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Installation filter stress in prefabricated vertical drains

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ABSTRACT: Modern prefabricated vertical drains (PVD) normally consist of a core and a filter (sleeve) made with polymeric materials. They are designed to be installed in soft clay deposits for accelerating consolidation under applied fill loads. Under proper design and installation of PVD and applied loading the flow of water into the PVD will take place approximately radially following Barron's (1948) theory. In large ground improvement projects involving soft clay deposits, installation of PVD is carried out early enabling completion of the consolidation settlement prior to infra-structure construction. Modern installation rigs are capable of installing PVD at significant speed. With the rapid development of polymer material and manufacture of products, cheaper PVD types are available for economical installation. These, however, may have inferior properties undesirable during installation. The tension developed during the installation process could exceed the strength of PVD components that will never be discovered, which might cause undue delay in the design consolidation time. Installation of a number of different PVD products was monitored with strain gages mounted on the filter sleeve. A tension of about 1000 N was measured near the shoe shortly after the commencement of mandrel withdrawal. The need to watch the stresses in PVD in relation to the material properties of the components, speed and depth of installation is highlighted. A minimum filter strength required for the integrity of PVD and a maximum rate of mandrel installation are proposed for ground improvement projects.

1 INTRODUCTION

Several million meters of prefabricated vertical drains (PVDs) are installed annually worldwide to accelerate consolidation of soft soil deposits. Recent projects in Singapore used more than 20 million meters of PVD annually. Rates of installation as much as 8,000 m to 30,000 m per 14-hour day per machine are not uncommon in these projects (Choa et al. 2001) amounting to mandrel withdrawal speeds of 1m/sec or more. To speed up installation new rigs whose mandrel insertion and withdrawal speeds exceed 1m/sec have been developed (Cortlever and Dijst, 2002).

PVD is normally spooled out and threaded through a hollow mandrel. It is attached to a shoe for anchoring in stiffer clay and to prevent soil intrusion into the mandrel. The shoe may vary from a simple reinforcement steel bar (re-bar) of 10 – 20 mm diameter to a thin mild steel plate to which a small mild-steel strip is welded as a handle. The PVD passed around the re-bar or mild-steel strip is stapled. Profuse soil intrusion into the mandrel during installation would develop shear on the filter. During the mandrel withdrawal, the higher the withdrawal speed the greater the shear force on the filter. If the shoe is firmly anchored in the clay, the upward shear force will translate into a tensile force in the filter.

Voskamp et al. (1998) measured a force of about 230–390 N, for a PVD installation with a 10-m-long mandrel. Tearing of the filter above ground was witnessed in Singapore in 1979, and also has been reported for paper filter prior to 1982 by Cortlever and Dijst (2002). Recently, Cortlever and Dijst (2002) measured a maximum force of 1634N on the filter when the installation mandrel penetrated a thin hard layer, and a force of about 622N during extraction. The strain-gauged PVD section passed over the pulley system in their field trial. Choa and Bo (2000) reported slow consolidation improvement with reduced drain spacing that was ascribed partially to different soil properties. The specified minimum filter strength for the same project was 588N (60 kg). Instances where the same PVD performed below design expectation in recent projects prompted monitoring of filter forces.

PVDs are extensively tested in laboratories for quality assurance. Since there are no criteria for quality assessment of construction in the field and behavior of PVD under kinked conditions, it was suspected that filter strength in deep installations typically more than 20m would be prone to greater stresses at high installation speeds. If they exceed the ultimate tensile strength of the filter, typically about 1000N, then the PVD core will be exposed to the soft clay, causing channels blockage. If a sufficiently large number of deep installations result in damaged filters at crucial depths, the consolidation of the clay in that region will not meet design expectations.

2 FIELD MEASUREMENT

Several instrumented PVDs were installed in a recently reclaimed land in Tuas, Singapore as part of a field trail. Monitoring instrumentation consisted of two specially prepared strain gages (SG) on the filter sleeve of the PVD following the strain gauging technique proposed by Chew et al. (1999). One gage (SG-A) was placed at 300mm and the other (SG-B) at 1000mm from the folded end of the PVD at the shoe, as shown schematically in Figure 1 and detailed in Karunaratne et al (2003).

Tuas land reclamation comprised a 14-m-thick sand fill overlying about 10m of soft clay, 1m of stiff clay, and sandstone. Field installation of PVDs was carried out using a conventional installation machine with a mandrel having a diamond-shaped cross section. The duration of the insertion of the mandrel for a typical PVD installation in a 25-30 m depth is about 20-25 seconds, with withdrawal requiring another 30 seconds. Figure 2 shows the tension measured by the two strain gages in one PVD (PVD-1).

