THE COMBINATION OF LOW CRESTED BREAKWATER WITH MANGROVES TO REDUCE THE VULNERABILITY OF THE COAST DUE TO CLIMATE CHANGE

MUHAMMAD ARSYAD THAHA
Civil Engineering Department, Hasanuddin University, Jl. Perintis Kemerdekaan km 10, Makassar 90245, Indonesia.

A.B. MUHIDDIN
Civil Engineering Department, Hasanuddin University, Jl. Perintis Kemerdekaan km 10, Makassar 90245, Indonesia

The potential impacts of climate change on existing coastal hazards are likely to increase. During this century our coastline is likely to be impacted by climate change. Impacts such as sea level rise and an increase in frequency and severity of storm events are likely to lead to a greater coastal inundation and erosion. Hard approach protection has been used despite the expensive cost and less environmentally friendly. It is necessary to develop an eco-protection concept using vegetation or combination of vegetation with civil structures. Combined model is likely to be cheaper and is environmentally sounder.

This paper presents the results of experimental research on the performance of mangroves as shore protection (Thaha, 2003) combined with a low crested rubble mount breakwater by Seabrook & Hall (1998) in Płarczyk KW et al. (2003). The results showed a maximum wave transmission can be reduce 48% up to 85% for tidal ranges of 2.00 m for a 50 m width of composite structures with mangrove relative roots density in the range of 0.009 to 0.073. The increase of transmitted wave height through the LB-BW (without mangroves) due to the sea level rise can be reduced by combining it with mangrove forests where the mangrove wave damping capacity will increase by the growing of mangrove roots density. The combined equation of wave transmission coefficients consisting of both mangrove roots and low crest breakwater parameter is presented at the end of this paper.

1. Background

Rapid development has already occurred in coastal areas. Population growth and the demand for coastal living are ongoing pressures. The potential impacts of climate change on existing coastal hazards are likely to increase. Recently, the world identifies that the coastline is likely to be impacted by climate change. Impacts, such as sea level rise and an increase in frequency and severity of storm events, are projected likely to lead to a greater coastal inundation and
erosion that may cause damage and loss of property, infrastructure, and environment. There are three kinds of shore protection systems namely natural, artificial and combination of natural and artificial protection. The common type of natural protections are vegetation and sand dune, while the artificial systems have been widely developed in many types such as breakwater, groin, training jetty, sea wall, revetment, dikes and others. Problems of coastal vulnerability due to climate change can be solved with the above three methods; however the most beneficial is the natural protection. Protection by natural vegetation especially mangrove is expected to be effective to reduce the vulnerability of the beach due to the climate change. This is because of the flexibility of mangrove growth in adapting the changes of tidal zones owing to sea level rise (SLR). From the coastal engineering point of view, clumps of mangroves in general are located at shallow water depths up to a transition in tidal conditions. Strings of solid mangrove roots have the ability to disipate wave energy, to hold sludge and to protect the coast from erosion, tidal waves, and wind storm (Dahuri et al. 1996). The disadvantage of mangrove is that it is unable to grow on sandy beach; therefore, mangrove is confined to muddy shore areas only. It is necessary to consider techniques to optimize the protective function of mangroves, especially on a sandy beach area with medium sized waves. Model of combination of Low Crested rubble mount Breakwater (LC-BW) with mangrove, particularly of species rhizophora, with the application of simple technology, is expected to be a solution in reducing the vulnerability of the coast due to climate change.

2. Wave Transmission Over The LC-BW

LC-BW such as detached breakwaters and artificial reefs are becoming common coastal protection measures (used alone or in combination with artificial sand nourishment). Their purpose is to reduce the hydraulic loading to a required level that maintains the dynamic equilibrium of the shoreline. To attain this goal, they are designed to allow the transmission of a certain amount of wave energy over the structure by overtopping and also some transmission through the porous structure (exposed breakwaters) or wave breaking and energy dissipation on shallow crest (submerged structures). The first complete set of transmission characteristics for exposed and submerged breakwaters/reefs were presented by Tanaka (1976) and Uda (1988) in Pilarczyk K.W et al. (2003), included in the scope of the preparation of Japanese Manual on Artificial Reefs (Yoshioka et al., 1993 in Pilarczyk K.W et al., 2003). These graphs are based on tests with regular waves and expressed in deep water wave parameters. Further comprehensive research has been performed by Seabrook & Hall (1998) and the result was presented in formula (Pilarczyk K.W et al., 2003):
\[
C_t = 1 - \left[ 0.047 \frac{B_d}{L_d} - 0.067 \frac{H_d}{B_d} + \exp \left(-0.65 \frac{d}{H_i} - 1.09 \frac{H_i}{B} \right) \right] \tag{1}
\]

where, \(d\) = water depth on structure crest; \(H_i\) = incoming wave height; \(B\) = crest width of LC-BW; \(L\) = wave length; \(d_{50}\) = mean diameter of LC-BW materials.

