WAVE TRANSMISSION AND DISSIPATION COEFFICIENTS OF A MODIFIED ARTIFICIAL MANGROVE ROOT SYSTEM

GOH HOOI BEIN

A thesis submitted in fulfillment of the requirements for the award of the degree of Master of Civil Engineering (Coastal and Maritime)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

August 2009

ABSTRACT

A modified Artificial Mangrove Root System (ArMS) has been proposed to improve the earlier model presented by Eldina (2007). The system may act as an alternative protection structure during the replanting of the young mangrove seedlings while enhancing to protect the marine life and shoreline. ArMS is designed to be porous enough so that it facilitates the exchange of water around it and allows sedimentation. Technically, ArMS acts as a partially or fully submerged breakwater which dissipates the incoming wave energy by the process of breaking, friction and transmission. Laboratory studies with a series of regular waves were conducted for 1-row, 2-row, 3-row, 4-row, and 5-row ArMS to determine the hydraulic performance in terms of its efficiency in reducing the incident wave and local velocities in various geometry and wave conditions. Wave attenuation coefficient was investigated by determining the transmission, reflection, and energy loss coefficients. The parameters that affect the wave attenuation are wave length, wave height, water depth, water velocity, and wave period. *Funke and Mansard* method was adopted to separate the incident and reflected wave. Transmitted waves were measured behind the model structure. Empirical equations to predict transmission, reflection and loss coefficients were derived using multiple linear regression analysis. The analytical predictive equations were developed using H_i/L, B/L, d/L, and d_s/d as the predictive variables. Experimental results showed that wave attenuation depends strongly on the structure geometrical factors. It increases as the width of the structure increase, or exposed to long wave length or period, or when the water depth is relatively large. On the other hand, line configuration of ARMS was found to have lower wave transmission compared to staggered configuration. ArMS gap effect is not significant in affecting wave attenuation performance. In general, the predicted data from derived analytical equations agreed well with the observed data. The comparison between the present and previous ArMS model found that the present model (0.63 porosity) produced lower wave transmission coefficient compared to the previous models (0.94 and 0.95 porosity).

ABSTRAK

Rekabentuk semula Sistem Akar Bakau Tiruan (*Artificial Mangrove Root System*-ArMS) daripada Eldina (2007) telah dilakukan dalam kajian ini. Sistem ini bertindak sebagai struktur pelindung alternatif untuk melindungi proses penanaman semula bakau, di samping sebagai pelindung kepada habitat hidupan laut dan garisan pantai. ArMS direkabentuk dengan keporosan yang mencukupi agar proses pertukaran air boleh berlaku di sekelilingnya dan membenarkan pemendapan. Secara teknikal, ia bertindak sebagai pemecah ombak separa atau tenggelam untuk melemahkan tenaga ombak melalui proses pemecahan, penggeseran, dan pemindahan. Kajian makmal bagi sesiri ombak seragam telah dilakukan ke atas 1-baris, 2-baris, 3-baris, 4-baris, dan 5-baris ArMS untuk mengenalpasti perlakuan hidraulik terhadap keberkesanannya mengurangkan ombak insiden dan halaju sekeliling dalam pelbagai geometri dan keadaan ombak. Pekali pelemah ombak dikenalpasti dengan menentukan pekali ombak hantaran, pantulan dan tenaga lesap. Antara parameter yang mempengaruhi pelemah ombak adalah panjang ombak, tinggi ombak, kedalaman air, halaju air dan tempoh masa ombak. Kaedah *Funke and Mansard* telah digunakan untuk mengasingkan ombak insiden dan ombak pantulan. Ombak hantaran pula diukur di belakang struktur model. Persamaan empirikal untuk meramal pekali ombak hantaran, pantulan, dan tenaga lesap telah diperolehi dengan menggunakan analisis regresi linear berganda. Persamaan peramal analitikal dibangunkan dengan H_i/L, B/L, d/L, dan d_s/d dianggap sebagai pembolehubah peramal. Keputusan eksperimen menunjukkan bahawa pelemah ombak dipengaruhi oleh faktor geometri struktur. Pelemah ombak akan meningkat apabila kelebaran struktur bertambah, atau terdedah kepada ombak atau tempoh ombak yang panjang, atau kedalaman air yang tinggi. Di samping itu, susunan ARMS berbaris menghasilkan hantaran ombak yang lebih kecil berbanding dengan susunan berperingkat. Kesan ruang pemisah antara ArMS tidak begitu mempengaruhi keupayaan pelemah ombak. Secara keseluruhan, didapati bahawa data yang diramal daripada persamaan empirikal setara dengan data yang diperolehi daripada pemerhatian. Perbandingan antara model terdahulu dan yang direkabentuk semula mendapati bahawa model yang direkabentuk semula (keporosan 0.63) menghasilkan pekali ombak hantaran yang lebih rendah berbanding dengan model terdahulu (keporosan 0.93 dan 0.94).

