PERFORMANCE OF PERFORATED PILES AS A WAVE ATTENUATOR

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ABSTRACT

Laboratory experiments on wave transmission through various types of piles with different perforations were conducted at the Coastal and Offshore Engineering Institute (COEI), Universiti Teknologi Malaysia *City Campus*, Kuala Lumpur. The study involved carrying out laboratory experiments on perforated pile models under unidirectional regular waves in a partially submerged set-up with water depth h = 0.19 m to 0.23 m; and under fully submerged set-ups at h = 0.27 m to 0.35 m. The experiments were conducted to study the performance of the one-row pile models as a wave attenuator using various pile types that are, Single Ring (SP), Double Ring (DP) and Single Small Ring Pile (SSP). Additional tests on two-row SP and DP models; and three-row DP models were also conducted to allow comparisons to be made with the one-row SP and DP models. The pile porosity used in this study was in the range of 0.0625 to 0.48. The effect of closely spaced pile of model spacing B = 0 was investigated and compared with piles arrangement with B = 0.5D and 0.75D. For the present study, the estimation of incident wave height H_i and reflected wave height H_r were obtained by using the Mansard and Funke (1980) equation. Two groups of wave gauges were used to measure the incident, reflected and transmitted waves. The first group, which consisted of three wave gauges positioned in front of the test model was to measure the incident and reflected waves, whilst the second group of two wave gauges positioned at the lee side of the model measured the transmitted waves. Analysis of transmission coefficient K_t and loss coefficient K_l were related to the non-dimensional structural geometric parameters that is, wave steepness (H_i/L), relative depth (h/L), porosity (ε), relative spacing of model (B/L) and relative width of model (W/L). Comparison of experimental results of K_t and K_l between the three types of pile models, SP, DP and SSP are presented. The DP model was found to give better wave attenuation compared to the SP and SSP models. Subsequently, experimental results of wave transmission coefficient K_t for two-row DP model (ε = 0.0625 and 0.48) are presented and compared to the results of previous studies by other researchers. Empirical equations for predicting the transmission coefficient have been developed for the one-row, two-row DP models with and without spacing, by using Multiple Regression Analysis. The experimental results showed that the two-row DP model under fully submerged condition with B = 0.5D and B = 0.75D were better able to attenuate waves up to 25% when T = 0.87 s to 1.03 s as compared to when T>1.03 s, where only 4% of wave is attenuated.

