EXPERIMENTAL INVESTIGATION OF PREFABRICATED VERTICAL JUTE DRAIN IN SOFT SOIL

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ABSTRACT

In this study, investigations were undertaken to analyze the feasibility of using prefabricated vertical drain (PVD) made of natural fibre like jute in accelerating the consolidation process of soft soil under surcharge. To do it, soft soil parameters consisting of index properties, shear strength properties and consolidation parameters of Mirpur (Dhaka) Clay have been investigated. Mechanical properties of jute filter fabric have been adopted from the work of Mohy (2005). Soil settlement has been observed for 4 weeks without the use of vertical drains and also with the use of synthetic and jute PVD. It is seen from the test results that jute PVD clearly fulfills almost all the requirements set by Roads & Highways Department of Bangladesh. Cost feasibility analysis shows that synthetic PVD is two times costlier than jute PVD.

KEY WORDS: PVD, Time-Settlement Profile, Radial Consolidation, Fibre Drain, Soft Soil.

1.0 INTRODUCTION

Soft clays present a number of special problems during and post construction period of any civil engineering work. Such soils have very low shear strength and poses high compressibility. However, excessive settlement of structures that continues for years together is the most pronounced out of all problems. Generally, the term 'soft soil' includes soft clay soils, soils with large fractions of fine particles such as silts, clay soils which contain high moisture content, peat foundations and loose sand deposits near or under the water table. Soft clays are characterized by high plasticity, high liquid limit, high natural water content and low shear strength. Soils with shear strength less than 25 kPa refer to 'soft soil' whereas less than 12 kPa refers to 'very soft soil', GoI (2005). On the other hand, the SPT N values are used to ascertain the consistency of the ground and its relative density. According to this identification system, SPT N value less than 2 indicates a 'very soft soil, whereas, the values of 2 to 4 indicate a 'soft consistency' of clay, Bergado et al (1996). When thickness of clay layer is more than the width of the clay formation then pore water needs to travel a longer path. To leverage the better coefficient of horizontal permeability, first vertical drainage path in the form of sand drain was installed in California, USA in 1934. Various government organizations of Bangladesh especially Roads & Highways Department have included the soft soil improvement technique in their specifications with the use of vertical drains. Vertical drain needs to remain useful as a drain over the required period and in most cases a few months and rarely over a year or more for consolidation process as opposed to permanent drains like synthetic PVDs, Abdullah (2008). Roads in Bangladesh are generally constructed over the embankments raised above the highest recorded flood level. In order to increase the consolidation rate preloading without vertical drains, preloading with sand drains and preloading with synthetic prefabricated vertical drains are commonly employed, GoB (2000 & 2006). Generally, road construction projects in Bangladesh require 2 to 3 years to complete. In these projects, synthetic PVDs used for ground improvement needs to function for 6 months to maximum 2 years, after which it becomes redundant. Due to its hydrophilic characteristics, untreated jute products are likely to biodegrade in saturated environment by 2 months to 4 months. Prodhan (2008) found that untreated jute is swelled and degraded within six months in water but some chemical treatments can increase the life span up to 5-20 years.

2.0 SOFT SOILS IN BANGLADESH AND ITS IMPROVEMENT TECHNIQUE

Occurrence of soft soils at various depths and at a varying layer thickness is very common in most parts of Bangladesh. These soft clay deposits are mainly available in the alluvial flood plain deposits, depression deposits and estuarine and tidal plain deposits in the country, Taiyab (2005). Hunt (1976) has grouped soils of Bangladesh into six groups namely, (1) Hill soils, (2) Raised alluvial terrace deposits, (3) The Himalayan piedmont deposits, (4) Alluvial flood plain deposits, (5) Depression deposits and (6) Estuarine and tidal flood plain deposits, Ansari et al (1993). In a study carried out by Serajuddin (1993) on the upper strata of about 2m to 3m in 12 greater districts of Bangladesh showed that about 91 percent of tested soil samples are silty and clayey soils and falls under A-4, A-6 and A-7 soil sub-groups according to AASHTO soil classification system. Majority of the soil samples have low to medium plasticity with soil particles 51 to 100 percent finer than # 200 sieve (0.075 mm). These vast alluvial silty and clayey deposits are highly compressible and are more pervious in the direction of bedding plane than perpendicular to it, Bashar et al (1993). Preloading being one of the most important improvement techniques is a method of preempting post construction settlements on soft soils. In Bangladesh, dredged material mostly of sand is used for preloading and as embankment core materials. Sometimes in very soft soils, placing of earthfill to design height may induce soil shear failure. In such cases, loads are placed in stages which are commonly known as 'staged construction method'. In this regard, various types of vertical drains such as sand drains, wickdrains or band-shaped synthetic or natural fibre prefabricated vertical drains have been proved to accelerate successfully the rate of consolidation.

