Consolidating soft ground with

CN DRAIN METHOD

TMI Thai Miltec International Co., Ltd.

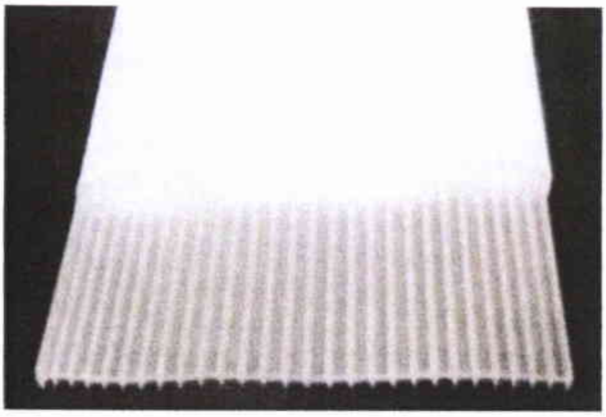
Introduction

The vertical drain with preloading method has been used to treat the soft ground for several decades. The vertical drains help to reduce the drainage path in the compressible soils, leading to greater rate of settlement when the soft soil is subjected to loading.

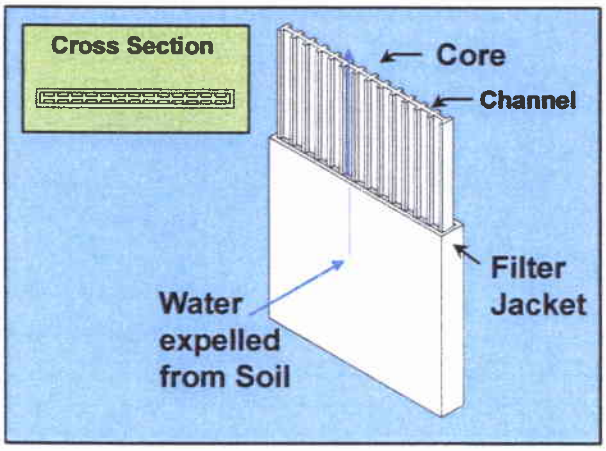
In early development, the vertical drains were consisted of sand columns. Today, the prefabricated vertical drains (PVD) have replaced the sand drains due to the ease of manufacturing and installation.

CN DRAIN, one type of PVDs manufactured by ***Chikami Miltec Inc. (Japan),*** has been widely used in Japan and Southeast Asia. Due to the great demand of PVDs in Asian region, a subsidiary company, named Thai ***Miltec International Co., Ltd***. was established to meet the production requirements. Since then, ***Thai Miltec International*** has become one of the leading PVD suppliers in SE Asia, supplying PVDs to countries including Thailand, Vietnam, Singapore, Indonesia etc.

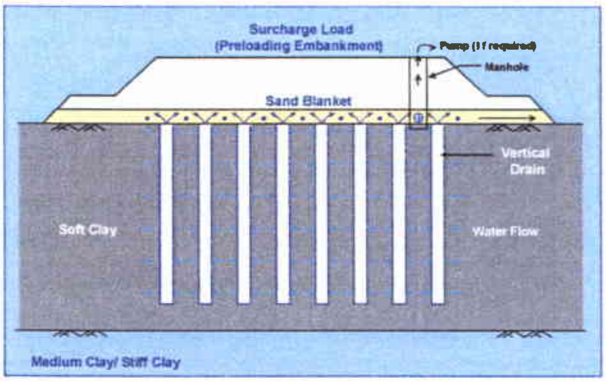
The CN Drain is well accepted by the engineers worldwide with proven track records. The CN drains have been manufactured with highest quality and standard.