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

The demand for new mangrove areas or enhancement of degraded mangroves is increasing to this day. According to Muhammad Akhir Othman (1994), nearly 30% of the coastline of Malaysia is undergoing erosion. Many of these areas are coastal mudflats, fringed by mangroves. Mangroves are forested wetland that are located in the upper intertidal zones of the tropics (Wu, et al., 2001). Mangroves play important roles in the nutrient cycle of tropical estuarine ecosystem, marine coastal ecological systems maintenance, sustaining the aquaculture, tropical shoreline stabilization and etc. Yet, activities such as land reclamation, shrimp farming, timber and charcoal production without control throughout the world destroyed the mangrove forest. From the view of coastal engineering, over cutting of mangrove forest may lead to a significant impact on shoreline erosion.

Mangroves are known to reduce wave energy as waves travel through them. It is an eco-friendly structure that can protect sensitive shorelines. Behind the mangroves, there are usually agricultural areas that are protected by bunds from tidal inundation. Thus, mangroves are used to protect the bunds from eroding. However, mangroves themselves are susceptible to erosion. The approaches to use conventional concrete breakwaters to protect the new mangroves areas are not advisable as this solution is too heavy, expensive as well as not environmentally safe.

According to Nyandwi (2001), beach structures, although are able to protect the beach, also could cause erosion. Therefore the construction of sea walls, jetties etc. must consider on their effects on the environment. Finding the best method in using natural system of coastal protection is therefore necessary.

Recognizing the benefits of mangrove forests, efforts have recently been made in some countries to re-establish the mangrove forests. (Wu, et al., 2001 and Hadibah Ismail, et al., 2005, Eldina, et al., 2005, and Eldina, 2007). Due to the consideration of protecting the mangrove forests, Eldina (2007) initiated an approach to replicate the mangrove root system itself as a coastal protection structure. The replicated structure, known as ArMS (Artificial Mangrove Root System), was designed by simplifying the complicated mangrove root system into a simple and easy-to-construct porous submerged structure. The root system was designed to follow a streamline shape and interconnected creating a very porous natural barrier. Besides, it is also designed to be placed in the inter-tidal zone to protect the mangrove or wetland habitat restoration while considering the aesthetic factor as for ecotourism point of view and with least impact to the environment. The mangrove root system was constructed with small sized steel bars called main roots that are welded on the trunk, layer by layer. The definition sketch and details of the ARMS model with the porosity of 0.94 are shown in Figure 1.1. The model with a porosity of 0.94 is constructed similar to the porosity of 0.95 with the same diameter steel bar but containing 9 layers with a gap between layers of 2 cm vertically as illustrated in Figure 1.2.

