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Development of Drains made of Natural Fibers for Accelerate Consolidation in Soft Soil

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ABSTRACT

A simple machine has been developed at the small jute mill in Majalaya, Bandung that uses coconut fiber and jute yarns to manufacture 100 % natural fiber prefabricated vertical drain. The machines implement weaving technology of jute yarns to form the filter sheath and coir yarn as core. The result of the assembly in manufacturing process is a Prefabricated Vertical Drain (PVD) made of natural jute fiber and coconut coir designed to accelerate consolidation of soft clayey soil. It has high tensile strength to withstand installation stresses and excellent water discharge capacity. The cross section of natural fiber PVD measures 80-120 mm in width and 8–12 mm in thickness and have a tensile strength of above 7 KN. In general, the properties of this drain are found comparable with other typical synthetic drains. The present drain differs from the others drain is that it is manufactured in existing jute mills machinery, the manufacturing process entails low energy consumption, and has capability of varying the width, thickness and weight per linear meter to suit different soft clayey soil conditions. An important feature of the jute burlap is its swelling nature that allows it to function as filter without clogging. And it is biodegradable and hence environmentally friendly.

KEY WORDS: *Cutting Force, Dynamometer, Lathe Machine.*

1.0 INTRODUCTION

The subsurface clay soil will settle if loaded by fill; the amount of consolidation settlement depends mainly on the compressibility of the subsurface clay and on the thickness of fill. The time required for consolidation depends on 2 main factors, namely on the permeability of the consolidating soil (linearly) and on the drainage path length (exponentially). The clay soil has a very small coefficient of permeability, causing very long time required for completing consolidation, especially if the consolidating compressible soil is very thick, meaning the drainage paths are very long.

One reclaimed area located on top of compressible clay soil, say 20 m thickness. Consolidation settlement calculation shows that if the ground surface elevation is filled to a design level of +6.00 m, settlement will occur about 1.60 m; and the 90% consolidation will be reached in a very long period, of more than 15 years. This will cause continuous filling and repair of the area and the revetment to maintain the design level elevation. To avoid such problem, the consolidation settlement has to be accelerated, so it will be completed before the reclaimed area to be used. This was earlier used to be done through vertical sand drains.

The cheaper material vertical drain as a substitute material proposed to be use to be installing in conjunction with preloading the area. The vertical drain means the prefabricated vertical drain (PVD), which is made of natural fibers. This PVD inserted by special equipment into the compressible soil, to form very vertical permeable drain. The penetration depth could be as deep as 30.00 m, depending on how thick is the compressible layer. Horizontal distance between vertical drain may varies between 80 cm to 150 cm, with the equivalent diameter of 10 to 15 cm, installed in triangle or rectangular configurations.

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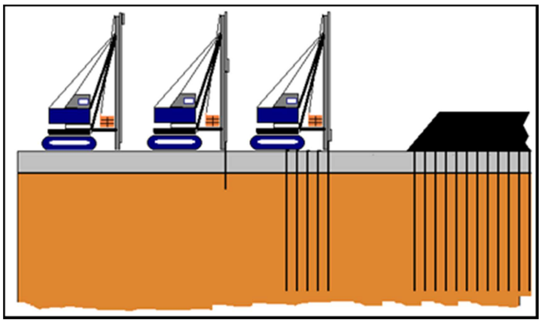

Figure 1: Sequence of installation of PVD

Figure 2: Installation of PVD Fibredrain

2.0 STRUCTURE OF RAW MATERIAL USED FOR JUTE BURLAP AND COIR ROPES

The raw materials used for the outer layer of PVD are jute fabric of jute (corchorus capsularis) or tossa (corchorus olitorius) or kenaf (hibiscus canabinnus) or rosella (hibiscus sabdariffa) fibers, which are processed into yarn, then woven. Jute or Kenaf plants are rain-fed plants that do not require much fertilizer and pesticide, a single trunked plant and fibrous, from which the skin of the tree can be made into yarn to make burlap sacks. This plant can reach a height of 2.5 meters at the age of 100-120 days with stem diameter reaching 1 - 1.5 inch. Jute fiber comes from the stem and outer skin tissue in Jute/Kenaf plants.

