# PERFORMANCE OF EMBANKMENT ON BAMBOO-GEOTEXTILE COMPOSITE REINFORCED SOFT CLAY

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*Special dedication to my family especially to my dad Othman bin Abdul Karim, my mum Katirah binti Slamat and all my brother and sisters and also to a special person, my wife Nilidawati binti Buhari for her patience and support all the times. Also special thanks to all my colleagues who had given the guidance and encouragements until the end of this research*

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# ABSTRACT

Road embankments and other constructions on deposits of natural soft clay are still a challenge in geotechnical engineering work. The used of various soil improvement methods to stabilise the soft clay need to be carried out in order to increase the bearing capacity and reduce the settlement. Most methods are costly while the time taken to complete the improvement works takes a long period. The Soft Soil Research Group of Universiti Teknologi Malaysia had proposed the combined used of bamboo as a green technology and a layer of low strength geotextile to become a reinforcement system called the “Bamboo-Geotextile Composite” (BGC). Full-scale embankments on BGC system reinforced soft clay (BGC embankment) together with an embankment on unreinforced soft clay (UR embankment) and also an embankment on high strength geotextile reinforced on soft clay (HSG embankment) had been constructed. Each embankment measured 10 m long, 16 m wide and about 3 m height. Semantan Bamboo of about 8 cm outer diameter with 48-94 MPa tensile strength and 43-49 MPa bending strength, and TS 40 Geotextile of 13.5 kN/m length tensile strength were selected as the materials for the system. In BGC system, the bamboo poles arranged in 1 m x 1 m square pattern were laid at the top of soft clay layer and the geotextile was then laid on top of bamboo. The objectives of this research are to determine the performance of BGC embankment and to develop a representative method of modelling the BGC embankment through the evaluation of field data using finite element (FE) model from PLAXIS 2D computer software. The embankments were monitored since the start of the construction until Day 418. Field monitoring data showed that the used of BGC system reduced more than 20% of immediate settlement and 57% of lateral movement during construction compared to UR embankment. The confinement of the soft clay in square pattern arrangement of bamboo increased the bamboo stiffness while the tensile resistance of horizontal ribs and compressive resistance of vertical ribs of bamboo prevented excessive settlement. The BGC system retained the surcharge load and distributed only small load to the underlain soft clay soil resulting in smaller consolidation settlement compared to UR and HSG embankments. The BGC system was best modelled as a geogrid element using PLAXIS 2D software. Although the drainage capability as well as the buoyancy effect of the BGC system could not be modelled, the settlement at the centre point of BGC embankment showed that the result from FE model differs only 1% from the field settlement at the end of construction while at Day 418, the model overestimated about 6%. For the lateral movement, the model predicted about 100% higher than the field value while the location of the maximum lateral movement was predicted to occur at a greater depth compared to the field performance. Hence, it can be deduced that the BGC embankment can be modelled using PLAXIS 2D software, in which the prediction for settlement can be better represented.