ABSTRAK

Kajian makmal bagi menentu kebolehupayaan beberapa jenis cerucuk berlainan jenis liang dalam penghantaran gelombang telah dilakukan di Institut Kejuruteraan Pantai dan Lepas Pantai (IKPLP), Universiti Teknologi Malaysia *City Campus*, Kuala Lumpur. Kajian tersebut melibatkan ujikaji makmal terhadap model cerucuk berliang yang ditindaki gelombang satu haluan dalam dua keadaan iaitu keadaan separa tenggelam pada kedalaman air, h = 0.19 m ke 0.23 m; dan dalam keadaan tenggelam pada h = 0.27 m to 0.35 m. Kajian makmal dilakukan bagi menguji kebolehupayaan satu baris model cerucuk melemahkan gelombang dengan menggunakan beberapa jenis cerucuk berliang iaitu 'Single Ring' (SP), 'Double Ring' (DP) dan 'Single Small Ring' (SSP). Kajian lanjutan terhadap dua baris model SP dan DP serta tiga baris DP dilakukan untuk tujuan perbandingan dengan model satu baris SP dan DP. Keliangan cerucuk yang digunakan di dalam kajian ini adalah dalam lingkungan 0.0625 ke 0.48. Kesan terhadap jarak susunatur di antara dua baris model pada jarak B = 0 juga dikaji dan dibandingkan dengan cerucuk yang diatur pada jarak B = 0.5D dan 0.75D. Untuk kajian ini, perangkaan bagi ketinggian gelombang permulaan H_i dan ketinggian gelombang pantulan H_r boleh didapati dengan menggunakan persamaan yang diperolehi melalui kajian yang dilakukan oleh Mansard and Funke (1980). Dua kumpulan tolok gelombang telah digunakan untuk mencerap gelombang permulaan, pantulan dan terhantar. Kumpulan tolok gelombang pertama yang terdiri daripada tiga buah tolok diletakkan berhadapan dengan model untuk mencerap gelombang permulaan dan gelombang pantulan. Manakala kumpulan kedua yang terdiri daripada dua buah tolok gelombang diletakkan di bahagian belakang model untuk mencerap gelombang terhantar. Analisa pekali gelombang terhantar K_t dan pekali tenaga gelombang yang hilang K_l ada hubungkait dengan parameter struktur geometri tak berdimensi iaitu, kecerunan gelombang (H_i/L), kedalaman relatif model (h/L), keliangan cerucuk (ε), jarak relatif antara baris model (B/L) dan kelebaran relatif model (W/L). Perbandingan keputusan ujian makmal K_t dan K_l di antara tiga jenis model, SP, DP dan SSP juga dipaparkan. Model DP didapati lebih berupaya melemahkan gelombang berbanding model SP dan SSP. Selain daripada itu, keputusan kajian pekali terhantar gelombang K_t untuk model dua baris (ε = 0.0625 dan 0.48) dipapar dan dibandingkan dengan keputusan kajian yang dilakukan oleh pengkaji-pengkaji terdahulu. Persamaan empirikal untuk meramal pekali terhantar gelombang telah diorak untuk model-model DP sebaris dan dua baris; di dalam keadaan susunan rapat dan berjarak dengan menggunakan Analisa Regrasi Berganda. Daripada keputusan ujikaji makmal ketika dalam keadaan tenggelam, model dua baris DP dengan jarak B = 0.5D dan B= 0.75D lebih berupaya untuk melemahkan gelombang sebanyak 25% apabila kala gelombang diantara T = 0.87 s ke 1.03 s berbanding hanya 4% gelombang terlemah apabila T > 1.03 s.

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CHAPTER 1

INTRODUCTION

1.1 General

The shore is defined as a narrow strip of land in immediate contact with the sea, whilst, the shoreline is the intersection of a specified plane of water with the shore (U.S. Army Corps Engineers, 2002). Factors such as global climate changes that cause sea level changes, storm surges or tsunamis could trigger changes to a shoreline that is not protected. Also, waves especially are the element in determining the geometry and composition of beaches. These waves, in combination with currents, tides and storm surges, are the main cause of coastal erosion problems; therefore, they significantly influence the planning and design of shore protection measures, coastal structures and waterways. The selection of structures to be used to protect the shoreline would depend on the wave characteristics and the morphology of the coastal region. Sheltering the harbour basins and harbour entrances against waves require the deployment of breakwaters.

Breakwaters can be defined as fixed or floating structures that protect a shore area or harbour. These structures are used to dissipate the energy of water waves, thereby reducing the wave impact on the area they protect.

Fixed breakwaters can be installed shore-connected or detached. The setting up can be submerged or emerged and the position can be alongshore or oblique. Studies have shown that the performance of fixed breakwaters in wave dampening is generally more encouraging than floating breakwaters. It is also found that the fixed submerged breakwaters can even suppress the incoming short waves completely. A study carried out by Williams and McDougal (1996) reveals that floating breakwater is a good alternative to conventional fixed breakwaters. But, fixed breakwaters are more recommended than floating breakwaters. Fixed breakwaters are able to sufficiently create the needed calm water.

Submerged fixed type breakwaters can either be man-made or in natural form, represented by bars or reefs. They become the greatest offshore defense, providing coastal regions with protection from hazardous wave attack (Pilarczyk, 2003). Further advantages of submerged breakwaters will be discussed in detail in the following section.