CN Drain with World Leading Core Shape and High Quality Filter Jacket



Functions of Filter Jacket and Core

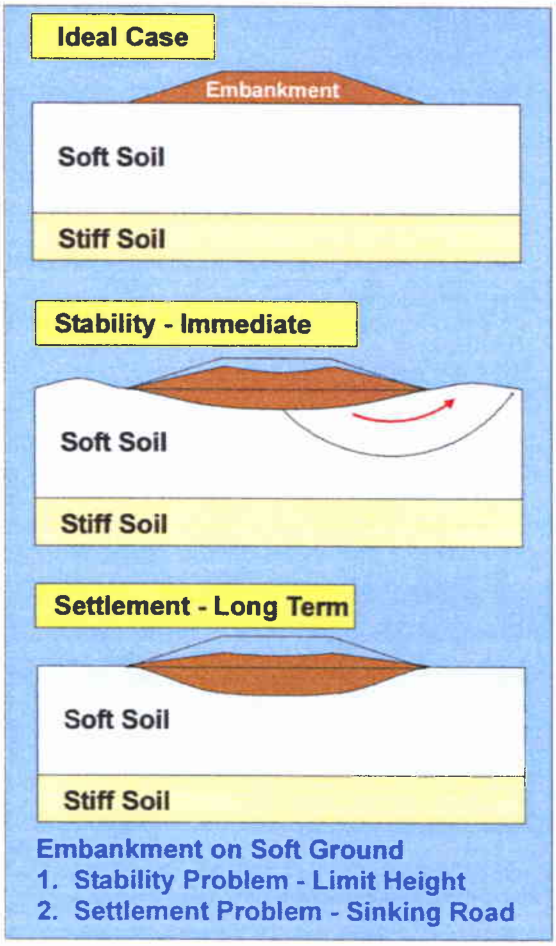


Typical Use of PVD Ground Improvement Method

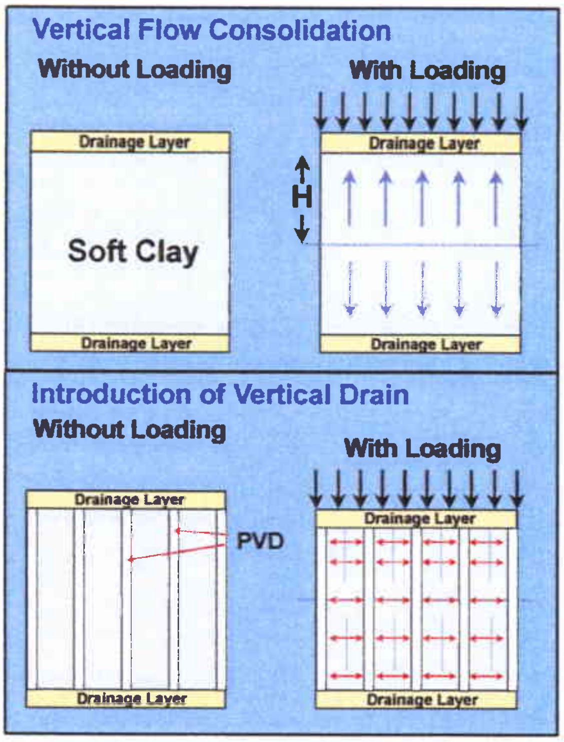
PVD Principles

Ground Improvement via PVD preloading method is commonly used to treat soft ground condition when there is a need to increase the stability and to reduce future settlement.

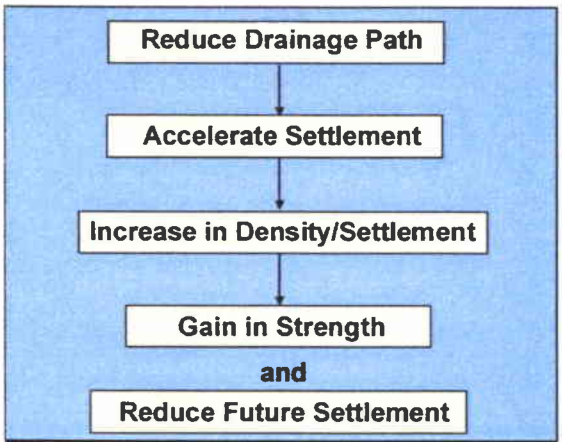
When the soft ground is subjected to a load (such as the embankment and traffic load), the embankment will settle or even fail if the load is significant. The vertical drain preloading method is introduced to ease the flow of water from the soft soil by reducing the drainage path as shown in the illustration. With shorter drainage path, the ground will settle at an accelerated rate during construction. With sufficient preloading, the final embankment will be rested on treated soil with far less future settlement. In addition, as the soil consolidates, its shear strength will also increase, improving the stability of the embankment. Therefore, the PVD method is considered as one of the most effective ground improvement techniques for treating soft soils.

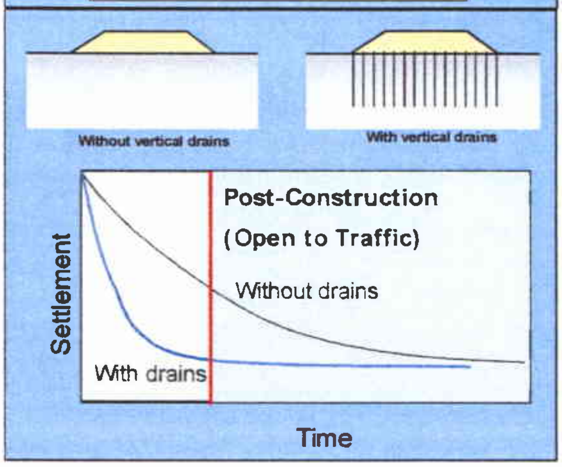


Settlement and Stability Problems



Method of Shortening Drainage Path in Soils by PVD Method





Benefits from PVD Preloading Method

Theory

The rate of settlement in a PVD system can be estimated from established theories.

For radial flow as in vertical drains, Barron (1948) proposed a solution for consolidation by radial drainage only as follows,

$$U_h = 1 - e^{[-8T_h/F]}$$

where $T_h = \dfrac{c_h t}{d_e^2}$

c_h = horizontal coefficient of consolidation

d_e = diameter of equivalent soil cylinder

Hansbo (1979) suggested that the factor, F, might consist of the following components with consideration of the effect of smear zone and well resistance:

$F = F(n) + F_s + F_r$

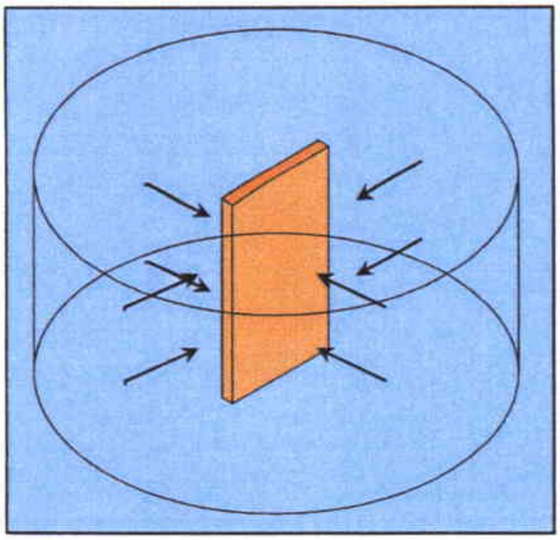
Where

$$F(n) = \ln\frac{d_e}{d_w} - 0.75$$

$$F_s = \left[\frac{k_h}{k_s} - 1\right]\ln\frac{d_s}{d_w}$$

$$F_r = \pi z(L - z)\frac{k_h}{q_w} = 0.001$$

From the above equations, one can estimate the rate of settlement with given drain properties and soil parameters.



Flow into PVD

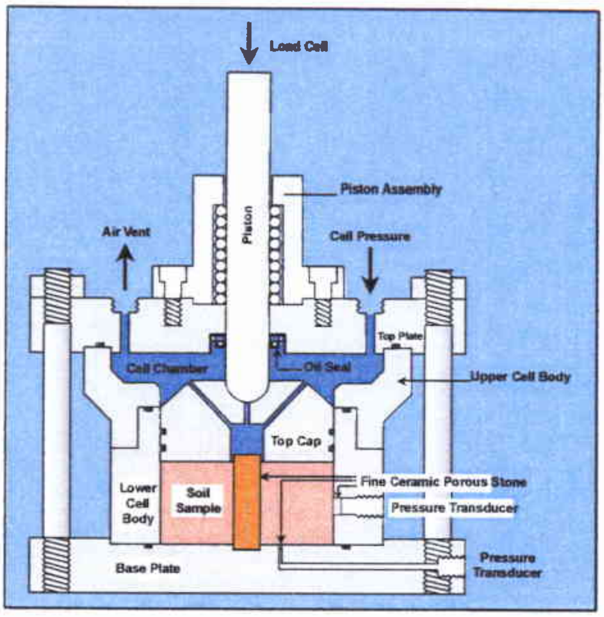
Professor Hansbo and Founder of Chikami Miltec Inc., Mr. Chikami (6)

References

Hansbo, S., 1979, "Consolidation of Clay by Band-Shaped Prefabricated Drains," ***Ground Engineering***, Vol. 12, No. 5, pp. 16-25

Important Soil Parameters

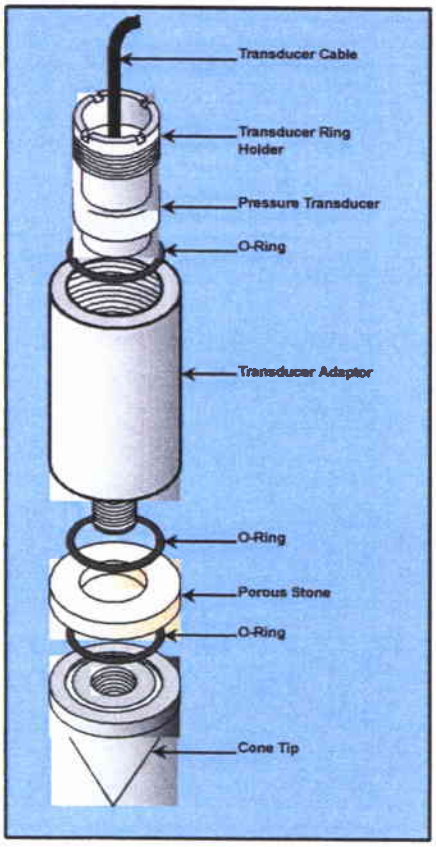
One of the most important soil parameters needed in the PVD preloading method is the horizontal coefficient of consolidation (c_h). To determine the c_h value of the soft soil, special field and laboratory testing equipment have been developed. For in-situ testing, dissipation test is commonly performed to yield the field c_h value at effective overburden stress. As for testing in the laboratory, Rowe cell is usually used, but a newly developed Constant rate of Strain (CRS) with radial flow capability can be a better alternative. The equipment gives a continuous stress-strain relationship as well as the c_h value for a wide stress range.



Constant Rate of Strain with Flow Drainage

References:

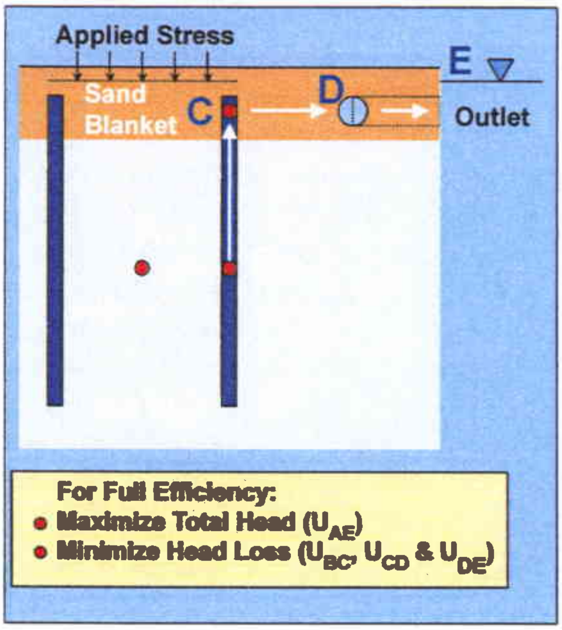
Seah, T. H., Tangthansup B., and Wongsatian, P. (2004). "Horizontal Coefficient of Consolidation of Soft Bangkok Clay". *Geotechnical Testing Journal, American Society for Testing and Materials*, Vol. 27, No. 5, pp. 430-440.



