Prefabricated Vertical Drains

Technical Design Manual

CeTeau stands for innovative ground improvement technologies with Prefabricated Vertical Drains. Prefabricated Vertical Drains (PVD), also called Wick Drains, are prefabricated drain strips consisting of a polypropylene core extruded into a configuration to transmit a maximum water flow on both sides of the core. The core is wrapped in a non-woven filter, ultrasonically welded at the edges.
The CeTeau® Vertical Drain System is one of the most widely used drain system in the world, with over 100,000,000 lm installed world wide. This manual serves as a guide to assist engineers with the selection and application of vertical wick drains.

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THE VERTICAL WICK DRAIN PRINCIPLE

When construction work such as road and airfield embankments, bridge approached, dykes, land reclamation or buildings on soft compressible soils, significant settlements may occur due to consolidation of these soils under the superimposed loads. To avoid serious and potentially expensive problems due to such settlements, it is desirable to cause this consolidation to occur at the outset of project, and in the shortest possible time – during the construction period.

Consolidation of compressible soils involves removal of pore water from the soil. This is traditionally done by applying a surcharge of preload to the construction area to "squeeze" the water out.
Unfortunately, compressible soils are also often low-permeability soils (peats, silts, clays), and as such the water is not easily squeezed out.

To facilitate the dewatering process, it is necessary to install vertical drains into the soil, to provide a conduit for the water flow. Traditionally, these drains took the form of sand columns – holes drilled into the low-permeability soil and filled with higher permeability sand. But these were relatively expensive, and inconvenient to place at close spacing.

PVD's are a very economical replacement for sand drains. They are relatively inexpensive, provide higher conductivity (up to 30 times more effective than a 300mm diameter sand drain) and can easy be installed at close spacing, thus shortening the path of the pore water in the impermeable soil and expediting the consolidation process.

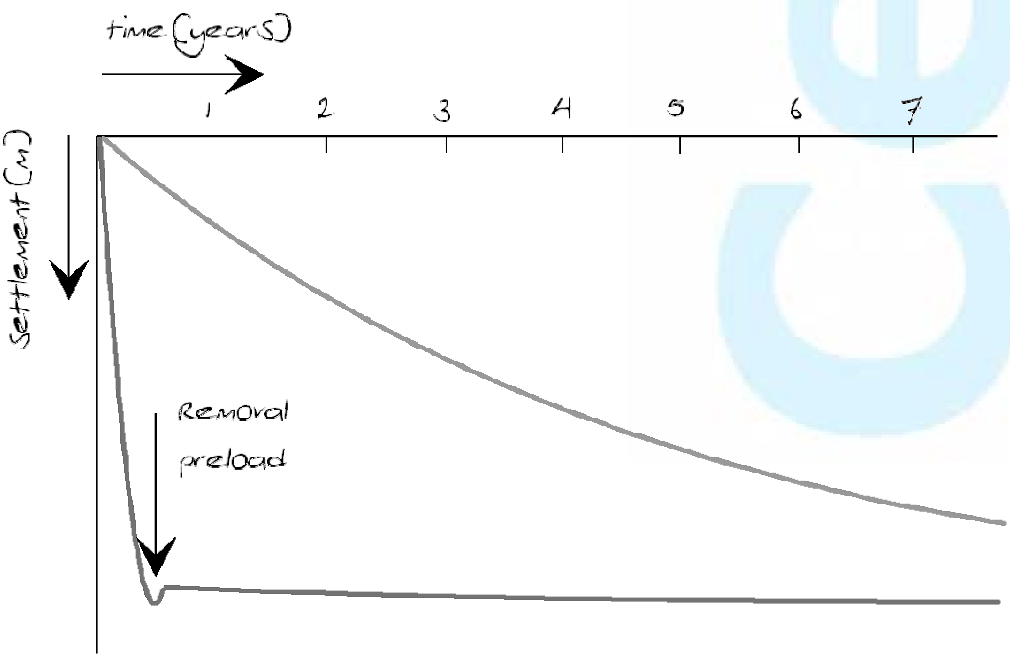

Fig. 1 – Effect of Prefabricated Vertical Drains During Consolidation

THE CETEAU® VERTICAL DRAIN SYSTEM

CeTeau® Vertical Drain is a prefabricated drainage strip. The core is a highly flexible polypropylene extrusion, having maximum water flow capacity along the grooves formed longitudinally on both sides of the core. Strict quality control is employed to insure the extrusion is consistent.

The filter fabric on the CeTeau® Vertical Drain is made from strong, durable, non-woven polypropylene or polyester geotextile, having a very high permeability. The geotextile fabric serves as a filter to allow passage of groundwater into the drain core while preventing piping of fines from the adjacent soils. The filter also serves as and outer skin to maintain the cross-sectional shape and hydraulic capacity of the core channels.