3.0 ANALYSIS OF VERTICAL DRAINAGE SYSTEMS

3.1 Sand Drains

To estimate the performance of the drains, a number of analytical approaches have been developed, all basically derived from Terzaghi's theory of one dimensional consolidation. This was later extended to take account of radial flow by Barron (1948) and a very informative review of these theories is given by Richart (1957), Mcgown et al (1982). For mathematical computation of sand drain, it is usual to approximate the problem to that of a cylinder of consolidating soil. Figure 1 shows the general pattern of the layout of sand drains. Notations used are:

(1) re = Radius of the equivalent influence circle.
(2) rw = Radius of sand drain well.
(3) rs = Radial distance from the centre line of the drain well to the farthest point of the smear zone. In case of no smear case, rw = rs.

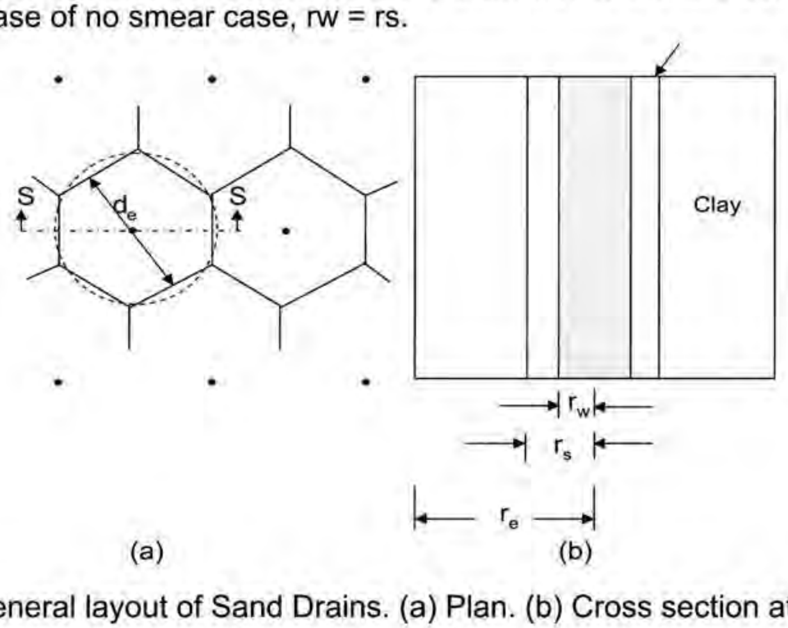

Figure 1: General layout of Sand Drains. (a) Plan. (b) Cross section at SS

The problem of equal strain case with no smear (rw = rs) was solved by Barron (1948). The solution of this equation is:

$$U_r = 1 - exp\left[\frac{-8T_r}{F(n)}\right] \quad \text{.......(1)}$$

Where,

$$F(n) = \frac{n^2}{n^2 - 1} ln(n) - \frac{3n^2 - 1}{4n^2} \quad \text{.......(2)}$$

Time factor for radial flow: $T_r = \frac{C_{vr}t}{d_e^2}$ ....(3)

C_{vr} = coefficient of consolidation in radial direction.

In the derivation of Terzaghi's one dimensional consolidation (Uv), radial drainage was not taken into account. At the same time, when average degree of consolidation for radial drainage was found out, one dimensional consolidation in the vertical direction was disregarded. But actually the dissipation takes place in both directions simultaneously. The total average degree of consolidation was first presented by Carillo (1942):

$$U = 1 - (1 - U_v)(1 - U_r) \quad \text{.......(4)}$$

3.2 Band Shaped PVDs

The first band (strip) shaped vertical drain was made of cardboard with internal ducts developed by Kjellman (1948). Currently, there are more than 50 different types of drains in the market. Two approaches to PVD design are possible. The first is equivalent sand drain approach that uses the PVD to estimate an equivalent sand drain diameter and then proceed with the design in a manner of sand drains. This is done by using actual cross-sectional area of the candidate PVD and making it into an open void circle. This open void circle is then increased using the estimated porosity of sand to obtain the equivalent sand drain diameter, Hausmann (1990).

