Cost Comparative Study of the H-Type Floating Breakwater

by

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14280

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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BACHELOR OF ENGINEERING (HONS)
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Approved by,

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(Dr Teh Hee Min)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK DARUL RIDZUAN

September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MUHAMMAD FADHIL BIN ABD RAZAK)

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ABSTRACT

This study was to determine and compare the cost between the breakwaters, including the conventional and the floating breakwater, with respect to the material cost. Information of various kind of breakwaters were gathered from the past researches and were used in this cost comparative analysis. Four main objectives were being focused, which were (i) to account the unit cost of the conventional breakwaters, (ii) to analyze the unit cost of the floating breakwaters, (iii) to estimate the unit cost material of H-Float model, and (iv) to conduct a cost comparative study of the H-Float against other types of floating breakwaters. Based on the study case of total water depth of 12.9 m and wave period of 8 seconds, the Y-frame breakwater takes the lowest estimation material cost (US $ 5556), followed by H-Float (US $ 9495), box-type (US $ 11925) and the conventional rubblemound breakwater (US $ 33898). This difference was mainly due to the different in sizing of the breakwater to perform the same performance (coefficient transmission, C_t = 0.5), thus inducing different material cost. However, although the material cost of the H-Float is slightly higher than the Y-frame breakwater, the use of H-float as a wave defense structure is also economically suitable to be implemented in future. More extensive research on this topic is also recommended.

Table of Contents

List of Figures

List of Tables

Symbols

H_i	incident wave height
H_t	transmitted wave height
C_t	transmission coefficient
L	wavelength
T	wave period
W	width of breakwater
H	height of breakwater
L	length of breakwater
D	draft of breakwater
V	volume of breakwater
d	water depth
W/L	relative breakwater width
D/d	breakwater draft-to-water depth ratio
λ	geometrical ratio

CHAPTER 1: INTRODUCTION

1.1 Background

Breakwaters are structures located in the sea and are used to protect an area against undesirable wave heights. There are two kinds of breakwater, namely bottom-founded and floating-type breakwater. The use of breakwater has been increasing in demand especially at the coastal areas where a lot of facilities are being developed for goods. Numerous functions such as recreational harbors, ship ports, marinas and marine agriculture where located at coastal area will require breakwaters. This is to provide some protection especially from the external sea waves that may hit the areas and limit the activities at such places.

In the earlier stages, bottom-founded breakwater are quite common as it would easily be constructed and have great potential of energy transmitter and energy absorber towards sea waves. However, due to industrial economic development for developing countries, numerous ports are nowadays established along coastline, where it can accommodate larger ships to stop and transfer all kind of good at the ports. As the port size increases, the required seabed level at the boundary will relatively go deeper. It is no doubt that fixed breakwaters can offer excellent protection for the coastal areas and higher durability in withstanding the destructive waves, however they contribute several drawbacks that may not be economically and environmentally friendly. Thus, researchers have developed several types of alternative structures to overcome the restrictions that are associated with fixed breakwaters. Thus, the method of reducing the wave effect are enhanced with the use of floating breakwater, which is much easier to be dealt with.

Basically, floating breakwaters are often applied where conventional breakwaters are less suitable to apply. This type of breakwaters have been used as one of the alternative way to overcome the destruction of waves towards the coastal areas. It also may be defined as a structure that combines the ability to reduce the height of ocean waves with advantages in terms of environmental friendly, transportation and cost, while being reusable and removable. Comparing the floating breakwaters to the fixed breakwaters, the former offers more advantages. The cost of floating breakwaters is insensitive to water depth and the breakwaters can be easily moved to serve to a new location with minimum effort, however they are not as strong as its counterpart. Table 1 shows the summarized advantages and disadvantages of both fixed and floating breakwaters (Nadia, 2013).

Table 1: Advantages and Disadvantages of Fixed and Floating Breakwater

	Fixed Breakwater	**Floating Breakwater**
Advantages	✓ Protection against high and long waves period ✓ Easily repaired ✓ Aquatic habitat ✓ Strong structure	✓ Easily arranged/moved ✓ Less sensitive to water depth ✓ Low construction cost ✓ Environmental friendly ✓ Low interference with water circulation and fish migration
Disadvantages	✓ Semi-permanent structure ✓ Limited water depth application ✓ High construction cost ✓ Potentially trap debris ✓ Poor water circulation behind structure	✓ Ineffective for high and long period wave ✓ High maintenance cost ✓ Failure in heavy storm

A number of researches were conducted over the years to study and investigate the best model characteristics and interactions in producing more reliable design of floating breakwaters. Series of tests and experiments were also conducted on these designed models, thus improving their performances, year by year of studies. Together with the study, some researchers were also came with some information about the cost of the breakwater. This may give some overview about the costing of the available breakwater, in relation to the cost of the respective year of the research. The most widely studied model of box-type floating breakwater has become the motivation for the design and development of the H-type floating breakwater (Teh *et al*, 2014) as shown in Figure 1.

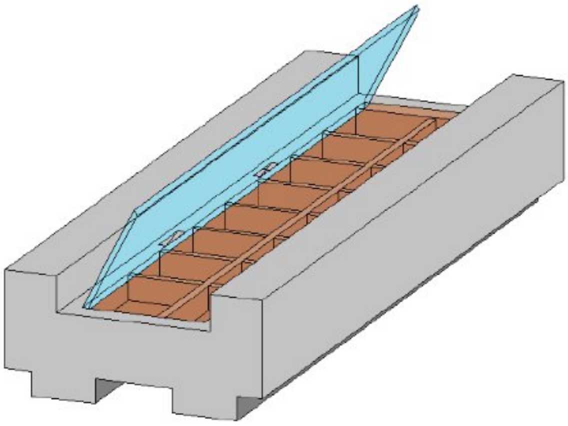

Figure 1: Design of H-type Floating Breakwater (Teh et al, 2014)

The new design of H-type floating breakwater, also known as H-Float, offers better results in attenuating wave energy compared to other conventional floating breakwater designs.

1.2 Problem Statement

Through decades, various types of breakwater has been studied and investigated their performance. This includes the conventional and floating breakwaters in this field. In selecting the type of breakwater to be implemented at site, cost is one of the most important thing to be considered, in order to select the effective economic breakwater. However, less information about the costing of breakwaters are available nowadays. Thus, in this study, construction material cost analysis of various breakwaters will be analyzed and discussed based on site condition and performance for the breakwaters. The H-Float model will also be evaluated to check whether the model is a cost-effective model or not.

1.3 Objectives

The objectives of this study are as follows:

1. To account the unit cost of conventional breakwaters
2. To analyze the unit cost of floating breakwaters
3. To analyze the cost estimation of H-Float breakwater model
4. To conduct a cost comparative study of the H-Float against other types of floating breakwaters.

1.4 Scope of Study

In this project, the scope of study are outlined as follows:

1. Literature review

   Previous information about breakwater performance and costing from available researches and experiments are gathered to explore the development phase of the floating breakwater design as well as their findings about the unit cost of the breakwater.

2. Analysis of data from literature review

   Data collected from literature review will be analyzed and discussed, focusing on the cost variation factors among the breakwater.

3. Develop a study case of material cost comparison on breakwaters

   A study case will be developed and the material cost of each breakwater options available will be compared for the most economical floating breakwater, including the H-Float. The use of H-Float as wave defense structure will be assessed.

CHAPTER 2: COST ANALYSIS OF CONVENTIONAL BREAKWATERS

This chapter discussed the fundamental concepts on the commonly used conventional breakwaters and the cost variation among them. This part will stress on the unit cost of the conventional breakwaters including the construction cost and transportation cost based on past researches available.

2.1 Rubble Mound Breakwaters

Rubble mound breakwater is one of the most conventionally used breakwater as a protector to a coastal area from excessive wave action. It is a bottom-founded breakwater that are built up across the sea depth. It primarily dissipate the incoming wave energy by creating a turbulent run up within and over the armour layer. Some of the energy may squeeze into the slope and dissipate through it. For steep wave that running up to the slope, some energy is converted to potential energy while the balance is reflected back to the seaward and also transmitted to the leeward side. According to Palmer and Christian (1998), the ability to limit the height of transmitted wave can judge the effectiveness of a particular breakwater. For the incident wave energy, some of it may dissipated internally during flow through the core layer, and the remainder will appear as a small wave on the leeward side.

Figure 2 show the typical cross-section of a rubble mound breakwater. The bulk core of the breakwater cross-section comprises of a relatively dense rockfill. This core is layered with one or two layers of rock as armour unit. The layer also may be made of precast concrete as its armour unit. The term “rubble” itself may including rock, riprap and precast concrete armour units (commonly used are tetrapods and accropodes), while the term “armour unit” representing both rock and precast concrete units.