Dissipation Probe for Field Test

Critical Components in PVD System

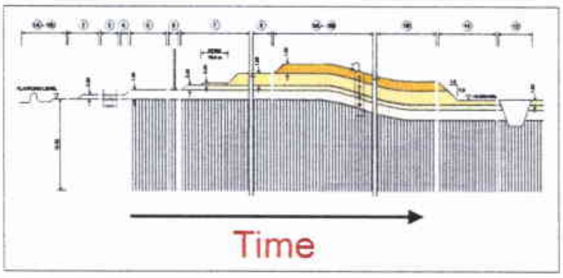
In order to achieve the highest rate of settlement, the hydraulic head loss from the PVD to the outlet has to be minimized. Firstly, the PVD itself should have a reasonable channel for the water to flow into from the surrounding soils under consolidation. The integrity of the PVD core is therefore very important to provide flow channel. The filter jacket of the PVD will also play a crucial role in preventing clogging of the channel. Above the original ground, a sand blanket is usually used to carry the water from the PVDs to the exposed ground. The quality of the sand is also critical in the PVD system, hence high quality clean sand is normally used. If there is a problem in releasing the water in the sand blanket, special subdrain can also be introduced. It should be kept in mind that the PVD method will only work with proper drainage system.



Installation

The PVD is usually installed with a PVD installation rig. A mandrel is used to protect and carry the PVD to required depth, and an anchor plate or rod at the tip of the mandrel/PVD is used to pivot the PVD when the depth is reached.

Once the PVD has reached the required depth, the mandrel is withdrawn from the ground, then the PVD is cut with a 20-30 cm of PVD above the ground surface for better drainage connection with the sand blanket.



Typical PVD Construction Sequence

Insertion of PVD Anchor

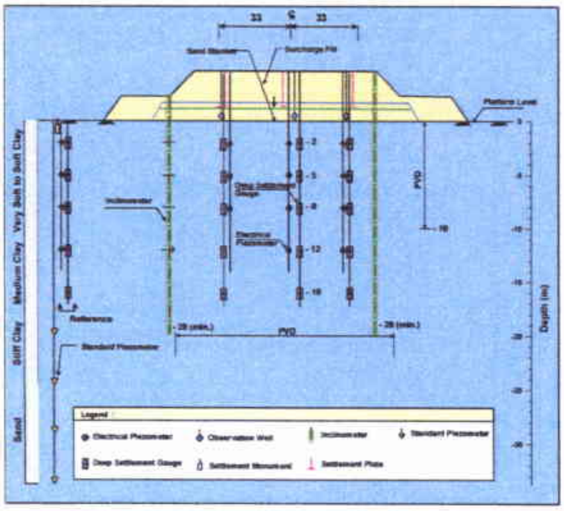
Typical PVD Installation on Ground

Offshore PVD Installation in Japan

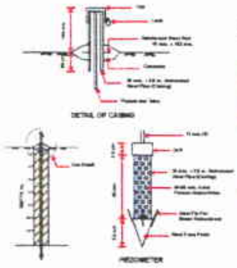
PVD Installation in Vietnam

Instrumentation

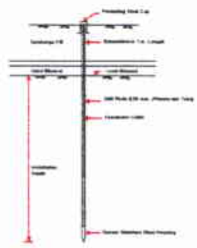
To verify the performance of the PVD system during construction, a monitoring instrumentation program is adopted. The monitoring instruments will assist in checking the vertical and horizontal ground movements as well as the pore water pressure in the soft soils and drainage layers.