The graphic below shows a typical cross-section of the CeTeau® Vertical Drain

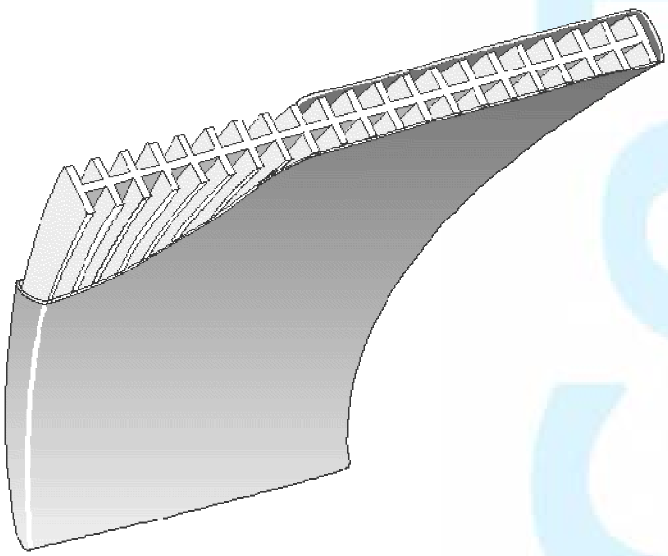

Fig. 2 – Cross-section of CeTeau® prefabricated vertical drain

THE CETEAU® VERTICAL DRAIN SYSTEM

CeTeau® Vertical Drain is installed using patented, proprietary equipment. The equipment is comprised of a structural mast (which in some cases also serves as equipment housing), a mandrel and mandrel propulsion equipment. The CeTeau® Vertical Drain, which is supplied in rolls 250-300m in length, is threaded through the mast into the mandrel and is held in place at the base of the mandrel by an anchor plate. The mandrel and the wick are then driven into the ground to the desired depth.
The anchor plate serves two purposes in the operation. First, it prevents soil from entering and clogging the mandrel as it is being driven into the ground, and secondly, it anchors the drain in place at the desired depth as the mandrel is being retracted. When the mandrel has been withdrawn, the wick is cut off above the ground surface, leaving a tail approximately 300mm long. Then a new anchor plate is installed, the mast is repositioned over the next location and the cycle is repeated.
There are various means of driving the mandrel, including a simple cable pull powered by a conventional crane, a vibratory head attached directly to the mandrel (although this technique is not recommended because of its detrimental effects on the surrounding soil), and a hydraulic cylinder powered by the hydraulics of an excavator. The hydraulic system has a mechanical advantage, allowing deeper penetration and greater applied force. When stiffer soils are encountered extra weight can be added to the mast to assist penetration or holes can be predrilled before the mandrel and drain are inserted.
As the ground surface in areas requiring prefabricated vertical drains is often soft and unstable. It may be necessary to prepare a working mat to facilitate mobility of the installation equipment. This mat also serves a second purpose of providing a free draining layer for the water being discharged from the drains.
This working mat is generally constructed of sand, as part of the preload or structure fill, and is typically 300mm or more in thickness.
In the event that good quality natural materials for the working mat are scarce, several options exist to both improve the stability of the surface soil and reduce the thickness of the working mat. Geotextiles or geogrids are very effective in strengthening the sub-base, and can significantly reduce the amount of fill needed to provide a suitable and stable working mat.
Efficiency may also be increased by replacing the free draining sand mat with prefabricated horizontal drains connected to the protruding wick tails. This is a very effective method to ensure fast and complete removal of all water discharged from the wick drain project.

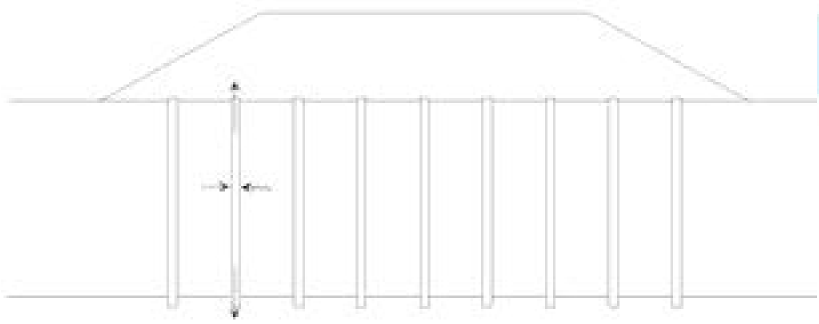

Fig. 3– Consolidation using prefabricated vertical drains

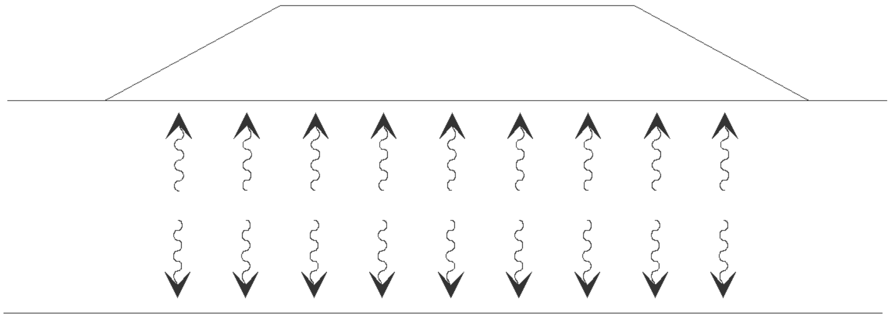

Fig. 4 – Consolidation without prefabricated vertical drains

THE VACUUM PRELOAD OPTION

A preload is usually required to properly compress the saturated soils and cause the water to flow through the drains to be discharged. When the applied preload becomes part of the structure, as in an embankment or bridge approach, the materials used for the preload are usually selected accordingly. However, when the ultimate required elevation is already close to the anticipated elevation after settlement, the added costs of applying the preload, and removing it again after consolidation has occurred, often renders the project economically unviable.