Equal void area method:

Equivalent diameter, $d_e = \frac{\sqrt{4Btn_d / p}}{n_s}$ ....(5)

Where,

B = width of synthetic strip/band drain

t = thickness of strip

$$n_d = \frac{\text{Void area}}{\text{Total crosssectional area of the strip}}$$

ns = porosity of sand drain

Equal circumference method:

The equivalent diameter of band drain is

$$d_e = \frac{2(b + t)}{p} \quad \text{.......(6)}$$

Where, b = width of band drain

t = thickness of band drain

Equation (6) is preferred by Hansbo (1979) and is usually more conservative than Koerner (1986), which means it results in a smaller equivalent diameter.

3.3 Jute PVDs

Jute being a biodegradable product, very few people could think and still can think of using this material in any permanent or longer duration works. But some treatment techniques may enhance the life of jute geotextiles up to or even more than 20 years, Khan (2008). A flexible prefabricated jute drain made out of jute fabric and coir ropes suitable for consolidating soft compressible soils, has been developed and field tested at Changi Airport by Lee et al., Rao, G. et al. (1994). They also developed and tested fibre drain (FD) at the National University of Singapore, Kabir et al (1994). This FD has been used in several countries in South East Asia. FD is a band shaped products consisting of four strands coconut coir enveloped by two layers of jute burlap filter. The drains were 100 mm wide and 10 mm thick, each having four rope channels for hydraulic conveyance. Figure 2 shows a piece of jute PVD.

Figure 2: Jute PVD

Abdullah et al. (1994) also developed vertical drains with jute and called them 'Banana Drains' (BD). BD is a special type of fibre drain where jute with higher content of lignin is used as lignin is more resistant to biodegradation.

4.0 LABORATORY INVESTIGATION

Construction of 6.3 km long link road project of Dhaka City Corporation (DCC) connecting Zia Colony of Dhaka Cantonment (Opposite to Hotel Radisson Water Garden) with Mirpur Cantonment is underway by an Engineer Construction Battalion (ECB) of Bangladesh Army. About 5.0 km length of this road project passes through low land and marshy areas, water bodies, fish ponds etc. where, soft clay soil exists at different layers, DCC (2007). Soft soil was collected from Mirpur end of the project. Kaliakoir Bypass of Bangladesh is one the projects where 'Flexi Drain', a type of synthetic PVD has been used. For the laboratory investigation of this product, a piece of synthetic PVD was also collected. In Bangladesh, for the production and development of jute products, Bangladesh Jute Research Institute (BJRI) and Bangladesh Jute Mills Corporation (BJMC) are the overall responsible organizations. Because of pioneering role in the jute sector by Bangladesh, International Jute Study Group (IJSG) and Jute Diversification Promotion Centre (JDPC) are also located in Bangladesh. For the purpose of this research, jute PVD sample was developed by BJRI and was prepared in the then Adamjee Jute Mills. This jute PVD consists of four strands of coconut coir (each of 3 mm diameter) covered with jute burlap. The jute burlap is known as DW (Double Works) Twill according to BJMC specification. In normal uses, this DW Twill is extensively used for making sack.

4.1 Determination of Properties of Jute PVD

The specifications for PVD include properties of both filter fabric and complete drain system. This study has covered laboratory tests related to hydraulic conductivity such as thickness, apparent opening size (AOS), permittivity (cross-plane-permeability) and transmissivity (in-plane permeability) of filter fabric and jute PVD system. DW Twill was tested for apparent opening size (AOS). Water is collected in the PVD via cross-plane filtration but it is the in-plane drainage property of PVD that takes the water out of the soil. This property known as 'permittivity (? = kn/t) has been investigated. In the same way, in-plane permeability called 'transmissivity' (? = kpt) has also been found out.