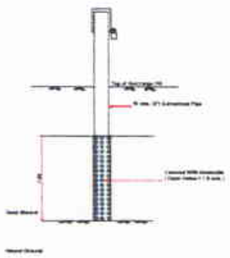
Typical Instrumentation Plan



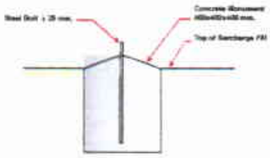
Standpipe Piezometer



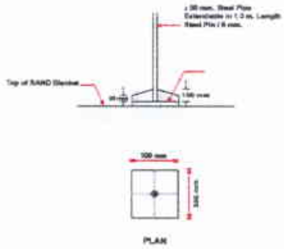
Electrical Piezometer



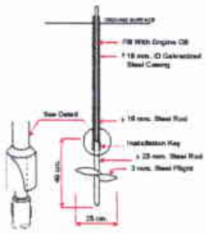
Observation Well



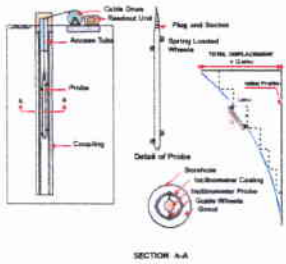
Surface Monument



Surface Settlment Plate



Deep Settlement Gauge



Inclinometer

Performance and Analysis

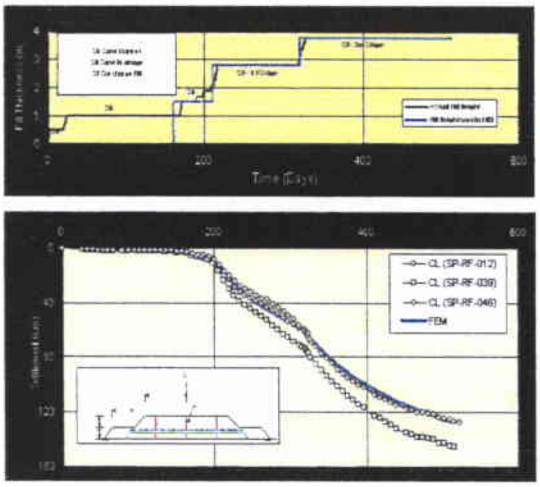
The performance of a PVD preloading embankment can be evaluated based on 1-D consolidation analysis or Finite Element method (FEM). For 1-D consolidation analysis, the measured settlement time curve is extrapolated using established method such as Asaoka method for predicting the degree of settlement which is required in surcharge removal.

The FEM analysis can be used to analyze the behaviour of the embankment with PVD ground improvement. The commercial program such as PLAXIS, which is widely used for modeling geotechnical problems, is one of the best tools available. This software has the capability of generating the mesh automatically once the dimensions and boundary conditions are defined. It also incorporates various soil models in the package, including Mohr-Coulomb, Cam-Clay etc. The interface behavior between different materials, such as soil and structure, can also be assigned in the software. Therefore, this program has been selected for modeling of the embankment deformation.

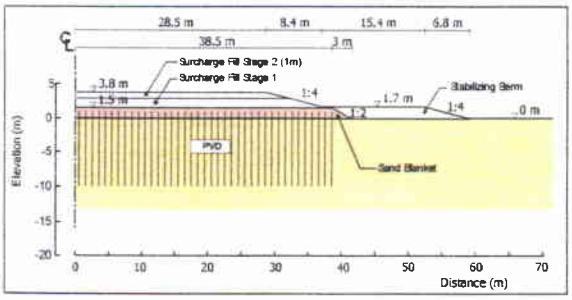
To simulate the PVD drainage condition, the flow model has to be converted into 2-dimensional (2-D) condition.

Measurement versus Prediction

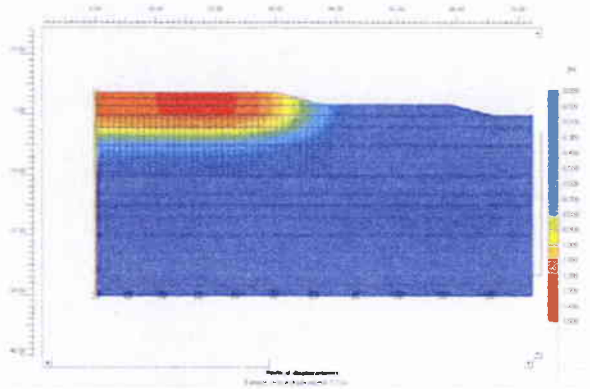
An example of the finite element analysis is shown attached figures, indicating excellent match with measurements.



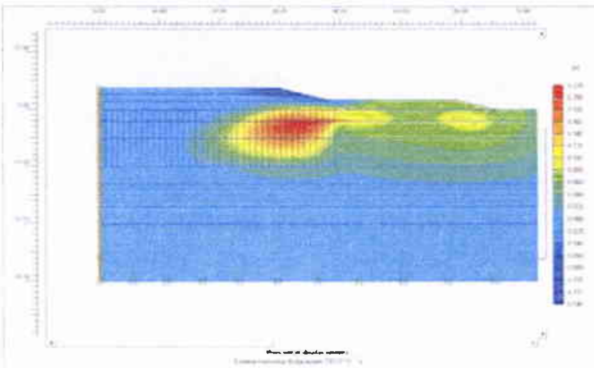
Example of Embankment loading and Settlement Curves



Example of FEM Analysis



Vertical Settlement from FEM Analysis



Horizontal Movement from FEM Analysis

Standard Specifications of CD Drains

CN drain can be tailored made to meet the design requirements, but the specifications of the standard drains are shown below:

- **CN Drain Standard Specifications**

alterable when required

	Material		Measurements		Discharge Capacity		Tensile	Permeability	AOS
							Strength	filter	filter
	core	Filter	Thickness	Width	Test Method	m^3/year	ASTM D4595	ASTM D4491	ASTM D4751
			mm	mm			kN	cm/sec	μ
A1	Polyolefin	Spunbonded Nonwoven	3.5 ±0.5	99.0 ± 5.0	ASTM D4716 200kPa, i=1.0	>2000	>2.5	$>1.0x10^{-3}$	<75
A6			3.5 ±0.5	99.0 ± 5.0	ASTM D4716 200kPa, i=1.0	>2000	>2.0	$>1.0x10^{-3}$	<75

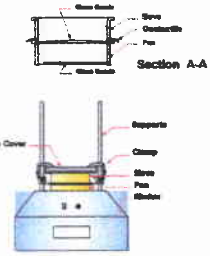
- **Required Specification of CN Drain Execution Records**

