2016

Natural prefabricated vertical drains-structure and geo-hydraulic properties

Thanh Trung Nguyen
University of Wollongong, ttnguyen@uow.edu.au

Buddhima Indraratna
University of Wollongong, indra@uow.edu.au

Cholachat Rujikiatkamjorn
University of Wollongong, cholacha@uow.edu.au

Publication Details

Nguyen, T. T., Indraratna, B. & Rujikiatkamjorn, C. (2016). Natural prefabricated vertical drains-structure and geo-hydraulic properties. In P. Long (Ed.), Geotechnics for Sustainable Infrastructure Development - Geotec Hanoi 2016 (pp. 651-658). Vietnam: Construction Publishing House.

Natural prefabricated vertical drains-structure and geo-hydraulic properties

Abstract

Over the past decades synthetic prefabricated vertical drains (SPVDs) have been used in many regions around the world to accelerate the consolidation of soil, but because these synthetic polymeric materials last for decades, they are now seen as having adverse effects on the natural environment. Natural prefabricated vertical drains (NPVDs) on the other hand, which are made from agriculture products such as jute, coir, and straw can discharge excess pore pressure effectively and they are also environmentally friendly thanks to their biodegradability. This paper outlines the fundamental characteristics of prefabricated vertical jute drains (PVJDs) such as their structure, tensile strength, and discharge capacity, because they are currently considered to be one of the most common types of NPVDs.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Nguyen, T. T., Indraratna, B. & Rujikiatkamjorn, C. (2016). Natural prefabricated vertical drains-structure and geo-hydraulic properties. In P. Long (Ed.), Geotechnics for Sustainable Infrastructure Development - Geotec Hanoi 2016 (pp. 651-658). Vietnam: Construction Publishing House.

Geotechnics for Sustainable Infrastructure Development - Geotec Hanoi 2016, Phung (edt). ISBN 978-604-82-0013-8

NATURAL PREFABRICATED VERTICAL DRAINS-STRUCTURE AND GEO-HYDRAULIC PROPERTIES

Thanh Trung Nguyen
University of Wollongong, Australia: ttn323@uowmail.edu.au

Buddhima Indraratna
University of Wollongong, Australia: indra@uow.edu.au

Cholachat Rujikiatkamjorn
University of Wollongong, Australia: cholacha@uow.edu.au

Keywords: prefabricated vertical drain, consolidation, natural fibres, discharge capacity, biodegradation

ABSTRACT: Over the past decades synthetic prefabricated vertical drains (SPVDs) have been used in many regions around the world to accelerate the consolidation of soil, but because these synthetic polymeric materials last for decades, they are now seen as having adverse effects on the natural environment. Natural prefabricated vertical drains (NPVDs) on the other hand, which are made from agriculture products such as jute, coir, and straw can discharge excess pore pressure effectively and they are also environmentally friendly thanks to their biodegradability. This paper outlines the fundamental characteristics of prefabricated vertical jute drains (PVJDs) such as their structure, tensile strength, and discharge capacity, because they are currently considered to be one of the most common types of NPVDs.

1. INTRODUCTION

Synthetic prefabricated vertical drains (SPVDs) are used worldwide to improve soft ground that is needed to develop infrastructure in estuarine coastal area, as indicated by Indraratna et al. (2015); indeed in recent decades they have completely replaced traditional sand drains, as Rawes (1997) noted. Although PVDs have many advantages over other soil improvement methods, conventional PVDs are made from synthetic polymeric materials which usually resist biodegradation, so they exist in soil for a very long time and cause extensive damage to the natural environment (Gregory and Andrady 2003). This is why a more environmentally friendly type of vertical drain is needed.

To this end, naturally occurring materials such as fibres have been emerging in recent decades as a very appropriate option to minimise their ecological footprint. The use of natural fibres such as jute, coir, and straw for vertical drains has received a lot of attention (Kim and Cho 2009; Indraratna et al. 2016; Nguyen and Indraratna 2016) since this type of drain was first introduced by Lee et al. (1987) in Singapore. Many field and laboratory investigations (Venkatappa Rao et al. 2000; Kim et al. 2001; Asha and Mandal 2012) have shown that natural prefabricated vertical drains (NPVDs) have enough discharge capacity to dissipate excess pore pressure effectively, and moreover they are flexible enough not be overly influenced by the normal kinking and bending due to the large settlement of soft soil (Kim et al. 2001) which usually reduces the discharge capacity of conventional SPVDs.