4.2 Description of the Steel Tank and Accessories

A steel tank was fabricated with 6 mm thick steel plate by rolling into a hollow cylinder whose both ends were open. Its height was 0.93 m (36.61 inch), inner and outer diameter was 0.502 m (19.75 inch) was 0.514 m respectively. Bottom end was closed with 6 mm thick round plate. A 2 mm thick rubber gasket was used between the cylinder and bottom cover plate to make it watertight. It created the condition of one-way drainage. The inside of the tank was rubbed with sand paper to make it smooth and greased sufficiently to reduce frictional resistance between soil slurry and the tank. Two dial gauges were used to note the reading of soil settlement. A perforated round steel plate of 3 mm thick and 49.5 mm diameter was prepared to place it on top of the soil slurry. This steel plate provided equal strain condition for radial drainage and equal distribution of surcharge on the soil slurry.

4.3 Performance (Settlement) Test without Vertical Drain

Soil slurry was prepared with mechanical mixer in the laboratory with known water content and then placed in the steel tank. The height of soil slurry was 825 mm and a density of 16.51 KN/m3 was achieved. After the conduct of vane shear test and water content determination, a sand blanket of 25 mm to 30 mm was placed above the soil slurry for easy drainage. Then a geotextile layer was laid on top of sand blanket. Finally perforated steel plate was placed on the geotextile layer. After the loads were applied, readings were taken in a sequence of 0, 5, 10, 20, 40, 60, 120, 240, 480, 1440 minute and so on. The test was run for 28 days. Vane shear apparatus was used to find out shear strength. Figure 3 shows the test methods.

Figure 3: Soil Being Settled without Vertical Drain.

4.4 In-Soil Performance Test with Synthetic and Jute PVD

Settlement tests were conducted using synthetic PVD followed by jute PVD in the same tank but with separate soil slurry. In both the cases a piece of PVDs were hung from a horizontal steel rod placed over the top of the tank. A flat plate was hung from the PVDs at the bottom. A gap of 40 mm between flat plate and bottom of the tank was intentionally maintained so that when settlement took place, PVDs remained still upright. It also helped in keeping the PVDs kinks-free and twist-free. Other arrangements and procedures were similar to first phase. Tests in both the cases continued for 28 days. Vane shear test and water content determination were done. To check the shear strength determined by vane shear test, unconfined compression test was also conducted. Figure 4 and 5 show the test set up with Synthetic and jute PVD.

Figure 4: Synthetic PVD Hung before Pouring the Slurry

Figure 5: Steel Tank Filled with Soil Slurry (Test with Jute PVD)

5.0 TEST RESULTS

5.1 Soil Properties

The in-situ soil looked blackish and once dried it became grey and very stiff. From the laboratory analyses, the particle-size distribution was obtained from sieve analysis and hydrometer analysis. From various laboratory investigations, the very soft consistency of soil was confirmed. Vane shear tests after the consolidation settlement confirmed that shear strength improved by 45% to 60% i.e. in the range of 9 kPa to 10 kPa. The complete properties that have been investigated in the laboratory are presented in the Table 1.

Table 1: Basic Properties of Test Soil.

Parameters	Symbol	Value
Specific Gravity	G_s	2.70
Liquid Limit	LL	48.4%
Plastic Limit	PL	20.8%
Plasticity Index	PI	27.6%
Natural Water Content	w_n	38.3%
Natural Unit Weight	$^{3}{}_{n}$	16.9 kN/m^3
% Sand (2 mm to 0.075 mm)	-	5%
% Silt (0.075 mm to 0.002 mm)		42%
% Clay (<0.002 mm)		53%
% of Material Finer than No. 200 Sieve		95%
Unconfined Compressive Strength of remolded and consolidated sample	q_u	11 - 13 kPa
Shear Strength by Vane Shear Apparatus	Su	5.5 – 10 kPa
Compression Index of remolded sample	C_c	0.12
Coefficient of consolidation	C_v	4.43 mm^2/min
Unified Soil Classification System	CL	Inorganic clay, Low to Medium Plasticity
AASHTO Soil Classification	A-7-6(27)	Clayey soil