		Material		Measurements		Discharge Capacity		Tensile	Permeability	AOS
								Strength	filter	filter
		core	Filter	Thickness	Width	Test Method	m^3/year	ASTM D4595	ASTM D4491	ASTM D4751
				mm	mm			kN	cm/sec	μ
A1	Thailand	Polyolefin	Spunbonded Nonwoven	3.5 ±0.5	99.0 ± 5.0	TRI-AXIAL 200kPa, i=1.0	>500	>2.0	$>1.0x10^{-3}$	<75
	Vietnam			3.5 ±0.5	99.0 ± 5.0	ASTM D4716 350kPa, i=1.0	>2000	>2.0	$>1.0x10^{-3}$	<75
	Vietnam			3.5 ±0.5	99.0 ± 5.0	ASTM D4716 200kPa, i=1.0	>2000	>2.0	$>1.0x10^{-3}$	<75
	Singapore			3.5 ±0.5	99.0 ± 5.0	NUS Method 350kPa, i=0.5	>2400	>2.5	$>1.0x10^{-3}$	<75
	Hong Kong			3.5 ±0.5	99.0 ± 5.0	ASTM D4716 200kPa, i=1.0	>1800	>1.5	$>1.0x10^{-3}$	<75
A6	Vietnam			3.5 ±0.5	99.0 ± 5.0	ASTM D4716 300kPa, i=0.5	>2000	>1.6	$>1.0x10^{-3}$	<75
	Japan			3.5 ±0.5	99.0 ± 5.0	TRI-AXIAL 350kPa, i=1.0	>1000	>2.0	$>1.0x10^{-3}$	<75
	Philippines			3.5 ±0.5	99.0 ± 5.0	ASTM D4716 350kPa, i=1.0	>700	>1.0	$>1.0x10^{-2}$	<75

Quality Control

The CN Drain is manufactured with utmost quality control. Routine quality control tests are performed to ensure that the product meets the requirements. The tests include filter weight check, apparent Opening Size (AOS), strength tests and discharge capacity tests.

Apparent Opening Size (AOS)

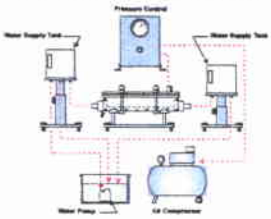



Purpose : To determine Opening Size of PVD Filter Jacket

Filter Weight Check


Purpose : To be used as quality control

In-Plane Discharge Capacity

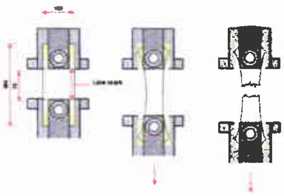



Purpose : To determine longitudinal flow properties of PVD

Triaxial Discharge Capacity

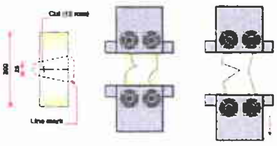

Purpose : To determine longitudinal flow properties of PVD

Tensile Grab Test



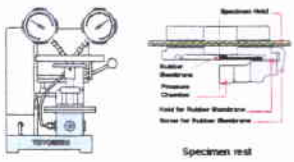

Purpose : To determine tensile strength of Geotextile

Trapezoidal Tear Test



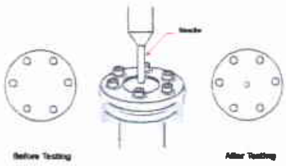

Purpose : To determine tearing resistance of Filter Jacket

Bursting Strength Test




Purpose : To determine burst resistance of Geotextile

PunctureStrength Test




Purpose : To determine puncture resistance of Geotextile

Production

The CN Drain is now manufactured in SE Asia to meet the regional demand and to reduce the delivery time and cost. The manufacturing facilities incorporate the newest production technology to produce highest quality of PVDs.