The tension in SG-A (at 300 mm from the shoe) increased gradually with installation depth to about 800 N during 93 seconds of descent into the ground. It anchored in the underlying stiff clay at about 24-m depth. At that depth the mandrel was held stationary for about 163 seconds. The monitored tension continued to increase until the mandrel was retracted, despite the fact that the PVD was free to roll off from the spool. At the initiation of mandrel withdrawal, a sharp increase in tension was recorded up to 1000 N in SG-A, which began to drop as the mandrel was withdrawn within about 46 seconds. The tension recorded in SG-A continued to decrease to a residual value, which practically stayed constant up to 23 minutes of monitoring. In contrast, SG-B (at 1000 mm from the shoe) recorded a smaller force throughout the installation but began to increase even after cutting the drain. (Karunaratne et al, 2003).

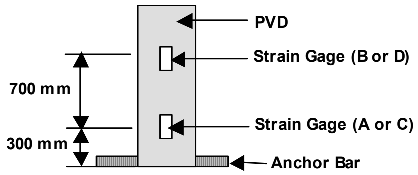

Figure 1. Instrumented PVD filter near the anchor shoe

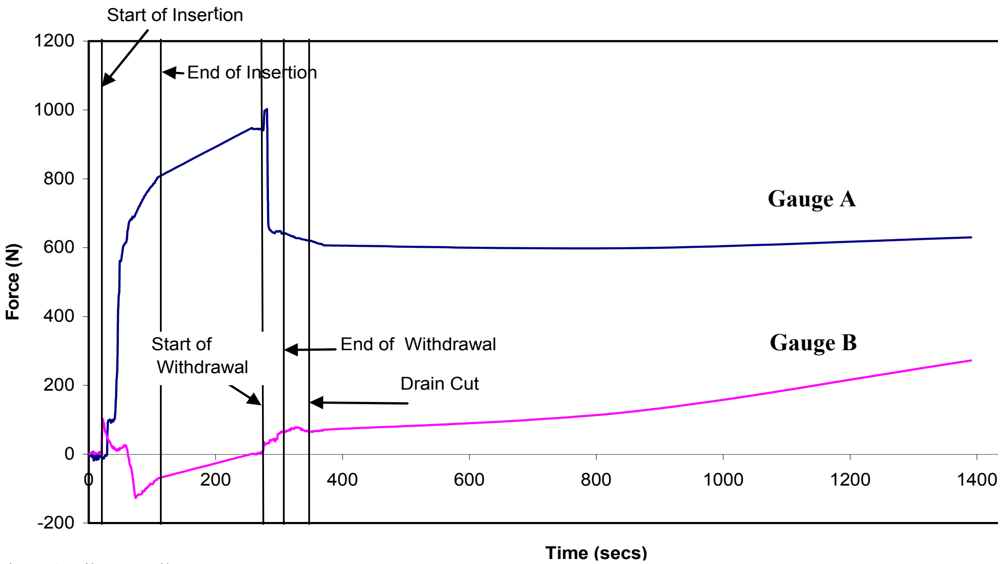

Figure 2. Filter Tensile Force

The second PVD (PVD-2) was similarly instrumented with strain gages SG-C and SG-D (corresponding to positions of SG-A and SG-B of PVD-1 respectively). With the normal installation speed, the insertion of PVD-2 in the full depth of 25m required about 25 seconds. The mandrel was withdrawn immediately afterwards. However, the strain gage cables laid outside the mandrel did not survive the upward mandrel movement.

When the mandrel reaches the full depth and its movement stops, as indicated in Figure 2, the core may partially transfer its tension – especially if it has already yielded - onto the filter causing filter tension to rise. Depending on the effectiveness in the anchorage of the shoe, the withdrawal of the mandrel imparts a shear force on the intruded soil, which in turn transmits a shear force onto the filter, causing the tension in the filter Tf to rise to its highest. As shown in Figure 2, the measured force on the filter reached a maximum and then dropped to a residual value depending on the interface friction between the intruded soil and the filter. Just prior to drain cut-off, the PVD is firmly anchored in the stiff clay at the bottom, and held partially in the (sand) fill at the top together with the mandrel. The sides of the hole created in the ground by the mandrel collapse on the drain. Under these conditions the PVD is in a state of locked-up tension. If the anchorage in the sand fill weakens prior to drain cut-off, the locked-up tension will pull the drain into the ground. This is observed for long drain lengths with the shortening of the core and/or filter sleeve of PVD. Figure 3 shows the stump of a PVD five minutes after cutting the drain, displaying shortening of the drain, which was held in tension during installation. This observation leads to the conclusion that the PVD, between the shoe and the ground surface, is in a state of tension immediately before the drain is cut despite the fact that the other end is free to roll out of the spool.

3 FIELD COMPARISON OF PVD INSTALLATION

In Pulau Tekong Reclamation Project three sets of instrumented PVDs were installed and monitored. In each set about five PVDs were instrumented and installed with different installation machines under varying speeds of insertion and withdrawal, roughly in the same depth of clay and reclamation fill (5m thick). The location of installation was 300mm and 600mm from the position of the anchoring shoe. Table 1 shows the details of the PVD properties, rig installation speeds, depths and measured tension.