5.2 Consolidation Parameters

Due to low shear strength of soil slurry, performance tests in the steel tank were carried out under low surcharge load (27.406 kPa). In the oedometer tests, loading stress was applied from 10 kPa to 200 kPa. The water content and initial density of soil slurry in the oedometer ring was 43.5 % and 16.51 KN/m3 respectively whereas in the steel tank water content was 43.38% with initial density being same. After the oedometer test, water content reduced to 37.5% and final density increased to 17.3 KN/m3. In the steel tank, final water content was 40.58%. The cv values from Taylor Method and Cassagrande Method were 4.66 mm2/min and 4.20 mm2/min respectively. In this investigation, both the values have been averaged which gave cv value of 4.43 mm2/min. For undisturbed sample, usual range of cv for inorganic clay with plasticity index greater than 25 is 0.19 mm2/min (0.1 m2/year) to 19 mm2/min (10 m2/year). For remolded clay, the values reduce to 25% to 50% i.e. lowest 0.048 mm2/min to highest 9.5 mm2/min, Head et al (1992). The results obtained from laboratory test remained well within the range. In both Taylor and Cassagrande Method, compression index obtained was same i.e. 0.12. It is found by Isalm (1999) that the cc value of Dhaka natural clay varies from 0.13 to 0.20 and that of reconstituted Dhaka clay varies from 0.25 to 0.30.

5.3 Properties of Jute PVD

In Table 2, all the required properties of PVD have been included. Then properties of synthetic PVD as mentioned in the design manual and that of jute PVD as obtained in the laboratory investigation are compared. Most of those properties are actually meant for filter jacket. The hydraulic conductivity properties were meant for PVD system as a whole.

Table 2: Comparison of Properties of Synthetic and Jute PVDs with RHD Specifications

Properties of PVD Jacket & Core	Propert-ies of	Test Designation	RHD Specificat-ions	Synthetic PVD Flexi Drain	Jute PVD
Apparent Opening Size, m	Filter	ASTM 4751-87	< 90	75	85
Grab Tensile Strength, KN	Filter	ASTM 4632-91	> 0.35	0.50	0.929 (MD) 0.75 (XMD)
Trapezoidal Tear Strength, KN	Filter	ASTM 4533-91	> 0.10	Not mentioned	0.464 (MD) 0.153 (XMD)
Puncture Resistance, KN	Filter	ASTM 4833-88	> 0.10	0.144	0.840
Burst Strength, KN	Filter	ASTM 3786-80 A	> 900	950 (kPa)	2373 (kPa)
Discharge Capacity at 7 days, 200 kPa at hydraulic Gradient of 1.0, m^3/year	Compos ite Drain	ASTM 4716-87	> 500	>2500	466.74
Equivalent Diameter, mm	Compos ite Drain	d_e=2(b+t)/À	> 50	65.70	61.75

5.4 Time-Settlement Profile without Vertical Drains

To compare the observed results of settlement in the steel tank with the settlement that should have occurred theoretically, first a time-settlement profile has been developed with the consolidation parameters (Cc, Cv, e0, clay layer thickness). Then a time-settlement profile has been drawn with the observed settlement readings. Both the profiles are shown in the Figure 6. It is seen that the total settlement (U = 100%) of clay layer thickness of 825 mm at a surcharge of 27.406 kPa would be 44.68 mm. Also from the Figure 6, theoretical settlement for 28 days is calculated to be 25.73 mm which is actually 57.6% of total settlement. On the other hand, from the time-settlement observations in the laboratory, it is seen that the total settlement occurred in 28 days is 25.82 mm. It is seen that shear strength was 6.01 kPa before consolidation settlement and 8.95 kPa after the removal of surcharge. The gain in shear strength was 47%.