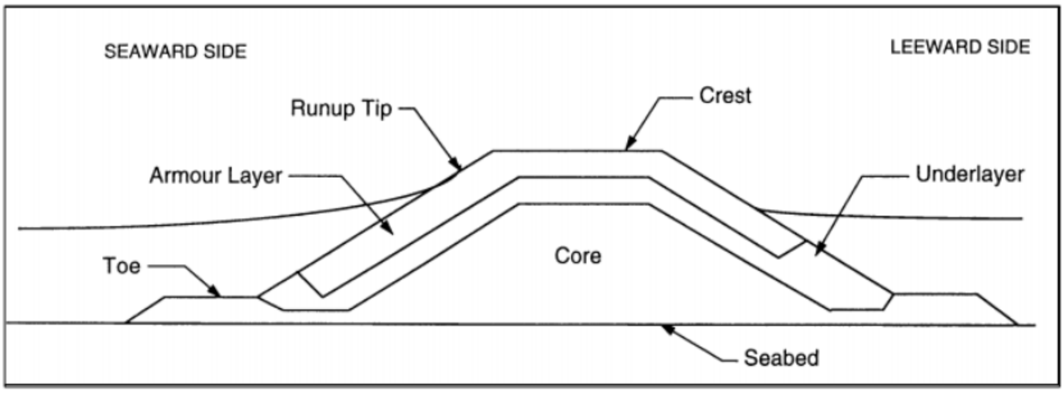

Figure 2: Typical Cross-section of a Rubble Mound Breakwater (Palmer and Christian, 1998)

The design of rubble mound breakwater is enhanced by applying different types of armour units, which is replacing the heavy armour rock (around 8 to 15 tons) by precast armour unit (Tutuarima and d'Angremond, 1998). The precast armour unit is including tetrapods and accropodes, as shown in Figure 3 below. The literature suggested that the design may become a potentially cost savings breakwaters in terms of rock supply, as it replaced the boulder to a concrete type armour.

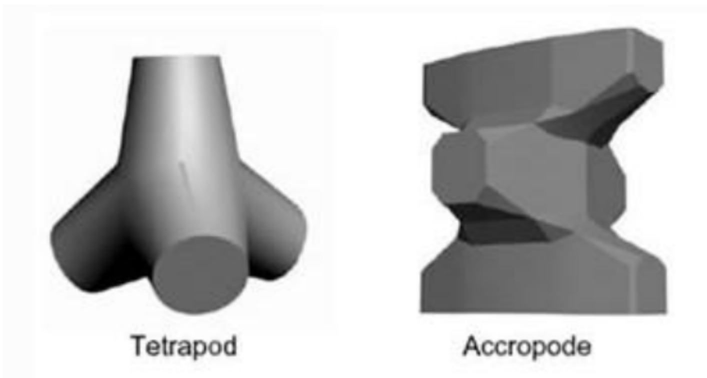

Figure 3: Tetrapod and Accropode (Southern Dredging & Marine Inc.,n.d.)

A quite similar design of the conventional rubble mound breakwater is a berm breakwater. The different between them is about the design of the berm breakwater which aims at limiting the damage costs the berm breakwater to gain the return period of 500 years (Tutuarima and d'Angremond, 1998). The cross-section of the berm breakwater is as shown in Figure 4 below. In this design, the incoming wave is prevented from overtop the breakwater.

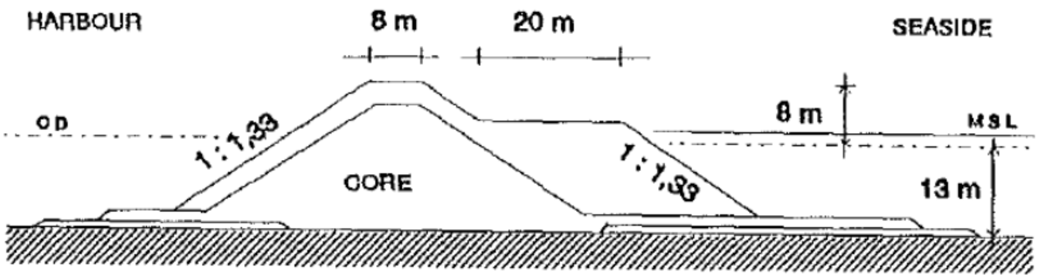

Figure 4: Typical Cross-section of Berm Breakwater Design (Hauer et. al, 1995)

2.2 Cost Variation of Conventional Breakwaters

Conventional breakwaters are designed according to collected information on site condition and wave data. The size and configuration of the deigned breakwater may vary, thus influence the cost of the breakwater. Numerous factors are included in determining the cost of the conventional breakwater. There are some listing about the cost by some of the past researches on these conventional type breakwaters. Hauer *et al.* (1995) outlines several average cost based on the activities included in the construction of the conventional breakwaters, as per shown in Figure 5 below. This cost was based on an analysis of cost for the opening of a quarry. They stressed that approximately USD 7.5/ton for total average production cost, regardless of the number and stone sizes/class. Also in the study, they had outlined several cost of the component items used for the berm breakwater, which are armour, core, gravel, textile, and nourishment, with respected to production, transportation and placement activities (Figure 6). Referring to the cost, armour component takes the highest cost including transportation and placement at site, although its production cost was quite lower than the cost of gravel and core, among the component listed. This was according to a transport distance of 75 km between quarry (as the main source of the berm breakwater components) and construction site.

Activities	Unit Cost
dredging	US \$ 5 / m^3
purchase and placing of geotextiles	US \$ 10 / m^2
placing of gravel filters	US \$ 7,5 / m^3
placing of core material	US \$ 3 / ton
placing secondary armour / rolling equipment placing secondary armour / floating equipment	US \$ 5 / ton US \$ 7,5 / ton
placing primary, lee & toe armour: stones < 5 tons / rolling equipment stones < 5 tons / floating equipment stones > 5 tons / rolling equipment stones > 5 tons / floating equipment	 US \$ 5 / ton US \$ 7,5 / ton US \$ 7,5 / ton US \$ 10 / ton

Figure 5: Average Costs Construction Activities (Hauer et al., 1995)

Component	Production costs [10^6 US \$]	Transport costs [10^6 US \$]	Costs placement [10^6 US \$]	Total costs [10^6 US \$]
armour	15.3	30.7	15.3	61.3
core	18.5	23.0	5.6	47.1
gravel	20.4	2.8	2.2	25.4
textiles	2.1	-	2.1	4.2
nourishment	0.3	0.6	0.3	1.2
total construction costs				139.0

Figure 6: Costs per Component Optimum Bermbreakwater Design (Hauer et al, 1995)

Another researchers, Tutuarima and d'Angremond (1998) later outlined the cost comparison between the conventional-type rubble mound and other types of breakwater including Berm Breakwater, Caisson and Composite Breakwater, as shown in Figure 7 below. This comparison was based on the minimum return periods to achieve lowest project cost and minimal capitalized damage cost, with the currency used in their research as Dutch guilder (the former currency of Netherlands before being replaced by the euro in 2002).

TYPE OF BREAKWATER	CONSTRUCTION COSTS (million DGL)
Conventional rubble mound	480
Bermbreakwater	270
Rubble mound + Cube units	250
Rubble mound + Tetrapods	245
Rubble mound + Accropods	195
Caisson breakwater	205
Composite breakwater	215

Figure 7: Construction Costs of Breakwater Types (Tutuarima and d'Angremond, 1998)

Cost of conventional breakwaters design also varies through the comparison of wave height at the desired location of the breakwaters. Massie (1976) had outlined the cost of conventional breakwater as function of wave height, as per shown in Table 2 below. This comparison includes the primary and secondary armour, as well as core and other considered items in the research. The design was to withstand a significant wave height ranging from 5.7 m to 7.5 m, with maximum armour unit mass (stone) of 20 tons.

Table 2: Cost as Function of Wave Height (Massie, 1976)

Design Wave Height (m)	**5.7**	**6.75**	**7.0**	**7.25**	**7.5**
Slope cot (θ)	1.68	2.78	3.10	3.45	3.82
Primary Armour					
Volume (m^3/m)	184.9	267.1	292.0	319.5	348.9
Cost/m	13 864	20 031	21 900	23 965	26 167
Secondary Armour					
Mass (kg)	7400	4500	4000	3600	3300
Layer thick (m)	2.8	2.4	2.3	2.2	2.2
Barge volume (m^3/m)	119.0	142.3	148.1	154.0	165.3
Cost/m	7 140	8 540	8 886	9 242	9 921
Crane volume (m^3/m)	39.8	42.9	43.7	44.5	47.4
Cost/m	2 985	3 219	3 278	3 338	3 555
Core					
Barge volume (m^3/m)	220.1	309.2	325.5	363.5	393.4
Cost/m	15 406	21 463	22 785	25 442	27 539
Other items cost/m	10 024	10 024	10 024	10 024	10 024
Total cost/m	**49 419**	**63 457**	**66 873**	**72 011**	**77 206**

The above cost outlined by Massie (1976) was only a rough estimation as the allocation prices are only as a relative cost indication, so there was no monetary units given. The literature suggested that the actual cost of the breakwater may have to be determined by any real case of respective project. He also stressed that the construction cost of the conventional breakwaters are also significantly influenced by the construction method chosen. This is due to the large volume of breakwater components (gravels, boulders, etc) may require a portion of the breakwater to be constructed under water at the desired site location.

