International Journal of the Physical Sciences Vol. 5(9), pp. 1406-1410, 18 August, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

Bamboo foundation mat for rubble mound breakwaters on mud deposits

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Accepted 28 July, 2010

From geotechnical viewpoint, soft mud is generally characterised by low shear strength. As a consequence of this, construction activity on mudflats could be very difficult, costly and even impractical. In this study, bamboo culms that are inexpensive and locally abundant were introduced as a bedding material for a low crested rubble mound breakwater. Bamboo mats could be used as an alternative cost-effective foundation on mud deposits. This paper presents a case study of a shore protection work on an intertidal mudflat on the west coast of Peninsular Malaysia. Structural monitoring conducted since completion of construction indicates that the amount and rate of foundation settlement is substantially limited. The effective function of bamboo mats recommends replicating this approach in construction activities on the muddy beaches.

Key words: Bamboo, foundation mat, breakwater, soft ground, construction.

INTRODUCTION

Construction of coastal structures (breakwaters, groynes, dykes, or other rubble mound structures) on mud deposits is very difficult and costly since the unconsolidated layer of soft mud is generally weak and highly compressible. Large and differential settlements or even overall slide may occur in the rubble mound structures erected on a soft ground (Bruun, 1985). This makes mud deposits unsuitable foundation materials. However, these geomaterials can be improved and stabilised through mechanical methods (using vertical drains, reinforcement, piles, deep mixing, etc) and/or chemical treatment (adding cement or lime) but either way could be prohibitively expensive for most local stakeholders and authorities. In addition, chemical alteration of substrate could cause ecological impacts on the habitat and associated biota. Although any changes induced by human activities to the environment are generally referred to as environmental impacts (Airoldi et al., 2005), environmentally friendly methods could be employed to reduce and minimise the adverse side effects of coastal protection projects.

It is technically feasible to reduce the overburden pressure imposed by a coastal structure (e.g. a mound breakwater) constructed on the mud deposits. This can be achieved by widening the foundation to spread out the structural load over a larger area of ground and/or providing weight at the toe of the breakwater by constructing a toe berm to increase the resistance against sliding (Bruun, 1985; Abramson et al., 2001), yet settlements could be large. In addition, a filter layer is also essential to prevent the materials of the structure from sinking into the soft ground, as well as preventing the fine particles of the bed from migrating upward to the internal part of the structure and through the toe berm. However, constructing a filter layer on soft mud is very difficult, if not impractical.

A group of researchers at the Institute of Ocean and Earth Sciences (IOES), University of Malaya have been looking for a practical approach to plant mangrove seedlings in the Sungai Haji Dorani (Sg Hj Dorani) study area in order to rehabilitate the beach. Because the Sg Hj Dorani is an exposed beach covered by soft mud, many young plants are often washed away by wave action. Intervention of a hard structure (e.g. detached breakwater) that can shelter the area from the wave action could be conducive to re-establishment of mangroves in this type of sites, which are exposed to wave action

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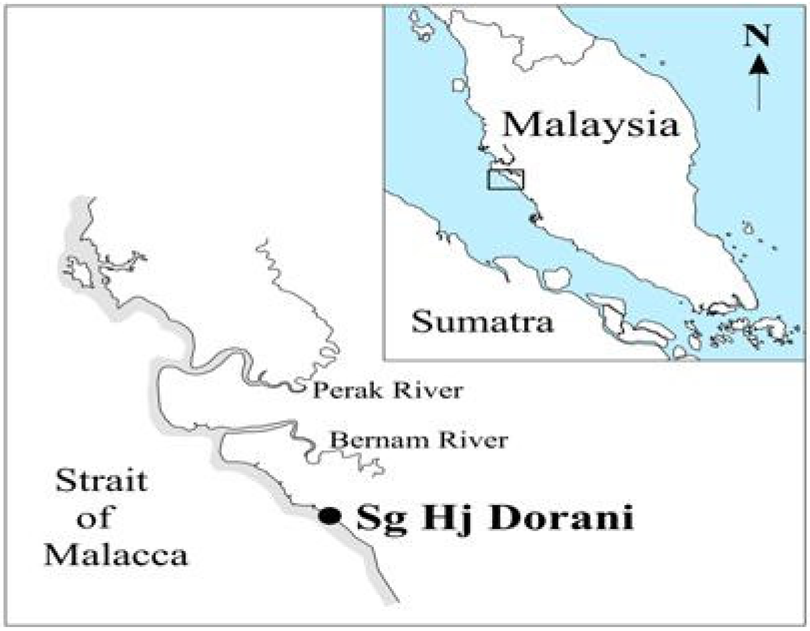

Figure 1. Study area located at the west coast of Peninsular Mayasia.