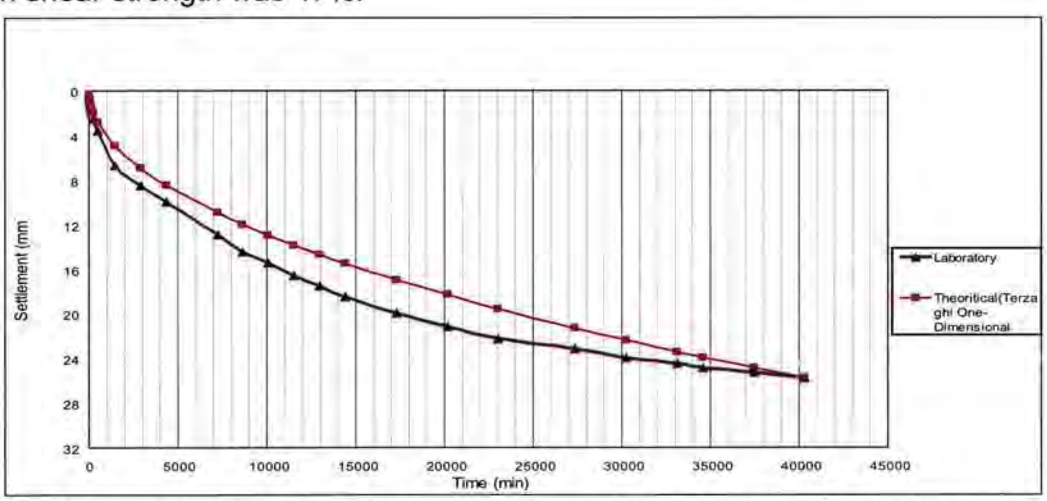

Figure 6: Comparison between Theoretical (Terzaghi) and Observed Settlement in the Laboratory (without Vertical Drain)

5.5 Time-Settlement Profile with Synthetic and Jute PVD

Actual settlement of 29.28 mm and 30.62 mm took place in the steel tank so that the actual average degree of consolidation became 65.53% and 68.83% by using synthetic and jute PVD respectively. Since in both cases, PVDs were hung before pouring the slurry in the steel tank, there was no smear at the boundary of the drain well. It is also assumed that coefficient of consolidation in the radial direction (Cvr) was same as coefficient of consolidation in the vertical direction (Cv). So, in case of synthetic PVD, the degree of consolidation due to radial drainage (Ur) became 98.61% whereas the same for jute PVD was 98.33%. With synthetic and jute PVD used in-soil; the same of settlement of first phase took place in only 16.8 days and 14.75 days respectively. The gain in shear strength was 55.46% and 58.76% respectively. The comparison among the observed settlements with synthetic and jute PVD with those of theoretical settlements are presented in the Figure 7 and 8.

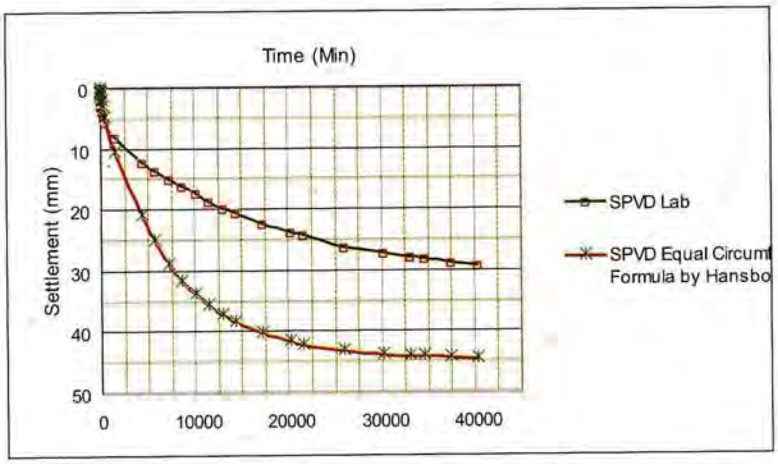

Figure 7: Comparison between Theoretical Radial Settlement and Observed Settlement with Synthetic PVD in the Laboratory

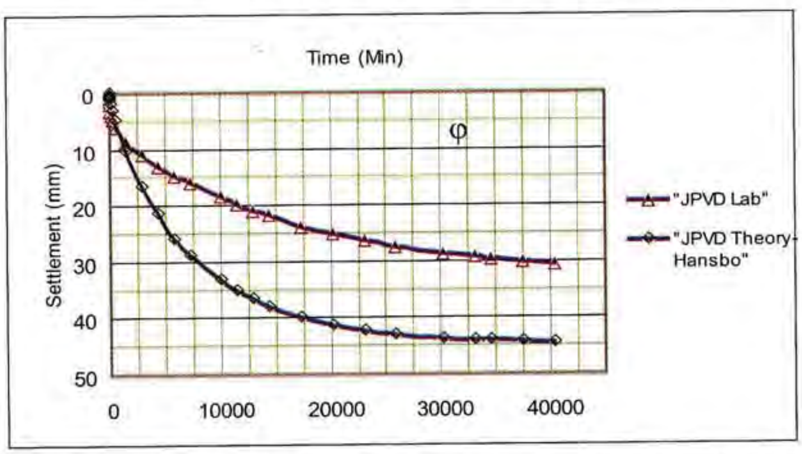

Figure 8: Comparison between Theoretical Radial Settlement and Observed Settlement with Jute PVD in the Laboratory.