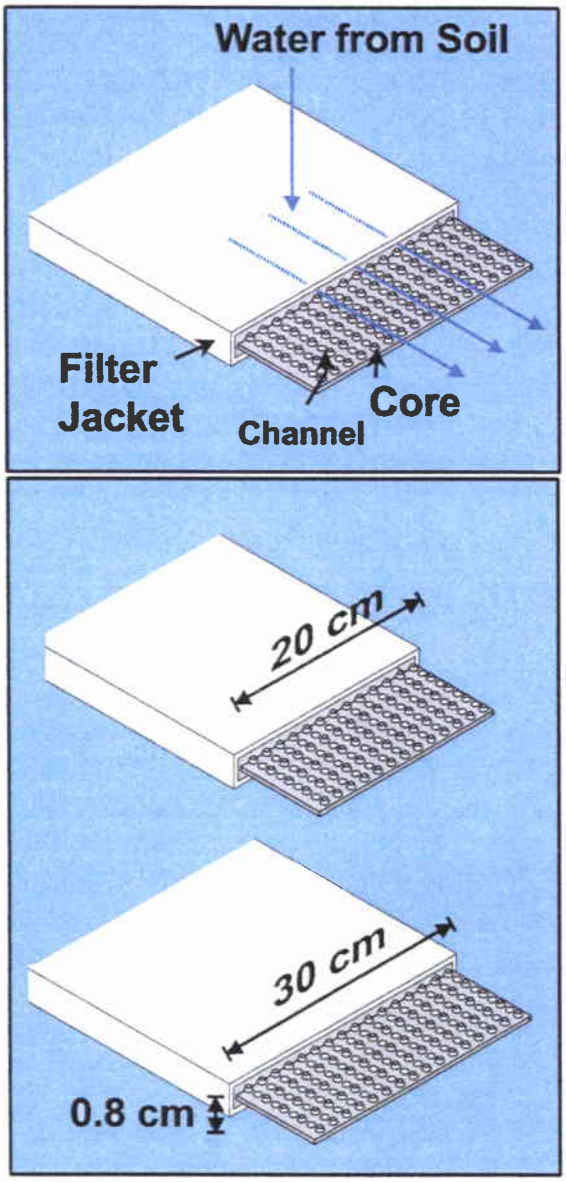
Project List

No.	PROJECT TITLE	COUNTRY	PVD QTY (M)	DELIVERY	REMARKS
1	NEW BANGKOK INTERNATIONAL AIRPORT WEST RUNWAY	THAILAND	18,300,000	APR '98	GROUND CONSOLIDATION
2	DEMARK BY-PASS PROJECT	INDONESIA	110,000	FEB '00	ROAD CONSTRUCTION
3	CEBU CITY SOUTH RECLAMATION PROJECT	PHILIPPINES	2,700,000	MAR '00	RECLAMATION
4	TSEUNG KWAN O PORT DEVELOPMENT AT AREA 137 STAGE 2	HONG KONG	1,895,400	AUG '00	RECLAMATION
5	NATIONAL HIGH WAY NO.18	VIETNAM	1,194,200	OCT '00	ROAD CONSTRUCTION
6	CAI LAN PORT EXPANSION	VIETNAM	2,373,600	JAN '01	RECLAMATION
7	TUEN MUN AREA 38 RECLAMATION STAGE □	HONG KONG	1,529,400	FEB '01	RECLAMATION
8	NATIONAL HIGH WAY NO.10	VIETNAM	243,800	APR '01	ROAD CONSTRUCTION
9	NEW BANGKOK INTERNATIONAL AIRPORT ROUND SIDE ROAD	THAILAND	3,256,800	MAY '01	GROUND CONSOLIDATION
10	RECLAMATION AT PALAU TEKONG (PART 1)	SINGAPORE	60,000	JULY '01	RECLAMATION
11	RECONSTRUCTION OF BRIDGES IN MEKONG DELTA AREA	VIETNAM	690,000	FEB '02	BRIDGES CONSTRUCTION
12	PAK SHEK KOK	HONG KONG	120,000	OCT '02	REMAINING ENGINEERING INSTRUCTIVE WORKS
13	NEW BANGKOK INTERNATIONAL AIRPORT EAST RUNWAY	THAILAND	4,100,000	FEB '03	GROUND CONSOLIDATION
14	NEW BANGKOK INTERNATIONAL NORTHERN SUPPORT ZONE	THAILAND	2,100,000	AUG '03	GROUND CONSOLIDATION
15	PENNY'S BAY RECLAMATION STAGE 2	HONG KONG	9,400,000	AUG '03	GROUND CONSOLIDATION
16	VU OAI - HOANH BO	VIETNAM	455,400	DEC '03	GROUND CONSOLIDATION
17	CAI TU BRIDGE	VIETNAM	60,000	July '04	GROUND CONSOLIDATION
18	BAC LIEU	VIETNAM	86,000	Nov '04	GROUND CONSOLIDATION
19	ROAD 188 (TUY LOAN-TUYEN SON ROAD NATIONAL HIGHWAY)	VIETNAM	158,400	Feb '05	GROUND CONSOLIDATION
20	ROAD 61	VIETNAM	218,400	Mar '05	GROUND CONSOLIDATION
21	NEW BANGKOK INTERNATIONAL THE THIRD RUNWAY	THAILAND	7,200,000	May '05	GROUND CONSOLIDATION
22	RED RIVER BRIDGE PACKAGE 2	VIETNAM	1,800,000	Aug'05	GROUND CONSOLIDATION
23	THANG LONG NORTH - VAN TRI URBAN INFRASTRUCTURE DEVELOPMENT PROJECT	VIETNAM	151,800	Dec'05	GROUND CONSOLIDATION
24	SAIGON - TRUNG LUONG HIGHWAY	VIETNAM	323,400	Jan'06	GROUND CONSOLIDATION
25	CAN THO BRIDGE	VIETNAM	1,400,000	Jan'06	GROUND CONSOLIDATION
26	SAIGON EAST-WEST HIGHWAY	VIETNAM	90,000	June'06	GROUND CONSOLIDATION
27	RED RIVER BRIDGE P.3	VIETNAM	330,000	July'06	GROUND CONSOLIDATION

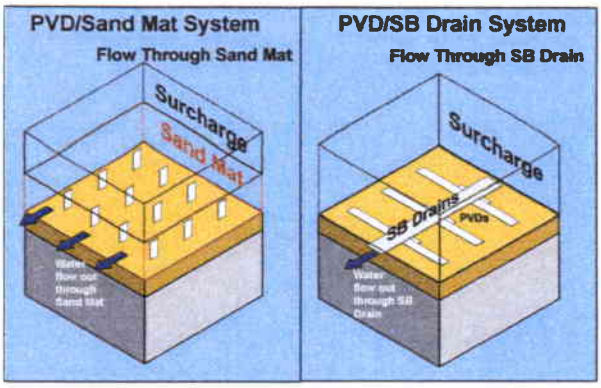
SB Drain Product (Horizontal Drains)

The SB drain, one type of horizontal drains, is designed to replace the sand blanket or underdrains. It consists of a core to allow water flow through its channels with a filter jacket as filter. The functions and dimensions of SB drain are illustrated in the figure. The SB drain is relatively flexible and stretchable; hence it can extend along with the ground or embankment deformation.