(Hashim et al., 2010). However, the greater challenge was encountered while erecting a coastal structure on the unconsolidated layer of mud. This paper presents a new approach to provide a sustainable foundation for low-crested rubble mound breakwaters on the mud deposits.

MATERIALS AND METHODS

Study area

Mangrove-colonised intertidal coasts and bare mudflats occupy the shorelines of the state of Selangor, on the west coast of Peninsular Malaysia. These mud deposits might have been supplied by large rivers, namely Perak River, Bernam River, and Selangor River and/or transported by waves and currents from deep sea to the coasts of Selangor. Coastal mud deposits are generally composed of clay and silt with small amounts of sand and organic materials (CEM, 2006). Examples of such mud deposits have been reported at the mouth of most large Asian rivers such as Huanghe (Yellow River), Changjiang (Yangtze River) and Zhujiang (Pearl River) (Saito et al., 2000), a quarter of the total coastline of China (Shi and Chen, 1996), the Amazon River banks, central and southern regions of Brazil (Kineke and Sternberg, 1995), southwest coast of India (Nair, 1976), the northeast coast of South America -French Guiana, Surinam, Guyana, and Venezuela- (Allison and Lee, 2004), and the Atchafalaya Bay, Southern Louisiana, USA (Allison et al., 2000).

The study area is located on the Sg Hj Dorani beach, at 03°38'N and 101°00'E, in the state of Selangor (Figure 1). The Sg Hj Dorani beach is covered by mud deposits. The beach is exposed to direct wave attack from SW (during southwest monsoon) and WNW (during northeast monsoon), with typical waves of 1 m significant height and a significant offshore wave height of about 1.50 m with a return period of 10 years according to the Malaysian Metrological Department. The beach has a semi-diurnal tidal regime with an annual maximum tidal range of 3.20 m.

Geotechnical properties of mud

Grain size distribution information for fine particles (i.e. silts and clays) is commonly obtained by the sedimentation test. The particle-size distribution of the mud in the study site was determined by conducting the sedimentation test throughout the hydrometer analysis with samples taken at depths of 5 to 100 cm. The results displayed that the mud contains a mixture of 22% clay-sized sediments 66% silt, 7% fine sand and 5% organic matter.

The value of unit weight of the mud varies from 1.23 g cm^{-3}, at the top of the mud layer, to 1.41 g cm^{-3}, at a depth of about 0.85 m, and the specific gravity (G_s) of the samples that obtained in a standard pycnometer test ranges from 2.45 to 2.65.

Moisture contents of fine-grained soils are often used to define empirical limits of consistency (semi-solid, plastic, and viscous fluid), known as the *Atterberg* limits. The plastic limit (L_P), where the soil changes from a semi-solid to a plastic (flexible) state, is defined as the moisture content at which the soil can no longer be rolled into a 3.2 mm diameter thread without crumbling. The liquid limit (L_L), where the soil changes from a plastic to a viscous fluid state, is defined as the moisture content at which a cut by a groove of standard dimensions will flow together at the base of the groove using the Casagrande apparatus. The *Atterberg* test (ASTM D 4318) mud samples taken from the study area have a liquid limit (L_L) of 153.7% and a plastic limit (L_P) of 55.52%, on average. Consequently, the plasticity index (I_P), the difference between the liquid and the plastic limits that defines the range of water contents within which the soil is in the plastic state, is about 98%. The natural moisture (or water) content of the mud is extremely variable, and range from 39 to 129%.