Again, theoretically, soil should be 100% saturated for oedometer test. But in this investigation, degree of saturation (wGs/e0) was 90%. In case of jute PVD, it is seen that AOS (0.85 mm) is near to the maximum limit (<0.90 mm). The implication is that, larger pore spaces would allow larger particles to intrude along with the flow of pore water. It will eventually cause soil piping in the drain-well and also tend to clog during the process of drainage. Again in-plane discharge capacity of PVD system as a whole at hydraulic gradient of 1.0 in one year time need to be more than 500 m3/year. In this case, Flexi Drain supersedes the requirement by 5 times (>2500 m3/year), whereas, jute PVD falls short of specification which is 466.74 m3/year. To overcome this situation, the design change in the jute PVD manufacturing is needed. In the in-plane permeability, core actually conveys the fluids. So, to conform to the specification, jute PVD may have 5 or 6 cores or larger diameter cores which will increase the hydraulic conductivity. Though, smear was avoided in the test, drain internal resistance and clogging could not be controlled. The settlements that occurred in 28 days for both jute PVD and synthetic PVD were very close. Time-settlement profiles without vertical drains, with synthetic PVD and with jute PVD are presented in the Figure 9. It is seen that jute PVD accelerated the settlement more than the synthetic PVD though in-plane discharge capacity of synthetic PVD is five times more than jute PVD. This issue may be explained as synthetic PVD having under-utilized in-plane discharge capacity. Filtration criterion (O95) of synthetic PVD was conservative than jute PVD. So pore water flow through jute PVD was more than synthetic PVD.

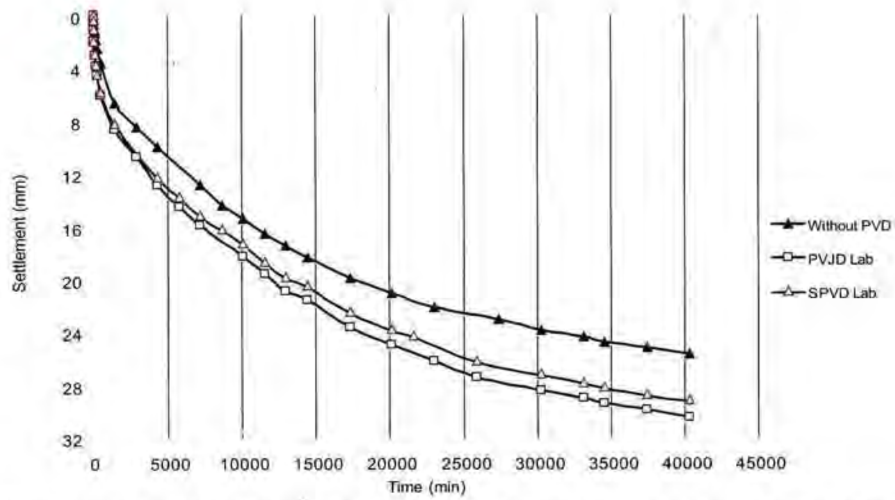

Figure 9: Settlement Profiles without PVD, with Synthetic PVD and with Jute PVD.