CHAPTER 3: COST ANALYSIS OF FLOATING BREAKWATERS

This chapter focused on the common floating breakwaters and the cost variation among them. Three floating breakwaters are selected in this chapter, which are box-type, Twin Pontoon-type Breakwater, Y-frame breakwater. This part also will stress on the unit cost of the floating breakwaters with regards to the construction cost based on past researches available.

3.1 Box-type Breakwater

Box floating breakwater was introduced by McCartney (1985) in his paper "Floating Breakwater Design", which was constructed of reinforced concrete module. For a large-scaled box breakwater, it can be made either steel or concrete and be used as barges. The box modules could either have flexible connections or are pre-tensioned or post-tensioned to make them act as one large single-unit breakwater. The advantages of this box-type breakwater is it has 50 years design life. Its structure allows pedestrian access for fishing and temporary boat moorage, besides also effective in moderate wave climate. The shape of the box breakwater (Figure 8) is simple to build but a high quality control is needed. In addition, the cost of constructing the box type breakwater is quite high. Mani (1998) stated in his paper, that barges of 175 ft (53.3m) by 26 ft (7.9m) cost about $230 000 and barges with 195 ft (59.4m) by 35 ft (10.7m) cost about $300 000 for new barges.

Figure 8: Solid rectangular box-type floating breakwater (McCartney, 1985)

3.2 Y-frame Breakwater

A different types of existing breakwaters had been studied by Mani (1991) for improved performance in reducing transmission coefficient. It was determined that the "relative width"; the ratio of width of the floating breakwater (B) to the wavelength (L) influence greatly the wave transmission characteristic of a breakwater. It was suggested that in order to obtain transmission coefficient below than 0.5, the B/L ratio should be greater than 0.3. However, the increment of width will increase construction cost of the breakwater thus making the handling and installation of the breakwater to become more difficult.

Y-Frame floating breakwater was designed with the aim to reduce B/L ratio and at the same time increasing the draft of the breakwater by the installation of row of pipes underneath the inverse trapezoidal pontoon. Figure 9 below illustrates the design of the Y-Frame floating breakwater.

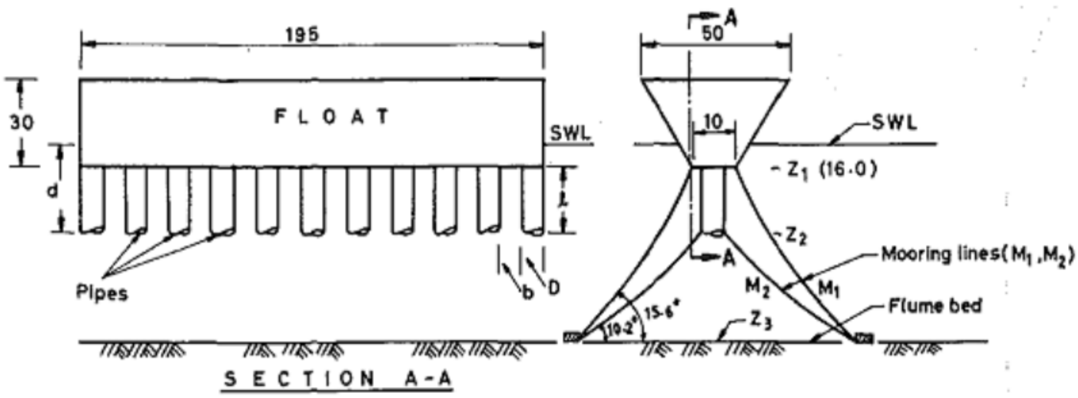

Figure 9: Details of the Y-Frame floating breakwater (Mani, 1991)

Based on the researcher, the cost estimation of the Y-Frame model is ranging between $1 300 and $2 600 per meter run. This was according to wave period of 10 sec and d/h = 0.46.

3.3 Cost Efficiency: Conventional Breakwaters versus Floating Breakwaters

The summary of the costing of breakwater suggested from the past researches are as outlined in Table 3 below. Rubblemound breakwater cost is quite high in relative to unit meter length. This is mainly due to the physical requirements of the breakwater that require high amount of material to fit a big cross section of the breakwater in the sea. This is also includes the construction method chosen by the designer on how to construct and build the breakwater.

Table 3: Summarization of Breakwater Costing

Breakwater Model	Range Cost ($)	Contributing Factors	Source
Conventional Rubblemound	70000/m – 80000/m	High volume, construction and damage cost	Massie (1976)
Box-type	200000 - 300000	Huge size (including width), material cost	McCartney (1985)
Y-frame	1300/m – 2600/m	Reduction in W/L ratio	Mani (1991)

For box-type breakwater, although its cross section may not as large as the rubblemound breakwater, but its rectangle size require large area to overcome the incident wave from the sea, thus make it quite costly due to material cost. This is supported by McCartney (1985) who agreed that the box-type breakwater is high cost compared to the mat-type, which may require towing to dry docks for maintenance, and problem with connectors if not adequately designed. However, this kind of breakwater has 50-year design life, and has proven its performance and agreed to be effective in locations with moderate wave climate McCartney (1985). A different design introduced by Mani (1991) had come out with a quite low cost floating breakwater, where he applied different approach in reducing the transmitted wave by introducing pipes underneath the breakwater to maintain the performance without the need to have a larger width of the breakwater. By installing the pipes, it helps to increase turbulence level and reflection characteristics of the breakwater. By reducing the width requirement, the cost of fabrication is also can be reduced. Thus, the Y-frame breakwater may become an efficient breakwater as it can serve the same performance at a lower cost.

CHAPTER 4: COST ESTIMATION OF THE H-FLOAT

4.1 Material Cost of the H-Float

Based on the study by Teh *et al* (2014), the design of the H-Float was as per shown in Figure 1 in the previous chapter, and the construction material and cost of the H-Float model are as in Table 4 below. The H-Float has the dimension of 1 m width, 1.44 m length and 0.5 m height.

Table 4: Construction Material Cost for H-Float

Component	Material	Material Cost	Reference
Autoclave lightweight concrete	Aerated autoclave concrete (AAC)	US \$ 60/m^3	Sddymachine.en.alibaba.com (n.d)
Fiberglass for coating	Fiberglass	US \$ 0.25/m^2 (fiberglasss mesh)	Yzchuangjia.en.alibaba.com (n.d)
Concrete for ballast chamber	Concrete (assume concrete grade 25)	US \$ 55.12/m^3 (MYR 192.67)	Building Material Price, CIDB Malaysia (2014)
Cover	Plexiglas	US \$ 3.6/kg	Au.alibaba.com (n.d)

Throughout the cross section of the breakwater, the Autoclave lightweight concrete takes up about 67.59% of the total overall cross section, while concrete for ballast chamber takes about 31.93% (with the assumption that the ballast is full with concrete) followed by the Plexiglas as the cover, about 0.48%. Thus, the lightweight concrete and concrete for ballast chamber will greatly influence the cost of construction of the H-Float. The increment of these component as a result of the sizing increment due to longer wave period and wave length, will result in higher construction cost of the H-Float.

4.2 Construction Cost of H-Float

The unit cost of H-Float depends on its size, and the size of the H-Float depends on the design water depth, wave period, and the level of the wave tranquility. The influence of the width on the wave transmission depends on the draft and the weight of the structure, where its performance is as shown in Figure 10 below.