Natural fibres are products of agriculture and as such are abundant in many developing regions. Indian and Sri Lanka are the major producers of coir fibre, followed by Thailand, Vietnam, the Philippines and Indonesia (Ali 2010), while more than 90% of the world's jute is manufactured in Bangladesh, China, India and Thailand (Rahman 2010). Other natural fibres such as straw, bamboo, and hemp can be found in South and Southeast Asia (e.g., Vietnam, Thailand), so increasing the use of NPVDs can bring huge benefits to the local economy and society of these developing regions, making NPVDs more valuable than synthetic drains.

Low productivity in manufacture is currently the major barrier to widening the application of NPVDs in practice. Most technologies used to manufacture NPVDs, including fibre extraction and braiding, are still based primarily on manual labour, which results in low productivity compared to the massive production of SPVDs. Moreover, NPVDs vary in materials and characteristics and there is a current paucity of studies and standards with guidelines for applying these drains in the field, all of which results in a great deal of inconvenience in practice. This is why the physical properties of natural fibres which can be used to produce NPVDs, and the engineering characteristics of these drains are in urgent need of investigation.

This paper provides the fundamental characteristics of NPVDs, including their common materials, structure and engineering characteristics, as well as comparison between NPVDs with SPVDs. Laboratory investigations are carried out on prefabricated vertical jute drains (PVJD), the most popular type of NPVDs used in current practices. Several micro-analytical techniques such as optical microscopy and scanning electron microscopy (SEM) are used to obtain a better understanding of the micro-porous structure of PVJDs.

2. STRUCTURE OF NATURAL FIBRE DRAINS

2.1 Materials

Of the raw natural fibres used to produce NPVDs, jute and coir are preferred due to their durability and abundance in developing regions. Jute contains more than 80% cellulose and less than 14% lignin, which makes it less durable than coir which has approximately 30% lignin (Som et al. 2009).

Coir is extracted from coconut husks, including the brown fibre obtained from mature coconuts and white fibre one from immature coconuts (Ali 2010). This difference in nature means that brown coir has much higher tensile strength and durability than white fibre, so in this study, only brown coir is considered.

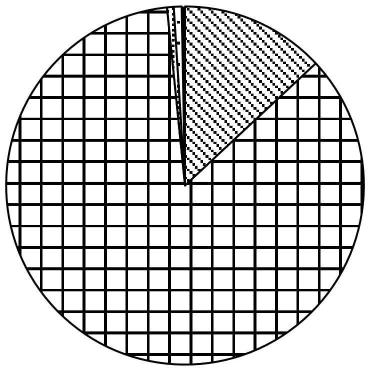


Figure 1. Chemical components of jute fibre (Som et al. 2009)

Laboratory investigations of the physical features of jute and coir, including their average diameter and tensile strength were carried out. The diameter of these fibres was determined via an optical microscope. Coir had a range of diameters varying from 102 to 502 μm. The coir density of 1135 kg/m^3 obtained in this study corroborated with those reported by previous studies (Ali 2010; Tran et al. 2015) which showed the density of coir varies from 670 to 1370 kg/m^3. Jute had an even wider range of equivalent diameters. For example the diameter of jute varied from 10 to 83 μm, which agreed with those reported by Kozlowski et al. (2009). In this study the density of jute was 1420 kg/m^3.

Tests were also carried out to obtain the tensile strength of jute and coir fibres. The strain applied in the tension test was 5 mm/minute. Since coir fibres were larger than jute fibres, the tensile strength of coir was tested on individual fibres, whereas jute fibres were tested as a bundle and the tensile strength was then averaged based on the tensile strength of the bundle and the total cross sectional area of individual fibres in the bundle.

Coir had a tensile strength from 125 to 215 MPa, and these corroborated with values stated in previous studies (Biswas et al. 2013). The tensile strength of coir usually ranges from 186 to 343 MPa, as reported by Defoirdt et al. (2010). Jute had a much higher tensile strength, ranging from 358 to 490 Mpa. Defoirdt et al. (2010) reported the tensile strength of jute as slightly smaller, from 307 to 399

Mpa, while Biswas et al. (2013) agreed with the range obtained in this study.