6.0 ECONOMIC FEASIBILTY OF USING JUTE PVD

In Bangladesh, usually intercity highways are 17 m (60 feet) wide at top surface. Again the height of such embankment varies from 1 m to as high as 10 m in some locations. In this analysis, depth of compressible layer is considered to be 10 m. Usually, in an unreinforced embankment, side slope of 1V:2H is used. In this study, both 1V:2H and 1V:1H side slopes have been considered and variable height of embankment has been taken as 4m, 6m and 8m. The present cost of 'Flexi Drain per metre is more than Tk. 100. For estimating the latest cost, sample of jute PVD has been prepared in Latif Bawany Jute Mills in Demra, Dhaka in July 2008 under the direction of BJMC. One piece of sample has been prepared by that mills and estimated cost for 1 m was Tk. 43.79. The cost which has been estimated by Latif Bawany Jute Mills included not only the raw materials and labour cost, but also the power, establishment, and other overhead cost. So, when commercial production of this item will be taken, its cost will no way cross Tk. 35 per metre. However, conservatively this cost per metre can be considered as Tk. 45. In an embankment with side slope of 1V:2H having roadway of 17 m will require 48 numbers of PVD per metre length at the bottom. Spacing of PVD has been set to be 1m centre to centre. If side slope is made steeper i.e. 1V:1H with soil reinforcement, then 31 numbers will be required. Jute PVD actually offers a cost saving of 55%. Figure 10 show the cost comparison of synthetic PVD with jute PVD per km of embankment.

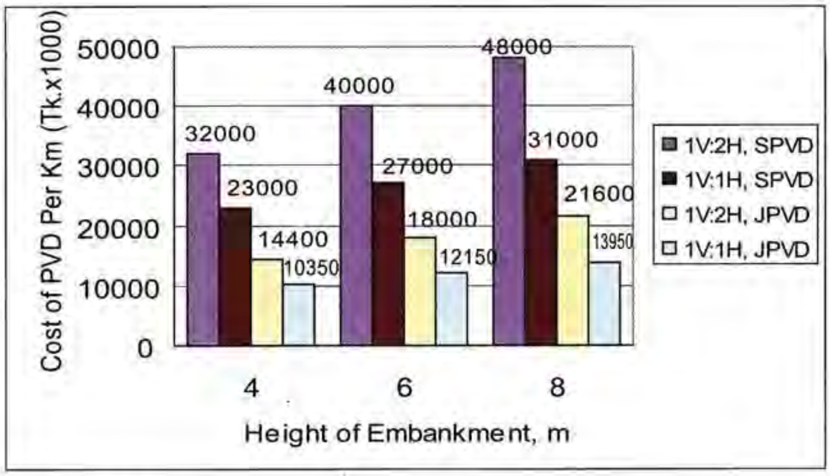

Figure 10: Cost Comparison of Synthetic PVD and Jute PVD for Embankment (1 km) of Different Slopes

6.1 Other Benefits of Jute PVD

Economic benefit of using PVD be it synthetic or natural fibre, is difficult to estimate. Use of PVD accelerates consolidation, thereby reduces project duration. It saves huge amount of money by saving time. It tries to eliminate post construction settlements thereby also eliminate future serviceability problems of structures. The cost of PVD certainly is less than that would be incurred in future due to non-use of PVD during initial construction. Since synthetic PVD has been used in many countries of the world including Bangladesh, its economic feasibility is already established. Considering the worldwide concern on environment, jute PVD can be a better option in meeting the environment preservation requirements.

7.0 CONCLUDING REMARKS

Laboratory investigations of Mirpur Clay provided all the required data to run the complete test including those to confirm the soft consistency of collected sample. Tests on jute PVD covered a range of physical, mechanical and hydraulic conductivity characteristics. These tests were intended to investigate properties of both filter jacket made of DW Twill and in-built jute PVD system. Test results for complete range of specification are available in the work of Mohy (2005) and some of the test results have been used directly from that research work. It is seen that the test results on DW Twill regarding these properties fulfill the specifications and also, to most extent, match in parallel with that of 'Flexi Drain'. The main part of the study encompasses the in-soil performance test of jute PVD and compare with that of synthetic PVD. In the first phase of the test, it is seen that the observed settlement of 25.82 mm in the steel tank and that of theoretical one were almost same, i.e. 57.8% and 57.5% respectively. In the second phase of the test, synthetic PVD was hung vertically and smear effect was avoided. The result showed that the total settlement of 29.28 mm took place which was 65.53% of the total settlement. In the third phase of the test, same set up was followed except that only jute PVD was used for radial drainage. The time-settlement profile showed that total 30.62 mm settlement took place which was 68.53%. This research also provided the information regarding the cost analysis of both jute PVD and synthetic PVD. By utilizing environment friendly natural product like jute, synthetic products can be avoided huge amount of foreign currency may be saved.

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