Geotextiles and Geomembranes 29 (2011) 391–401

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Prefabricated and electrical vertical drains for consolidation of soft clay

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ARTICLE INFO

Article history:
Received 4 January 2010
Accepted 28 November 2010
Available online 28 January 2011

Keywords:
Prefabricated vertical drains (PVD)
Electrical vertical drains (EVD)
Discharge capacity
Laboratory testing
Field testing
Soft clay

ABSTRACT

The use of prefabricated vertical drains to consolidate soft clay is a common ground improvement method. In large projects laboratory testing of PVDs for selection and quality assurance is considered important. This paper presents a review of PVD laboratory testing. The need to provide simulated site conditions in the test is emphasized. In addition instrumented PVDs show that installation stresses in deep soft clay deposits could cause filter rupture under tensile failure. It is also shown that the maximum required discharge capacity of a PVD is obtained by equating the flow rate of the PVD under the installation and consolidation states to the maximum rate of volume reduction of the influential clay cylinder of the PVD. Consolidation can be enhanced much faster in clay soils if vertical drains manufactured with conducting polymer are used. Some laboratory tests, field tests and field applications of such electric vertical drains (EVD) are presented. A minimum current density at appropriate applied voltage is required to benefit from the electric osmosis (EO) application. EVD in dewatering clay soils, extracting heavy metals in clay soils and few other geotechnical applications are also presented.

1. Introduction

For several decades prefabricated vertical drains have been in use for consolidation of soft clay. Since PVDs are more QA/QC dependable, they are used in ground improvement projects involving thick deposits of soft clay. Many different types of PVDs are available in the market; but some of them have delivered disappointing consolidation rates. The standard laboratory tests on PVDs appear to have failed in isolating these substandard PVDs. A series of tests designed to understand and simulate field conditions reveal that discharge capacity of a PVD is subject to deformation of the PVD core and filter, clay intrusion, axial strain and kinking as well as installation stresses. The latter can cause filter rupture and completely block the flow path. The paper compiles a summary of these findings for consolidation of clay soils.

With the advent of conducting polymer, EVDs have been installed for passing DC voltages, to further accelerate the consolidation of soft clays. The electro-osmotic (EO) process is found to be quite useful for dewatering clay soils, extracting heavy metals and strengthening such soils.

2. Desired characteristics of PVDs

It is a common practice to use PVDs to accelerate the consolidation of soft clay deposits. Annually several million meters of PVDs are installed worldwide to improve soft soil deposits. In 2001, projects in Singapore recorded an annual consumption of more than 20 million meters. Rates of installation as high as 30 000 linear meters per 14-h day per machine have been reported in these projects (Choa et al., 2001). Installation rigs with mandrel insertion and withdrawal speeds exceeding 1 m/s have been developed for these projects (Cortlever and Dijst, 2002). Installation stresses need to be examined for PVD performance.

PVDs normally consist of a core and a filter (sleeve) made with polymeric materials. The core should have adequate capacity to convey the water inflowing from the consolidation of cylindrical clay defined by the tributary volume of a single PVD. The inflowing water should first transmit rapidly enough through the PVD filter. This demands a proper selection of filter criteria including its thickness. A coarse single filter will not effectively arrest clay intrusion. A filter too thin and/or of smaller modulus is prone to (tensile and puncture) failure during installation, fast clogging and consequent reduction of water flow capacity, and intrusion into grooves of the core (Koerner, 1997; Karunaratne and Chew, 2000).

3. Laboratory testing of PVD

During laboratory testing of PVDs, neither a stiff platen nor a foam rubber lining gives a discharge capacity as low as a layer of soft clay packed around a PVD, jacketed in a rubber membrane under an applied all round pressure, similar to triaxial testing procedure. This has been confirmed by Holtz et al. (1991), Loh et al.

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0266-1144/$ – see front matter © 2010 Published by Elsevier Ltd.
doi:10.1016/j.geotexmem.2010.12.005

(1997), Karunaratne et al. (1998) and Miura et al. (1998) among others. A detailed account of these tests has been published (Karunaratne and Chew, 2000) after several decades of research at the National University of Singapore (NUS). A summary of these findings is presented in this paper.

Fig. 1 shows the discharge capacity of a PVD tested under the above conditions using stiff platens, foam rubber and clay in both ASTM (D4716-97) and NUS apparatus (Ver II). Lateral pressure on the PVD was applied by means of a hydraulic jack in the ASTM apparatus and pneumatically in the NUS apparatus. Both specimen lengths were 300 mm. It is clear that the lowest discharge capacity was recorded in the NUS apparatus when the PVD was surrounded with a thin coating of clay and encased in a rubber membrane. Stiff platens preclude the potential clay intrusion into the PVD grooves which leads to reduced discharge capacity. Therefore it is important to have a clay layer surrounding the PVD. The clay is preferably extracted from the same site so as to simulate the clay intrusion even through the filter. Change of clay may alter the particle size that may pose an unrealistic amount of clay intrusion, for instance kaolinite in place of montmorilonitic clay.

Laboratory investigation further showed that 300 mm was too short a length due to the end constraints in the apparatus. A 1000 mm length was proven to be the realistic minimum for NUS apparatus which was re-designated as Ver III. The PVD was kept in a vertical position and embedded in soft clay under appropriate lateral pressure levels applied via pneumatic pressure to simulate the field environment. The water was passed upwards through the PVD to expel any initially entrapped air. The discharge capacity (or flow rate) was measured under constant head conditions. Ver III apparatus could accommodate standard PVDs and provide vertical strain or sinusoidal deformation while subjected to lateral pressure via clay embedment, as shown in Fig. 2 (Karunaratne and Chew, 2000). The 1 m specimen length also permits application of kinking on the drain specimen.