1.2 Background of the Problem

One of the primary concerns when constructing harbours and marinas is on reducing wave energy entering the sheltered area, whilst maintaining water circulation within the harbour. Conventional rubblemound breakwaters and berm breakwaters are commonly adopted to create sheltered coastal areas. These kinds of breakwaters are simply a large volume of rock materials that are piled up and protrude above the water surface. They are often constructed with trapezoidal cross-section, having various slope angles on both seaward and the shoreward sides. These arrangements are able to minimize the wave transmission and wave overtopping.

Even though rubblemound breakwaters function to reduce the wave transmission due to the energy lost in the voids of the structure, they have a very large footprint and can be very expensive. These drawbacks will be dramatically increased if the depth of water increases. The size of footprint is especially problematic in environmentally sensitive regions. Due to their impermeable nature, these breakwaters can also reduce water circulation, hence, deteriorating the water quality within the coastal areas. Rubblemound breakwater can also be aesthetically unappealing. Two other factors that inhibit the application of rubblemound breakwater as described by Black and Mead (2000) are the high construction costs and difficulties of predicting beach response.

In contrast with the rubblemound breakwaters, fixed submerged breakwaters are becoming more widely used due to their smaller size of footprint and better aesthetical values with low environmental impact (Black and Mead, 2000). Furthermore, to achieve perfect water tranquility conditions, large structures such as rubblemound breakwaters may not be the right choice (Pilarczyk, 2003). In this situation of controlling wave disturbances in partially enclosed water bodies, submerged permeable breakwaters are preferred (Rao *et al*, 1999).

1.3 Problem Statement

Without protection structures, the coastal areas would be exposed to problems due to unpredictable wave turbulence as a result of climate changes, in combination with currents, tides and storm surges. Various coastal structures such as breakwaters, seawalls and dikes are normally adopted to provide the necessary protection. However, with the need to take into account the environmental aspects in all coastal protection structures design, the construction of low crested or submerged structures are becoming more commonly practiced as coastal protection measures (Black and Mead, 2000)

Among the submerged type of breakwaters, many researchers have considered perforated pile breakwaters as the recommended solution to coastal engineering problems. These pile breakwaters are likely to be more economical and advantageous compared to other types of conventional breakwaters (Hutchinson and Raudkivi, 1984 and Rao *et al*, 1999). One of the advantages of the pile breakwaters is minimal interference with littoral drift. Moreover, wave energy dissipation taking place in pile breakwaters are further reduced by providing perforations on the surface of the cylinders when used as piles (Rao *et al*, 1999).

Perforated piles in more than one row are proposed to be a better alternative as well as viable solution in providing the required tranquility in coastal areas. Greater wave energy is expected to be dissipated when more turbulence is created using double ring perforated piles in more than one row. Nevertheless, more evidences are required to prove these statements.

1.4 Objectives of the Study

The objective of the study is to investigate the performance of partially and fully submerged perforated pile breakwaters. The specific objectives are listed as follows:

(i) To study the performance of Single Ring (SP), Double Ring (DP) and Single Ring Small (SSP) perforated pile test models as wave attenuators.

(ii) To identify the most effective perforated pile arrangement to attenuate waves.

(iii) To develop an empirical equation to predict wave transmission characteristics for the best perforated test model by using multiple regression analysis.

1.5 Scope of the Study

The scope of the work is stated as follows:

1. The study mainly involves undertaking experimental work to investigate the physical processes taking place around submerged pile test models.

2. Two-dimensional (2-D) hydraulic model tests for three types of perforated pile models with various porosities are used in this study.

3. Through the experimental analysis, the study focuses in obtaining information on the performance of the test models in transmitting waves when influenced by various wave parameters namely wave steepness (Hi/L), water depth (h), relative spacing of model (B/L), porosity (ε) and relative width of model (W/L).

4. The final product of the study is an empirical equation to predict wave transmission characteristics of the best test models between SP, DP and SSP types.

5. The study assesses and correlates the research outcomes with the results from the previous studies conducted by other researchers.