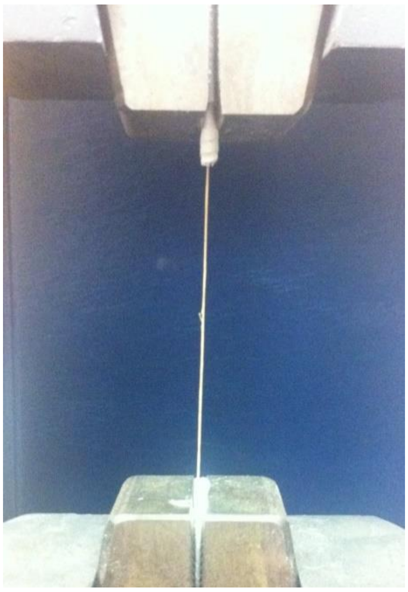


Figure 2. Tension test on single fibre

Although straw was also used in Kim and Cho's investigation (2009) which showed that a straw drain was reasonably successful at accelerating soil consolidation, this natural material still has quite low tensile strength and decays faster than jute and coir. This explains why straw drains have not been used very much in practice.

2.2 Structures

NPVDs with various structures have been used in the laboratory and field over the past years, but basically, a natural fibre drain consists of the filter and the core. The filter usually consists of several layers of geotextile made from natural fibres such as jute and hemp, while the core consists of various structures and materials. The major function of core is to maintain the form of the whole drain to ease the installation at field while the filter is created to retain soil particles. The core of drain can also contribute to the hydraulic conductivity and the significance of this contribution is varying with the structure of drains.

NPVDs with a circular cross section were used by Kim et al. (2001), and Kim and Cho (2009). In this format (Figure 3), natural fibres such as coir and straw are wrapped with one or two layers of jute which act as the filter for the drain, which is approximately 31 to 33 mm in diameter. The hydraulic conductivity of this drain relies mainly on porous characteristics of the core which is actually a complex (twisted) fibre bundle.

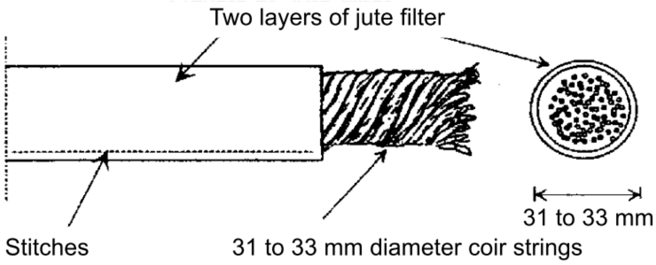


Figure 3. Circular shape of NPVD (Kim et al. 2001)

Most NPVDs are band shaped with different thickness and core structure. The thickness of these NPVDs can vary from 6 to 16.5 mm while their width is within a range from 80 to 120 mm. Asha and Mandal (2012) investigated NPVDs with different cores (Figure 4) and concluded that the stiffer the core the higher the discharge capacity. NPVD-01 and 02 have the same core structure (5 strands of coir) but different filter sheaths (woven and non-woven geotextiles, respectively), whereas NPVD-3 and 04 use the same woven geotextile for the filter but different cores, i.e., coir mat and corrugated coir mat, respectively. The drains supported by coir mat can resist external compression better than those with coir strands and hence provide a higher discharge capacity; this indicates how the structure of NPVDs can influence their discharge capacity.

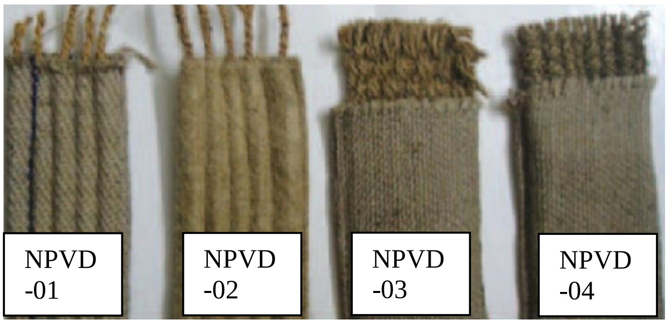
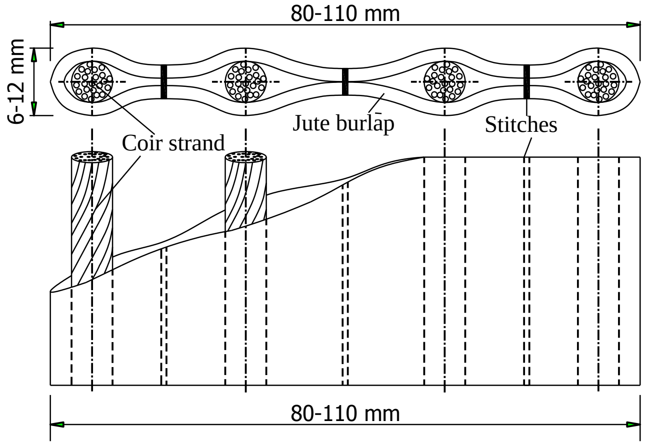