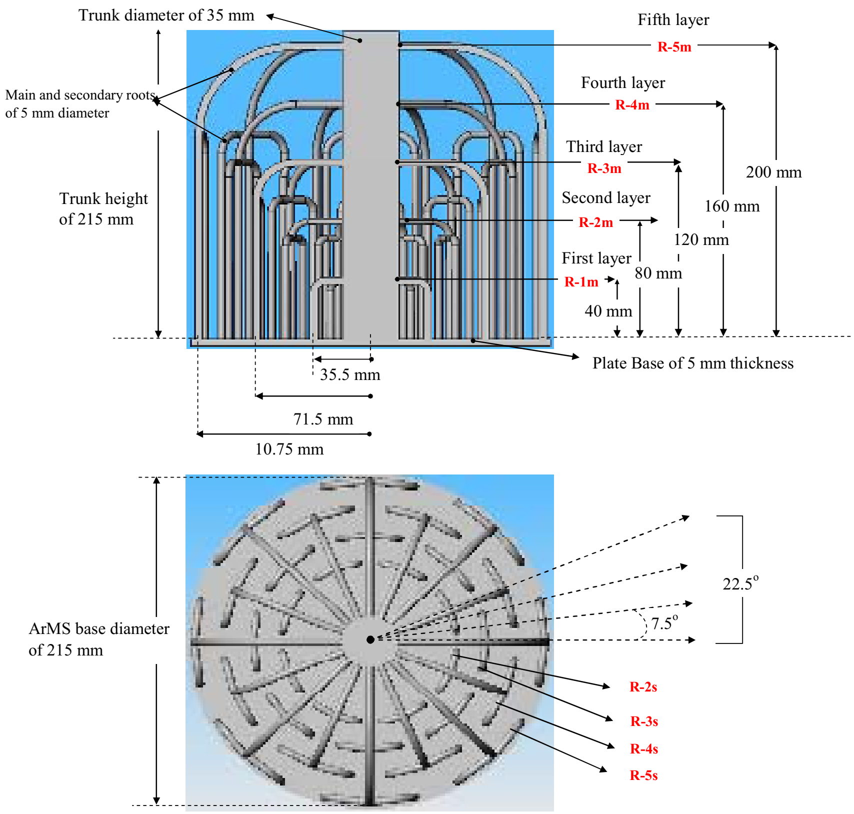

Figure 1.1 Definition sketch and details of a unit of ArMS structure of 0.95 porosity (Eldina, 2007)

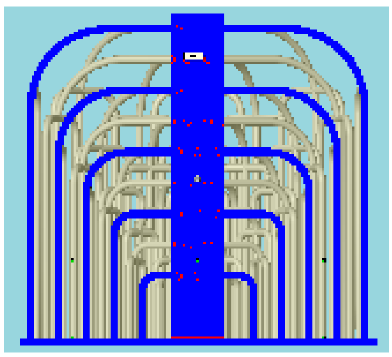

Figure 1.2 Slice section of a unit of ArMS model of 0.94 porosity (Eldina, 2007)

Physical experiments and numerical modeling were conducted by Eldina (2007) to study and investigate the mechanism of wave transmission and reflection, under a wide range of design conditions. The observation of porosity effects from her experimental results are plotted in Figure 1.3.

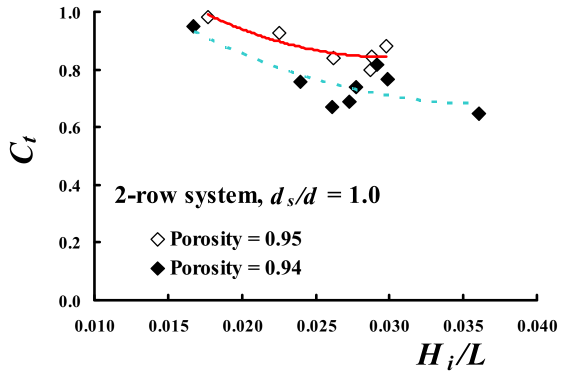

Figure 1.3 Effect of porosity on H_i/L and C_t at d_s/d = 1.0 of 2-row system (Eldina, 2007)

From the results obtained, it was found that for a 2-row ArMS system, with porosity = 0.94 it transmitted wave energy lower than that of an ArMS system with porosity = 0.95. It shows that reducing the porosity of a unit ArMS will decrease wave transmission. However, Eldina (2007) indicated that a structure with a higher porosity is preferred so as to protect the wetland habitat rehabilitation zone. Based on Eldina (2007)'s observation, modifications for improving the existing ArMS structure are found to be necessary.

It is advisable to minimize the transmission of wave energy through a breakwater. According to Eldina (2007), a structure with higher porosity transmitted more wave energy than a lower porosity structure. Therefore a reduction of porosity for the existing ArMS model was made. The porosity of the structure developed is reduced from 0.95 and 0.94 to 0.63.

In this research, a High Density Polyethylene (HDPE) was used to replace the steel which was used to construct the earlier ArMS models. The reason for material replacement is mainly to solve the corrosion and costing problem. HDPE is a material that will not be corroded by the sea water, and it can be obtained easily in various sizes in the market with much lower cost than steel.

From the structural engineering perspective, there are several limiting conditions which, if exceeded, can lead to failure of the designed ArMS. A larger base is designed for the existing ArMS structure in order to avoid the overturning problem. Besides, the bending stress failure which is directly related to pipe deflection need to be considered as well. Corrugated Polyethylene Pipe Association (1996) recommended that every pipe size should not exceed HDPE's bending stress limits of 3,000 psi at deflection levels of 5%. Therefore, the initiative to bend the main root of each layer at 90 degrees is not possible anymore when using HDPE for the modified ArMS model.

The model developed by Eldina (2007) consists of five layers of the main roots, the gaps between layers are 4.0 cm vertically, and the placement of the layer follows a staggered form. Each layer contains 8 pieces of main roots of 5.0 mm diameter with a clear spacing of 0.9 cm. Therefore the modified model structure is simplified by reducing the number of layers of the root system in order to reduce the complexity of the existing model.