An attractive option to reduce costs in the case is to utilize a preload vacuum simulation technique called CeTeau Vacuo®. The system consists of installing prefabricated vertical drains, individually connected below the surface to vacuum transmission pipes. These pipes are then connected at surface level to a horizontal tubing system by means of specially developed airtight T-couplings. The so-called drainage screens, a row of vertical drains that are connected at the top to a horizontal line, are brought outside the surcharge (if any) and connected to a combined vacuum air pump that has been developed in-house.
The applied vacuum produces the same pressures as a traditional preload system of up to 3-5m in height.

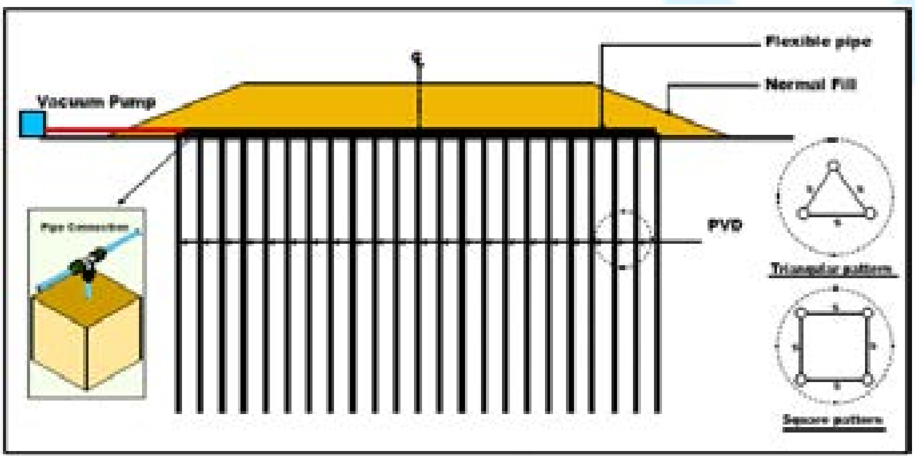

Fig. 5 – Consolidation using prefabricated vertical drains with vacuum preload arrangement

DESIGNING WITH THE CETEAU® VERTICAL DRAIN SYSTEM

The principle underlying vertical drainage is simple, but the theoretical description of the operating mechanism is quite complex.

Wick drain spacing is usually calculated by means of Barron's formula, as follows:

$$C_h = \frac{D^2}{8t}\left[\frac{1}{1-\left[\frac{d}{n}\right]^2} \times \ln\frac{D}{d} - 0.75 + 0.25\left[\frac{d}{D}\right]^2\right] \times \ln\frac{1}{1-U}$$

(Formula 1)

Where:

C_h	=	Consolidation Coefficient for Horizontal Flow ($m^{2/}s$)
D	=	Diameter of the Sphere of Influence of the Drain (m)
t	=	Consolidation Time (s)
d	=	Equivalent Diameter of the Drain (m)
U	=	Average Degree of Consolidation

The C_h value is determined from laboratory tests of soil samples. The compression test is the most common method, and the C_h value is a function the C_v value thus found. (For clay soils, $C_h \approx 1$ to 4 times C_v.)

Drains are most efficiently placed in a triangular pattern, but they can be arranged in a square pattern (although a triangular pattern is nearly 2.5 times more efficient). The diameter of the sphere of influence (**D** in formula 1) is based on the existence of a soil cylinder, and to account for overlap and gaps between such cylinders. The design drain spacing for triangular pattern should be 0.95, and that of a square pattern should be 0.88 times that calculated value of **D.**

The drain diameter (**d** in formula 1) assumes a cylindrical drain. The equivalent diameter of the CeTeau® Vertical Drain is derived from the following equation:

$$d = \frac{\text{circumference}}{\pi}$$

At a width of 100mm and a thickness of 3mm, the circumference (perimeter in this case) of the drain is 206mm, making the equivalent diameter of the drain 65mm. The flow towards a flat drain is less efficient than flow towards a cylindrical drain, and therefore, the drain diameter is conservatively taken to be 50mm.

