilangan (C_l) dikaitkan dengan parameter-parameter tanpa dimensi geometri struktur, iaitu lebar relatif (B/L), draf relatif (D/L) dan sela relatif (G/L), dan parameter-parameter hidraulik, iaitu kecuraman ombak (H/L) dan kedalaman relatif (d/L). Dua parameter komposit tanpa dimensi baru, iaitu nombor *BD* dan nombor *BDG* telah diperkenalkan dan diperiksa. Keputusan ujikaji bagi C_t telah dibandingkan dengan hasil keputusan daripada pelbagai rekabentuk pemecah ombak terapung yang lain. Persamaan empirikal bagi meramal pekali penghantaran ombak telah dihasilkan bagi setiap sistem yang dikaji dengan menggunakan Analisis Regresi Linear Berbilang. STEPFLOAT dengan lebar struktur yang lebih pendek secara relatif mempunyai keupayaan pelemahan ombak yang lebih baik berbanding dengan kebanyakan pemecah ombak yang lain. Keputusan ujikaji menunjukkan bahawa sistem komposit STEPFLOAT bertambatan cerucuk dengan susunan 3-baris, G = b dan G = 2b berupaya mengurangkan tinggi ombak sehingga 80% daripada tinggi ombak tuju bagi kala ombak kurang daripada 1.33 saat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND NOTATIONS

List of Abbreviations

ANOVA	-	analysis of variance
ASCE	-	American Society of Civil Engineers
CEM	-	Coastal Engineering Manual
COEI	-	Coastal and Offshore Engineering Institute
DC	-	direct current
EPDM	-	*ethylene-propylene diene monomer*
ERDC	-	U.S. Army Engineer Research and Development Center
GDP	-	gross domestic product
HDPE	-	*high-density polyethylene*
i.e.	-	that is (Latin *id est*)
LCD	-	liquid crystal display
MLT	-	mass-length-time system
MPTT	-	modified power transmission theory
PDH	-	principle of dimensional homogeneity
PPD	-	*Pusat Pengajian Diploma*
PTT	-	power transmission theory
PVC	-	*polyvinyl chloride*
RIBS	-	Rapidly Installed Breakwater System
RM	-	Malaysian Ringgit
SBR	-	styrene-butadiene rubber

SS	-	sea state
SSFBW	-	Stepped-Slope Floating Breakwater (fundamental design)
STEPFLOAT	-	Stepped-Slope Floating Breakwater (improved design)
SWL	-	still-water level
UTM	-	*Universiti Teknologi Malaysia*
VIF	-	variance inflation factor
WAMIT	-	Wave Analysis MIT (numerical program developed by the Massachusetts Institute of Technology)

List of Notations

a	-	wave amplitude
a_0, a_1, a_2	-	regression coefficients for the second order polynomial trend line
b	-	characteristic breakwater pontoon size or dimension
b, c	-	constants for the exponential trend line
B	-	unstandardized coefficient for independent variable
B	-	breakwater width
B_f	-	wave flume width
B_i	-	partial regression coefficient [i = 1, 2, 3, …]
B_o	-	regression constant
B/L	-	relative width
BD/dL	-	BD number = $\left(\frac{B}{L}\right)\left(\frac{D}{L}\right)\left(\frac{L}{d}\right)$
BDG/dL^2	-	BDG number = $\left(\frac{B}{L}\right)\left(\frac{D}{L}\right)\left(\frac{G}{L}\right)\left(\frac{L}{d}\right)$
C	-	wave celerity
C_l	-	loss coefficient
C_r	-	reflection coefficient

C_t	-	transmission coefficient
$[C_t]_{\text{red}}$	-	percentage of C_t reduction
d	-	water depth
D	-	draft or depth of submergence
d/L or d/gT^2	-	relative water depth
D/L	-	relative draft
E_i	-	incident wave energy
E_l	-	dissipated wave energy or energy loss
E_r	-	reflected wave energy
E_t	-	transmitted wave energy
f	-	frequency or a mathematical function
F	-	F ratio (= regression mean square/residual mean square)
g	-	gravitational acceleration = 9.81 m/s^2
G	-	gap between modules or pontoon spacing
G/L	-	relative gap or indicative of gap size to wave length ratio or relative pontoon spacing
H	-	wave height
H_1	-	wave height at $x_p = 0$
H_2	-	wave height after travelling a distance, x_p
H_i	-	incident wave height
H_i/gT^2	-	wave steepness parameter
H_i/L or H/L	-	wave steepness
H_o	-	deep water wave height
H_r	-	reflected wave height
H_t	-	transmitted wave height
k	-	number of fundamental dimensions
k	-	wave number ($=\frac{2\pi}{L}=\frac{2\pi}{CT}$)
L	-	wave length
L_o	-	deep water wave length
n	-	number of dimensional variables