# ABSTRAK

Tambakan jalan dan binaan lain di atas endapan tanah liat lembut semulajadi masih lagi menjadi cabaran dalam kerja-kerja kejuruteraan geoteknik. Penggunaan pelbagai kaedah pembaikan tanah untuk menstabilkan tanah liat lembut perlu dilakukan untuk meningkatkan keupayaan galas dan mengurangkan enapan. Kebanyakan kaedah adalah sangat mahal dan mengambil masa yang lama untuk selesai. Kumpulan Penyelidikan Tanah Lembut Universiti Teknologi Malaysia telah mencadangkan pengunaan gabungan buluh sebagai teknologi hijau dan selapis geotekstil yang berkekuatan rendah, untuk menjadi sistem tetulang dikenali sebagai "Komposit Buluh-Geotekstil" (BGC). Tambakan-tambakan berskala penuh di atas tanah liat lembut yang diperkukuh dengan sistem BGC (tambakan BGC) bersama-sama dengan tambakan ke atas tanah liat lembut tidak diperkukuh (tambakan UR) dan juga tambakan di atas tanah liat lembut diperkukuh dengan geotekstil berkekuatan tinggi (tambakan HSG) telah dibina. Setiap tambakan adalah berukuran 10 m panjang, 16 m lebar and lebih kurang 3 m tinggi. Buluh Semantan yang bergaris pusat luaran lebih kurang 8 cm dengan kekuatan tegangan 48-94 MPa dan kekuatan lenturan 43-49 MPa, dan Geotekstil TS40 dengan kekuatan tegangan 13.5 kN/m panjang, telah dipilih sebagai bahan untuk sistem bertetulang tersebut. Bagi sistem BGC, batang buluh diatur dalam bentuk segiempat sama 1m x 1m di atas lapisan tanah liat lembut dan kemudian geotekstil dihampar di atasnya. Objektif peyelidikan ini adalah untuk menentukan prestasi tambakan BGC dan untuk membangunkan suatu kaedah perwakilan bagi memodelkan tambakan BGC melalui penilaian data lapangan menggunakan model unsur terhingga (FE) dari perisian komputer PLAXIS 2D. Tambakan-tambakan telah dipantau dari awal pembinaan sehingga Hari Ke-418. Data pemantauan lapangan menunjukkan bahawa penggunaan sistem BGC telah mengurangkan enapan serta merta lebih daripada 20% dan 57% pergerakan sisi semasa pembinaan berbanding dengan tambakan UR. Pengurungan tanah liat lembut dalam bentuk segi empat sama meningkat kekukuhan buluh manakala rintangan tegangan rusuk ufuk dan rintangan mampatan rusuk tegak buluh boleh menghalang enapan berlebihan. Sistem BGC menahan beban yang dikenakan dan hanya menyebarkan beban yang kecil kepada lapisan tanah liat lembut menyebabkan enapan pengukuhan yang lebih kecil berlaku jika dibandingkan dengan tambakan UR dan HSG. Sistem BGC terbaik dimodelkan sebagai elemen geogrid dengan menggunakan perisian PLAXIS 2D. Walaupun keupayaan saliran dan kesan apungan sistem BGC tidak dapat dimodelkan, enapan di titik tengah tambakan BGC di akhir pembinaan menunjukkan keputusan dari model FE hanya berbeza 1% daripada data lapangan manakala pada Hari Ke-418, model FE meramal lebih iaitu sekitar 6% enapan. Bagi pergerakan sisi, model meramalkan 100% nilai yang lebih besar dari nilai lapangan manakala kedudukan pergerakan sisi maksimum diramalkan berada pada kedalaman lebih besar dibandingkan dengan prestasi lapangan. Oleh itu, dapat disimpulkan bahawa tambakan BGC boleh dimodelkan menggunakan perisian PLAXIS 2D yang mana ramalan terhadap enapan boleh dimodelkan dengan lebih baik.

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# LIST OF SYMBOLS

| | |
|---|---|
| $N$ | : SPT- N Value |
| $S_u$ | : Undrained shear strength |
| $w$ | : Natural moisture content |
| $w_L$ | : Liquid limit |
| $w_P$ | : Plastic limit |
| $I_p$ | : Plasticity Index |
| $\gamma$ | : Unit weight of soils |
| $\gamma_b$ | : Bulk unit weight |
| $\gamma_d$ | : Dry unit weight |
| $\phi$ | : Friction angle |
| $\phi_u$ | : Undrained friction angle |
| $c$ | : Cohesion |
| $c_u$ | : Undrained cohesion |
| $\phi'$ | : Effective Friction angle |
| $c'$ | : Effective Cohesion |
| E | : Energy |
| $E$ | : Young's Modulus / Modulus of Elasticity |
| $E_{50}$ | : Secant modulus at 50% peak strength |
| $E_0$ | : Initial slope |
| $\varepsilon$ | : Working strain |
| $\sigma$ | : Working stress |
| $\gamma_{sat}$ | : Unit weight of saturated soils |
| $\gamma_{unsat}$ | : Unit weight of unsaturated soils |
| $k_x$ and $k_h$ | : Horizontal permeability |
| $k_y$ and $k_v$ | : Vertical permeability |

| | |
|---|---|
| $k$ | : Coefficient of permeability |
| C | : Carbon |
| N | : Nitrate |
| Ca | : Calcium |
| Mg | : Magnesium |
| K | : Kalium |
| $\gamma_{dmax}$ | : Maximum dry unit weight of soils |
| $w_{opt}$ | : Optimum moisture content |
| $E_b$ | : Modulus of elasticity of bamboo |
| $A$ | : Cross sectional area |
| $EA$ | : Axial stiffness |
| $w_b$ | : Weight of bamboo |
| $\sigma_b$ | : Bending Strength |
| $\sigma_t$ | : Tensile Strength |
| $E_b$ | : Bending Modulus of Elasticity |
| $E_t$ | : Tensile Modulus of Elasticity |
| $c_{inter}$ | : Soil cohesion interaction |
| $\phi_{inter}$ | : Friction angle interaction |
| $R_{inter}$ | : Interaction parameter |
| $\upsilon$ | : Poisson's ratio |
| $\upsilon'$ | : Effective Poisson's ratio |
| $\varepsilon_V$ | : Strain along the vertical axis |
| $\varepsilon_H$ | : Strain along the horizontal axis |
| H | : Diameter |
| $\lambda^*$ | : Modified compression index |
| $\kappa^*$ | : Modified swelling index |
| $\lambda$ | : Slope of compression line in Normal Consolidation Line |
| $\kappa$ | : Slope of swelling line |
| $\mu^*$ | : Modified creep index |
| $e$ | : Void ratio |
| $c_v$ | : Coefficient of consolidation |
| $\psi$ | : Dilatancy angle |
| F | : Safety factor |
| $G_s$ | : Specific gravity |