The studies of the modified ArMS model that altered the wave motions are yet to be investigated. Moreover, the turbulence intensity might be increased in the vicinity of the structure due to flow separation which is especially true for porous coastal structures have yet to be verified (Losada, et al., 1995).

Modification to design guidelines which requires theory of complex marine processes around the modified ArMS system also needs to be established. Wave transmission and overtopping are the two phenomena that allow wave energy to pass over or through the ArMS structure. The other part of the wave energy will be dissipated by wave breaking on and over the structure and some of the energy will be reflected. The prediction of the amount of energy transmitted behind them is a crucial point in design practice for generating the design formulae for wave transmission of the ArMS structure.

1.2 Research Objectives

The objectives of the research are as follows:-

- To modify the existing Artificial Mangrove Root System developed by Eldina (2007) in the expectation that it may improve the wave dissipation performance.

- To investigate the influences of wave height, wave period, water depth, width of the structure (in terms of row numbers), velocity, structure arrangement configurations, gap, depth of submergence of the modified model due to various configurations and flow conditions in a physical model of the modified Artificial Mangrove Root System by studying its wave transmission, wave reflection and energy loss characteristics.

- To determine the velocity profile changes around the mangrove root system.

- To derive empirical relationships of the model in order to predict the hydrodynamic behavior of the mangrove root system as a means to optimize the design configuration for mangrove restoration and replanting projects.

1.3 Scope of Research

The characteristic of flow passing the Artificial Mangrove Root System and the engineering services that the roots may provide were studied and/or quantified (Hadibah Ismail, et al., 2005). The physical measurements of the hydrodynamic interaction of the waves and water levels with respect to ArMS system alignment have been investigated by determining the hydraulic performance of the mangrove root system in dissipating wave energy.

In this research, the performance of the modified ArMS design is expected to be varied with mangrove arrangement, gap, wave height, and water depth. The transmission coefficient, K_T for the modified model structure will be defined using relationships with non-dimensional parameters obtained from laboratory measurements of currents, waves and water depths. Besides, the velocity profile before and after the ArMS system will be determined as well.

The scope of work mainly includes model design and some other development processes involved for the artificial mangrove root system. Most of the design criteria of the ArMS structure were derived according to the specifications of the previous model. The modified structure is expected to have improved its efficiency in wave dissipation. It also should be porous enough in a way that it should facilitate the exchange of water around it and allow sedimentation to happen.

In promoting the use of bio-technical or bio-engineering approaches to coastal protection, established scientific investigations and wave-structure interactions on the proposed artificial mangrove root system hydrodynamics have been investigated. A series of laboratory experiments was conducted to investigate the hydrodynamic response in a one-dimensional hydraulic wave flume available at Coastal and Offshore Engineering Institute (COEI), UTM *International Campus*. The setting up of the laboratory experiment for the hydrodynamics test was conducted under the wave only condition. The estimations of wave reflection and transmission are useful in characterizing the effectiveness of the structure, the detailed velocity measurements are essential for the understanding of the physical process involved. According to Sakakiyama (2002), the detailed velocity measurements are essential for validating any mathematical/ numerical models that are to be used for designing a coastal structure.

Finally, the dimensionless variables to describe the hydraulic properties of wave and ArMS system interaction were developed. The data collected from laboratory studies are used for the derivation of empirical equations using Multiple Linear Regression Analysis. Different functions were tried in order to yield the empirical equations with the best correlation. The computation was made using SPSS

vii. The data collected from laboratory studies for the derivation of empirical equations should be verified by conducting site specific prototype studies.

REFERENCES

Abdul Khader, M. H., and Rai, S. P. (1981). *Wave attenuation due to closely spaced circular cylinders*. In Proc. of the Intnl. Assoc. for hydraulic Research, XIX Congress, New Delhi, 1981. pp. 93-102.

Allsop, N. W. H., Francol, L., Bellotti, G., Bruce, T. and Geeraerts J. (2005). *Hazards to people and property from wave overtopping at coastal structures*. In Coastlines, Structures and Breakwaters 2005 (Allsop N. W. H. (ed.). Thomas Telford, London, 2005, pp.153–165.

Alvarez, E., Rubio, R. and Ricalde, H. (2006). *Shoreline restored with geotextile tubes as submerged breakwaters, Back to the beach in México.* Geosyntehtics, 2006. Vol. 24, No. 1, pp. 20-27, IFAI, EUA.