Design and construction of rubble mound breakwater

Breakwaters are known to reduce the wave energy reaching the shore through reflection or diffraction. Therefore, on the basis of a desk study, a low crested breakwater was designed to provide a suitable sheltered area for mangrove replanting in the study site. The structure is composed of three segments separated by 5 m

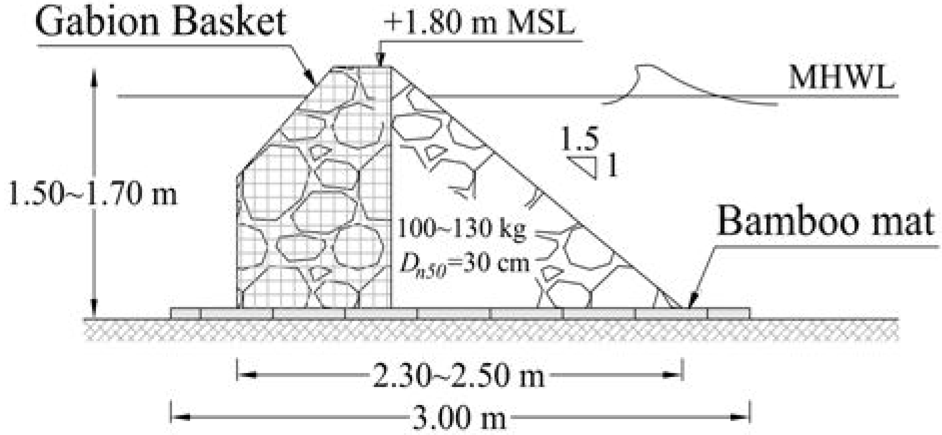

Figure 2. Cross section of the rubble mound breakwater; Source: Hashim et al. (2010).

gaps that allow water circulation around the structure to avoid a decline of water quality due to low flow. This 90 m long rubble mound structure shelters an area of about 7000 m^2 of the beach in the lee of the structure. The structure was built of quarried rock with a seaward slope of 1.5. As depicted in Figure 2, the seaward slope was armoured by heavy stones whereas gabion baskets filled by smaller stones were placed along the shoreward slope. The structure design was described in details by Hashim et al. (2010); hence this paper focuses on the foundation mat.

Bamboo mat

Sustainable construction materials that can be inexpensively provided in bulk and simple techniques of construction are two most important aspects of a cost-effective approach that could be practical and affordable for local stakeholders and authorities. Bamboo is such a sustainable material harvested from renewable natural resources. It has manifold advantages. For instance, it grows very fast and often reaches its maximum mechanical resistance in 3–6 years, depending on the species and the plantation (Albermani et al., 2007; Amada and Untao, 2001; De Flander and Rovers, 2009; Yu et al., 2003); it has great tensile strength (Ghavami, 2005), flexibility and durability. Further, its strength to weight ratio is considerably high in comparison to conventional materials such as timber, steel and concrete (Albermani et al., 2007).

Bamboo is been used extensively in developed and developing countries around the world. Bamboo culms (stems) have been traditionally used as structural members in rural housing and for other construction purposes (e.g. fencing, foot bridges, scaffolds, etc) in South-East Asia, India, and South America.

Bamboo is a member of the grass family with a rapidly growing woody stem. The stem is a hollow cylinder which is generally referred to as a “culm”. Length, diameter, wall thickness, and mechanical properties of bamboo culms vary widely depending on the species; physical and mechanical properties of a bamboo culm usually reduce the height of the culm from the base to the top of the bamboo (Janssen, 1981; Ghavami, 2005). Longitudinal cellulose fibres of the bamboo culm make it a naturally reinforced composite. These strong fibres have a higher concentration towards the outer edge of the culm in that the culm could be considered a functionally graded material (Amada and Untao, 2001; Ghavami, 2005). The fibres make up 60 to 70 % of the weight of the total culm tissue (Liese, 1987).

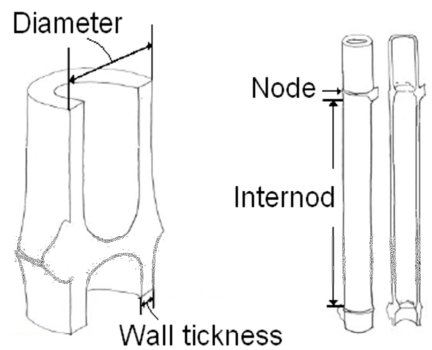

Figure 3. Sections of bamboo culm and associated terminology [Modified after Janssen, (1981)].

In this study, bamboo culms which are strong, lightweight and durable were used to make foundation mats. The average oven-dry density of bamboo culms was 557.3 kg m^{-3}, with an average diameter of 8 to 10 cm and a wall thickness of 0.8 to 1.2 cm (Figure 3). The culms were cut into 3 m lengths and tied together by ropes to form the mats as illustrated in Figure 4. Hollow tubes that are naturally shaped between nodes of the culm result in a very low density material that the bamboo mats could float on the water. This could reduce the foundation settlements on the saturated unconsolidated mud. Further, using the bamboo mats differential settlements of the breakwater structure could be limited. The firmly tied culms prevent mud particles from migrating upwards through the foundation, so that no filter layer was applied for the rubble mound structure (Hashim et al., 2010).