Figure 4. Different structures of band shaped NPVDs (Asha and Mandal 2012)

The most commonly used NPVD in practice is a combination between one or two layers of jute sheath working as the filter of drain and 4 to 5 coconut cores (Figure 5). This type of NPVD is also known as a prefabricated vertical jute drain (PVJD) to indicate the major role that jute fibres play in the drain. While in other types of NPVD, coir fibres are the main contributor to the discharge capacity because they create a large component in the whole porosity of the drain, coir strands used in PVJDs are mainly to reinforce the drain rather than to provide porosity for discharging excess pore pressure. A PVJD is better because it is simple to manufacture and also provides enough discharge capacity to dissipate excess pore pressure. Moreover, since they are only 6 to 12 mm thick, which is smaller than drains with coir mats, they can be installed easily with the mandrel used to install conventional SPVDs.



a)

b)

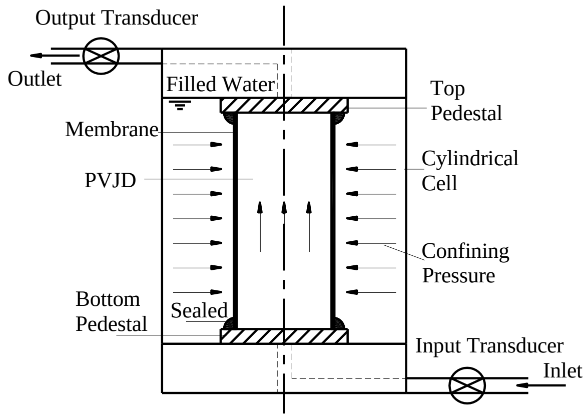
Figure 5. A typical PVJD: a) Schematics; and b) Real PVJD

3. ENGINEERING CHARACTERISTICS OF PREFABRICATED VERTICAL JUTE DRAINS

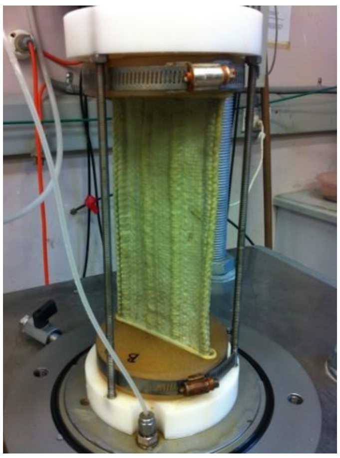
This section represents laboratory investigations into the fundamental engineering characteristics of PVJDs provided by the National Jute Board of India. A discharge capacity test, a tension test of the complete drain, and micro-analyses of the porous structure of the drain were carried out.

3.1 Discharge capacity

Discharge capacity is the most important feature of a drain and can be determined by laboratory and field works (Rawes 1997). The test model in this study was built by regarding the Delft PVD discharge capacity test (Rawes 1997) where the drain was positioned vertically at the centre of a cylindrical cell (Figure 6). Samples of PVJD were wrapped in 0.25 mm thick soft membrane before being placed inside the system. Both ends were capped by pedestals that were modified to adapt to the drain size and then a layer of silicon was applied to the outside of the connection between the pedestals and drain to prevent leakage. After fixing the drain in position, water was gradually poured into the cell. A confining pressure was generated onto the cell and controlled by a hydraulic actuator. The pressure in the cell was first set at 10 kPa, and then increased to different magnitudes, i.e., 50, 100, and 200 kPa. At each level of confining pressure, water was driven from the bottom inlet along the jute drain and collected at the drain outlets. By considering the difference between the input and output pressures through the drain and the volume of water collected at the outlet in a unit of time, the discharge capacity of drain could be determined. The impact of water temperature on the test result was also evaluated in accordance with ASTM D4716 (2008).