The average degree of consolidation (**U**) is usually expressed as a percentage, or a value between 0 and 1. Thus a 90% consolidation can be written as **U = 0.90.**

Experience has shown that the drain spacing is usually grater than 1.0 meter. For a CeTeau® Vertical Drain with effective diameter of 0.05m, the value $(\mathbf{d}/\mathbf{D})^2$ is less than 2.5×10^{-3} and of little influence in the outcome of the calculation. Therefore, the following simplified formula is often preferred.

$$C_h = \frac{D^2}{8t} \left[\ln \frac{D}{d} - 0.75 \right] \ln \frac{1}{1 - U}$$

(Formula 2)

In this formula it is assumed that the vertical discharge capacity of the drain is infinite, However, the discharge capacity of the CeTeau® Vertical Drain is finite, and can be included in the formula as follows:

$$C_h = \frac{D^2}{8t} \left[\ln \frac{D}{d} - 0.75 + z\pi \; (2l - z) \frac{K_c}{q_w} \right] \ln \frac{1}{1 - U}$$

(Formula 3)

Where:

$\mathbf{C_h}$	=	Consolidation Coefficient for Horizontal Flow ($m^{2/}s$)
D	=	Diameter of the Sphere of Influence of the Drain (m)
t	=	Consolidation Time (s)
d	=	Equivalent Diameter of the Drain (m)
U	=	Average Degree of Consolidation
z	=	Distance to the Flowpoint (m)
l	=	Drain Length at Unilateral Flow (m) (half length at Bilateral Flow)
$\mathbf{k_c}$	=	Permeability of the Soil (m/s)
$\mathbf{q_w}$	=	Discharge Capacity of the Drain (m^s/s)

The discharge capacity (**q_w**) of the CeTeau® Vertical Drain is approx. 1.8 x 10^{-4} m^3/s. A sand column with a diameter of 300mm has a **q_w** of approx. 6 x 10^{-6} m^3/s, or *approx. 3% of the CeTeau® Vertical Drain*. The **k_c** value of the soil to be consolidated generally varies from 10^{-7} to 10^{-10} m/s. The table below presents the **k_c** values and the **k_c / q_w** ratio in the orders of magnitude for various types of soil. These figures are based on a CeTeau® Vertical Drain with a **q_w** of 10^{-5} m^3/s.

SOIL	k_c (m/s)	k_c / q_w (m^{-2})
Coarse Sand	10^{-2} to 10^{-3}	10^{3} to 10^{2}
Medium Coarse Sand	10^{-3} to 10^{-4}	10^{2} to 10
Fine Sand	10^{-4} to 10^{-5}	10 to 1
Silty Sand	10^{-5} to 10^{-6}	1 to 10^{-1}
Sandy Silt	10^{-6} to 10^{-9}	10^{-1} to 10^{-4}
Peat	10^{-7} to 10^{-9}	10^{-2} to 10^{-4}
Clay	10^{-9} to 10^{-11}	10^{-2} to 10^{-6}

Fig. 6 –Discharge capacities of various soils

When working through the formula it will appear that when the ratio **k_c / q_w** becomes greater than 10^{-4} m^{-2}, the drain capacity will be of influence on the consolidation rate. For CeTeau® Vertical Drain, this condition occurs when the soil has a **k_c** > 10^{-9} m/s.
The formula only offers the possibility of determining the consolidation at a given depth **z.** The following graph shows how consolidation time varies at various depths for unilateral flow and a 20m thick layer of soil.