n.a.	-	not available
R	-	correlation coefficient
R^2	-	square of the correlation coefficient
t	-	time
T	-	wave period
T_{model}	-	wave period of model
$T_{prototype}$	-	wave period of prototype
W	-	breakwater width
W/L	-	relative width
x	-	horizontal distance or dummy variable representing independent non-dimensional variable
x_p	-	horizontal distance in wave flume
$\Delta C_{t\,[2\text{-}3]}$	-	difference of C_t between 2-row and 3-row STEPFLOAT systems [$= C_{t\,\text{2-row}} - C_{t\,\text{3-row}}$]
$\Delta C_{t\,[3\text{-}b]}$	-	difference of C_t between 3-row and G = b STEPFLOAT systems [$= C_{t\,\text{3-row}} - C_{t\,G=b}$]
$\Delta C_{t\,[0\text{-}b]}$	-	difference of C_t between G = 0 (or 2-row) and G = b STEPFLOAT systems [$= C_{t\,G=0} - C_{t\,G=b}$]
$\Delta C_{t\,[2b\text{-}b]}$	-	difference of C_t between G = 2b and G = b STEPFLOAT systems [$= C_{t\,G=2b} - C_{t\,G=b}$]
ε	-	phase lag induced by reflection process
η	-	displacement of the water surface relative to the SWL
η_t	-	total wave surface profile
θ	-	direction of wave advance ($=\frac{2\pi x}{L} - \frac{2\pi t}{T}$)
ν	-	fluid kinematic viscosity
ρ	-	fluid density
ρ_s	-	density of structure
ω or σ	-	wave angular or radian frequency ($=\frac{2\pi}{T}$)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Many citizens from maritime nations have settled close along the coast in order to make a living, engage in trade and access communication links. The coast provides a source of food and income through fishing activities and recently has provided areas for recreation. Malaysia and most of the countries in Southeast Asia region are not seen as countries of extremes, either extremes of climate or extremes of natural events. Hence, it sometimes escapes attention and awareness that a large proportion of these countries' population are exposed to wave disturbance and threatened by coastal erosion. Coastal problems have caused a significant impact on the economy of many countries. As a result, it is unavoidable that the government and local shore property owners need to contend with these problems by implementing some programmes of investment in shore protection and coastal shelter to reduce the risk of loss of life and property.

Most sites for small craft harbours, marinas and coastal aquaculture facilities will be found to need some form of perimeter protection. The physical conditions of a proposed site may be relatively calm for most of the time due to natural protection. However, the wave climate of the site could be moderately rough under storm conditions due to the arrival of far field waves and eventually significant protection may be required. Competent coastal shelter and shore protection may take the form of stone barriers, wave screens or vertical barriers, which are either solid or semipermeable such as floating breakwaters.

Breakwaters, either fixed or floating, are structures constructed to protect the shoreline, other coastal structures, marinas, etc. by reflecting and/or dissipating the incident wave energy and thus reduce wave action in the leeside of the breakwater system. Permanently fixed breakwaters provide a higher degree of protection than floating breakwaters. However, a fixed breakwater may not be competitive cost wise with a floating breakwater in relatively deeper water depths and it may also cause a lot of detrimental effects to the environment.

Increasing construction costs and environmental constraints encourage alternative considerations to the traditional fixed breakwaters for coastal shelter and shore protection. Floating breakwaters have later gained wide attention and subsequently appeared to be a good choice for wave suppression during most weather conditions. They are considered as cost-effective and environmentally-friendly substitutes for the conventional type of breakwaters for the perimeter protection. In recent years, many research institutions such as Indian Institute of Technology Madras, U.S. Army Engineer Research and Development Center, The University of Auckland, State University of New York, Sharif University of Technology, University of New Hampshire, Australian Water and Coastal Studies Pty. Ltd., University of Wuppertal and Suez Canal University, have been involved with the design and development of floating breakwaters for application within semi-protected coastal areas from high energy wave condition.

1.2 Background of the Problem

The energetic power of water waves are often difficult to deal with and it has been the most challenging aspect for coastal engineers. Many coastlines of the world are facing the need for beach stabilization out of the effects of beach erosion. Coastal erosion has become a more significant environmental issue nowadays as it poses threats to many lives, valuable resources and properties, as well as commercial activities in coastal areas. Human lives, sandy beaches, tourism and industrial development, infrastructure, agriculture, aquaculture, residential and mangroves are among the examples of the sacrifices of the destructive wave attack.

The increase in the number of private pleasure crafts and small commercial vessels has generated a demand for convenient and accessible sheltered mooring. Many naturally protected or semi-sheltered waters along coastlines in established population centers have been developed to accommodate the influx of vessels. As a result, artificial man-made structures will be required to provide perimeter protection from incident waves where nature offers little or no protection.