| | |
|---|---|
| $C_c$ | : Compression index |
| $P_c$ | : Pre-consolidation pressure |
| $m_v$ | : Coefficient of compressibility |
| $C_r$ | : Swelling index |
| $C_u$ | : Coefficient of uniformity |
| $C_g$ | : Coefficient of gradation |
| $D_{10}$ | : Effective size |
| $D_{30}$ | : Diameter finer than 30 % |
| $D_{60}$ | : Diameter finer than 60 % |

# LIST OF APPENDIX

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Research

The coast of Malaysia is characterised by a coastal plain of soft clay which is similar to the parts of central plains of Thailand and eastern side of the island of Sumatera, Indonesia. Soft clay presents several challenges for the geotechnical engineers whereby these problems being transformed to stability and settlement within the soft soil. However, the frequency of embankments construction over soft compressible natural deposits is increasing due to lack of suitable land for infrastructures and other developments. These soft soils are characterised by high compressibility and low bearing capacity; moreover, these soils frequently occur as saturated soils with high moisture contents near or exceeding the liquid limit. The choice of construction method in this formation is not only governed by direct costs but also the cost benefits, duration of completion long term and maintenance costs.

Numerous methods are available to mitigate difficulties arising from construction of built facilities over these soft soils. These include various methods of soft ground improvement and foundation treatment as well as the use of reinforced concrete slab supported on piles driven to set, known as "pile raft". The use of pile raft is known to be very costly. Previous studies (Abang Ali and Abang Ali, 1984, and Ghavami *et al.*, 2003) showed the potential use of bamboo in construction industry and as geotechnical engineering materials. The stiffness and relatively high tensile strength and bending resistance of bamboo, make it suitable to be used as soil-reinforcing material. Bamboo has fast growing rate and occurs in abundance in most part of tropical countries, including Peninsular Malaysia. This material is light, strong, and has high strength in bending and tensile and easy to be processed. According to Abang Ali and Abang Ali (1984), the ultimate tensile stress of bamboo specimens ranged between 153 $N/mm^2$ and 440.6 $N/mm^2$. For an average ultimate tensile strength of 343.1 $N/mm^2$, surprisingly this strength for bamboo is high compared with mild steel which normally recorded at 250 $N/mm^2$.

Hence the use of bamboo as reinforcement of soft clay, in particular in road or highway construction, has a big potential. However, before any method could be adopted it has to be examined first for its performance. This could be carried out by constructing full-scale, fully instrumented trial embankments to monitor the settlement, lateral movement, pore water pressure, total pressure and other parameters, within the embankment and the foundation soil. The performance of these trial embankments monitored using respective soil instrumentations could be used for modelling using numerical analysis method. Hence, the performance could be predicted and the findings are useful for future work.

In Asia, bamboo is quite common for bridges, scaffolding and housing, but it is usually a temporary exterior structural material. In many densely populated regions of the tropics, bamboos supply suitable material that is sufficiently cheap and plentiful to meet the extensive need for economical housing (Thammicha, 1989). According to Ghavami *et al.* (2003), bamboo has a potential to be used as construction materials because it strong, lightweight and low cost. From the laboratory test results, Khatib (2009) found that Bamboo-Geotextile Composite reinforcement method increased the bearing capacity of soft clay much better than when using bamboo only or geotextile only. Marto *et al.* (2010) emphasized that this BGC system is a sustainable, cost effective soft clay reinforcement method. Loke

(2000) tried this method in an embankment construction over a very soft clay, and found that this method provides significant cost savings whereby savings up to 45-65% can be achieved as compared to using high strength geotextile only with conventional filling method.