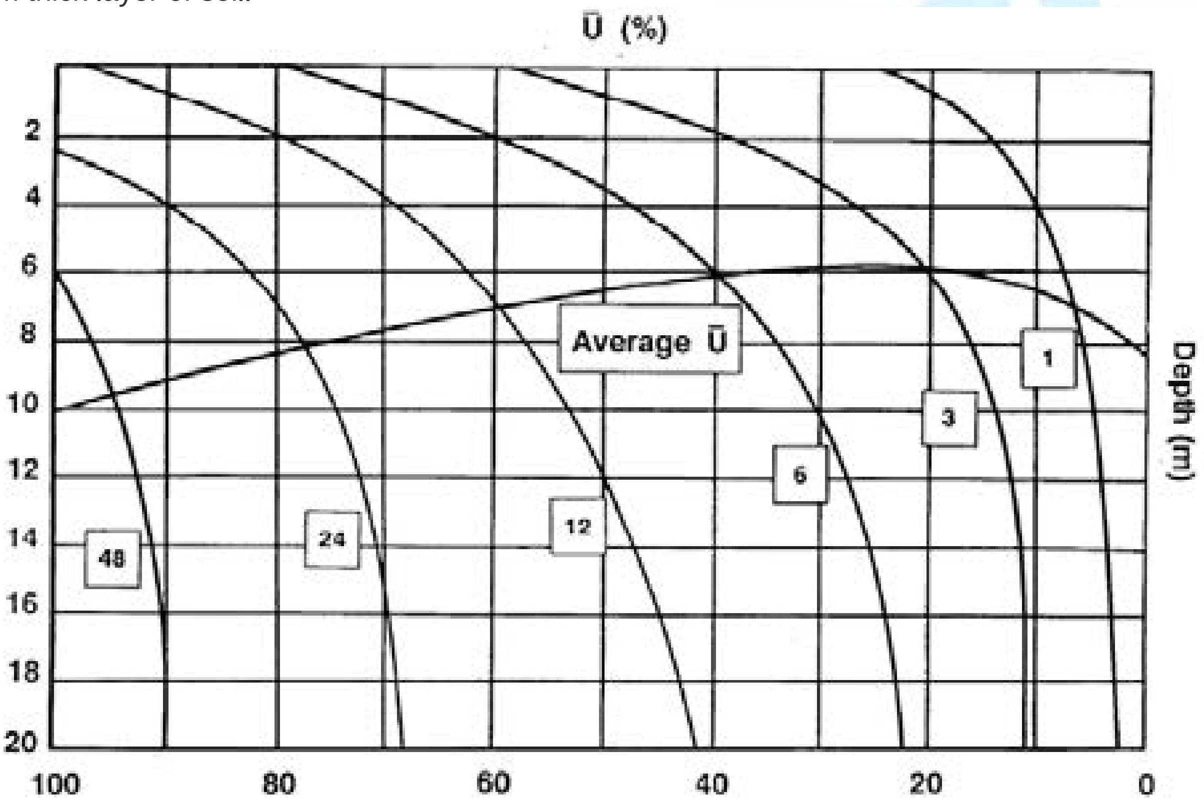

Fig. 7 –Effect of drain depth on consolidation time

The variation of average consolidation plotted against time follows a curve which remains between 0.3 ℓ and 0.5ℓ. When **z** = 0.4 ℓ is substituted as an approach into formula (3), the following formula is obtained.

$$C_h = \frac{D^2}{8t}\left[\ln\frac{D}{d} - 0.75 + 0.64\,\pi\,l^2\,\frac{K_c}{q_w}\right]\ln\frac{1}{1-U}$$

(Formula 4)

This formula can be presented in graphical form, to determine wick spacing, as shown by Figure 8 (see Page 12). The following example demonstrates use of the graphical solution. For cases where $\mathbf{k_c}$ / $\mathbf{q_w}$ = $10^{-2,}$ 10^{-3}, and 10^{-4} respectively.

> NOTE : *The given values are provided for illustrative purposes only, and values may not represent actual physical properties of CeTeau® Vertical Drain*

$\mathbf{C_h}$	=	6.5×10^{-8} m^2 / s
t	=	12 months
U	=	70%
ℓ	=	20m
$\mathbf{q_w}$	=	1.2×10^{-5} m3 /

Draw a vertical line from $\mathbf{C_h}$ = 6.5×10^{-8} m^2 / s to the oblique line corresponding to twelve months. From this point of intersection, draw a horizontal line to the oblique line corresponding o 70% consolidation. From this point, draw a vertical line to the oblique line corresponding to a depth of 20m, and from there a horizontal line to the scale along the edge indication the drain spacing. (Note that there are two sets of oblique lines for values of $\mathbf{k_c}$ / $\mathbf{q_w}$ 10^{-2} m^{-2} and 10^{-2} m^{-2} respectively, from which a horizontal line to the spacing scale is to be drawn, and that for $\mathbf{k_c}$ / $\mathbf{q_w}$ 10^{-4} m^{-2} , the vertical line is to be extended to the bottom scale.) The graphical solution shows that the required drain spacing is 1.09m for $\mathbf{k_c}$ / $\mathbf{q_w}$ = 10^{-2} m^{-2}, 1.83m for $\mathbf{k_c}$ / $\mathbf{q_w}$ = 10^{-3} m^{-2}1,2.03m for $\mathbf{k_c}$ / $\mathbf{q_w}$ = 10^{-4} m^{-2}. In terms of drain quantities, these spacing represent ratios of **3.5:1.2:1**. Therefore, it can be seen that the drain capacity can be of considerable influence on the quantity of drain required.

When designing with the CeTeau® Vertical Drain system, it is not always practical to assume that the entire thickness of the compressible layer must be provided with drains. It is often more practical and economical to provide 50% or 75% of the layer thickness with drains. This decision will depend upon how settlement varies with depth and upon the different in $\mathbf{C_h}$ values at various depths. This is demonstrated in the example of a motorway which is planned through an area underlain by a 40m thick compressible layer. The expected settlement during the hydrodynamic period amounts to a total of 1m, 80% of which is to take place in the upper 20m of the layer. The variation of settlement over the total depth is illustrated by the graph on the following page:

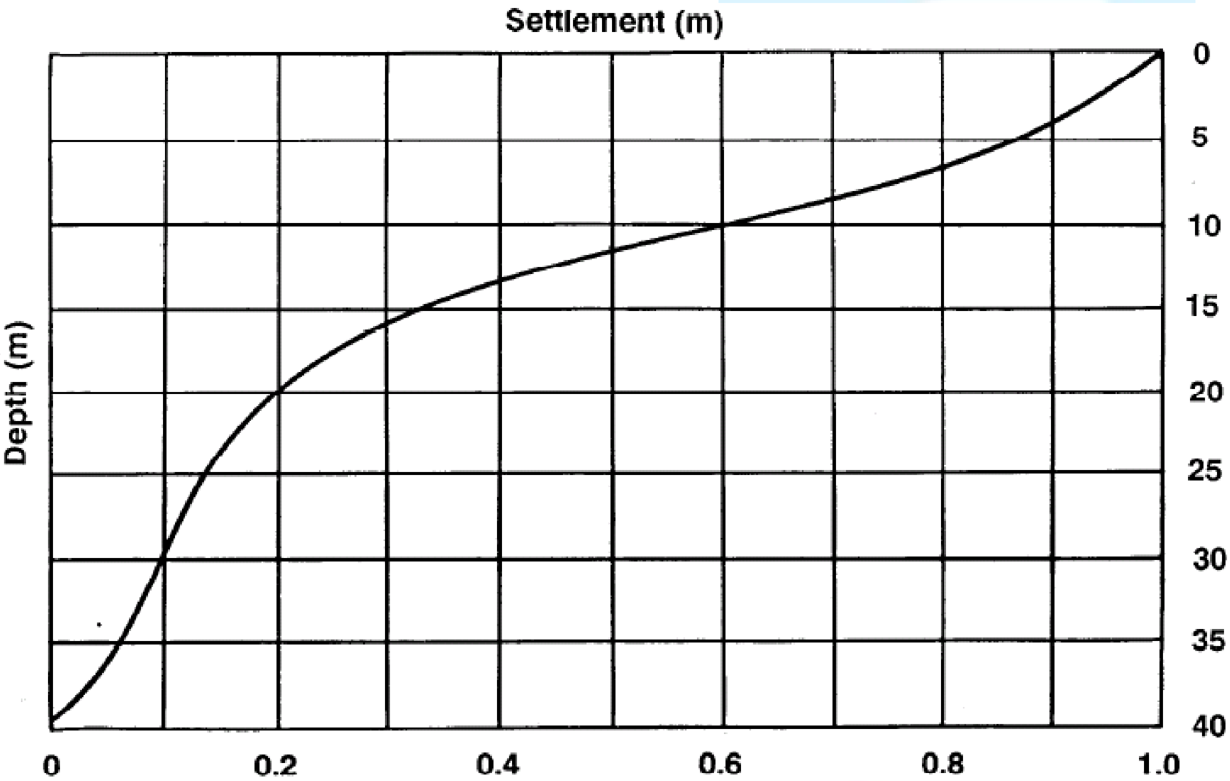

Fig. 9 – Variation of Settlement as Compared to the Total Depth of the Compressible Layer

The total area to be consolidated is 10,000m^2. The average $\mathbf{C_h}$ value of the entire layer is 10^{-7} m^2 / s. The road surface is to be applied at the end of twelve months, but reaching a 99% consolidation in twelve months does not seem feasible because the number of drains to be used would become excessive (240,000m).

A residual settlement of 25% after twelve months is considered acceptable. Therefore, a consolidation of 75% is required within twelve months. The following solutions are feasible :

1. Installation of drains down to 40m. Degree of consolidation then becomes 0.75. For a square pattern, formula (1) then yields a drain spacing of 2.14m. For the entire area this means the installation of 87,300m of drain.
2. It is assumed that the first 0.75m of settlement occurs only in the upper 20m thick compressible layer, which implied that **U** in this upper portion of the layer must become 0.75/0.80 = 0.937. For a square pattern, this requires a drain spacing of 1.59m (formula 1). The drain length will be 20m. and thus the total length of drain required will be 79,100m. This is a reduction of 10% compared to solution 1.
3. Installation of drains down to 25m. A 100% consolidation of the upper 25m means a settlement of 0.89m. Therefore, a consolidation of 75% in twelve month period requires that **U** = 72,300m of drain, resulting in a further saving of 10%

A probable further advantage of solutions 2 and 3 is that the residual settlement will take place over a longer period than would have been the case if the entire thickness of the layer had been provided with a drainage system as in solution 1. Besides the saving s in the quantity of wick, the shorter length of the wicks will also result in saving in the costs of installation.

The difference in the quantity of drains in the above example becomes even greater when the $\mathbf{k_c}$ / $\mathbf{q_w}$ ratio is taken into account.
Furthermore, the variation of the $\mathbf{C_h}$ value can be of influence on the drain spacing.

There have been situations where the rate of consolidation is not influenced by the drain spacing. This is believed to be the result of layering of the soil. If there are closely spaced highly permeable layers of sand between the clay or pet layers. The overstressed pore water will find these sand layer and follow this path to the nearest drains.

CONCLUSION

The technology surrounding the use and application of prefabricated vertical drain is continually growing. The concept of vertical drainage utilizing prefabricated drains has been applied to many non-traditional applications and end uses. CeTeau encourage innovative proposals from our clients for new and novel applications.

Our involvement with a wide variety of geosynthetics such as geomembranes, geotextiles, geogrid, geocell, gabion and prefabricated drains uniquely qualifies us to combine prefabricated vertical drains with other products for economical and effective solutions to complex geotechnical problems.