Alvarez, E., Rubio, R. and Ricalde, H. (2005). *Beach Restoration with geotextile tubes as submerged brakewaters in Yucatán, México., Articulo de Simposium internacional* "Tsunami Reconstruction with Geosynthetics - Protection, Mitigation and rehabilitation of Coastal and Waterway Erosion Control". Bangkok, Tailandia. Diciembre, 2005.

Armono, H. D. (1999). *Flow Field around Single and Multiple Hollow Hemispherical Artificial Reefs used for Fish Habitat.* Master Thesis. Memorial University of Newfoundland. St. John's Newfounland, Canada.

Armono, H. D. (2003). *Hemispherical Shaped Artificial Reefs*. Ph.D. Thesis. Queens University. Kingston, Canada.

Avgeris, I., Prinos, P. and Karambas, T. V. (2002). *Effects of porous submerged breakwaters on wave evolution in shallow waters.* In: Proceedings of 5th International Conference on Hydroscience and Engineering, Warsaw, Poland.

Balaji, R. and Sundar, V. (2002). *Hydraulic Performance of Double Screen Breakwaters*. Proc. 5th Intl. Conf on Hydro-Science & Engg, Warsaw Univ. of Tech., Sept 18-21, 2002, Theme E, paper NO: 58.

Bridgman, P. W. (1963). *Dimensional Analysis.* New Haven, CT: Yale University Press.

Brinkman, R. M., Massel, S. R., Ridd, P. V. and Furakawa, K. (1997). *Surface wave attenuation in mangrove forests*. Proceedings of the 13th Australasian Coastal and Ocean Engineering Conference 2:941–79.

Burger, B. (2005). Wave *attenuation in mangrove forests: Numerical modeling of wave attenuation by implementation of a physical description of vegetation in SWAN.* MSc thesis. Delft University of Technology. September 2005.

Coastal Engineering Research Center. (1984). "Shore Protection Manual, Vols. I & II. ," U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Corrugated Polyethylene Pipe Association (1996). *HDPE Pipe Deflection: The Bending Stress Problem*. *Structural Design Method for Corrugated Polyethylene Pipe*, Corrugated Polyethylene Pipe Association.

Danehy, R. J. and James, M. H. (1996). *Stream Habitat Quantification by Use of the Froude Number.* Stream Systems Technology Center. Quarterly newsletter. Stream Notes.

Davis, R. and FitzGerald, D. (2004). *Beaches and Coasts*. Malden (MA)/Oxford/Victoria (Australia): Blackwell Press. 419 pp.

de Vos, W.J. (2004). *Wave attenuation in mangrove wetlands Red River Delta, Vietnam.* Master thesis Civil Engineering and Geosciences. Delft University of Technology. June 2004.

Dean, R. G., and Dalrymple, R. A. (1991). Water Wave Mechanics for Engineers and Scientists. World Scientific, Singapore, 353 pp.

Eldina Fatimah (2007). *Hydraulic Performance of an Artificial Mangrove Root System.* Ph.D. Thesis. Universiti Teknologi Malaysia.

Eldina Fatimah, Hadibah Ismail, Ahmad Khairi Abdul Wahab (2005). *Preliminary Investigations On Wave-Structure Interactions of an Artificial Mangrove Root System (ARMS).* Proceedings of Seventh Annual Institution of Engineers Water Resources Colloquium, Petaling Jaya. June 2005; pp. 1-1 – 1-10.

Franks, T. and Falconer, R. (1999). *Developing procedures for the sustainable use of mangrove system*. Agricultural Water Mangement 40. pp. 59-64.

Friebel, H.C. and Harris, L.E. (2004). *A new wave transmission coefficient model for submerged breakwaters*. 29th International Conference on Coastal Engineering. Lisbon, Portugal. September 19-24, 2004.

Furukawa, K., Wolanski, E., Mueller, H. (1997). *Currents and sediment transport in mangrove forests, Estuarine*. Coastal and Shelf Science Vol. 44, no. 3, pp. 301-310.

Goda, Y. (2000). *Random Seas and Design of Maritime Structures,* 2nd Ed. World Scienticfic Publishing Co. Inc. Singapore. 443 pp.

Gordon, G. T. (2000) *Wave Transmission on Multi-layered Wave Screens*. Master of Science (Engineering) Thesis. Queen's University, Kingston, Ontario, Canada.

Hamill, L. (1999). *Bridge Hydraulics: Theory and Practice.* Taylor & Francis Group. 1999. 384pp.

Hadibah Ismail, Eldina Fatimah, Ahmad Khairi Abd Wahab (2005). *Wave Energy Dissipation Over Pseudo-Mangrove Roots.* Innovations & Technologies in Oceanography for Sustainable Development (ITOS 2005) September 26-29, Kuala Lumpur.