It is for these reasons that breakwaters of various dimensions and designs have been widely employed in locations exposed to wave attack. The purpose of installing a breakwater is to reduce the incident wave heights to a level commensurate with the intended use of the site in the leeside of the structure. Cost-effective design and the required degree of wave protection will dictate possible breakwater alternatives.

The rubble mound breakwater offers advantages in the form of excellent perimeter protection. It provides a high degree of wave protection and has been widely used to attenuate surface water waves. The breakwater is a fixed gravity structure constructed of organized pile of graded rocks with a sloped surface, a broad base and a narrow top or crest, consisting of stones which are large enough to prevent or limit movement under most wave conditions. Nevertheless, there are many sites in marine setting where the traditional fixed breakwater is not suitable. Construction of fixed breakwaters are often more expensive in deeper water depth. Poor foundation condition is another disadvantage of the application of this fixed structure.

An additional negative aspect is that such a structure will not allow the transport of sediment along the shoreline. It creates unacceptable sedimentation and water quality problems due to poor water circulation behind the structure. The base of the fixed breakwater will lead to the bottom loss for plant and animal habitat. As it is a permanent fixed structure, a rubble mound breakwater must be high enough to provide reasonable protection under most storm flood level conditions. If it were to be built at a lower level, its effectiveness could be severely reduced.

In recent years, coastal engineers become more environmentally conscious. Coastal engineering projects often have a significant effect on natural ecosystems and the ensuing environmental damage may make things worse for future generations. In seeking to revolutionize towards softer engineering solutions by encouraging the provision of technically, environmentally and economically sound and sustainable perimeter protection measures, a move towards schemes designed to work with nature rather than against it has begun to emerge. Floating breakwater has later appeared to be a cost-effective substitute for the conventional type of breakwaters in providing the required level of protection while working with the power and resources of nature.

The demand made the concept of the first locally designed floating breakwater technology possible. In 2002, Teh (2002) has completed his study on wave dampening characteristics of the fundamental design of a stepped-slope floating breakwater, namely

SSFBW. Foreseeing the potential of the stepped-slope floating breakwater system to be commercialized in the market for the benefit of communities, an improved cost-effective and practical design to suit the local needs is necessary in order to put forward the system into the industry. Therefore, the present study is carried out as a continuation of the work done by Teh (2002).

1.3 Statement of the Problem

There has been quite a number of floating breakwaters available in the market but until the present invention of the STEPFLOAT breakwater, there is no truly outstanding solution that has been put forward into the local maritime industry. While attention was given to the preservation and conservation of natural environment, most floating breakwaters which utilized the concept of wave reflection in their designs, have neglected the safety of moving vessels in the vicinity of the floating breakwater system. Therefore, there arises a need for an economical and environmentally-friendly yet viable floating breakwater that has an acceptably high efficiency in dissipating wave energy, instead of reflecting it, to provide the required level of tranquility in areas it desires to protect. As a result, the first locally designed floating breakwater technology has been developed. However, the fundamental design of the SSFBW was still in the stage of infancy. Practical requirements such as manufacturing problem, jointing system, mooring method, material and economics as well as the viability of the system need to be considered and incorporated into the improved design of the STEPFLOAT. Thus far, modifications to the fundamental design of the SSFBW system as well as the mooring method are required not only to enhance the efficiency of the floating breakwater system, but also to improve the practicability of the system.

1.4 Objectives of the Study

1. The primary objective of this research is to evaluate and predict the wave attenuation efficiency of the improved design of a composite stepped-slope floating breakwater system, i.e. STEPFLOAT, as a wave attenuator.

2. It is also intended to assess the wave reduction capabilities and the stability of the structure on several system arrangements (i.e. 2-row, 3-row, G = b and G = 2b systems) and on three types of mooring systems. Analyses of wave-structure interaction based on measured laboratory data also need to be performed in order to allow comparisons of results among the STEPFLOAT breakwater model with different system arrangements and mooring methods.

3. Also, it is the goal of this study to develop empirical model for each system arrangement in the form of functional relationship of various dimensionless parameters of breakwater geometry and wave conditions, to predict the performance of the STEPFLOAT breakwater system.

1.5 Scope of the Study

The scope of work throughout the study is orderly stated as follows:

1. Literature review based on various sources of references such as theses, technical papers, technical reports, books, patents, articles, etc has been conducted to provide sufficient knowledge and understanding on wave attenuation concepts, wave protection systems, laboratory and field studies for the design and investigations on the performance of a floating breakwater system.