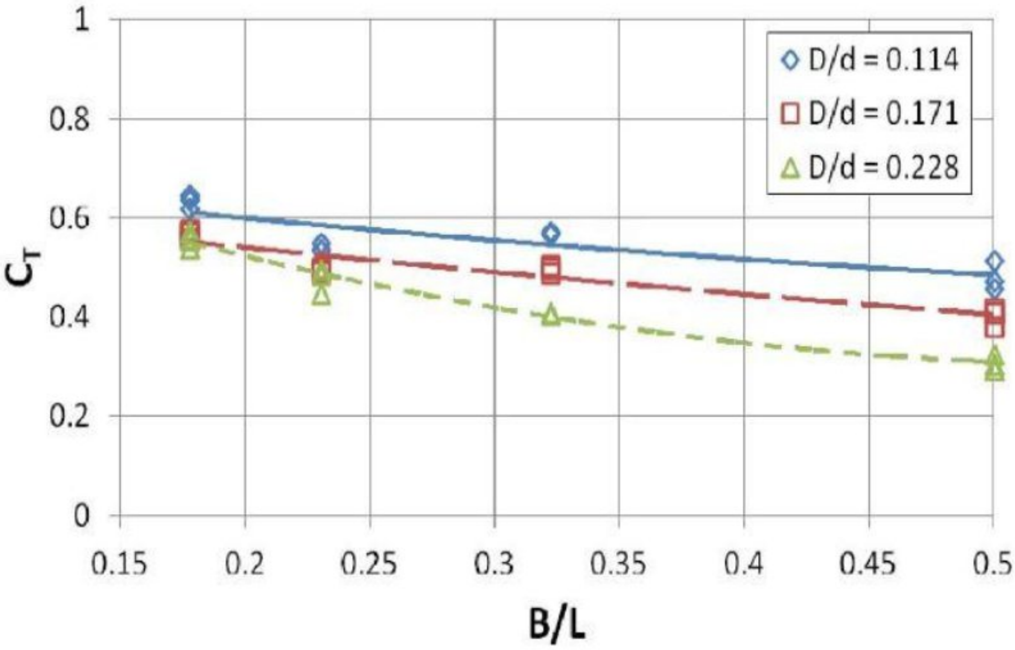

Figure 10: Wave Transmission Coefficient of H-Float (Teh et. al, 2014)

When the structural width is increased while the draft is kept constant, the mass will increase too. A wide and heavy structure is hard to put it onto oscillation, thus performs better. However, in sea condition with longer period waves and wavelength, the H-Float may require larger width to maintain its performance, thus yielding a high cost breakwater. At lower wave period and wave length, the H-Float may perform better in attenuating wave if compared to longer wave period with respecting to the same breakwater sizing. This is in line with Teh *et al* (2014) that prove the result of their experiment that the H-Float is hydraulically efficient and capable to attenuate a short-period wave.

CHAPTER 5: CASE STUDY

In this chapter, a study case was developed and the construction material cost of each breakwater options were assessed to find the most economic breakwater to be used. Various sources of price were collected to be included in this analysis. Then, the evaluation of the H-Float as wave defense structure was performed to check whether the model is economic to be used at the selected location of the case study.

5.1 Case Study Details

In this case study, site condition and wave data were selected from the book "Coastal Engineering (Volume III – Breakwater Design)', edited by Massie (1976), from Coastal Engineering Group, Department of Civil Engineering, Delft University of Technology, Delft, The Netherlands. The site condition data were used to develop the outlined breakwaters to assess their cost. The parameters for the design were outlined in Table 5 below:

Table 5: Design Parameter for Case Study

Design Parameter	Value	Unit
Water depth, h relative to MSL	10.0	m
Water level, h' relative to MSL	2.9	m
Total water depth, d	12.9	m
Wave height, H	4.5	m
Wave period, T	8	s
Bottom slope, m	0.01	-
Transmission Coefficient, C_t	0.5	-

Transmission coefficient is quantified by ratio of the transmitted wave height, H_t to the incident wave height, H_i, such that

$$?_? = \frac{?_?}{?_?} \qquad (5.1)$$

Wave transmission is the phenomenon in which wave energy is passing over, under or through a breakwater, creating a reduced wave (transmitted wave) at the lee side of the structure (Verhagen *et al.*, 2009). Chakrabarti (1999) in his paper "*Wave Interaction with an Upright Breakwater Structure*" stated that the effectiveness of a floating breakwater in attenuating wave energy can be measured by the amount of wave energy that is transmitted past the floating structure. The breakwater is considered to be effective if the transmission coefficient is small, since it shows that the amount of energy that has transmitted past the structure is much less than the energy level of incident wave. The greater the wave transmission coefficient, the lesser will be the wave attenuation ability, and vice versa.

Wavelength, L of the wave can be determined through the airy wave theory, with function of depth and wave period.

$$? = \frac{??^?}{??} ???h \frac{???}{?} \qquad (5.2)$$

Where:

g is the acceleration of gravity,

T is wave period,

d is water depth.

However, the use of the above equation involves some difficulty since the unknown *L* appears on both sides of the equation. Tabulated values of *d/L* and *d/L₀* in Table C-1, Shore Protection Manual 1984, where L_0 is the deepwater wavelength, was used to simplify the solution.

$$?_? = \frac{??^?}{2?} = \frac{(9.80665)(8)^?}{2?} = 99.9?$$

Comparing the value of *d/L* and d/L_0 in the Table C-1 (Figure 11 in Appendix), the wavelength L of the wave was 78m.

5.2 Breakwater Material Cost Comparison

In this study of cost comparison of breakwaters, the main item selected for comparison was the component cost, which covers the material cost of the breakwater. The discussed breakwaters in the previous chapter were assessed for their cost based on the data given.

5.2.1 Conventional Rubblemound Breakwater

The design of the conventional rubblemound breakwater was based on the design method outlined in the book "Coastal Engineering (Volume III – Breakwater Design)'. The storm data used in this design were based on Table 13 and Figure 12 in Appendix. Based on Figure 13 (in Appendix), taking wave height = 4.5 m and wave period, T = 8 s, thus the design were based on 5 storm events per year occurrence. Assuming the maximum armor unit mass is 11 tons, the slope of the breakwater was determined by applying the Hudson formula.

$$\cot ? = \frac{?_? ??^?}{?_? \Delta^? ?} \qquad (5.3)$$

where

g is the acceleration of gravity,

H is the design wave height,

K_D is the damage coefficient,

W is the weight of the armour unit,

Δ is relative density of armour,

ρ_a is the armour unit density,

θ is the slope angle.

The armour unit was taken as stone rubblemound with damage coefficient of 3.5 (Massie, 1976) and density of 2700 kg/m^3, thus the slope of the breakwater was calculated. Wave steepness was expressed by selecting the rubble slope as 1:1.5 (Figure 14 in Appendix), yield R/H = 1.04. For the calculation of the minimum crest width, equation below is used:

$$? = ?\ {}^{?}?_{\Delta}\left(\frac{?}{???}\right)^{\frac{?}{?}} \qquad (5.4)$$

where

B is the crest width,

K_Δ is the packing coefficient,

m' is the number of armour unit across the crest.

Selecting m' = 3 and K_Δ for quarry stone = 1.02. For the thickness, t of the armour layer, the same formula was applied, with the number of armour units in the layer, m was taken as 2. After designing the toe, all dimensions were tabulated in Table 6 below.

Table 6: Design Summary of Rubblemound Breakwater

Parameters	**Value**
Breakwater slope, θ	33.69^o (cot θ = 1.50)
Crest elevation, z_c	7.58 m above MSL
Minimum crest width, B	4.89 m
Primary armour layer thickness, t_p	3.26 m
Secondary armour layer thickness, t_s	2.97 m
Slope of breakwater toe protection, θ	26.80^o (cot θ = 1.98)
Filter gravel layer thickness, t_f	2.00 m

The components of the breakwater and its material assumptions were as listed in Table 7 below.

Table 7: Component Classification and Cost for Rubblemound Breakwater

Component	Material	Material Cost	Reference
Filter gravel	Crushed Gravel/bricks	US $ 57.82 / m^3	Corkhill Bros, 2014
Toe stone	Boulders (large river rocks)	US $ 70.21 / m^3	
Primary and secondary armour	Boulders (large river rocks)	US $ 70.21 / m^3	
Core	Sand and gravel	US $ 44.60 / m^3	

The cost estimation of the rubblemound breakwater was tabulated in following Table 8 below. Note that the estimation cost was based on the construction material cost.

Table 8: Cost Estimation for Rubblemound Breakwater

Component	Volume (m^3/m)	Material Cost (US $ / m^3)	Total Cost (US $ / m)
Filter gravel	79.08	US $ 57.82	4572.60
Toe stone	4.08	US $ 70.21	286.80
Primary armour	130.37	US $ 70.21	9153.10
Secondary armour	136.89	US $ 70.21	9611.40
Core	230.36	US $ 44.60	10274.07
Total estimation cost			33897.95

5.2.2 Box-type Breakwater

The box-type breakwater was scaled up according to the performance required, which is C_t value of 0.5. Referring to the Figure 15 (in Appendix) with 12 feet breakwater width, the ratio of width to wavelength, *W/L* value was 0.28. Using Froude's model law and the known wavelength from this case study as 78m, the model-to-prototype relations were obtained. The actual width of the breakwater was

$$? = (0.28)(78\ ?) = 21.84\ ?$$

This was lead to the geometrical ratio, λ of

$$? = \frac{?_{?\ ????}}{?_{?????????}} \ \frac{21.84\ ?}{(12\ ??)(0.3048\,?\,/\,??)} = 5.97$$

This scale ratio was used to assess the new size of the box-type breakwater to achieve the C_t value of 0.5, as detailed in Table 9 below.