Delft Hydraulics (2002) in Pilarczyk K.W et al. (2003) had used the formula for validation of result of physical modelling of wave transmission by submerged breakwaters for AmWaj Island Development Project in Bahrain. This formula will be used in combination with mangrove protection formula for developing combined equation for designing combined system.

3. Technical Performance of Vegetation as Wave Damper

Research on the reduction in wave height that extends through the clumps of plants conducted among others by Boeters et al. (1993), Dubi A. and Torum A. (1993) in Verhagen (1998). Boeters et al. examined the wave height reduction by reed plants (a type of small plants with sturdy stems, found in the Netherlands) that have a growing density of 100-400 trees/m². The results were presented in the form of empirical equations where the transmission coefficient is the exponential function of parameter of \(H_b\) (transmitted wave height), \(B\) (wide clump of plants), \(H_i\) (incoming wave height), \(C_h\) is Chezy coefficient of reed plants \((C_h = 0.05\) in clumps with a range 125 trees/m² and \(C_h = 0.12\) for the range of 400 trees/m²), and \(\theta\) (angle of incidence wave). Dubi A. and Torum A. (1993) examined the wave height reduction by kelp plant (laminaria Hyperborean) one macroalga species that is widely available in Norway as under water plants with a height of 1-2 meters with a growing density ranging from 10-15 trees/m². The results are also in the form of empirical equations in exponential function of the width parameter plant clumps of kelp \((B)\). According Schiereck & Booij (1995) in Verhagen (1998) although not yet verified, the equation of the reed plants are assumed can be used for mangrove with a value of \(C_h\) mangrove ranging from 10 to 20 (m⁰.⁵/s) and the value of \(C_h = 20\) (m⁰.⁵/s) for dense forest. Study on the wave damping by rhizophora shrub (one of the famous mangrove species such shown in Figure 1a) have been performed by Thaha et al. (2003). Physical model simulations in laboratory have been conducted in the scale model 1 to 10. There are 9 types of model varied in root density \((\zeta)\) and shrub thickness \((B)\) have been simulated, each with 3 values of wave height and period in a water tank of 18 m length and 1 m width. The result was presented in the form of empirical formulation where the wave transmission coefficient \((C_t)\) in a dimensionless variable such written below:
Relative root density ($\zeta$) depends on average number of roots on each tree of rhizophora and density of plant. The value of $\zeta$ is calculated from occupied volume of root (submerged volume of roots) divided by certain water volume. Figure 1b) shown that the value of $\zeta$ much affected by nos of roots and plant density. The value of $\zeta$ will increase as one or both variables increase. Mangrove trees density ($T_d$) were classified into 3 categories namely low density ($T_d \leq 0.25$ nos/m²), moderate density ($0.25$ nos/m² $< T_d < 1$ nos/m²) and high density ($T_d \geq 1$ nos/m²).

4. The Combination LC-BW with Mangroves

LC-BW is an inflexible system of protection, while the mangrove as a green belt is a flexible protection system. It is estimated that the combination of both would compensate the disadvantages of each other and give better sharing in reducing wave height as well as maintaining the coastal environment. Model combination (LC-BW with Mangroves) is intended to get an effective, efficient and environmentally friendly coastal protection system. Combined model is expected to have sufficient and sustainable effectiveness to protect beaches from
erosion and/or abrasion due to the threat of sea level rise, and for coastal stabilization by combining the capabilities of each in reducing wave. Efficiency can be achieved both from the rubblemount structure of LC-BW with a smaller volume of material compared with non-overtopping breakwater, and from the plantation of mangroves is relatively easy and not costly. From the environmental aspect, the model can be considered as eco-protection system in addition to its role in protecting the coast. It also plays an important role in supporting the ecological environment to control the global warming. This model is also strongly supports the development of a coastal city to become the Water Front Green City, which is recently a topic of discussion in reducing the impacts of climate change. Thickness composition of the LC-BW and Mangroves could be varied to reduce the wave height up to certain scale. Figure 2 shows a typical section of the protection model LC-BW combination with Mangroves.