The process of obtaining fiber is as follows, after the trees are cut felled and then the tree trunks should be cleaned from the leaves. Bundle the stems and then soaked it in water flowing slowly, for 5-8 days to facilitate peeling the outer shell of the plant. After the skin is peeled off, then washed it clean, so as not to contain dirt and mud, and dried it in the hot sun to dry. Once completely dry, then bundled neatly to minimize tangle, and raw materials ready to deliver to the factory.

Somewhat different from jute or kenaf fiber processed, comparing with the process of coconut husk. The fibers found on the outer skin of the coconut fruit, processed by dry process, using a coir peeler machine. This machine serves as a peeling machine, and simultaneously decomposed coconut fiber. Important things to note in this process are the water content of the coconut husk, and the engine rotation on the peeler. Mistake adjustment of engine rotation and the determination of wetness of coconut husk, will greatly result in damage to coco fiber and affect the short length of fiber, so that the material of coco fiber will be difficult to be spun into a coir rope.

3.0 STRUCTURE OF JUTE BURLAP OF PVD FIBREDRAIN

In accordance to achieve high standard and high performance of PVD Fibredrain, the manufacturer should determine a process control for each step of the production process. After going through long research and development process by PT INS and PT Ekko Hejo Bandung, some aspects and working standards in PVD manufacturing process are recorded and used as reference in production process.

Jute cloth woven fabrics required several stages of the process, starting from the preparation process of yarn consisting of raw material process jute fiber into sliver on carding machine process. Work at this stage needs to be done appropriately to get the desired sliver number. The next step is in the spinning process to make the sliver into HS (warp) yarn and LS (weft) yarn. The standard number of yarns used is 28 - 32 lbs / 14400 yards for HS (warp) and 12 - 14 lbs / 14400 yards for LS (weft).

Besides the yarns count, the standard twist unit known as the twist per inch (TPI) and yarn regularity also should be considered in the yarn spinning process. The yarn irregularity will greatly affected to the process of weaving machine. Especially to achieve high productivity levels and reduce defects in jute fabrics, and also to reduce breakdown time during the weaving process.

After going through the process of preparing weaving in beaming and roll winding machines, both types of yarns are installed in the weaving machine. The HS thread in the beam will serve as a warp, while the LS thread on the cones serves as weft.

The weaving process for making jute fabric is done on S4A or S4B cyclone weaving machine with low rpm between 220 - 240 rpm. The density of the fabric is designed in terms called porter x shot, porter of warp = 8 and double shot of weft = (2)x8, this is adjusted to the AOS specification requirements on the PVD to be made.

The number of threads in the beam used must be calculated appropriately, in order to achieve the required fabric density standard and fabric width required. The production output was achieved between 300 - 320 yards of fabric per 7 hours per machine, with the appropriate level of efficiency.

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Figure 3: The S4A Weaving machineries

Figure 4: Jute fabric from S4A weaving m/c

4.0 STRUCTURE OF COCONUT COIR OF PVD FIBREDRAIN

As is known that coconut husk is part of the outer shell of coconut fruit, which is coarse and short fibrous. In the textile industry, coconut husks are recognized to have low spinning-ability, making it a challenge to be spun with common spinning machines and must meet certain quality requirements. On the other hand, the properties of the coir ropes have been studied from generation to generation and it is concluded that the coir straps have considerable tensile strength and do not decay for more than 2 years at worst environment when properly spun.

In fulfilling the needs of the coir rope industry, PT INS and PT Ekko Hejo has been conducting research and development to create a simple machine that can produce coir ropes on an industrial scale.

Figure 5: A simple spinning m/c for coir rope

At this stage was designed a type of machine that have double function, as a carrier and scraper of coir fiber as well as a spinning machine to make coir rope. The machine designed at approximately 1000 rpm, using bobbin accessories of lightweight steel material. Production capacity per machine is about 22 lbs per hour, equivalent to 750-800 yards coir rope. The design diameter of the coir rope and the TPI unit remains a major factor in achieving the required level of productivity and quality, as well as other operational matters that may affected to machines performance. Finally, the standard design structure of coir rope used for PVD was form of twisted coir rope of two rope strands, with 8 – 10 mm in diameter, and rope count 400-440 lbs/14.400 yards.