2. A review of the previous design of the SSFBW system and the mooring method in order to produce modifications and improved design of the STEPFLOAT system has been carried out.
3. Planning and design of appropriate and suitable research methodology to conduct the laboratory experiments.
4. Fabrication of the STEPFLOAT model and the construction of the composite STEPFLOAT system with an assembly of several modules connected to one another by a stainless steel bolt-and-nut system. This part of the study was conducted in collaboration with the industry, i.e. SEGINIAGA Rubber Industries Sdn. Bhd.
5. Design and building of the vertical piling system with aluminium rods, steel pipes and U-shape steel bars.
6. Setting up of the equipment and apparatus as well as setting up the model of the floating breakwater system in the laboratory.
7. A series of laboratory tests on the STEPFLOAT with different mooring systems and various system arrangements under wave only condition was conducted.
8. Experimental data on wave reduction capabilities, the physical mechanism of the wave-structure interaction and stability of the structure, were observed, recorded and systematically documented.
9. Dimensional analysis and parametric analysis were performed. Measured laboratory data was further analyzed using Multiple Linear Regression Method to yield empirical wave-structure relationships for pile-supported STEPFLOAT to predict the performance of the floating breakwater system.
10. Assessment and comparisons of results of the STEPFLOAT with the previous study on the SSFBW design as well as studies on other floating breakwaters done by other researchers.

1.6 Significance of the Study

1.6.1 An Alternative Engineering Solution for Shore Protection and Coastal Shelter

The STEPFLOAT system may provide an alternative solution for coastal protection with a functional cost-effective engineering design while protecting and enhancing the environment. The amount of money spent on imported technologies and products or conventional breakwater construction for coastal protection would therefore be greatly minimized. Long-term dependence on costly imported technologies would be an impractical solution and it is not worthwhile. Therefore, a locally designed floating breakwater system would be an alternative engineering solution to minimize the unnecessary loss to the country's resources.

1.6.2 Multi-Purpose Breakwater Facility

The design and development of the multi-purpose STEPFLOAT breakwater system would eventually benefit the communities, especially those shore property owners or citizens who reside near the coastal area, as the STEPFLOAT system has multi-purpose functions such as wave attenuator, walkway platform and encourage marine habitats. Other advantages that can be provided by the STEPFLOAT system as a multi-purpose breakwater facility will be further discussed in Chapter III.

1.6.3 An Impetus for Future Research and Development (R & D)

The rubble mound breakwater has found frequent application in Malaysia's coastal water due to its durability and the high degree of wave protection. Even though it has been proven as an effective wave attenuation structure, the rubble mound breakwater is limited to its potential application in certain regions and it causes environmental degradation. It is for these reasons that floating breakwater designs are of interest for perimeter protection. The STEPFLOAT system is the first floating breakwater technology designed locally. Its promising results with good wave attenuation capability have gained momentum for further research and development. It is believed that this potential floating breakwater system would be the impetus for continuing future research and development in Malaysia in this particular engineering design and other coastal and marine engineering aspects, especially technologies for shore protection and coastal shelter.

1.6.4 References and Guidelines for Future Research Development

Laboratory experiments have been carried out to gather some information about the performance of the new design and improved floating breakwater system to provide data and information for the preliminary design of the prototype-scale field version of the STEPFLOAT system. Results and findings as well as empirical models from the laboratory investigations in the present study could be very useful information, references and guidelines for future research development by other researchers, who attempt to investigate this particular field of study.

1.6.5 Great Potential for Commercialization

The present study on STEPFLOAT system aims to assess the performance of the improved floating breakwater system design and does not involve any commercial interest. However, the success of this study, with encouraging results and findings on the performance of the system, would determine the potential of the STEPFLOAT system to be commercialized in the market in future. An increasing demand for mooring in coastal water in Malaysia and simultaneous shortage of suitable construction sites that are naturally sheltered from wave action generate a need for artificial cost-effective perimeter protection devices. Keizrul Abdullah (2005) reported that Malaysia with an extensive coastline of 4809 km has a total eroding coastline of 1372 km. Coastal erosion and wave attack on other coastal facilities for aquaculture activities, leisure purposes, etc. have also fostered the development of the environmentally-friendly floating breakwater system to ameliorate the risk of livelihood and properties of the coastal communities. It is believed that for these reasons, the potential use of floating breakwaters in Malaysia and perhaps in South East Asia countries would boom a vast popular demand for perimeter protection from the more traditional harder defences to solutions that we now term as “soft engineering”.

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Floating breakwaters are usually made of HDPE, recycled plastic, or rejects without sand content resulting in the following (Ibrahim, 2006): â€¢ The zero percent sand content rejects float over water and have a very low absorption rate compared to other mixing ratios, 67% less than the following absorption rate of the 30% sand mix. â€¢ The density of the zero percent sand content rejects is higher than the HDPE by 2%. â€¢ The zero percent MSW reject mix is less stiff by 59% thus reacting better to sudden loads.Â Accordingly, usage of rejects with zero percent sand mix in the production of a floating breakwater is recommended. However, foam injection could be investigated and might be utilized due to its superior properties for floating breakwater. Read full chapter.