Table 9: Characteristics of Box-type Breakwater

Dimension	Prototype	Model	
Width, B	12 ft	71.65 ft	21.84 m
Length, l	96 ft	573.23 ft	174.72 m
Depth, d	5 ft	29.86 ft	9.1 m
Draft, D	3.5 ft	20.90 ft	6.37 m
Volume, V	5760 ft^3	1226286 ft^3	34724.55 m^3

This dimension was calculated with the assumption that the breakwater was a solid-box breakwater, based on its classification from the literature illustrated by

McCartney (1985) as a '*Solid Rectangle*' box breakwater. According to the literature, this box-type breakwater unit were commonly made of reinforced concrete. Taking the material as autoclave aerated concrete (light weight concrete) with cost of US \$ 60/m^3 (sddymachine.en.alibaba.com, n.d), the total material cost of the breakwater unit was US \$ 2083473. Dividing with the overall length of 174.72 m, the unit cost material of the box-type breakwater was US \$ 11925 per meter run.

5.2.3 Y- Frame Breakwater

In determining the cost of the Y-frame breakwater to the outlined criteria, the same method of geometrical scaling was applied to this breakwater. Referring to the Figure 16 (in Appendix), the value of *W/L* obtained for Y-frame breakwater was 0.15. Applying Froude's model law, the actual width of the breakwater with respected to wavelength of 78 m was

$$? = (0.15)(78\ ?) = 11.70\ ?$$

Thus, the geometrical ratio, λ was

$$? = \frac{?_{?\,????}}{?_{?????????}} \frac{11.70\ ?}{0.5\ ?} = 23.4$$

This scale ratio was used to assess the new size of the Y-frame breakwater to achieve the C_t value of 0.5, as detailed in Table 10 below. There were no information about the pipe thickness, thus the prototype's pipe thickness was assumed to be 0.001m, which will make the model's pipe thickness to be 0.0234m. Mani (1991) had stated that the pipe gap to diameter ratio, *b/Di* to be 0.22, thus getting the breakwater pipe gap as 0.46 m.

Table 10: Characteristics of Y-frame Breakwater

Dimension	Prototype	Model
Width, *B*	0.50 m	11.7 m
Length, *l*	1.95 m	45.63 m
Float height	0.30 m	2.06 m
Float volume	0.18 m^3	2248.67 m^3
Draft, *D*	N/A	5.93 m
Pipe length	0.2-0.4 m	3.87 m
Pipe diameter, *Di*	0.09 m	2.11 m
Pipe gap, *b*	0.02-0.09 m	0.46 m
Number of pipes	N/A	17

Based on data above, the cross section of the pipe was 0.153 m^2, while the total volume of pipe was 10.072 m^3. Assuming the pipe to be a steel pipe with density of 7850 kg/m3, the weight of the pipe used was 79068 kg. Taking the float material as autoclave aerated concrete (light weight concrete) with price of US $ 60/m^3 (sddymachine.en.alibaba.com, n.d), the material cost of the float unit is US $ 134920, while price of steel is taken as US $ 1.5/kg (Heubach.trustpass.alibaba.com) to make the steel cost to become US $ 118602. Overall material (float and pipes) cost will be US $ 253522. Dividing to the length of the breakwater, the unit material cost for the Y-frame breakwater will be US $ 5556 per meter run.

5.2.4 H-Float

The same approach was taken in determining the cost of the H-Float breakwater to the desired criteria, with respect to wavelength of 78 m. *W/L* ratio obtained for H-Float breakwater was 0.23 (Figure 10 in previous chapter). Applying Froude's model law, the actual width of the breakwater was

$$? = (0.23)(78\ ?) = 17.94\ ?$$

Thus, the geometrical ratio, λ was

$$? = \frac{?_{?\ ????}}{?_{?????????}}\ \frac{17.94\ ?}{1\ ?} = 17.94$$

Referring to the model configuration outlined by Teh *et al.* (2014), the new size of the model was tabulated in Table 11 below. This was including the assumption that all material covered in the construction material were scaled up and fully occupied based on the respective materials with the respective scale ratio, according to the Froude's model law.

Table 11: Characteristics of H-Float Breakwater

Dimension		Prototype	Model
Width, *W*		1 m	17.94 m
Length, *l*		1.44 m	25.83 m
Float height, *h*		0.5 m	8.97 m
Cross sectional area	AAC	0.254 m^2	81.75 m^2
	Ballast	0.12 m^2	38.62 m^2
	Plexiglas	0.0018 m^2	0.58 m^2
Float volume	AAC	0.366 m^3	2111.85 m^3
	Ballast	0.17 m^3	997.73 m^3
	Plexiglas	0.0026 m^3	14.97 m^3

Taking the price of autoclave aerated concrete (light weight concrete) of US \$ 60/m^3 (sddymachine.en.alibaba.com, n.d), the cost of the concrete for ballast as US \$ 55.12/m^3 (Building Material Price, 2014) and cost for Plexiglas (Density = 1180 kg/m^3) as US \$ 3.6/kg, total construction material cost would be US \$ 245280. Dividing the material cost with the length of the H-Float, the unit material cost of this floating breakwater would be US \$ 9495 per meter run.

5.3 Discussion

The construction cost material for the specified site condition for each breakwater options as illustrated above was summarized in Table 12 below.

Table 12: Summary of Construction Cost Material of Breakwaters

Breakwater Model	Estimated material cost (US $ / m)
Conventional rubblemound	33898
Box-type	11925
Y-frame	5556
H-Float	9495

Based on the Table 12 above, it was shown that the Y-frame floating breakwater had the lowest estimated material cost among the breakwaters, followed by the H-Float, Box-type, and the conventional rubblemound. It is important to note that, the cost estimation was according to the construction cost material of the particular breakwaters. In reality, there are also some other related cost that are put into consideration, which can classified as other cost. In the meanwhile, indirect cost may include the fabrication process of the floating breakwater, where it requires molding and storage during the fabrication of the breakwater units. Damage cost is also to be considered as breakwaters will be monitored for maintenance.

The different in cost of these breakwater types may according to several factors. In this case study, the major difference was the sizing of the breakwater to perform the same performance (coefficient transmission, C_t = 0.5), which yield different cost of the construction material. A bigger width is required to confront a long wavelength of sea water. In this case, the model configuration of the Y-frame floating breakwater with the presence of row of pipes installed underneath, took a significant advantage of reducing the width requirements of the breakwater (W/L = 0.15), thus reducing the material cost induced. The H-Float, however, applying the innovative geometrical configuration, which performed better than the box-type (W/L = 0.23 for H-Float, compared to W/L=0.28 to box-type).

For conventional breakwater, Massie (1976) has specified that the total project cost is based on the following variables; (i) location of the breakwater, (ii) crest elevation, (iii) type of breakwater, (iv) construction details such as armour unit type used, and (v) the wave climate. Also, for rubblemound breakwater construction, the total cost is also influenced by the method of construction chosen. Two common method chosen in constructing this rubbemound breakwater are by applying barges and working crane over the crest Massie (1976). These may vary the overall construction cost of the breakwater.

It was also stated by Mani (1991) in his paper that in the location where the wave period of 10 sec coming from the sea, it is quintessential to provide breakwaters with greater width and draft. However, the use of the Y-frame floating breakwater (width around 7 to 14 m) may perform the same but lower in production cost. Also, it is important to note that the cost of material used of the breakwater may varies according to the current market value of where the breakwater is build. Sometimes, it is more economical to import materials from other country which has lower material cost if the local material is too costly, and vice versa. However, since large amount of material are needed to construct the rubblemound breakwater (gravel/boulders/sand), a local supply seems to be much economical to keep the transport cost at a minimal rate (Massie, 1976).

In addition to floating breakwaters, a common section that will be equipped to all floating breakwaters is the mooring system, where it will restrict and maintain the floating breakwater at the same position during its operation. This mooring system is consisting of the anchor at the sea bed, mooring cables and hooks attached at the breakwaters. As the depth of the water level increases, the cost of this mooring system is also increase (longer mooring cable will be needed), but at a lower rate compared to the sizing requirement of the breakwater. This also may add to the total cost of the floating breakwater.