![Diagram](image)

Figure 2. Typical section of combined model LC-BW with Mangroves

Total width \( (B) \) of the combination model as shown in Figure 2 consists of the width of LC-BW \( (B_1) \) on the sea side and the width of Mangroves \( (B_2) \) on the land side. A maximum non breaking waves propagate pass through the combination model under High Water Level (HWL) will be the focus of study. The best level of structure crest is slightly above the Low Water Level (LWL). The incoming wave height \( (H_i) \) that propagate insert the LC-BW area will reduce to transmitted wave height \( (H_{t1}) \) by friction of LC-BW material on the width of \( B_1 \) which can be calculated with the formula \( H_{t1} = C_{t(1)} \times H_i \) where \( C_{t(1)} \) is \( C_t \) in Equation (1). Transmitted wave height \( (H_{t(2)}) \) above the LC-BW crest will then be transmitted into \( H_{t(2)} \) after passing through the Mangroves width of \( B_2 \) which can be calculated with Equation (2). Thus, the \( H_i \) in Equation (2) is \( H_{t(1)} \) or \( C_{t(1)} \times H_i \). Therefore, the Equation (2) can then be rewritten:
\[ C_{t(2)} = H_{t(2)} \frac{H_{i}}{H_i} = m \exp\left( -n\zeta C_{t(1)} H_{i} B_{2} \frac{2}{L_{c}^{2} \cos \theta} \right) \]  \hspace{1cm} (3)

with \( C_{t(2)} \) = combined transmission coeff.; \( H_{t(2)} \) = transmitted wave height through Mangroves; \( C_{t(1)} \) = \( C_t \) in Equation (1); \( H_i \) = incoming wave height; \( L_c \) = wave length over the LC-BW.

4.1. The Effect of Relative Mangrove Density

The effect of relative root density of Mangroves (\( \zeta \)) will be studied in 2 categories, Low Density of Mangrove (LD Mangrove) and High Density of Mangrove (HD Mangrove). A width of 50 m will be tried for combination model by simulation with various composition of \( B_1 \) and \( B_2 \) using possible maximum incoming wave height \( (H_i) = 1.10 \) m; wave period \( (T) = 8 \) s; water front depth \( (h) = 5.80 \) m; water depth over the crest \( (d) = 1.50 \) m and mean diameter of rubble \( (d_{50}) = 0.62 \) m. As a representation of LD Mangroves used \( \zeta = 0.009 \) (obtained from Figure 1b), then the influence of LD Mangrove to the transmission coefficient \( C_{t(2)} \) hereinafter referred to as \( C_t \) is calculated with equation (3) and the results are presented in Figure 3a). While, the influence of HD Mangrove (representing by \( \zeta = 0.039 \)) is presented in Figure 3b).

\[
\begin{array}{c}
\text{a) } C_t \text{ for LD Mangrove} \\
\text{b) } C_t \text{ for HD Mangrove}
\end{array}
\]

Figure 3. Relationship between \( B_2/B \) with \( C_t \) for LD & HD Mangrove.

Figure 3a) shows \( C_t \) curve for LC-BW, LD Mangroves, and a combination of both. LD Mangrove curve shows the greater the value of \( B_2/B \) (in the range of 0.1 to 0.9) the lower \( C_t \) values in the range of 0.86 to 0.74. On the LC-BW curve shows for greater value of \( B_2/B \) (or smaller value of \( B_1/B \) \( C_t \) values increase in the range of 0.52 to 0.70. The combination curve shows that \( C_t \) values increase...
slightly in the range of 0.44 to 0.52. These results indicate that the influence of LC-BW to the \( C_t \) is more dominant for low value of \( \zeta \). Nevertheless, the influence of LD Mangrove on \( C_t \) is significant enough (see deviation of LC-BW (A) curve and Combined (A + B) curve in Figure 3a). Curve of HD Mangroves in Figure 3b) shows that the greater value of \( B_2/B \) (in the range of 0.1 to 0.9) the smaller of the \( C_t \) values in the range of 0.83 to 0.46. On the LC-BW curve shows for greater value of \( B_2/B \) (or the smaller value of \( B_1/B \)) \( C_t \) values increase in the range of 0.52 to 0.70. The Combination curve shows that the \( C_t \) values decrease much more in the range of 0.42 to 0.32. These results indicate that the influence of Mangroves to the \( C_t \) is more dominant for high value of \( \zeta \). HD Mangrove has much significant influence on the \( C_t \) (see deviation of LC-BW (A) curve and Combined (A + B) curve in Figure 3b).