Figure 6: Coco fibers feed into spinning m/c

5.0 STRUCTURE AND LABORATORY TEST OF PVD MADE OF NATURAL FIBERS

Making PVD is done through a series of stages of sewing

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machine continuously, by gradually entering 4 strands of coir into 2 layers of burlap cloths. This work is done with high speed and high accuracy, so that the end product of the PVD in accordance with the standard. The connecting process of the PVD's length was also done in this sewing stage, to obtain a length of 250 meters per bundle without interrupted.

The natural fiber PVD reported in this paper is made of organic materials, jute/kenaf fiber and coconut shell fiber. The core consist of four axial coir strands enveloped within the filter comprising two layers of burlap cloth to form a rectangular strip measuring 80-120 mm by 8-12 mm. Three continuous stitches running longitudinally in PVD's.

Figure 7: PVD made of natural fibers, named Fibredrain.

Duplicating woven burlap cloth works as a tension member and, at the same time as filters to percolate pore water from contacting clay strata. On the other hand, four coir ropes inside the jute fabrics work as a water channel in vertical direction. The tensile strength of this natural fiber PVD is more than 7 KN, and the permeability in axial direction is 1 x 10-4 m/sec to 3 x 10-4 m/sec following the acting earth pressure on the surface of the natural fibers PVD. The laboratory test result conducted on PVD was very encouraging and are comparable to any drain materials. PVD made from natural fibers is a worthy option for consolidating soft soils.

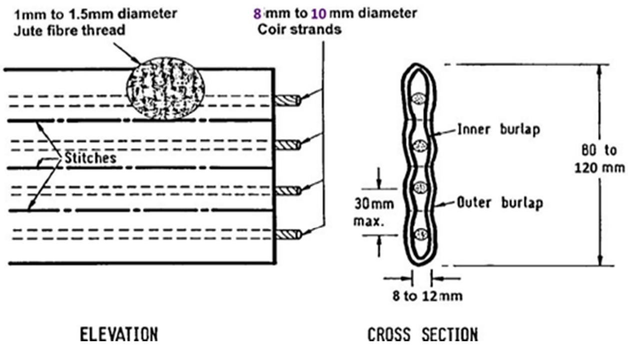

Figure 8: Show a cross section of natural fibers PVD

Tabel.1: Relevant physical properties of natural fibers PVD Fibredrain

Properties	Typical Value tested by B4T	Test Method	Min Spec by FHWA*
Filter material	Natural (Coir / Jute) fiber		
Weight (gram/m^2)	600-650	ASTM D3776	
Grab tensile strength (kN)	9.19	ASTM D4632	0.356
Trapezoidal tear (kN)	0.8465	ASTM D4533	0.111
Mullen burst strength (kN/m^2)	> 1,382	ASTM D3786	898
Puncture strength (kN)	0.631	ASTM D4833	0.223
Elongation at break (%)	42	ASTM D4632	
Permeability (m/sec)	$2.48x10^{-4}$	ASTM D4491	
A.O.S. (□m)	75-90	ASTM D4751	90 -120
Drain properties			
Discharge capacity (m^3/sec)	$9.2x10^{-5}$ at 100 kPa $7.2x10^{-5}$ at 200 kPa $5.3x10^{-5}$ at 300 kPa	ASTM D4716 ASTM D4716 ASTM D4716	5 $x10^{-5}$ at 100 kPa
Weight (gram/m)	300		
Width (mm)	80 -100		
Thickness (mm)	8 -10		
Bale length (m)	250, 500 & 1,000		
Bale weight (kg)	75, 150 & 300		