a)



b)

Figure 6. Discharge capacity tests: a) Schematics of the test; and b) Drain sample with membrane after testing

Figure 7 shows the discharge capacity of the PVJDs compared to those measured in other studies, including Kim et al. (2001), and Asha and Mandal (2012). The characteristics of the NPVDs used in this comparison are summarised in Table 1. The discharge capacity of the current PVJD with regards to the increasing confining pressure is relevant to the values stated in previous studies using different types of NPVD and the same hydraulic gradient (i.e., $i = 0.5$). The discharge capacity of the current drain is around 5.4×10^{-6} m^3/s (0.47 m^3/day) which is less than several values reported in previous investigations but still within a common range. Deviations of these measurements can be attributed to different features of natural fibre drains and the experimental methods used in those studies. As a higher confining pressure is applied, the discharge capacity is lower, but the discharge capacity of drain gradually reaches a stable level, even though the confining pressure continues to increase. This indicates a state whereby the fibres cannot be re-arranged any further under compression and the porosity of the drain decreases to a minimum value.

Name	Sheath or filter	Core	Size (mm)
Current PVJD	1 layer of jute geotextile	4 Coir strands, D(4-5) mm	100x8
FD1- Kim et al., (2001)	2 Layers, Woven Jute (Circular Shape)	Coir strings, D(31-33) mm	D33
FD2- Kim et al., (2001)	2 Layers, Woven Jute	3 Coir strands, D7.5 mm	108x7.5
NPVD1- Asha and Mandal (2012)	1 Layer, Woven Jute, 700g/m^2, 1.8mm thick	Coir strand, D5 mm	90x9
NPVD2- Asha and Mandal (2012)	1 Layer, Non-Woven Jute, 680g/m^2, 8mm thick	Coir strand, D5 mm	90x11
NPVD3- Asha and Mandal (2012)	1 Layer, Woven Jute, 700g/m^2, 1.8mm thick	Flat coir mat, 10 mm thick	90x12
NPVD4- Asha and Mandal (2012)	1 Layer, Woven Jute, 700g/m^2, 1.8mm thick	Corrugated coir mat, 13mm thick	90x16.5

Table 1. Properties of NPVDs in the discharge capacity comparison

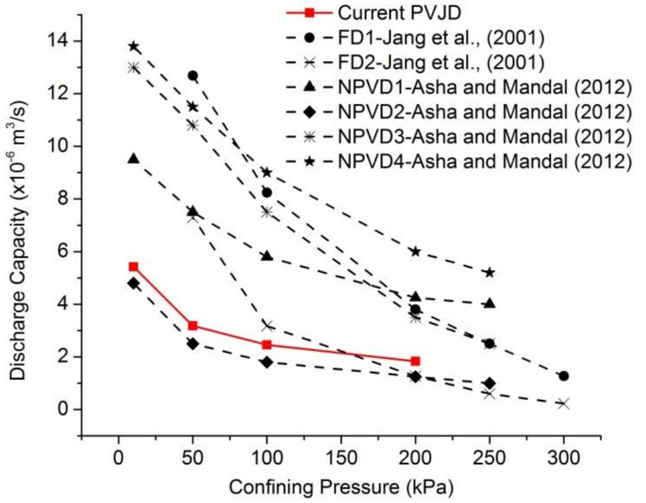


Figure 7. Discharge capacity of the current PVJD compared to other NPVDs

The study indicates that the discharge capacity of PVJD with 4 coir strands and one layer of jute sheath is comparable to other NPVDs. Note that previous PVJDs which were shown to have enough discharge capacity to accelerate consolidation in the field, as reported by Lee et al. (1994) in an earlier study, had the same coir strands but two layers of jute sheath.