The construction process took place during low tides. Since the project site was located in the intertidal zone, the site was not covered by sea water during low tides making it easier for the contractor to carry the materials to the spot. To construct the rubble mound breakwater, the bamboo mats where placed on the sea floor first, and then the gabion baskets were set up on the mats and filled with stones. Finally, the armour units were placed on the seaward side of the structure to form the seaward slope. The armour units were granite quarry rocks collected from a mine near the project site.

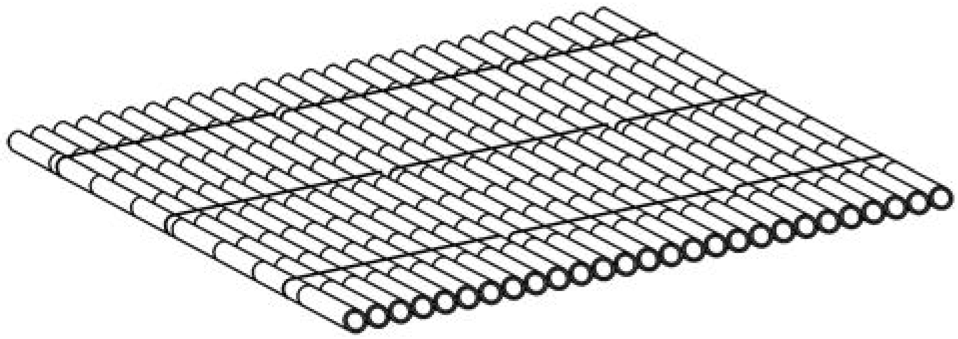

Figure 4. Bamboo foundation mat for rubble mound structures on muddy beaches

Table 1. Foundation settlement of the rubble mound breakwater, July 2008 to June 2010.

Date	Segment 1				Segment 2				Segment 3			
	A	B	C	D	A	B	C	D	A	B	C	D
JUL 2008	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCT 2008	3.6	5.4	4.2	6.6	7.1	6.5	13.6	8.1	7.3	7.0	8.1	8.5
JAN 2009	0.9	0.5	1.1	1.8	1.0	0.9	0.6	1.2	1.0	1.2	1.7	1.1
APR 2009	0.5	0.3	0.8	0.4	0.7	0.3	0.4	0.6	0.2	0.6	0.5	0.7
JUL 2009	0.3	0.1	0.2	0.1	0.0	0.2	0.1	0.3	0.0	0.1	0.4	0.3
OCT 2009	0.0	0.0	0.2	0.1	0.0	0.2	0.3	0.2	0.0	0.2	0.1	0.2
JAN 2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
APR 2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JUN 2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	5.3	6.3	6.5	9.0	8.8	8.1	15.0	10.4	8.5	9.1	10.8	10.8

*The numbers shown in the table are settlement amounts occurred between each monitoring intervals; the units are cm.

Monitoring

Field monitoring was conducted quarterly between July 2008, just after completion of construction, and June 2010 to investigate the foundation settlements. Four cross-sectional profiles were considered on each segment of the breakwater; two profiles on the trunk section and two on the tips of the breakwater were surveyed by a high-end Topcon total station.

RESULTS AND DISCUSSION

The foundation settlements measured between July 2008 and June 2010 are summarised in Table 1. The maximum total settlement was limited to 15.0 cm. No settlement has been observed since October 2009 (16 months after completion of construction), indicating that the primary consolidation was almost completed by that time. No differential settlements were observed in the breakwater which shows the integrity of the foundation mats.

Bamboo is vulnerable to longitudinal splitting due to its unidirectional fibrous structure. Limited number of split in bamboo culms was observed which could have occurred during construction of rubble mound, perhaps as a result of dumping stones on the mats, but the mats were not damaged. Since the applied loads on the bamboo culms in the mats were not longitudinal loads, the longitudinal splitting is not likely to occur. However, stone dumping on the mats should be avoided to decrease the chance of splitting.