The SB drain reduces the quality control problems associated with the natural sand in the construction, improving the construction time as a result



Function of SB Drains and Dimensions



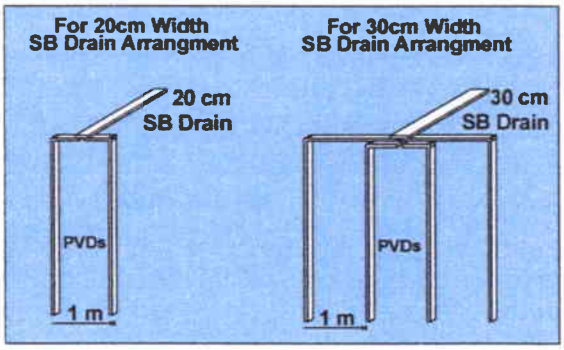
Substitution of Sand Blanket with SB Drains

Installation of SB Drains along with CN Drains

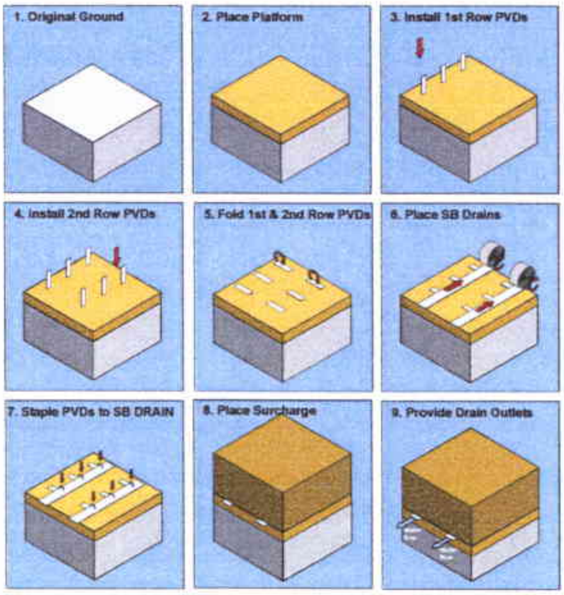
Installation of SB drains in Confined area

Installation and Applications

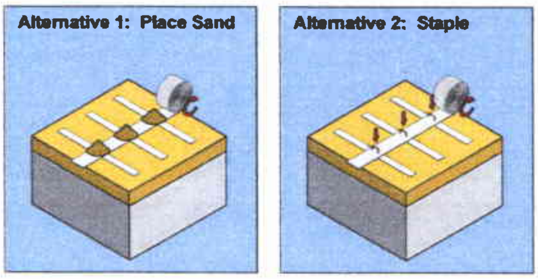
As a replacement for sand blanket in the PVD system, the SB Drain is used based on similar discharge capacity criterion as the sand blanket material, and various arrangements of SB drain in the PVD system can be made according to the requirements.



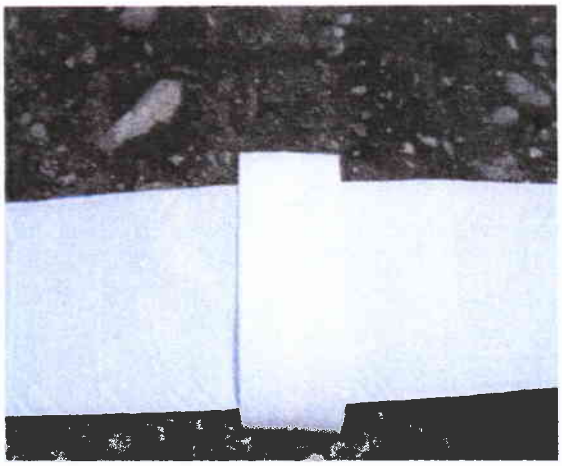
Examples of SB Drain connection to PVDs



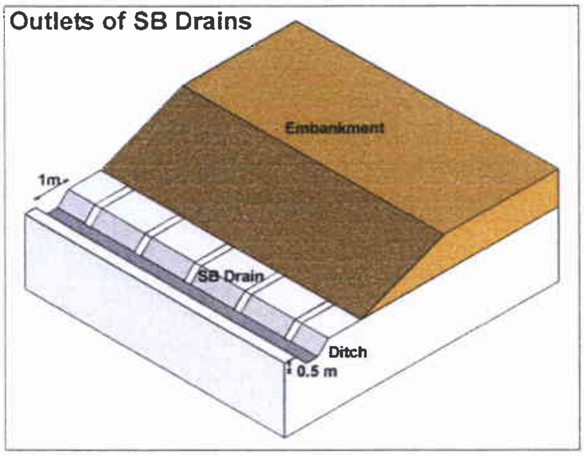
Installation Sequence of PVD and SB Drains



Different Methods of PVD and SB Drain Connection



Connection of PVD to SB Drain



Outlet of Drainage with SB Drains

Collecting Ditch in SB Drain System