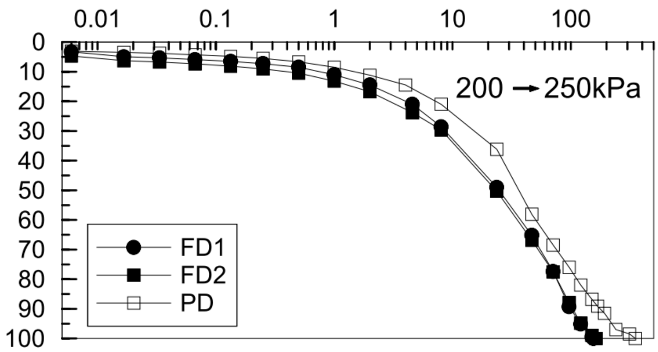


Figure 8. Consolidation induced by fibre drain (FD) and polymeric drain (PD) under large compression (Kim et al. 2001)

Previous studies showed that the discharge capacity of NPVDs is generally not influenced much by the bending and kinking of drain. Kim et al. (2001) carried out a laboratory investigation and concluded that NPVDs (FD1 and FD2 in Figure 8) could resist bending caused by a large settlement of soil, whereas a conventional polymeric drain (PD) had its discharge capacity reduced considerably under the same condition, resulting in a deviation between consolidation curves induced by the two types of drain. Banerjee (2012) also stated that kinking only led to a minor reduction in the discharge capacity of NPVDs even when the drain was kinked by almost 30%. This is because the discharge capacity of the polymeric drain is based on the parallel channels while the natural fibre drain has fluid flowing in the inter-space between individual fibres.

3.2 Tensile strength

Figure 9. Tension test on the whole drain

A tension test was carried out on the entire PVJD (Figure 9). The average tensile strength of the drain was 3.4 kN which is enough to bear the tension generated during installation. In regards to to previous studies (Rawes 1997) showed that the minimum tensile strength of a drain should be greater than 0.5 kN.

3.3 Micro-analyses on PVJD

Micro-analysis techniques such as the scanning electron method (SEM), observation under an optoncal microscope, and CT scanning were applied onto the PVJD to better understanding the microstructure of this fibre drain. Figure 10 shows the typical results obtained from micro-analyses. CT scanning (Figure 10a) shows a unit channel of the drain, including one coir strand surrounded by a number of jute bundles which work as a filter for the drain. The cross sections of coir fibres in a bundle (strand) are shown in Figure 10b, which indicates that the coir fibres are almost round. Figure 10c represents a bundle of jute fibres captured by the SEM, which shows that jute fibres have irregular shape.

Figure 10 shows that the porosity of the drain consists of: (*i*) the void within individual fibre bundles (inter-fibre porosity), and (*ii*) those depositing at the interval space of fibre bundles (inter-bundle porosity). It is clear that without being confined, inter-bundle porosity plays a major role in the whole porosity of the drain, but this component of porosity can potentially be reduced significantly by external loads, i.e., compression which re-arranges the fibre bundles. The interal porosity of individual fibre bundles, especially of coir strands which are more robust than jute fibres, is more stable, and therefore its contribution to the porosity of the whole drain increases while the inter-bundle porosity decreases under confing pressure. Note that these porous characteristics explain the hydraulic behaviour of the drain under confining pressure.