4.2. The Sensitivity of Combined Model to the Sea Level Rise (SLR)

Global warming will cause sea level rise. If predicted sea level rise is about 50 cm/100 years or 15 cm/30 years, then in the next 30 years and 50 years into the future sea-level elevation (HWL) will rise 15 cm and 25 cm from the current level. To test the sensitivity of the \( C_t \) against sea level rise, then a simulation have been performed to measure the effect of the increased density of mangrove roots in 5 years by 10%, 20% and 30%. Base line condition is young mangroves with low density values about \( \zeta = 0.009 \), the number of roots is still minimum. Simulation results are presented in Figure 4a), Figure 4b) and Figure 4c).

![Figure 4a)](image1)
![Figure 4b)](image2)
![Figure 4c)](image3)

Figure 4. The sentivity of \( C_t \) under SLR condition due to the increasing value of \( \zeta \) in 5 year.
From Figure 4a) shows that the increasing value of $\zeta$ for 10% within five years gave a significant effect in reducing the $C_t$ values from the base line ranging from 0.44 to 0.52 in a SWL + 2.00 (or about 56% to 48%) become 0.42 to 0.47 in a SWL + 2.15 and become 0.41 to 0.43 on a SWL + 2.25. Nevertheless, that the curve tends to rise in the high value of $B_2/B$ suggests that the influence of LC-BW is still more dominant than the mangrove. In contrast to the increase value of the $\zeta$ by 30% within 5 years as shown in Figure 4c) in which $C_t$ values decrease drastically from the base line range from 0.44 to 0.52 on a SWL + 2.00 become to 0.41 to 0.33 on a SWL + 2.15 and 0.38 to 0.15 on a SWL + 2.25 or about 62% to 85%. The drastic decline trend of $C_t$ curve in the greater value of $B_2/B$ indicates that the influence of Mangroves is more dominant than the LC-BW. The computation results are presented in the relationship between crest water depth ($d$) as a representative of sea level rise with transmitted wave height both without and with mangroves ($H_{t1}$ and $H_{t2}$) on the increasing $\zeta$ value by 10%, 20% and 30% as shown in Figure 5. It shows that the LC-BW transmitted wave height without mangroves ($H_{t1}$) in the various widths ranging from 5 m to 45 m increase from 0.64 m to 0.72 m on a SWL + 2.15 and continues to increase to 0.76 m in the SWL + 2.25. Much different results shown by the curve of the wave transmission in the combined model (LC-BW + Mangroves), where the increasing $\zeta$ of 10% within 5 years, the transmitted wave height ($H_{t2}$) can be maintained in the constant value approximately 0.51 m - 0.56 m although incoming wave height ($H_i$) increase from 1.1 m to 1.35 m. Moreover, if the $\zeta$ value increase 20% and 30%, then the transmitted wave height to be decreased 0.47 m and 0.35 m respectively or 91.26% and 69.13% respectively although both water depth ($d$) and wave height ($H_i$) increase due to the SLR.

Figure 5. Comparison of transmitted wave height with and without mangrove.
5. Conclusions and Recommendations

1. LC-BW is an inflexible system of protection, while the mangrove as a green belt is a flexible protection system. LC-BW has the ability to reduce a large wave height while mangroves can improve its ability to dampen wave height with increasingly dense of both plants and roots. The nature of this flexibility seems to be an alternative solution to the increasing threat of coastal vulnerability due to climate change.

2. Additional mangroves layer into the LC-BW is able to retain or even decrease the transmitted wave height despite the increase of both incoming wave height and water depth due to the sea level rise. This capability is generated and developed by the increase of mangrove roots density with age, and density of plants. When the wave propagate over the 45 m width of LC-BW without mangrove, transmitted wave height will increase by 19% for the sea level rising of 25 cm. While, in the addition to mangrove layers, the increase of 10% of the mangrove density within 5 years can retain the increase of transmitted wave height. Moreover, an increase density of mangrove up to 30% within 5 years could reduce the transmitted wave height up to 69%.

3. Combined model can be applied either as a breakwater or revetment. Applications in the field can be done on a sandy beach by preparing the plantation of mangrove areas at the rear side of the LC-BW filled with mud substrack, and by protecting with geotextile sheet at the base as well as on the soil surface. In the early growth phase, it must be maintained that the wave does not hit the plant. This can be done either by LC-BW itself or by using temporary protection until the roots become stronger.

4. It is expected that the proposed model (called eco-protection system) can be an alternative solution in reducing the impact of global warming and that it can also be applied for the development of Water Front Green City.

References