Fig. 3 shows, the effect of lateral pressure and the thickness of clay packing on the flow rate of a PVD measured with Ver. III apparatus. The flow decreased with increasing confining pressure and clay packing thickness (up to 40 mm) at a minimum of about 3 h after pressure application, reflecting the sustained filter intrusion into the core.

Fig. 4 shows an example of discharge capacity of a PVD when tested as above. Its variation of discharge capacity with lateral pressure and hydraulic gradient is evident. This emphasizes that

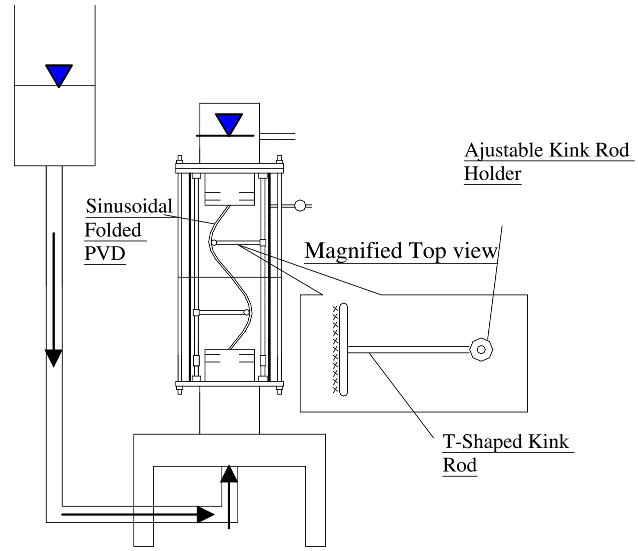

Fig. 2. PVD discharge capacity testing apparatus (NUS Ver. III) with provision for clay packing, lateral pressure, vertical and lateral deformation, and vertical water flow under constant head condition.

the testing environment needs to closely simulate the ground conditions where PVDs are to be installed. Deviations may lead inadvertently to unsafe assessments of PVDs which may undermine the imposed factors of safety of the project.

4. Filter sleeve

The operating hydraulic gradient across the filter sleeve of a PVD shortly after installation in a clay deposit under surcharge would decrease with time as pore pressure dissipates. At shallow depths the effective lateral pressure on the PVD is small and vice versa. Therefore the discharge capacity of the PVD near the ground surface (the usual drainage boundary) at a relatively short time after PVD installation would be higher than that at a later stage or at greater depths, if the soft soil is already under excess pore pressure from surcharge application. A critical depth based on the details such as surcharge, excess pore pressure, external drainage conditions and depth of clay deposit etc. of a given project should be established prior to selection of the lateral pressure, if testing is to be more rationally carried out.

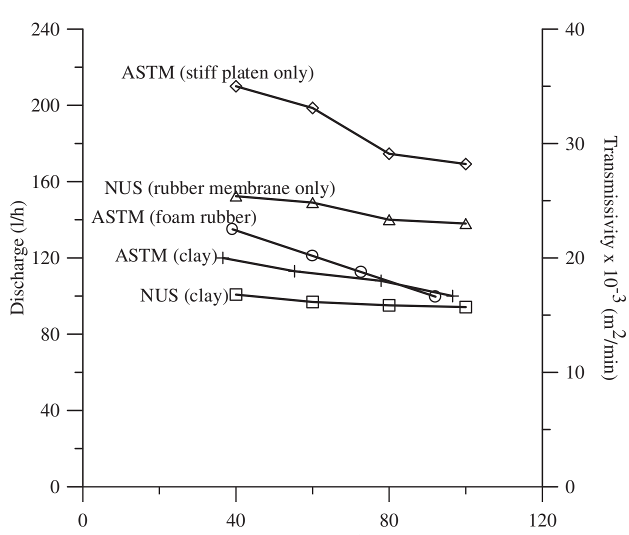

Fig. 1. PVD discharge capacity in different testing set-ups.

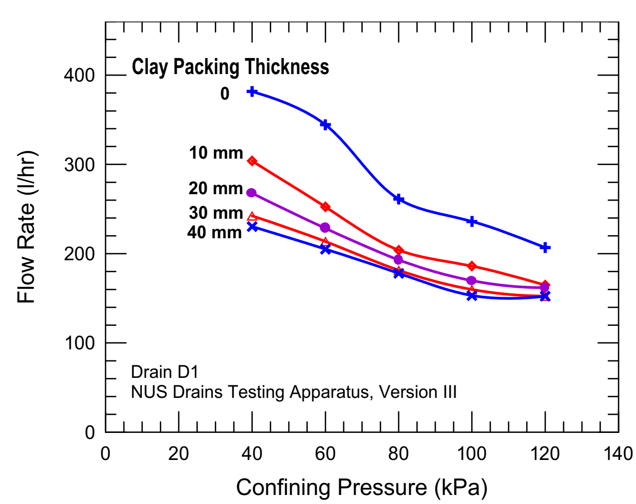

Fig. 3. Effects of lateral pressure and thickness of clay packing on drainage flow rate.