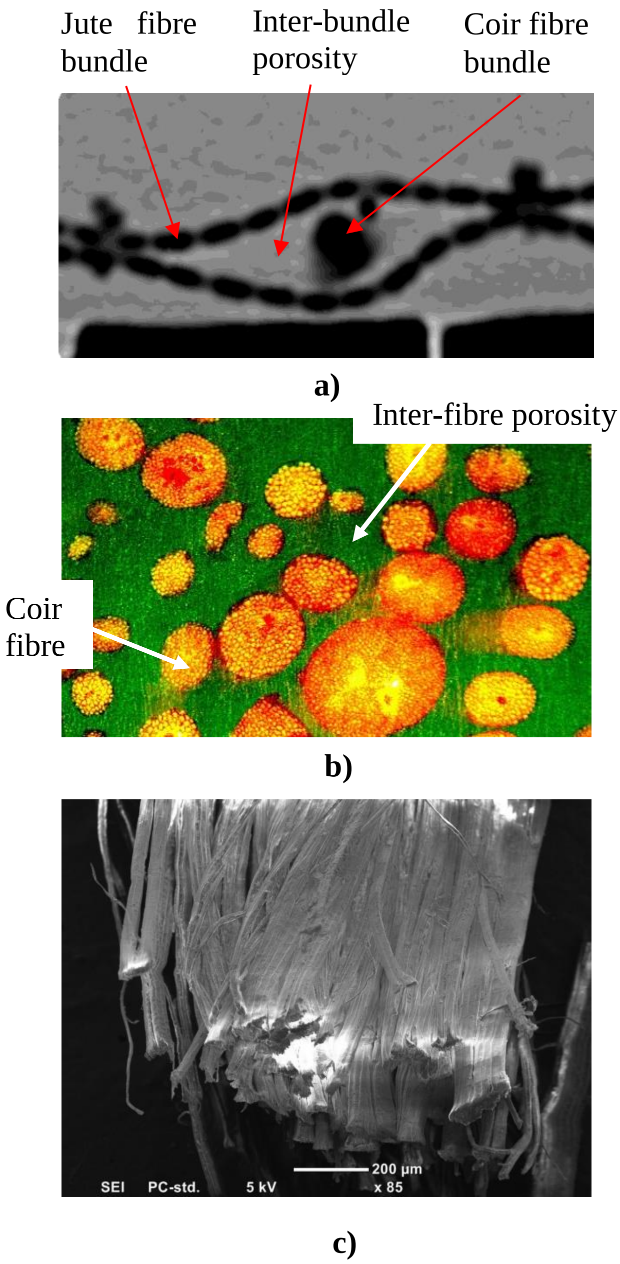


Figure 10. Micro-observations: a) Under CT scanning; b) Coir fibres under optical microscope; and c) Jute fibres unnder SEM

3.4 Biodegradation

The major advantage of natural fibres is their biodegradability over time however these materials can decay too fast when exposing to adverse environments such as acidic soils, leading to a severe reduction of engineering characteristics of the drain. The degradation of natural fibres has been shown in previous studies such as Kim and Cho (2009) and Saha et al. (2012), which indicates a considerable influence of the environmental condition on the durability of fibre engineering properties. Therefore the discharge capacity of the drain must be considered with respect to the degradation of natural fibres over time. This complicated aspect which has been discussed by Indraratna et al. (2016) is not subjected in this study.

4. CONCLUSIONS

Structure plays an important role in the geo-hydraulic behaviour of natural fibre drains. An intensive laboratory investigation into the fundamental characteristics of a prefabricated vertical jute drain (PVJD), including the tensile strength, discharge capacity, and porous structure, is outlined in this paper. Jute and coir fibres were the two components of this drain; jute worked as the filter and coir functioned as the core. Most of the porosity of this drain resulted from the pore being located at the interval space of fibre bundles; however this component of porosity could largely be reduced by the confining pressure. Fluid travels almost within the inter-space between individual fibres, making the discharge capacity of the drain resist well the bending and kinking. The discharge capacity of the drain was 0.47 m^3/day which was comparable to other drains. With an average tensile strength of 3.4 kN, a drain such as this can be installed by the conventional method using a mandrel.

ACKNOWLEDGEMENT

The authors acknowledge the Australia Research Council who funded this research, and also thank the National Jute Board of India for providing the PVJD.

REFERENCES

Ali, M. 2010. Coconut fibre- A versatile material and its applications in engineering. In Second International Conference on Sustainable Construction Materials and Technologies, Ancona, Italia. pp. 1441-1454.

Asha, B.S. and Mandal, J.N. 2012. Absorption and discharge capacity tests on natural prefabricated vertical drains. Geosynthetics International, 19: 263-271. doi: 10.1680/gein.12.00013.

ASTMD4716. 2008. Standard test method for constant head hydraulic transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products. American Society for Testing and Materials, West Conshohocken, Pennsylvania, USA. , Pa.

Banerjee, P.K. 2012. Environmental textiles from jute and coir. In Handbook of natural fibres: Processing and applications. Edited by R. M. Kozlowski. Woodhead publishing. pp. 401-427.

Biswas, S., Ahsan, Q., Cenna, A., Hasan, M. and Hassan, A. 2013. Physical and mechanical properties of jute, bamboo and coir natural fiber. Fibers and Polymers, 14(10): 1726-1767. doi: 10.1007/s12221-013-1726-3.