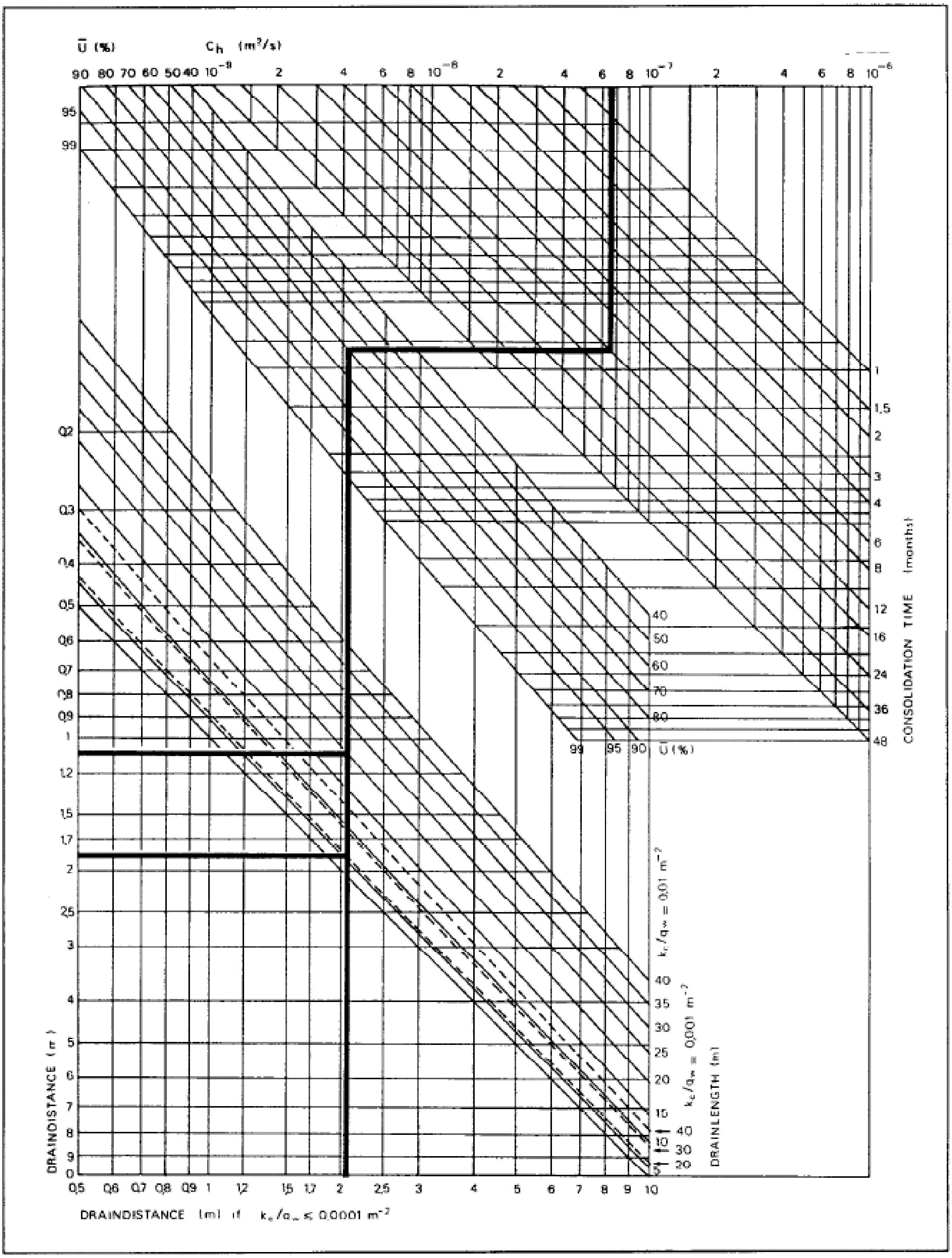

Fig. 8 – Prefabricated vertical drain spacing graph

STANDARD WICK DRAIN INSTALLATION SPECIFICATIONS

Scope:

The work covered under this specification includes the installation of vertical wick drains at the locations shown on the drawings and as directed by the Engineer.

Construction:

Where shown on the plans, or as directed by the Engineer, vertical drains shall be installed subsequent to the construction of the sand drainage blanked, and prior to placement of the surcharge material, or permanent embankment. The Contractor shall take all reasonable precautions to preserve the survey stakes.

The Contractor shall demonstrate that his equipment, methods, and materials produce a satisfactory installation in accordance with these specifications. For this purpose, the Contractor will be required to install several trial drains at locations within the work area, as designated by the Engineer. Trial drains conforming to these specifications will be paid for at the same unit price as the production drains.

The vertical drains shall be installed in the locations shown on the plans, or as directed by the Engineer. Drains that deviate from the plan location by more than 15cm, or that are damaged, or improperly installed will be rejected. Rejected drains may be removed or abandoned in place, at the Contractor's option. Replacement drains shall be offset approximately 500mm from the location of the rejected drain. All rejected drains will be replaced at the Contractor's expense.

Drains shall be installed vertically, within a tolerance of not more than 1cm per 50cm. The equipment shall be carefully checked for plumpness, and the Contractor shall provide the Engineer with a suitable means of verifying the plumpness of the mandrel and of determining the depth of the drain at any time.

Connections in the vertical drain material shall be done in a professional manner that ensures continuity of the drain without diminishing the flow characteristics of the wick material. Splices shall be a minimum of 15 cm in length. The prefabricated drain shall be cut such that at least a 15cm length protrudes above the top of the sand drainage blanket at each drain location.