However to date, there is no published research data on the use of bamboo-geotextile composite as an improvement method of soft clay soil except for the work by Khatib (2009) using Ministry of Science, Technology and Innovations (MOSTI) IRPA grant (Project Number : 03-02-06-0118 EA001), entitled “The Performance of Soft Clay Reinforced with Bamboo-Geotextile Composite overlaid by Granular Soil”. The work was quite limited as it was based on laboratory physical model tests only. Therefore, to further enhance the findings on bamboo-geotextile composite as a new reinforcement method, this research had been continued, under an E-Science research fund (Project Number 03-01-06-SF0236) from MOSTI, entitled “Full-Scale Test of Trial Embankment on Bamboo-Geotextile Composite Reinforced Soft Clay”. This research was the collaboration between Universiti Teknologi Malaysia (UTM), Research Centre for Soft Soil (RECESS), Universiti Tun Hussein Onn Malysia (UTHM), Forest Research Institute (FRIM) and TenCate Geosyntetics Asia Sdn. Bhd. (formally known as Polyfelt Asia). In this research, full-scale instrumented trial embankment on bamboo-geotextile composite reinforced soft clay, as well as an embankment on unreinforced soft clay and embankment on soft clay reinforced with high-strength geotextile, had been constructed so that the performance of the embankments could be monitored and compared. The trial embankments had been constructed at RECESS UTHM as this location is known to be deposited by soft clay. The performance of the embankments had been monitored during construction periods and continued for about 14 months starting from 31st May, 2009, from the day of the completion of the embankment’s construction.

## 1.2 Statement of Problem

The application of bamboo to improve the bearing capacity and reduce the settlement of soil has been proved to be an economical alternative approach for soil improvement. With high tensile strength and good bending properties, bamboo is suitable to be used as an earth reinforcing material. Together with low-strength geotextile as a separator, this Bamboo-Geotextile Composite (BGC) system could be used as cheap soft clay reinforcement for embankment construction. Engineering problems are usually solved by using simplified analyses or theoretical approaches. Nowadays, there are many different methods of calculations available for analyzing engineering problems such as analytical analysis using limit analysis and limit equilibrium, and numerical method. The finite element analysis is one of the numerical methods, and has been applied in many applications of engineering problems, including for analyzing geotechnical engineering. It is a numerical method to determine approximate solutions of integral equations, based on eliminating the differential equation into an approximation of differential equations (Cook *et al.*, 2001). With the monitoring results of full-scale trial embankments, together with the used of PLAXIS finite element software, the performance of embankment could be predicted. This research is aimed at predicting the performance of Bamboo-Geotextile Composite reinforced soft clay through finite element modelling using PLAXIS software, in particular the settlement, as important criteria in embankment construction. Based on the results obtained, the used of BGC, as a new alternative for a cost effective solution on bearing capacity problem of soft clay, could be used with more confidence.

## 1.3 Aim and Objectives of Research

The aim of this research is to determine the representative modelling of Bamboo-Geotextile Composite (BGC) reinforcement, installed at the interface between embankment and soft clay, from the evaluation of field performance of unreinforced embankment (UR embankment) and BGC reinforced embankment (BGC embankment). In order to achieve the aim of research, the following objectives had been formulated:

(i) To compare the field performance of unreinforced (UR), Bamboo-Geotextile Composite reinforced (BGC), and High-Strength Geotextile reinforced (HSG) embankments constructed on soft clay.
(ii) To determine the soil design parameters by back-analysing from the prediction using finite element method (FEM) and the field settlement of UR embankment.
(iii) To predict the settlement, pore water pressure and lateral movement of BGC embankment through FEM using the soil design parameters obtained from back analysis of UR embankment and the comparison with the field performance of BGC embankment.

At the end of this research, some charts were developed to give a preliminary guideline to the engineer for the construction of embankments on bamboo-geotextile composite reinforced soft clay.

## 1.4 Significance of Research

The long term field performance of embankment on Bamboo-Geotextile Composite reinforced soft clay had been analysed and prediction using finite element software revealed some good results. The prediction on settlement with some charts produced could benefit the authorities involved when BGC is chosen to be used as reinforcement of soft clay. The findings of this research will give a new alternative of a cost effective solution for bearing capacity problem of soft clay soils.

## 1.5 Scope of Research

The site for trial embankments is located at Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat, Johor, where the soft clay dominates. The full-scale of trial embankment had been constructed at UTHM to monitor the settlement, lateral movement, pore water pressure, total pressure and deformation of bamboo to evaluate the performance of BGC reinforcement system. Three trial embankments had been constructed each on natural foundation soil (soft clay) known as unreinforced embankment, on BGC reinforced soft clay and on high strength geotextile reinforced soft clay. These trial embankments had been monitored using Hydrostatic Profiler, Inclinometer, RST Strain Gauge Piezometer, Total Earth Pressure Cell, Strain Gauge Liquid Settlement System, Surface Settlement Marker and Strain Gauge, to monitor the performance of trial embankment, over 14 months period. The graphs obtained from these instrumentations had been evaluated to determine the field performance of the embankments. However, field monitoring results from UR and BGC embankments only had been used in the prediction of BGC performance using finite element software. The field performance of HSG embankment was still used for field performance comparisons between BGC and other embankments.