Harris, L. E. (1995). *Engineering design of artificial reefs*. Oceans '95, Marine Technology Society, Washington, D.C., Vol. 2, pp. 1139-1148.

Harris, L. E. (2002). *Submerged Reef Structures for Beach Erosion Control*. ASCE Coastal Structures. pp. 1155-1163. 2003.

Harris, L. E. (2002). *Submerged reef structures for habitat enhancement and shoreline erosion abatement*. U.S. Army Corps of Engineers Coastal & Hydraulic Engineering Technical Note (CHETN), Vicksburg, MS.

Herbich, J. B. (2000). *Handbook of coastal engineering*. Mc Graw Hill. New York, USA.

Hornberger, G. M., Raffensperger, J. P., Wiberg, P. L., Eshleman, K. N. (1998). *Elements of Physical Hydrology.* Johns Hopkins University Press. May 1998. 276pp.

Huang, Z. (2006). *An experimental study of wave scattering by a vertical slotted barrier in the presence of a current*. Ocean Engineering Volume 34, Issue 5-6, April 2007. pp. 717-723.

Hughes, S. (1993). *Physical Models and Laboratory Techniques in Coastal Engineering.* Advanced Series on Ocean Engineering, Volume 7. World Scientific Publishing Company. November 1993. 568 pp.

Kaly, U. L. and Jones, G.P. (1998). *Mangrove restoration: a potential tool for ecosystem management of coastal fisheries*. Ambio 27(8): 656-661.

Kleinbaum, K., Muller, and Nizam (1998). *Applied Regression Analysis and Other Multivariable Methods, 3rd Edition*. Pacific Grove, Duxbury Press, Chapter 8 (Multiple Regression Analysis) page 112.

Kanayama, K. and Fujiwara, T. (1976). *Transmission of wave past a rigid vertical thin barrier*. Technology reports of the Yamaguchi University. Vol.1(4) pp. 427-438.

Kobashi, D. and Mazda, Y. (2005). *Tidal flow in riverine-type mangroves. Wetlands Ecology and Management*. 13, 615-619.

Koether, G., Oumeraci, H. (2002). *Underwater-Filter Systems: An Innovative Reef for Coastal Protection.* Proc. 28th Int. Conf. on Coastal Engineering (ICCE), ASCE, Cardiff.

Koh, R. (2000). *Theoretical Analysis on Wave Transmission, Reflection and Stability of Rubble Mound Breakwater with a Granular Model*. International Society of Offshore and Polar Engineers. Cupertino, California, USA. Volume III. 645-650.

Krauss, K. W. and Allen, J. A. and Cahoon, D. R. (2003). *Differential rates of vertical accretion and elevation change among aerial root types in Micronesian mangrove forests*. Estuarine, Coastal and Shelf Science 56, Issue 2. Elsevier, London .2003, pp. 251-259

Kriebel, D. L., and Bollmann, C. A. (1997). *Wave transmission past vertical wave barriers*. Proc., 25th Int. Conf. on Coastal Engineering (ICCE), ASCE, Reston, Va., 2470–2483.

La, T. C., Vo, L. H. P. (2006). *Influence of Wave Motion in Mangrove Forest*. Proceedings of The Ninth Workshop of OMISAR (WOM-9) on the Application and Networking of Satellite Data November 1-3, 2002, Ho Chi Minh City, Vietnam.

Lee, J. F and Cheng, Y. M. (2007). *A theory for waves interacting with porous structures with multiple regions***.** Ocean Engineering - ASCE. Volume 34, Issues 11-12, August 2007, Pages 1690-1700.

Liu, W. C., Hsu, M. H and Wang, C. F. (2003). *Modeling of Flow Resistance in Mangrove Swamp at Mouth of Tidal Keelung River, Taiwan*. *Journal of Waterway, Port, Coastal and Ocean Engineering*. Vol. 129, No. 2, March/April 2003, pp. 86-92.

Losada, I. J., Lara, J. L., Christensen, E. D. and Garcia, N. (2005). *Modelling of velocity and turbulence fields around and within low-crested rubble-mound* *breakwaters*. Coastal Engineering - ASCE. Volume 52, Issues 10-11, November 2005, Pages 887-913.

Luznik, L., Gurka, R., Smith, W.A.M., Nimmo, Zhu, W., Katz, J. and Osborn, T. (2004). *On the Structure of Turbulence and Reynolds Stress Distribution in the Bottom Boundary Layer of the Coastal Ocean*. XXI ICTAM, 15-21 August 2004, Warsaw, Poland.