It may be necessary to pre-auger or use some other method to clear obstructions and facilitate the installation of the drains through the working platform or stiffer natural deposit above the compressible soil strata. The depth in which pre-augering is used shall be subject to the approval of the Engineer, but should not extend more than 50cm into the underlying compressing soils.

Where obstructions are encountered within the compressible strata, which cannot be penetrated by augering or spudding, the Contractor shall abandon the hole. At the direction of the Engineer, the Contractor shall then install a new drain within 50cm of the obstructed drain. A maximum of two attempts shall be made, as directed by the Engineer, for each obstructed drain

The prefabricated vertical drain shall be installed to the depth specified on the drawings or refusal. The refusal length of each wick drain may vary based on the geological formations encountered over the site. Refusal shall be defined as installation of the prefabricated vertical drain to non compressible layer underlying the compressible layer of soil to be consolidated. Through the use of the soils logs taken at the project site the engineer shall define the compressible layer versus the non compressible layer. The prefabricated drain installation equipment will indicate refusal when the tip of the mandrel meet resistance and stops or slows at the approximate dept of the non-compressible layer. The finished installation depth of the wick drain shall not extend more than 0.3m into the non-compressible layer. In some cases the Engineer may wish to limit this depth based in the design of the vertical drain.

Installation of the drains should be coordinated with the placement of geotechnical instrumentation as shown on the plane. Special care should be taken to install drains in such a manner so as not to disturb instrumentation already in place. The replacement of instrumentation damaged as a result of the Contractor’s activities will be the responsibility of the Contractor.

Equipment:

Vertical drains shall be installed with equipment which will cause a minimum of disturbance to the sand blanket or the subsoil during the installation. The prefabricated drains shall be installed using a mandrel or sleeve that will be advanced through the compressible soils to the required depth using constant load, or constant rate of advancement methods, only. Use of vibratory or failing weight impact hammers will not be allowed. Jetting shall not be permitted for installation of the drain, except, with the approval of the Engineer, to lubricate the mandrel when working in highly plastic clays.

The mandrel shall protect the prefabricated drain material from tears, cuts and abrasions during installation and shall be withdrawn after the installation of the drain. The drain shall be provided with an “anchor plate “or rod at the bottom, to anchor the drain at the required depth at the time of mandrel removal. The projected cross-sectional area of the mandrel and anchor combination shall not be greater than $70cm^2$.

At least three weeks prior to the installation of the drains, the Contractor shall submit to the Engineer, for review and approval, details of the sequence and method of installation. The submittal shall at the minimum contain the following specific information :

1. Size, type, weight, maximum pushing force, and configuration of the installation rig
2. Dimensions and length of mandrel
3. Details of drain anchorage,
4. Detailed description of proposed installation procedures
5. Proposed methods for overcoming obstructions
6. Proposed methods for splicing drains

Approval by the Engineer will not relieve the Contractor of his responsibilities to install prefabricated vertical drains in accordance with the plans and specifications. If, at any time, the Engineer considers the method of installation does not produce a satisfactory drain, the Contactor shall alter his method and/or equipment as necessary to comply with the plans and specifications.

Materials:

The prefabricated vertical drain material shall consist of a continuous plastic drainage core wrapped in a non-woven geotextile material. The geotextile wrap shall be tight around the core, and shall be securely seamed in a manner that will not introduce any new materials nor present an obstruction that will impede flow in the channels of the core. The prefabricated wick drain material used shall meet the following specifications:

Width drain	≥ 100 mm
Thickness drain	≥ 3 mm
Shape of Core	Rib core
Drainage Channel	> 40 channels
Tensile strength drain	> 2.5 kN
Discharge capacity at 300 kPa i=0.1	> 80x10-6 m^3/s
Discharge capacity buckled at i=0.5,200 kpa 25% deformation	> 25x10-6 m^3/s
Discharge capacity at 300 kPa i=0.1 and30^{o} Z kinked	> 60x10-6 m^3/s
Grab tensile strength Filter	>0.5 kN
Tear strength filter	>0.1 kN
Permittivity filter	> 1 s^{-1}
Soil retention filter O90	< 80 µm

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Contractor requirements:

The contractor shall submit a 1m sample of the vertical drain material to the Engineer prior to usage and shall allow three weeks for the Engineer to evaluate the material. The sample shall be stamped or labeled by the manufactured as being representative of the drain material having the specified trade name. Approval of the sample material by the Engineer shall be required prior to site delivery of the wick drain material.
The Contractor shall state which prefabricated vertical drain he intends to install at the time of the preconstruction conference. The drains shall be free of defects, rips, holes or flaws. During shipment, the drain shall be protected from damage, and during storage on-site the storage area shall be such that the drain is protected from sunlight, mud, dirt, dust, debris, and detrimental substances. Manufactured certification shall be provided for all drain material delivered to the project.

Measurement for payment:

Prefabricated vertical drains will be measured by the linear meter. Quantity shall be rounded to the nearest meter including protruding portion, of drains installed, in accordance with the plans or as directed by the Engineer.

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