1.6 Significance of Research

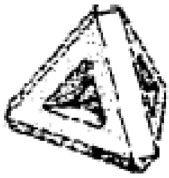
The development of coastal facilities in Malaysia has necessitated proper management of the sea front and thus warrants the construction of coastal protective structures. Shore-parallel detached breakwaters have been successfully built along many coastlines to mitigate erosion as they provide a good shelter on their leeside.

According to Mottet (1985) as reported by Armono and Hall (2000), concrete perforated breakwater blocks such as tetrapod, tetrahedron, or trileg as shown in Figure 1.1(a) and 1.1(b) are commonly used as cover layers for submerged breakwaters because they have greater stability than stone armour units. However, the conventional design of breakwater as mentioned in the above paragraph, though have performed very well, tend to cause tearing of fishing nets. Therefore, the researchers have recommended changes to a smoother and rounder shaped breakwater as an alternative solution. Reefball Development Group (1997) and Mottet (1985), as reported by Armono and Hall (2000), indicated that cylindrical shapes, turtle blocks, and reef balls are some of the examples of artificial reefs used to provide shoreline protection which are more environmentally friendly. The innovative design of this kind of shapes can be observed from Figure 1.2.

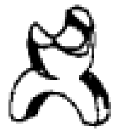
A. Tetrapod
Sizes: 1 to 50 tons

B. Modified Tetrapod
Sizes: 0.5 to 30 tons
Void: 56%

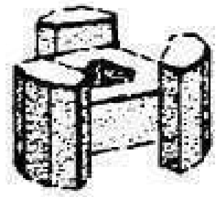
Figure 1.1(a) : Manufactured Concrete Breakwater Blocks (Source: Mottet, 1985)



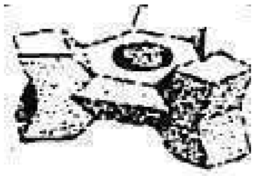
A. Tetrahedron
Weights: 0.25 to 50 tons



B. Nagai
Weights: 1 to 16 tons
Void: 42 to 50% (arranged)
56% (random order)

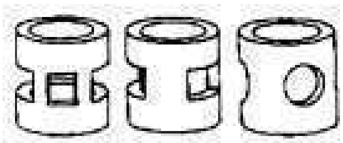


C. Trileg A

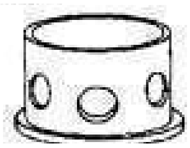


D. Trileg B
Weights: 0.5 to 10 tons

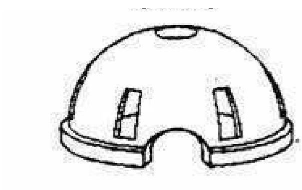
Figure 1.1(b) : Manufactured Concrete Breakwater Blocks (Source: Mottet, 1985)



A. Cylindrical Shape



B. Large Cylinder
Volume: (0.17 to 4.6 m^3)
Volume: (39.76 m^3)



C. Turtle Block
Volume: (2.73 m^3)

D. Reefball

Figure 1.2 : Smooth-shaped Reefs (Source: Mottet, 1985 and Reefball Development Group, 1997)

This study is significant in proposing an alternative system for shore protection measures and coastal restoration. The study will help to overcome the problem of shortage of natural materials such as quality rock to build reliable coastal protection structures.

1.7 Thesis Structure

The thesis consists of six chapters. Chapter 1 includes the general introduction, background of the problem, problem statement, objectives and scope of the study. It also states the significance of the study.

Chapter 2 presents the literature review of previous studies related to the research. This chapter provides explanation on the important mechanism on the wave energy dissipation and wave parameters that influence the wave transmission.

Chapter 3 describes the methodology of the work carried out to achieve the objectives of this study. This chapter also conveys information on the experimental work, data acquisition, processing and technique of analysis.

Chapter 4 mainly presents the results obtained from this study. The chapter informs general observations made, discusses results on exploratory data analysis and wave transmission performance with respect to the identified significant wave parameters and elaborates results on comparison between tested models.

Chapter 5 discusses on regression analysis, develops empirical equations based on best results test model and verification and validation of the previous research using proposed equations.

Chapter 6 concludes the thesis and topics to continue this research.

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