Bamboo is a natural material that is prone to degradation and insect attacks. However, there is a lack of sufficient study on durability of bamboo under different environmental conditions. Ghavami (2005) stated that it is vital to dry bamboo because a decrease in humidity content can improve physical and mechanical properties of bamboo and reduce transport costs. He suggested that, "bamboo can be dried in air, green house, and oven or by fire". Based on the observations made during this study, bamboo culms have shown no decline after 2 years of being saturated with seawater and loaded under the rubble mound structure. However, in this project, as the consolidation process of subsoil takes place, the importance of the bamboo mats decreases. Therefore, bamboo mats are necessary for only 2 or 3 years of service life. Further, the main objective of the project was to protect the mangrove seedlings planted in the lee of the breakwater which in less than 5 years will become mature trees and the protective structure will not be needed any more.

In conclusion, bamboo is a sustainable and renewable material with a growing use in engineered construction. As such the effective use of bamboo could reduce the pressures on the natural forests especially in developing countries, facilitating the conservation of the global environment (Yu et al., 2003). Bamboo has been widely used in building construction with various advantages for centuries, but this is the first time it is being introduced as a foundation mat for a rubble mound structure in the Sg Hj Dorani beach. The effective function of bamboo mats in this project recommends the use of this natural material on mud beaches as foundation mats for rubble mound structures.

ACKNOWLEDGMENT

The financial support given by FRIM (Forestry Research Institute of Malaysia) is gratefully acknowledged by the authors. Also, the support of IOES (Institute of Ocean and Earth Sciences), and the University of Malaya for facilitating the research work is appreciated.

REFERENCES

Abramson LW, Lee TS, Sharma S, Boyce GM (2001). Slope stability and stabilization methods. 2nd ed. New York: John Wiley and Sons, INC.

Airoldi L, Abbiati M, Beck MW, Hawkins SJ, Jonsson PR, Martin D, Moschella PS, Sundelöf A, Thompson RC, Åberg P (2005). An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. Coast. Eng., 52: 1073-1087.

Albermani F, Goh GY, Chan SL (2007). Lightweight bamboo double layer grid system. Eng. Struct., 29: 1499-1506.

Allison MA, Lee MT (2004). Sediment exchange between Amazon mudbanks and shore-fringing mangroves in French Guiana. Mar. Geol., 208: 169-190.Allison MA, Kineke GC, Gordon ES, Goni MA (2000). Development and reworking of a seasonal flood deposit on the inner continental shelf off the Atchafalaya River. Cont. Shelf Res., 20: 2267-2294.

Amada S, Untao S (2001). Fracture properties of bamboo. Composites: Part B., 32: 451-459.

Bruun P (1985). Design and construction of mounds for breakwaters and coastal protection. Amsterdam: Elsevier.

CEM (2006). Coastal Engineering Manual. Coastal Engineering Research Centre, US Army Corps of Engineering, Vicksburg, Mississippi, USA.

De Flander K, Rovers R (2009). One laminated bamboo-frame house per hectare per year. Constr. Build. Mater. 23: 210-218.

Ghavami K (2005). Bamboo as reinforcement in structural concrete elements. Cement Concrete Comp., 27: 637-649.

Hashim R, Kamali B, Mohd Tamin N, Zakariah R (2010). An integrated approach to coastal rehabilitation: Mangrove restoration in Sungai Haji Dorani, Malaysia. Estuar. Coast. Shelf S., 86: 118-124.

Janssen J (1981). Bamboo in Building Structures. PhD thesis, Eindhoven University, Eindhoven, The Netherlands.

Kineke GC, Sternberg RW (1995). Distribution of fluid muds on the Amazon continental shelf. Mar. Geol. 125: 193-233.

Liese W (1987). Research on bamboo. Wood Sci. Technol., 21: 189-209.

Nair RR (1976). Unique Mud banks, Kerala, southwest India. The American Association of Petroleum Geologists Bulletin (AAPG Bull.), 60: 616-621.

Saito Y, Wei H, Zhou Y, Nishimura A, Sato Y, Yokota S (2000). Delta progradation and chenier formation in the Huanghe (Yellow River) delta, China. J. Asian Earth Sci., 18: 489-497.

Shi Z, Chen JY (1996). Morphodynamics and sediment dynamics on intertidal mudflats in China (1961–1994). Cont. Shelf Res., 16: 1909-1926.

Yu WK, Chung KF, Chan SL (2003). Column buckling of structural bamboo. Eng. Struct., 25: 755-768.