The laboratory and the in-situ tests on the soils had been done by previous researchers. PLAXIS 2D Version 8.2 software had been used for modelling work using the finite element method (FEM) to compare and back analysed the monitoring results from full-scale test on unreinforced embankment. Once the representative soil properties are achieved, the BGC embankment is modelled and the best method of modelling BGC embankment using PLAXIS software was explored by comparing with field results.

# REFERENCES


Abang Ali, A. A and Abang Ali, A. A. R. (1984). *Basic Strength Properties of a Few Selected Malaysian Bamboos*. Jurnal Institusi Jurutera Malaysia No. 34 : 68-71.

Ahmad, S.A. and Peaker, K.R. (1977). Geotechnical Properties of Soft Marine Singapore Clay. *International Symposium on Soft Clays*, Bangkok, Thailand,

Ambily, A.P. and Gandhi, S.R. (2007). *Behavior of Stone Columns Based on Experimental and FEM Analysis.* Journal of Geotechnical and Geoenvironmental Engineering. ASCE / April 2007.

Apimeteetamrong, S., Sunitsakul, J. and Sawatparnich, A. (2007). Performance of Highway Embankments on Bangkok Clay. *Soft Soil Engineering* – Chan & Law (eds) © 2007: Taylor & Francis Group, London, ISBN 13 978-0-415-42280-2.

Azmy, H. M., H. Norini and W.M. Wan Razali. (1997). *Management Guidelines and Economics of Natural Bamboo Stands*. FRIM Technical Information No. 15, FRIM, Kepong, Malaysia.

Balasubramaniam, A.S., Phien-Wej, N., Indraratna, B. and Bergado, D.T. (1989). Predicted Behaviour of a Test Embankment on a Malaysian Marine Clay. *International Symposium on Trial Embankments on Malaysian Marine Clays*. 6-8 November 1989, Kuala Lumpur.

Barták, J., Hilar, M. and Pruška, J. (2002). *Numerical Modelling of Overburden Deformations*. Acta Polytechnica Vol. 42 No. 1/2002.

Batista, I.S. (2003). *A Case Study on the Performance of Embankment on Treated Soft Ground*. Degree of Master of Engineering in Civil and Environmental Engineering. Massachussetts Institute of Technology. 2 June 2003.

Bergado, D.T., Balasubramaniam, A.S. and Chai, J.C. (1994). Prediction of Behavior of Reinforced Embankments on Muar Clay Deposit. *Prediction versus Performance in Geotechnical Engineering*, Balasubramaniam et al. (eds) © 1994 Balkema, Rotterdam, ISBN 90 5410 3558.

Boonsinsuk, P. (1994). Back Analysis of Cut Slope Instability in Soft Bangkok Clay. *Prediction versus Performance in Geotechnical Engineering*, Balasubramaniam et al. (eds) © 1994 Balkema, Rotterdam, ISBN 90 5410 3558.

Brand, E.W. and Premchitt, J. (1989) Moderator's report for the predicted performance of the Muar test embankment. *Proc. Intl. Symp. on Trial Embankment on Malaysian Marine Clays*, Kuala Lumpur, 2:32-49.

Colleselli, F. and Cortellazo, G. (1994). Foundation Behaviour of a Levee in the Po Delta. *Prediction versus Performance in Geotechnical Engineering*, Balasubramaniam et al. (eds) © 1994 Balkema, Rotterdam, ISBN 90 5410 3558.

Cook, R.D,. Malkus, D.S, Plesha, M. E. and Witt R. J. (2001). *Concepts and Applications of Finite Element Analysis* , University of Wisconsin-Madison, Fourth Edition.

Dannenmann, B.M.E., Choocharoen, C., Spreer, W., Nagle, M., Leis, H., Neef, A. and Mueller, J. (2007) The Potential of Bamboo as a Source of Renewable Energy in Northern Laos. *Conference on International Agricultural Research for Development*. University of Kassel-Witzenhausen and University of Göttingen, October 9-11, 2007.

Das, B.M. (2005). *Fundamentals of Geotechnical Engineering. Second edition.* Imprint, Australia: Thomson.

Deschamps, R. and Yankey, G. (2006). *Limitations in the Back-Analysis of Strength from Failures*. Journal of Geotechnical and Geoenvironmental Engineering © ASCE / April 2006. DOI : 10.1061/ (ASCE)1090-0241(2006)132:4 (532)

Ghavami K, Allameh S.M., Sánchez C.M.L. and Soboyejo W.O. (2003). *Multiscale Study of Bamboo Phyllostachys Edulis*.

Gofar, N. and Kassim, K.A. (2005). *Introduction to Geotechnical Engineering. Part 1.* Singapore : Prentice Hall. 2005. ISBN 981-067561-5.

Gouw, T.L. (2007). *Manual on Short Course on PLAXIS*, Faculty of Civil Engineering, UTM. 14-16 May 2007.