Flexidrain 767 (D1) and Mebradrain 7007 (D2) were installed in three different instances with five individual PVDs instrumented in each case, so that a minimum of three PVDs would give reliable results. Two different installation rigs were employed with varying speeds bordering fast rates (as high as 2.87 m/sec). The effects of the installation, withdrawal, waiting time (short or long duration) at the bottom of installation were varied in these trials. The strain gauges were monitored and converted to tension using calibration factors. Table 1 shows that the total depth of installation was between 20m and 24m, unit rates of insertion varied from 1.19 to 2.87 m/sec and withdrawal rates varied from 1.34 to 2.87 m/sec. The tension developed in the filter varied from 251N to 1278N at 300mm from the shoe, the higher values being attributed to faster withdrawal rates. Predicted values are based on parabolic variation of shear strength from the toe to about 1m up the PVD filter.

Figure 3. Gap left in the PVD five minutes after installation and cutting off the spool showing the lock-up tension

4 DISCUSSION

As the mandrel is pushed deeper into the soft ground, the PVD is stretched out of the spool. The tension develops in the PVD in this instance shared between the core and the filter, depending on their relative stiffness, and the efficiency of the pulley system over which the drain has to pass and the speed of the mandrel. As the latter penetrates into the soil, some soil may intrude into the mandrel if the shoe does not seal the mandrel completely satisfactorily. This soil tends to wedge between the filter sleeve and the interior surface of the mandrel. How high it will rise up the mandrel will depend on the type of soil, speed of mandrel, depth and the sealing efficiency of the shoe. This soil also exerts a shear force on the filter and the mandrel, and a normal pressure on the core, the magnitude of which decreases with the distance from the shoe.

During withdrawal the maximum strain develops nearer the shoe and, therefore, tension in the filter and the core should decrease upwards from the shoe. As the tension Tc increases in the core with increased insertion depth, the core might yield at some stage due to stress concentration. Further strain in the core would increase tension in the filter. The relatively small tension Tf, bordering between compression at SG-B or SG-D (Figure 2), indicates that the intruded soil has probably not reached 1000 mm along the filter.

5 CONCLUSIONS

Strain Gauge A (300mm above the shoe) displayed a higher filter force than that at B (600mm or 1000mm above the shoe). This is attributed to the soil intrusion into the space between the mandrel and the filter during the mandrel insertion. If there were no intrusion, the filter force would be smaller at the shoe, and larger at the top end of the PVD due to the self-weight of PVD. As the mandrel is withdrawn, the intruded soil transmits a shear force onto the filter generating larger tensile forces. This occurs at or near the shoe, depending on the extent of soil intrusion during installation.

At a depth of 26m of installation, the maximum filter tension could reach about 1300 N upon withdrawal of the mandrel at 2.87m/sec or faster. Higher the rate of withdrawal, higher the tension developed in the filter sleeve. Higher tensile stresses develop in installed PVD at faster withdrawal stage.

On the contrary, the higher the speed of penetration of the mandrel, the smaller the chance of soil intrusion and hence smaller the installation stresses.

Therefore, it is prudent to install PVDs at a faster rate and withdraw at a slower rate, which would necessitate higher filter strength and/or slower withdrawal speed in thicker soft deposits.

The shoe and the mandrel section should also be properly designed for preventing or minimizing soil intrusion. Alternatively, a PVD with higher tensile strengths in the core and the filter may be used for deeper PVD installation.

A tensile strength of 1000N will be needed for the PVD filter for installation depths not exceeding 25m at speeds of installation smaller than 1m/sec. Larger depths and faster installation may demand even stronger filters.

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Table 1. Field measurement data

Drain Type	D1	D2	D2
Installation Rig	PC 1000	RH 40-E (C-1)	PC1000
Mandrel shape	Rhombic	Rectangular	Rhombic
Shoe Type	Re-bar	Plate + handle	Re-bar
Date of Test	4 October 2001	11 Oct 2001	14 Nov 2003
Total depth of Installation	22.7 m	20.1 m	24.3 m
Thickness of Sand fill	4 m	4 m	5 m
Soft clay thickness	About 17 m	About 16 m	About 19.3 m
Other installation Remarks	Jacking in Sand (10 sec)		1.5 m
Duration (& Unit rate) of insertion (excluding jacking time)	NORMAL 19 sec (1.19 m/sec)	FAST 7 sec (2.87 m/sec)	NORMAL 16.6 sec(1.46 m/sec)
Waiting Time at maximum depth of penetration	NORMAL (3 sec)	SHORT (4 sec)	LONG (30 sec)
Duration (& Rate) of Withdrawal	NORMAL 17 sec (1.34 m/sec)	FAST 7 sec (2.87 m/sec)	NORMAL 17.9 sec (1.36 m/sec)
Anchored Soil	Reddish clay	Reddish brown clay	Reddish brown clay
Tension at 300 mm from toe	300 N	1278 N	251 N
Tension at 600 mm from toe	320 N	Damaged	142 N
Predicted maximum tensile force in filter	480 N	1278 N	377 N