6.0 DESIGN PARAMETER AND FORMULA

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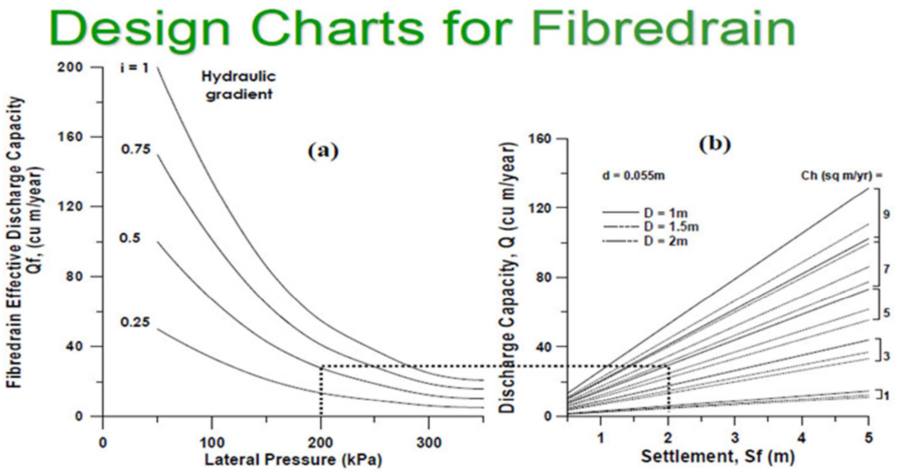

From the Design Chart, obtain the value of D and C_h corresponding to the hydraulic gradient, lateral pressure and final settlement. Substitute D and C_h in

Degree of consolidation $U = 1 - \exp^{[-8Ch\, t\, /\, (D2\mu)]}$ (1)

where;

- C_h = Apparent coefficient of consolidation with horizontal flow
- D = Influence diameter of PVD
- t = Time
- μ = ln (D/d) – ¾
- d = Equivalent drain diameter = ½ (drain width + drain thickness)

Discharge capacity $Q = 2\pi\, S_f\, C_h/\mu$**,** (2)

where;

- S_f = Final settlement
- C_h = Effective horizontal coefficient of consolidation

7.0 DISCHARGE FLOW CAPACITY

The field performance of PVD, including from natural material, is depends on the interaction between PVD and the soil. To account for reduced field discharge flow capacity of PVD's, the discharge flow capacity determined in the laboratory should be reduced by suitable reduction factors. Koerner (1997) suggested that the field flow rate Q_r should be determined from the laboratory tests in accordance with ASTM D4716, at lateral pressure of 200kPa under hydraulic gradient of 1.0 by a reduction factor R such that:

Field discharge capacity $Q_f = Q_l / R$ (3)

R = (Fi x Fd x Fc x Fb x Fk)

Where;

- Fi = is filter deformation, with magnitude 1.5 - 2.3
- Fd = is core deformation, with magnitude 1.0 - 2.5
- Fc = is chemical clogging, with magnitude 1.0 - 1.2
- Fb = is biological clogging, with magnitude 1.0 - 1.2 and
- Fk = is kinking due to settlement, with magnitude 1.0 - 4.0

The reduction factor R as suggested, ranges from 1.5 to 36. The large range of values of R illustrates why some types of PVDs were only partially successful in some projects.
If the required flow rate for a given project is Q_r then the factor of safety FS is given by

$FS = Q_f / Q_r$ (4)

Where Q_f is determined by equation (3) and Q_r is estimated by equation (2)

8.0 CONCLUSIONS

From the field performance of PVD made from natural material in Indonesia, Japan and South Korea, the following conclusions are as follow.

1. The PVD made from natural fibers have similar performance as drains, and have superior advantages in certain fields of usage, compare with sand drains and other material PVDs. Especially under the circumstance that the dredging of marine sand has been prohibited legally by environmental reasons
2. PVD from natural fiber was installed in several projects in Indonesia, Japan and South Korea, achieved over 90% consolidation in about 4-6 months with the penetration depth from 15.00 m to 30.00 m, depending on the thickness of the compressible layer. Horizontal distance between PVD between 80 cm to 150 cm, in triangle or rectangular configurations
3. The clogging and kinking potential of PVDs from natural fiber is negligible and the reduction of axial discharge flow capacity was taken into account by factor of safety
4. The high tensile strength and robustness of PVDs from natural fiber is beneficial to withstand installation stresses and high impact

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5. The PVDs from natural fiber is biodegradable and requires low energy consumption in production from natural fiber, hence ecologically harmonious and environmentally friendly.

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