Hamid, N.H., Mohmod, A.L. and Sulaiman, O. (2003). Variation of Moisture Content and Specific Gravity of Gigantochloa scortechinii Gamble along the Internodes Sixth Height. *XII World Forestry Congress*. http://www.fao.org/DOCREP/ARTICLE/WFC/XII/0030-B4.HTM. Accessed on 17 March 2010.

Hanim, M. (2005). *Penyiasatan Tapak dan Ciri Kebolehmampatan Tanah Liat Lembut di Tapak Tambakan Cubaan*. Degree Project Report of Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia. 2005.

Hartlen, J. and Wolski, W. (1996). *Embankments on Organic Soils*. Developments in Geotechnical Engineering, 80. Netherlands : Elsevier Science B.V., 1996.

Hirman, H. (2009). *Performance of Full Scale Embankment on Soft Clay Reinforced with Bamboo-Geotextile Composite at the Interface*. Master Project Report of Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.

Holtz, R.D. (2001). *Geosyntetics for Soil Reinforcement*. The Ninth Spencer J. Buchanan Lecture. Collage Station Hilton. 2001.

Huat, B.B.K., Sew, G.S. and Ali, F (2004). *Tropical Residual Soils Engineering*. London : Taylor & Francis Group. ISBN 90 5809 660 2.

Irsyam,M., Krisnanto,S. and Wardhani,S.P.R. (2008). Instrumented Full Scale Test and Numerical Analysis to Investigate Performance of Bamboo Pile-Mattress System as Soil Reinforcement for Coastal Embankment on Soft Clay. *Geotechnical Engineering for Disaster Mitigation and Rehabilitation* Liu, Deng and Chu (eds) 2008 Science Press Beijing and Springer-Verlag GmbH Berlin Heidelberg.

Janssen, J.J.A (1981). *Bamboo in Building Structures.* Degree of Doctor of Technical Sciences, Eindhoven University of Technology.

Jingchun, W., Weihong, H. and Riqing, X. (2006). Back Analysis of Parameters for Construction Garbage as Road Fill. GeoCongress 2006: Geotechnical Engineering in the Information Technology Age Proceedings of GeoCongress 2006. *ASCE Conf*. Proc. doi:10.1061/40803(187)258

Khatib, A. (2009). *Bearing Capacity of Granular Soil overlying Soft Clay Reinforced with Bamboo-Geotextile Composite at the Interface*. Ph.D Thesis, Universiti Teknologi Malaysia.

Krause, Q. and Ghavami, K. (2009). Transversal Reinforcement in Bamboo Culms. *Proceedings of the 11th International Conference on Non-conventional Materials and Technologies (NOCMAT 2009)*. 6-9 September 2009, Bath, UK

Lancellotta, R. (2009). *Geotechnical Engineering*. Taylor and Francis. ISBN 9780415420037.

Leroueil,S., Magnan,J. and Tavenas, F.(1990). *Embankments on Soft Clays*. England : ELLIS HORWOOD LIMITED, Market Cross House, Cooper Street, Chichester, West Sussex, PO19 1 EB.

Liese, W. (1992). The Structure of Bamboo in Relation to Its Properties and Utilization. Bamboo and Its Use. *International Symposium an Industrial Use of Bamboo*. Beijing, China. 7-11 December 1992.

Liu, C. and Evett, J.B. (2005). *Soils and Foundations*. SI Edition. Singapore : Prentice Hall, 2005.

Liu, J.L., Liu, J.Q. and Chen, L.W. (2008). Study on the Mechanism of Embankment Reinforced with Geotextile by Finite Element Method. *Proceedings of the 4th Asian Regional Conference on Geosynthetics*. June 17-20, 2008 Shanghai, China.

Loke, K. H. (2000). Geosynthetic-Proven and Innovative Method for Soft Soil Stabilization. *Seminar on Ground Improvement-Soft Clay. August, 23-24. Kuala Lumpur,* 34-42.

Low, K. S., and Tey, H. B. (2000). Bamboo-Goetextile Soil Reinforcement System for The New Miri Supply Base Complex Project. *Proceedings of the 2nd Asian Geosynthetic Conference*. May, 29-31. Kuala Lumpur, Malaysia. 2, 121-126.

Madhyannapu, R.S., Puppala, A.J., Hossain, S., Han, J. and Porbaha, A. (2006). Analysis of Geotextile Reinforced Embankment over Deep Mixed Soil Columns:Using Numerical and Analytical Tools. *GeoCongress 2006*.