For H-Float, the cost comprises of the bigger volume of material usage compared to the Y-frame, thus make it at higher cost compared to the latter. However, the cost of the H-Float may potentially be reduced when the ballast chamber is not fully occupied with concrete (to adjust the draft). As the innovation of the H-Float is quite new, it is potentially be enhanced its performance to reduce cost.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Throughout this study, the unit cost material of conventional and floating breakwaters were analyzed based on data collected from various sources including past researches and books available in libraries. The cost estimation of H-Float also was conducted based on the material cost of the breakwater. Lastly, a study case was performed to assess the material cost comparison of the H-Float against the other breakwater options. Based on the study case of total water depth of 12.9 m and wave period of 8 seconds, the Y-frame breakwater takes the lowest estimation material cost (US $ 5556), followed by H-Float (US $ 9495), box-type (US $ 11925) and the conventional rubblemound breakwater (US $ 33898). This difference was mainly due to the different in sizing of the breakwater to perform the same performance (coefficient transmission, C_t = 0.5), thus inducing different material cost. However, although the cost of the H-Float is slightly higher than the Y-frame breakwater, the use of H-float as a wave defense structure is also economically suitable to be implemented in future. More extensive research on this topic is also recommended.

6.2 Recommendation

The cost estimation of both conventional and floating breakwaters were assessed based on material cost as the main parameter. However, few recommendations are suggested for this cost comparative study:

- The material price for breakwaters should be collected based on local price as the price may vary based on resource availability of the local area.
- The addition of construction method cost may be essential to estimate the cost of the breakwaters in a more precise value.
- The material and configuration of each breakwaters (conventional and floating) should be clearly configured to ease the assessment of the breakwater costing.
- The H-Float is one of the recent developed model for floating breakwaters. Thus, further development on this model is recommended to enhance its attenuating ability with respect to a longer period wave, thus potentially reduce its width requirements, and hence reduce the material cost.
- Extensive research may be performed to find the most economical breakwater, with respected to the material improvement of the existing breakwaters. This aims for the lowest material cost possible, but maintaining or better performance.
- A cost projection of the breakwaters may become beneficial to predict and estimate the cost of breakwater in future application. This may include the material cost and the construction cost of the breakwater with respect to the economic status projection.

REFERENCE

Au.alibaba.com. n.d <http://au.alibaba.com/product/60100161681-Jumei-hot-sale-excellent-quality-plexiglass.html?s=p>

Building Material Price, CIDB Malaysia, 2014. < http://www.cidb.gov.my/cidbv4/index.php?option=com_content&view=article&id=184&Itemid=328&lang=en>

Chakrabarti, S. 1999. Wave interaction with an upright breakwater structure. *Ocean Engineering* 26, pp. 1003-1021.

Corkhill Bros, 2014<http://www.corkhillbros.com.au/index.php/pricelists/price-list-for-mugga-lane-2>

Ferreras, J., Peña, E., López, A., and López, F. 2014. ”Structural Performance of a Floating Breakwater for Different Mooring Line Typologies.” *J. Waterway, Port, Coastal, Ocean Eng.*, 140(3), 04014007.

Hauer, M., W. op den Velde, J.K. Vrijling, K. d'Angremond. 1995. “Comparison Construction Costs Conventional Rubblemound Breakwaters / Bermbreakwaters”, *Proc. 3"1 Seminar on Ports and Inland Waterways*, Goa 1995, Publ. by PIANC/PCDC, Brussels

Heubach.trustpass.alibaba.com. n.d. <http://heubach.trustpass.alibaba.com/product/140414740-103342523/Best_quality_ASTM_202_stainless_steel_pipes_price_per_kg.html>

Howard, T., Riley, B., Upsall, B., and Horvitz, G., 2013. Structural Design of Deep Water Pontoon Mooring Anchors. Ports 2013: pp. 1087-1096.

Mani, J.S. 1991. “Design of Y-Frame Floating Breakwater”. *J. Waterway, Port, Coastal, Ocean Eng*. 1991.117:1005-119

Massie, W.W., 1976. "Breakwater Design". *Coastal Engineering,* Vol III. Department of Civil Engineering, Delft University of Technology.

McCartney, B.L., 1985. "Floating Breakwater Design". *Journal of Waterway, Port, Coastal and Ocean Engineering*, 111, pp.304–317.

Nadia, N.A., 2013. "*Wave Interactions of the H-Type Floating Breakwater*". Undergraduate dissertation, Civil Engineering Dept, Universiti Teknologi PETRONAS, Tronoh, Perak, Malaysia.

Palmer, G. P., Christian, C. D. 1998. "Design and construction of rubble mound Breakwaters", *IPENZ Transactions*, Vol. 25, No. 1/CE, 1998

Sddymachine.en.alibaba.com. 2014. <http://sddymachine.en.alibaba.com/product/1853246311-219486391/2014_New_autoclaved_aerated_concrete_block_price.html>

Shore Protection Manual. 1984. 4th ed., 3 Vol. U.S. Army Engineer Waterways Experiment Station,U.S. Government Printing Office, Washington, DC

Southern Dredging & Marine Inc.,n.d. "Caribbean Islands Breakwater Construction" Retrieved 25th October 2014, from http://www.southerndredgingandmarine.com/caribbean-islands-breakwater-construction

Teh, H.M and Kurian, V.J. and Hashim, A.M. 2014. "Hydraulic Investigation of the H-type Floating Breakwater". *International Conference OCEAN'S 14*, 7-10 April 2014, Taipei.

Tutuarima, W.H., d'Angremond, K. 1998. Cost Comparison of Breakwater Types. *Coastal Engineering,* 1998

Verhagen, H.J., d'Angremond, K., and van Roode, F.2009. *Breakwaters and Closure dams.* VSSD, 2009.

Yzchuangjia.en.alibaba.com (n.d) <http://yzchuangjia.en.alibaba.com/product/496343890-50352437/Coated_alkali_resistant_fiberglass_mesh.html>