Defoirdt, N., Biswas, S., Vriese, L.D., Tran, L.Q.N., Acker, J.V., Ahsan, Q., Gorbatikh, L., Vuure, A.V. and Verpoest, I. 2010. Assessment of the tensile properties of coir, bamboo and jute fibre. Composites Part A, 41: 588-595. doi: 10.1016/j.compositesa.2010.01.005.

Gregory, M.R. and Andrady, A.L. 2003. Plastic in the marine environment. In Plastics and Environment. Edited by A. L. Andrady. John Wiley & Sons, New Jersey. pp. 379-401.

Indraratna, B., Nguyen, T.T., Carter, J. and Rujikiatkamjorn, C. 2016. Influence of biodegradable natural fibre drains on the radial consolidation of soft soil. Computers and Geotechnics, 78: 171-180. doi: http://dx.doi.org/10.1016/j.compgeo.2016.05.013.

Indraratna, B., Rujikiatkamjorn, C. and Chu, J. 2015. Ground improvement case histories: Embankments with special reference to consolidation and other physical methods. Butterworth Heinemann (an imprint of Elsevier), Oxford, UK.

Kim, J.H. and Cho, S.D. 2009. Pilot scale field test for natural fiber drain. In Geosynthetics in civil and environmental engineering. Edited by G. Li, Chen, Y. & Tang, X. Springer Berlin Heidelberg. pp. 409-414.

Kim, Y.W., Park, J.Y. and Jang, Y.S. 2001. Consolidation efficiency of natural and plastic geosynthetic band drains. Geosynthetics International, 8(4): 283.

Kozlowski, R., Kicinska-Jakubowska, A. and Muzyczek, M. 2009. Natural fibres for interior textiles. In Interior textiles: Design and developments. Edited by T. Rowe. Woodhead Publishing, Cambridge.

Lee, S.L., Karunaratne, G.P., Ramaswamy, S.D., Aziz, M.A. and Das Gupta, N.C. 1994. Natural geosynthetic drain for soil improvement. Geotextiles and Geomembranes, 13(6–7): 457-474. doi: http://dx.doi.org/10.1016/0266-1144(94)90008-6.

Lee, S.L., Ramaswamy, S.D., Aziz, M.A., Das Gupta, N.C. and N. C. & Karunaratne, G.P. 1987. Fibredrain for consolidation of soft soils. In Post- Vienna Conference on Geotextiles, Singapore. Vol. 2, pp. 238-58.

Nguyen, T.T. and Indraratna, B. 2016. Hydraulic behaviour of parallel fibres under longitudinal flow: a numerical treatment. Canadian Geotechnical Journal, 53(7): 1081-1092. doi: http://www.nrcresearchpress.com/doi/abs/10.1139/cgj-2015-0213#.VviZaeJ97IU.

Rahman, M.S. 2010. Jute- a versatile natural fibre. Cultivation, Extraction and Processing. In Industrial applications of natural fibres: Structure, properties and technical applications. Edited by J. Mussig. A John Wiley and Sons, Ltd, Publication, United Kingdom.

Rawes, B.C. 1997. Critical Parameters for Specification of Prefabricated Vertical Drains. Geosynthetics International [Online], 4. Available: http://www.icevirtuallibrary.com/content/article/10.1680/gein.4.0088.

Saha, P., Roy, D., Manna, S., Adhikari, B., Sen, R. and Roy, S. 2012. Durability of transesterified jute geotextiles. Geotextiles and Geomembranes, 35: 69-75. doi: http://dx.doi.org/10.1016/j.geotexmem.2012.07.003.

Som, N., Chattopadhyay, B.C. and Sanyal, T. 2009. A manual on use of jute geotextiles in civil eingieering, 4th Edition. Jute Manufactures Development Council, Kolkata, India.

Tran, L.Q.N., Minh, T.N., Fuentes, C.A., Chi, T.T., Van Vuure, A.W. and Verpoest, I. 2015. Investigation of microstructure and tensile properties of porous natural coir fibre for use in composite materials. Industrial Crops and Products, 65: 437-445. doi: http://dx.doi.org/10.1016/j.indcrop.2014.10.064.

Venkatappa Rao, G., Sampath Kumar, J.P. and Banerjee, P.K. 2000. Characterization of a braided strip drain with coir and jute yarns. Geotextiles and Geomembranes, 18(6): 367-384. doi: http://dx.doi.org/10.1016/S0266-1144(00)00006-6.