Marto, A ,Makhtar, A.M. and Khatib A (2010). Bearing Capacity of Granular Soil overlying Soft Clay Reinforced with Bamboo-Geotextile Composite at the Interface, *6th Int. Conference on Innovation in Architecture, Engineering and Construction (AEC), Penn- State University, USA, 9-11 June 2010*

Marto, A. (2009). *The Construction and Monitoring of Embankment on Soft Clay Reinforced with Bamboo at the Interface*. IEM Short Course on Soft Soil Engineering Seminar (SSES'09), Pan Pacific Hotel, Johor Bahru, Johor, 30 July 2009.

Marto, A , Khatib A, and Hasbi, B.H. (2008). Bearing Capacity of Footings on Bamboo-Geotextile Composite Reinforced Soft Clay. *International Conference on Geotechnical and Highway Engineering,GEOTROPIKA 2008*, 26-27 May 2008, Kuala Lumpur.

Mohamed, A., Haron, N., and Wan Mohd, W. R. (1997). *Management Guidelines and Economics of Natural Bamboo Stands*. FRIM Technical Information Handbook No. 15. Forest Research Institute of Malaysia (FRIM). Kepong, Kuala Lumpur. 1997.

Mohamed, A. (1992). *A Note on the Occurence of Flowering of Gigantochloa Ligulata (Buluh Tumpat).* JTFS. 4(4):354-355

Mohd Hanapiah, M.Z. (2009). *Performance of Full Scale Embankment on Soft Clay Reinforced with High Strength Geotextile at the Interface*. Master Project Report of Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.

Nagaraj, T.S. and Miura, N. (2001). *Soft Clay Behaviour : Analysis and Assessment*. A.A. Balkema, Rotterdam. 2001. ISBN 9058093298.

Nakase, A. and Takemura, J. (1989). Prediction of Behaviour of Trial Embankment Built to Failure. *International Symposium on Trial Embankments on Malaysian Marine Clays.* 6-8 November 1989, Kuala Lumpur.

Nazir, R. (2006). *Manual on Short Course on PLAXIS,* Faculty of Civil Engineering, UTM. 14-16 May 2007.

Othman, A.R. and Malek, J. (2003). *Garis Panduan Perladangan Buluh di Malaysia.* FRIM Technical Information Handbook No. 33. Forest Research Institute of Malaysia (FRIM), Kepong, Kuala Lumpur. 2003.

Othman, A.R., Md Noor, H. and Malek, J. (2007). *Harvesting Technique in Natural Stands of Buluh Semantan (Gigantochloa scortechinii).* FRIM Reports No. 87, 2007.

Pakatan Geo Services Sdn. Bhd. (2008). *Soil Investigation Reports at RECESS, UTHM*.

PLAXIS (2000). PLAXIS Version 8 Manual. A.A Balkema Publishers.

Poulos, H.G., Lee, C.Y. and Small, J.C. (1989). Prediction of Embankment Performance on Malaysian Marine Clays.. *International Symposium on Trial Embankments on Malaysian Marine Clays.* 6-8 November 1989, Kuala Lumpur.

Poungchompu, P. (2009). *Development of a Timber Raft & Pile Foundation for Embankments on Soft Ground*. Degree of Doctor of Philosophy in Civil Engineering, Saga University, Japan. 2009.

Price, D.G. (2009). *Engineering Geology : Principles and Practice*. Springer, Berlin. 2009. ISBN: 9783540292494,3540292497

Rao, K.N. (2006). *Numerical Modeling and Analysis of Pile Supported Embankments.* Degree of Master of Science in Civil Engineering. The University of Texas at Arlington. May 2006.

RST Instruments (2004). *RST Strain Gauge Piezometer Instruction Manual*. November 26, 2004.

RST Instruments (2004). *Total Earth Pressure Cell Instruction Manual*. October 13, 2004.

RST Instruments (2009). *Strain Gauge Liquid Settlement System Instruction Manual*. January 20, 2009.

RST Instruments (2009). RST MEMS Digital Inclinometer System Instruction Manual. December 14, 2009.

Rowe, P.W. (1972). The Relevance of Soil Fabric to Site Investigation Practice. *Geotechnique*, Vol. 22, pp 195-300.

Sallam, A. (2009). *Application of Finite Element Analysis in Geotechnical Engineering*. Florida Engineering Society Journal, May 2009.

Setiyo, N. I and Sudibyo, G. H. (2005). Pemanfaatan Lamina Bambu pada Balok Komposit Glulam Beton. *Proseding Seminar Nasional Perkembangan Bambu di Indonesia*. 17 Januari 2005 Yogyakarta, Indonesia, 63-71.

Simpson, B. (2000). Partial factors: where to apply them?. LSD2000: *International Workshop on Limit State Design in Geotechnical Engineering* Melbourne, Australia. 18 November 2000.

Sivakugan, N. (2001). *Compaction*. www.geoengineer.org/files/Compaction-Sivakugan.ppt., 2001. Accessed on 17 January 2011.