APPENDIX

Table C–1 – Continued

d/L_o	d/L	$2\pi d/L$	TANH $2\pi d/L$	SINH $2\pi d/L$	COSH $2\pi d/L$	H/H'_o	K	$4\pi d/L$	SINH $4\pi d/L$	COSH $4\pi d/L$	n	C_G/C_o	M
.09000	.1322	.8306	.6808	.9295	1.3653	.9422	.7324	1.661	2.538	2.728	.8273	.5632	10.65
.09100	.1331	.8363	.6838	.9372	1.3706	.9411	.7296	1.672	2.568	2.756	.8255	.5645	10.55
.09200	.1340	.8420	.6868	.9450	1.3755	.9401	.7268	1.684	2.599	2.785	.8238	.5658	10.46
.09300	.1349	.8474	.6897	.9525	1.3810	.9391	.7241	1.695	2.630	2.814	.8221	.5670	10.37
.09400	.1357	.8528	.6925	.9600	1.3862	.9381	.7214	1.706	2.662	2.843	.8204	.5682	10.29
.09500	.1366	.8583	.6953	.9677	1.3917	.9371	.7186	1.717	2.693	2.873	.8187	.5693	10.21
.09600	.1375	.8639	.6982	.9755	1.3970	.9362	.7158	1.728	2.726	2.903	.8170	.5704	10.12
.09700	.1384	.8694	.7011	.9832	1.4023	.9353	.7131	1.739	2.757	2.933	.8153	.5716	10.04
.09800	.1392	.8749	.7039	.9908	1.4077	.9344	.7104	1.750	2.790	2.963	.8136	.5727	9.962
.09900	.1401	.8803	.7066	.9985	1.4131	.9335	.7076	1.761	2.822	2.994	.8120	.5737	9.884
.1000	.1410	.8858	.7093	1.006	1.4187	.9327	.7049	1.772	2.855	3.025	.8103	.5747	9.808
.1010	.1419	.8913	.7120	1.014	1.4242	.9319	.7022	1.783	2.888	3.057	.8086	.5757	9.734
.1020	.1427	.8967	.7147	1.022	1.4297	.9311	.6994	1.793	2.922	3.088	.8069	.5766	9.661
.1030	.1436	.9023	.7173	1.030	1.4354	.9304	.6967	1.805	2.956	3.121	.8052	.5776	9.590
.1040	.1445	.9076	.7200	1.037	1.4410	.9297	.6940	1.815	2.990	3.153	.8036	.5785	9.519
.1050	.1453	.9130	.7226	1.045	1.4465	.9290	.6913	1.826	3.024	3.185	.8019	.5794	9.451
.1060	.1462	.9184	.7252	1.053	1.4523	.9282	.6886	1.837	3.059	3.218	.8003	.5803	9.384
.1070	.1470	.9239	.7277	1.061	1.4580	.9276	.6859	1.848	3.094	3.251	.7986	.5812	9.318
.1080	.1479	.9293	.7303	1.069	1.4638	.9269	.6833	1.858	3.128	3.284	.7970	.5820	9.254
.1090	.1488	.9343	.7327	1.076	1.4692	.9263	.6806	1.869	3.164	3.319	.7954	.5828	9.191
.1100	.1496	.9400	.7352	1.085	1.4752	.9257	.6779	1.880	3.201	3.353	.7937	.5836	9.129
.1110	.1505	.9456	.7377	1.093	1.4814	.9251	.6752	1.891	3.237	3.388	.7920	.5843	9.068
.1120	.1513	.9508	.7402	1.101	1.4871	.9245	.6725	1.902	3.274	3.423	.7904	.5850	9.009
.1130	.1522	.9563	.7426	1.109	1.4932	.9239	.6697	1.913	3.312	3.459	.7888	.5857	8.950
.1140	.1530	.9616	.7450	1.117	1.4990	.9234	.6671	1.923	3.348	3.494	.7872	.5864	8.891
.1150	.1539	.9670	.7474	1.125	1.5051	.9228	.6645	1.934	3.385	3.530	.7856	.5871	8.835
.1160	.1547	.9720	.7497	1.133	1.5108	.9223	.6619	1.944	3.423	3.566	.7840	.5878	8.780
.1170	.1556	.9775	.7520	1.141	1.5171	.9218	.6592	1.955	3.462	3.603	.7824	.5884	8.726
.1180	.1564	.9827	.7543	1.149	1.5230	.9214	.6566	1.966	3.501	3.641	.7808	.5890	8.673
.1190	.1573	.9882	.7566	1.157	1.5293	.9209	.6539	1.977	3.540	3.678	.7792	.5896	8.621
.1200	.1581	.9936	.7589	1.165	1.5356	.9204	.6512	1.987	3.579	3.716	.7776	.5902	8.569
.1210	.1590	.9989	.7612	1.174	1.5418	.9200	.6486	1.998	3.620	3.755	.7760	.5907	8.518
.1220	.1598	1.004	.7634	1.182	1.5479	.9196	.6460	2.008	3.659	3.793	.7745	.5913	8.468
.1230	.1607	1.010	.7656	1.190	1.5546	.9192	.6433	2.019	3.699	3.832	.7729	.5918	8.419
.1240	.1615	1.015	.7678	1.198	1.5605	.9189	.6407	2.030	3.740	3.871	.7713	.5922	8.371
.1250	.1624	1.020	.7700	1.207	1.5674	.9186	.6381	2.041	3.782	3.912	.7698	.5926	8.324
.1260	.1632	1.025	.7721	1.215	1.5734	.9182	.6356	2.051	3.824	3.952	.7682	.5931	8.278
.1270	.1640	1.030	.7742	1.223	1.5795	.9178	.6331	2.061	3.865	3.992	.7667	.5936	8.233
.1280	.1649	1.036	.7763	1.231	1.5862	.9175	.6305	2.072	3.907	4.033	.7652	.5940	8.189
.1290	.1657	1.041	.7783	1.240	1.5927	.9172	.6279	2.082	3.950	4.074	.7637	.5944	8.146
.1300	.1665	1.046	.7804	1.248	1.5990	.9169	.6254	2.093	3.992	4.115	.7621	.5948	8.103
.1310	.1674	1.052	.7824	1.257	1.6060	.9166	.6228	2.104	4.036	4.158	.7606	.5951	8.061
.1320	.1682	1.057	.7844	1.265	1.6124	.9164	.6202	2.114	4.080	4.201	.7591	.5954	8.020
.1330	.1691	1.062	.7865	1.273	1.6191	.9161	.6176	2.125	4.125	4.245	.7575	.5958	7.978
.1340	.1699	1.068	.7885	1.282	1.6260	.9158	.6150	2.135	4.169	4.288	.7560	.5961	7.937
.1350	.1708	1.073	.7905	1.291	1.633	.9156	.6123	2.146	4.217	4.334	.7545	.5964	7.897
.1360	.1716	1.078	.7925	1.300	1.640	.9154	.6098	2.156	4.262	4.378	.7530	.5967	7.857
.1370	.1724	1.084	.7945	1.308	1.647	.9152	.6073	2.167	4.309	4.423	.7515	.5969	7.819
.1380	.1733	1.089	.7964	1.317	1.654	.9150	.6047	2.177	4.355	4.468	.7500	.5972	7.781
.1390	.1741	1.094	.7983	1.326	1.660	.9148	.6022	2.188	4.402	4.514	.7485	.5975	7.744
.1400	.1749	1.099	.8002	1.334	1.667	.9146	.5998	2.198	4.450	4.561	.7471	.5978	7.707
.1410	.1758	1.105	.8021	1.343	1.675	.9144	.5972	2.209	4.498	4.607	.7456	.5980	7.671
.1420	.1766	1.110	.8039	1.352	1.681	.9142	.5947	2.219	4.546	4.654	.7441	.5982	7.636
.1430	.1774	1.115	.8057	1.360	1.688	.9141	.5923	2.230	4.595	4.663	.7426	.5984	7.602
.1440	.1783	1.120	.8076	1.369	1.696	.9140	.5898	2.240	4.644	4.751	.7412	.5986	7.567
.1450	.1791	1.125	.8094	1.378	1.703	.9139	.5873	2.251	4.695	4.800	.7397	.5987	7.533
.1460	.1800	1.131	.8112	1.388	1.710	.9137	.5847	2.261	4.746	4.850	.7382	.5989	7.499
.1470	.1808	1.136	.8131	1.397	1.718	.9136	.5822	2.272	4.798	4.901	.7368	.5990	7.465
.1480	.1816	1.141	.8149	1.405	1.725	.9135	.5798	2.282	4.847	4.951	.7354	.5992	7.432
.1490	.1825	1.146	.8166	1.415	1.732	.9134	.5773	2.293	4.901	5.001	.7339	.5993	7.400

Figure 11: Table C-1(Shore Protection Manual, 1984)

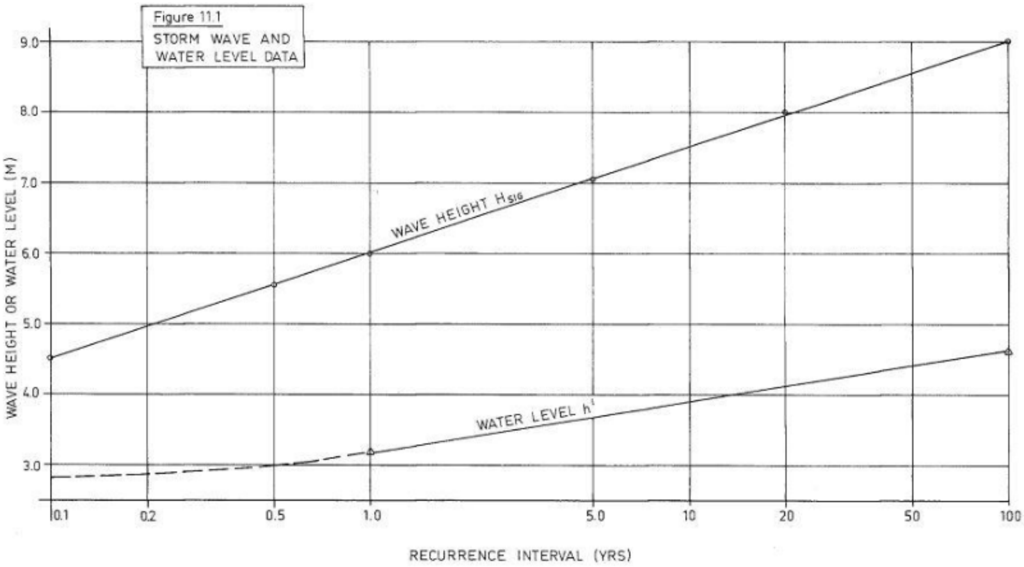

Figure 12: Storm Wave and Water Level Data (Massie, 1976)

Data from figure 11.1

Recurrence Interval (yrs)	H_{sig_o} (m)	T (s)	h' (m)	Wave length λ_o (m)	total depth h (m)	h/λ_o (-)	$\frac{H}{H_o}$ (-)	$\frac{H_o}{\lambda_o m^2}$ (-)	P (-)	γ (-)	H_{sig} (m)	frequency P ($\frac{storms}{year}$)	
0.1	4.5	7.4	2.8	85.	12.8	0.1506	0.9133	529.	0.1	0.49	4.1	10	
0.2	4.9	8	2.9	100.	12.9	0.1290	0.9172	490.	0.1	0.49	4.5	5	
0.5	5.5	9	3.0	126.	13.0	0.1028	0.9308	437.	0.1	0.49	5.1	2	
1	6.0	10	3.2	156.	13.2	0.0845	0.9487	385.	0.1	0.49	5.7	1	
5	7.0	11	3.7	189.	13.7	0.0725	0.9667	370.	0.1	0.49	6.7	0.2	broken wave
10	7.5	11.5	3.9	207.	13.9	0.0673	0.9766	362.	0.1	0.49	6.8	0.1	broken wave
20	8.0	12	4.2	225.	14.2	0.0631	0.9858	356.	0.1	0.49	7.0	0.05	broken wave
50	8.5	12.5	4.4	244.	14.4	0.0590	0.9958	348.	0.1	0.49	7.1	0.02	broken wave
100	9.0	13	4.6	264.	14.6	0.0553	1.006	341.	0.1	0.49	7.2	0.01	broken wave
500	10.0	14	5.1	306.	15.1	0.0493	1.025	327.	0.1	0.49	7.4	0.002	broken wave