Mani, J. S. (1989). *Wave damping characteristics of pile breakwaters*. Proceedings of 3rd National Conference on Dock and Harbour Engineering, Applied Mechanics Department, K.R.E.C., Surathkal, India, pp. 181–187.

Mani, J. S. and Jayakumar, S. (1995). *Wave transmission by suspended pipe breakwater*. Journal Waterway, Port, Coastal, and Ocean Engineering 121(6): 335-338.

Mansard, E. P. D. and Funke, E. R. (1980*). The Measurement of Incident and Reflected Spectra Using a Least Squares Method. Proceedings of 17th Int. Conf. Coastal Eng.*, pp. 154-172, ASCE.

Massel, S.R., Furukawa, K., Brinkman, R.M. (1999). *Surface wave propagation in mangrove forest.* Fluid dynamics Research, 24, pp.219-249.

Mazda, Y., Kobashi, D. and Okada, S. (2005). *Tidal-scale hydrodynamics within mangrove swamps*. Springer. Wetlands Ecology and Management, Volume 13, Number 6, December 2005. pp. 647-655(9).

Mazda, Y., Kanazawa, N., Wolanski, E. (1995). *Tidal asymmetry in mangrove creeks*. Hydrobiologia, Volume 295 (1-3) Pages 51 - 58.

Mazda, Y., Wolanski, E., King, B., Sase, A., Ohtsuka, D. and Magi, M. (1997a). Drag force due to vegetation in mangrove swamps. Mangroves and Salt Marshes 1:193–99.

Mazda, Y., and Magi, M. (1997b). *Mangroves as a coastal protection from waves in the Tong King delta, Vietnam*. Mangrove and salt marshes 1:127-135.

Mazda, Y. and Magi, M. (2006a). *Wave reduction in a mangrove forest dominated by Sonneratia sp*. Wetlands Ecology and Management (2006) 14:365–378.

Mazda, Y. and Ikada, Y. (2006b). *Behavior of the groundwater in a riverine-type mangrove forest*. Wetlands Ecology and Management (2006) 14:477–488.

Muhammad Akhir Othman (1994). *Value of mangroves in coastal protection*. Sasekumar, A., Marshall, N., and Macintosh, D. J. (eds), Ecology and conservation of Southeast Asian marine and freshwater environments including wetlands. Regional seminar, Kuala Lumpur , MALAISIE (04/11/1991). Hydrobiologia 285: 277-282.

Neelamani, S., and Rajendran, R. (2002). *Wave interaction with T -type breakwaters*. Ocean Engineering, Vol. 29, pp.561-589.

Nyandwi, N. (2001). *Survey of the extent of human-induced beach erosion problems in Tanzania*. In: Richmond, M.D. and Francis, J. (Editors), Marine Science Development in Tanzania and Eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania. 28 June Ð 1 July 1999, Zanzibar, Tanzania. IMS/WIOMSA. 121-129pp.

Othman, I. M. A. (1994). *Value of mangroves in coastal protection*. Hydrobiologia 285: 277-282, 1994. Sasekumar, A., Marshall, N.& Macintosh, D. J. (eds), Ecology and Conservation of Southeast Asian Marine and Freshwater Environments including Wetlands.

Panizzo, A. and Briganti, R. (2007). *Analysis of wave transmission behind low crested breakwaters using neural networks*. Coastal Engineering Volume 54, Issue 9, Pages 643-656.

Papini, N. (2003). Wave *Interaction with a Pile-Supported Breakwater*. Master Thesis. University of Hawaii, Manoa.

Penchev V., Scheffermann J., Shukrieva, S. and Zimmermann C. (2007). *Evaluation of Reef Breakwater Efficiency by Physical and Numerical Simulations.* Annual Book Franzius Institute, vol. 92, January 2007.

Pilarczyk, K. W. (2003). *Design of low-crested (submerged) structures: An overview*. 6th COPEDEC (Int. Conf. on Coastal and Portal Engng. In Develop. Countries), Sri Lanka.

Pilarczyk, K. W. and Zeidler, R. B. (1996). *Offshore Breakwaters and Shore Evolution Control*, A. A. Balkema, Rotterdam (balkema@balkema.nl).

Quartel, S., Kroon, A., Augustinus, P. G. E. F., van Santen, P., Tri, N.H. (2006). *Wave attenuation in coastal mangroves in the Red River Delta, Vietnam*, Journal of Asian Earth Sciences, Volume 29, Issue 4, p.576-584.