Srokosz, P. (2008). *Back Analysis in Geotechnics – Examples of Shape Determination*. Foundations of Civil and Environmental Engineering. No. 12, 2008. Ponzan University of Technology. ISSN 1642-9303

Tenaga Gerudi Sdn. Bhd. (2002). *Soil Investigation Reports at Universiti Tun Hussien Onn Malaysia (UTHM).*

Tanchaisawat, T., Bergado, D.T., Lai, Y.P., Piyaboon, S. and Anujorn, P. (2008). "Numerical Simulation of Geogrid Reinforced Lightweight Geomaterials on Soft Ground Area". *Proceedings of the 4$^{th}$ Asian Regional Conference on Geosynthetics,* June 17-20, 2008, Shanghai, China, pp 286-290.

Tanchaisawat, T., Bergado, D.T. and Voottipruex, P. (2009). "2D and 3D Simulation of Geogrid Reinforced Geocomposite Material Embankment on Soft Bangkok Clay". *Geosynthetics International*, 16, No. 6, 420-432. [doi: 10.1680/gein.2009.16.6.420].

Terzaghi, K., and Peck, R. B. (1967). *Soil Mechanics in Engineering Practice*. A Wiley International Edition, 729 p.

The Malaysian Highway Authority (1989). Trial Embankments on Malaysian Marine Clays. *Proceedings of the International Symposium*, 6-8 November 1989, Kuala Lumpur. Volume 1.

The Malaysian Highway Authority (1989). Trial Embankments on Malaysian Marine Clays. *Proceedings of the International Symposium*, 6-8 November 1989, Kuala Lumpur. Volume 2 (Preprints).

TML. *Strain Gauges :* TML Strain Gauges Catalog. Tokyo Sokki Kenkyujo Co. Ltd.

Vaessen, M.J. and Janssen, J.J.A. *Analysis of the Critical Length of Culms of Bamboo in Four-point Bending Tests*. HERON, Vol. 42, No. 2 (1997) ISSN 0046-7316.

Whitlow, R. (1996). *Basic Soil Mechanics*. Third Edition. England. ISBN 0-582-23631-2. 1996

Wong, P.K., Day, R.A. and Poulos, H.G. (2011). *Coffey Geotechnics* Pty Ltd, Sydney, Australia

Xie, K.H., Pan, Q.Y., Zeng, G.X. and Zhu, X.R. (1994). Prediction Versus Performance on the Behaviour of Soft Clay Ground Improved by Vertical Drains. *Prediction versus Performance in Geotechnical Engineering*, Balasubramaniam et al. (eds) © 1994 Balkema, Rotterdam, ISBN 90 5410 3558.

Xin, J. (2009). A Comparative Study of Various Commercially Available Programs for Numerical Analysis of Reinforced Soil. *International Conference on Transportation Engineering 2009 (ICTE 2009).*

http://www.consoil.se/applications.php (1996)

http://www.uow.edu.au/eng/research/landslide/landslidemonitoring/index.htm (1988)

**LIST OF PUBLICATIONS**

Marto, A., Othman, B. A., Mohd. Hanipiah, M. Z. and Hirman, H. *Performance of Bamboo-Geotextile Composite Reinforced Embankment on Soft Clay*. 3rd International Graduate Conference on Engineering, Science and Humanities (IGCESH 2010), 2-4 November 2010, Universiti Teknologi Malaysia, Johor Bahru, Malaysia. ID 171 page 119.

Marto, A., Ismail, B. N., Bakar, I. and Othman, B. A. *2D Finite Element Analysis of Bamboo Reinforced Embankment.* International Conference on Geotechnical and Transportation Engineering (GEOTROPIKA 2010), 1-3 December 2010, Kota Kinabalu, Sabah, Malaysia.

Marto, A. and Othman, B. A. *The Potential Use of Bamboo as Green Material for Soft Clay Reinforcement System.* 2011 International Conference on Environment Science and Engineering (ICESE 2011), 1-3 April 2011, Bali, Indonesia. Published at IPCBEE vol.8 (2011) © (2011) IACSIT Press, Singapore.

Kasim, F., Marto, A. and Othman, B. A. *Numerical Analysis of Bamboo-Geotextile Composite Reinforced Embankment on Soft Clay.* International Conference on Advances in Geotechnical Engineering 2011 (ICAGE 2011), 7-9 November 2011, Perth, Australia.

Othman, B. A., Marto, A., Kasim, F., Bakar, I. and Mohd Hanipiah, M. Z. *The Performance of Embankment Reinforced with High Strength Geotextile on Soft Clay*. 2011 (SEPKA 2011), Universiti Teknologi Malaysia, Johor Bahru, Malaysia.