Figure 13: Wave Shoaling (Massie, 1976)

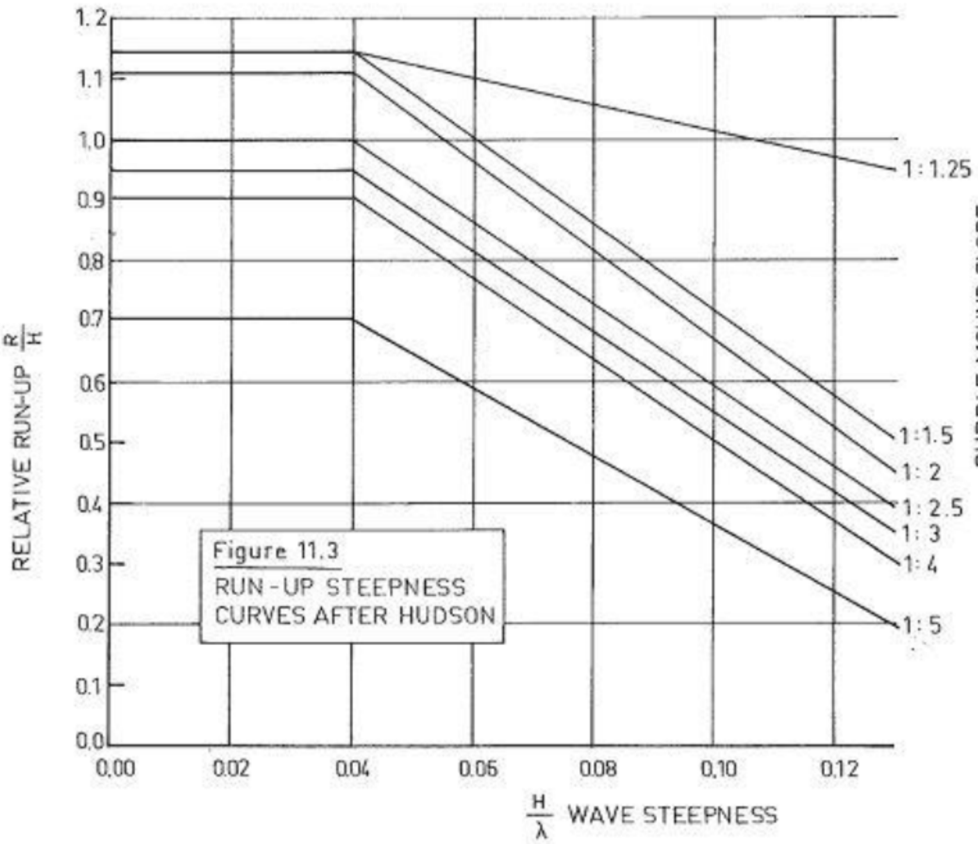

Figure 14: Run-up Steepness Curves After Hudson (Massie, 1976)

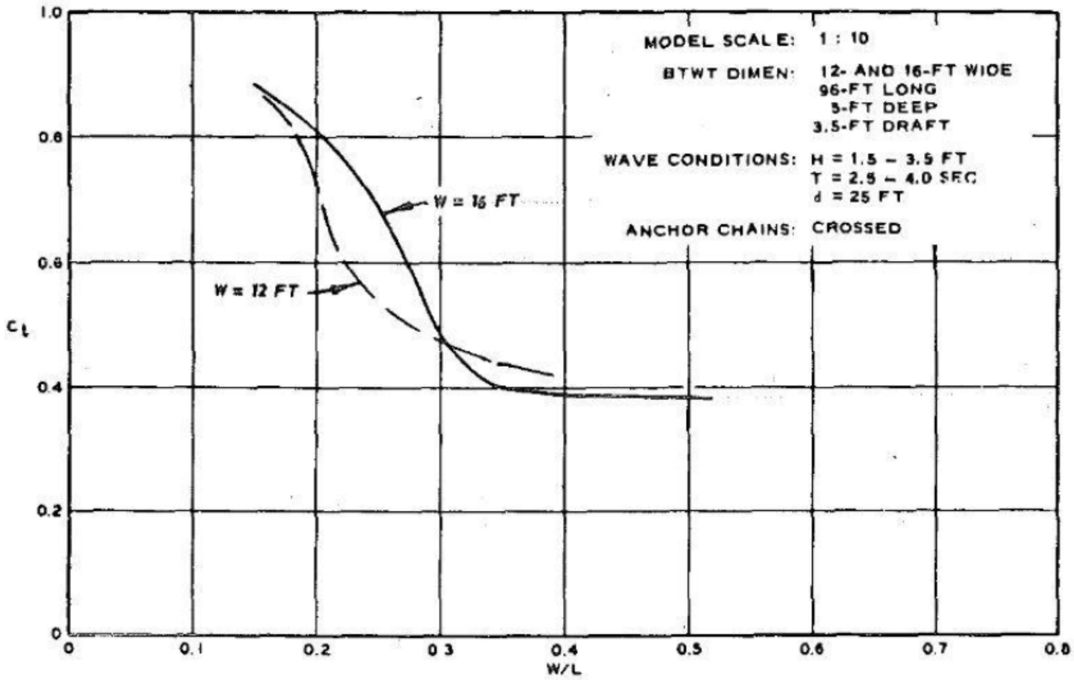

Figure 15: Wave Transmission Coefficient, C_t, versus W/L ratio, for Box-type Breakwater (McCartney, 1985)

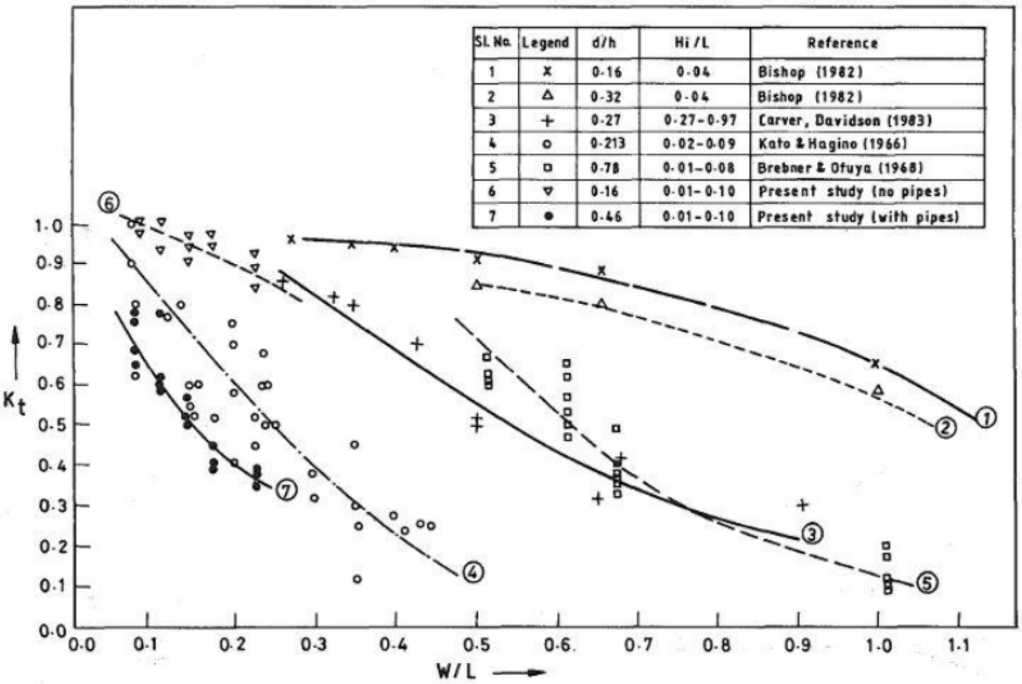

Figure 16: Variation of K_t with W/L - Comparison (Mani, 1991)

Table 13: Storm Data (Massie, 1976)

Recurrence interval (yrs)	Significant wave height, H_{sig} (m)	Period, T (s)	Water level relative to MSL (m)
0.1	4.5	7.4	
0.5	5.5	9	
1	6.0	10	3.2
5	7.0	11	
20	8.0	12	
100	9.0	13	4.6