Ranasinghe, R. and Turner, I. L. (2005). *Shoreline response to submerged structures: A review***.** Coastal Engineering. vol.53 no.1, 65 – 79 pp.

Rao, S. and Sathyanarayana, V.S. (1999). *Laboratory investigation on wave transmission through two rows of perforated hollow piles*. Ocean Engineering 26, pp. 675–699.

SPSS Inc. (1998) "SYSTAT® v.8.0". (Technical Software).

Sakakiyama, T. (2002). *Numerical Simulation of Wave and Current to Estimate Sand Lift-out Through Rubble Mound*. Proceedings of The Twelfth (2002) International Offshore and Polar Engineering Conference Kitakyushu, Japan, May 26–31.

Schuster, J. C., ed. (1980). *Hydraulic Laboratory Techniques*. U.S. Department of the Interior, Bureau of Reclamation, 208 pp.

Seabrook, S. R. (1997). *Investigation on the Performance of Submerged Rubblemound Breakwaters*. Master of Science (Engineering) Thesis, Queen's University, Ontario, Canada, August, 1997.

Sorensen, R. M. (2006). *Basic Coastal Engineering*. Springer Verlag, 3rd ed., XIV, 324 pp.

Shirlal, K. G. and Rao, S. (2007). *Ocean wave transmission by submerged reef—A physical model study*. Elsevier, Amsterdam, Ocean Engineering, vol. 34, pp. 2093-2099.

Struve, J., Falconer, R. A., Wu, Y. (2003). *Influence of model mangrove trees on the hydrodynamics in a flume*. Estuarine, Coastal and Shelf Science 58. pp. 163-171.

Suh, K., A. M., Shin, S., Cox, D. T. (2006) *Hydrodynamic Characteristics of Pile-Supported Vertical Wall Breakwaters*. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 132, No. 2, March/April 2006, pp. 83-96.

Suh, K., Hoo, Y. J., Chong, K. P. (2007). *Wave reflection and transmission by curtainwall–pile breakwaters using circular piles*. Ocean engineering, Elsevier, Amsterdam. Volume 34, Issues 14-15, vol. 34, pp. 2100-2106.

Tanaka, N., and Sato, S. (1976). *Topographic change resulting from construction of a harbor on a sandy beach: Kashima Port*. Proceedings of the 15th International Conference on Coastal Engineering, American Society of Civil Engineers. New York: Vol. 2, pp. 1824 – 1843.

Tomlinson, P. B. (1986). *The Botany of Mangroves*. Cambridge Tropical Biology Series. 1986. NY Cambridge Univ. Press. 413 pp.

Van der Meer, J.W., Briganti, R., Zanuttigh, B., and Wang, B. (2005). *Wave transmission and reflection at low-crested structures: Design formulae, oblique wave attack and spectral change.* Special Issue of Journal of Coastal Engineering, Elsevier, 52 (2005) 915 – 929.

Van Oosten, R., Peixó Marco, J., van der Meer, J. W. and Verhagen, H. J. (2006). *Wave transmission at low-crested structures using neural networks*. ASCE, ICCE 2006, San Diego, pp. 4932 - 4944.

Wersberg, S. (1985) *Applied Linear Regression*. 2nd Edition. Wiley, New York, USA.

Wolanski, E. J. (1992). *Hydrodynamics of mangrove swamps and their coastal waters*. Hydrobiologia 247: 141-161.

Wolanski, E. J., Mazda, Y., Furukawa, K., Ridd, P. V., Johnson, K., Spagnol, S. and Stieglitz, T. C. (2001). *Water circulation in mangroves, and its implications for biodiversity.* I*n*: Wolanski, E. (Ed.) (2001). Oceanographic processes of coral reefs: physical and biological links in the Great Barrier Reef. pp. 53-76.

Wu, Y., Falconer, R.A., Struve, J. (2001). *Mathematical modeling of tidal currents in mangrove forests*. Environmental Modeling & Software, Elsevier, Volume 16, Number 1, pp. 19-29(11).

Yoshioka, K., Kawakami, T., Tanaka, S., Koarai, M. and Uda, T. (1993). *Design Manual for Artificial Reefs*. In Coastlines of Japan II, Coastal Zone'93", ASCE.

Zanuttigh, B., van der Meer, J. W., Andersen, T. L., Lara, J. L., Losada, I. J. (2008). *Analysis of Wave Reflection From Structures with Berms Through an Extensive Database and 2DV Numerical Modelling*. ASCE, Proc. ICCE 2008, Hamburg.