Mebradrain System 6.0

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Title - Editor

The Mebradrain® System

Vertical drainage

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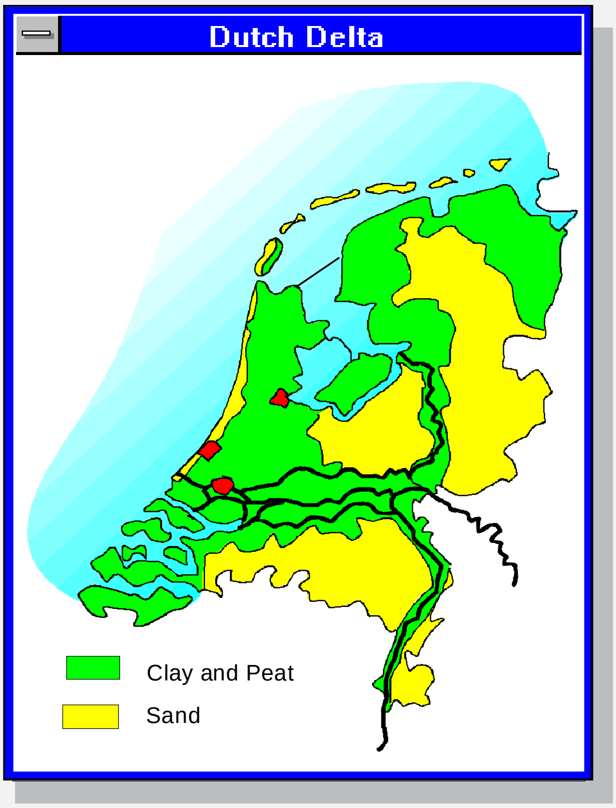
The Mebradrain® System

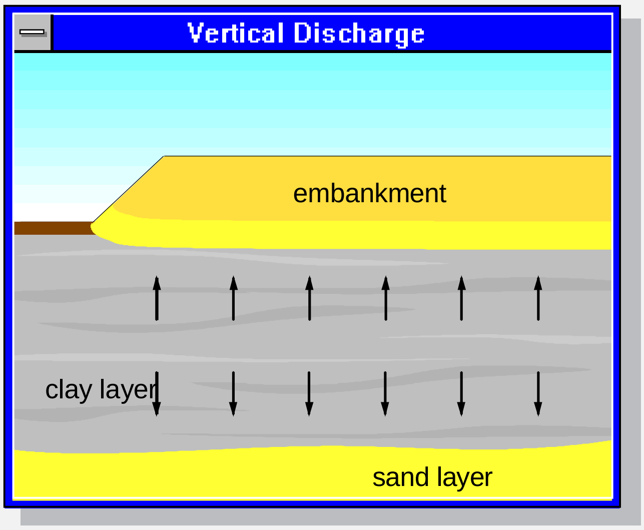
1. GENERAL

Prefab vertical drains were first used in Sweden in 1937. These drains were manufactured in cardboard, the so-called cardboard wick. Approx. 10 years earlier sanddrains were developed in California to expedite consolidation. Especially in the Netherlands sanddrains were applied on a large scale since 1950. Dutch soil mainly consists of clay and peat layers which can sometimes reach great depths. A sandy surcharge was often placed on top of compressible subsoil in those places where an industrial or residential estate or infrastructure had to be developed. Settlements in the subsoil were expedited by using sanddrains.
The synthetic drain was introduced in 1972 for a building pit at the Hemweg power station in Amsterdam. Its development was then accelerated. Synthetic drains are superior to sanddrains because of their flexibility and better filtration, and they became a formidable competitor. Nowadays, sanddrains are hardly ever used.
Because of the great demand for a high-quality synthetic drain, Geotechnics Holland by developed the Mebradrain in 1978. Mebradrain has since grown into the vertical drain which is used most often in the world. In the meantime, more than 500,000,000 m of Mebradrain have been applied in 39 different countries.
This paper covers many aspects of the synthetic drain, from application to quality control, from design methodology to laboratory tests.



2. WERKING

2.1 Principle

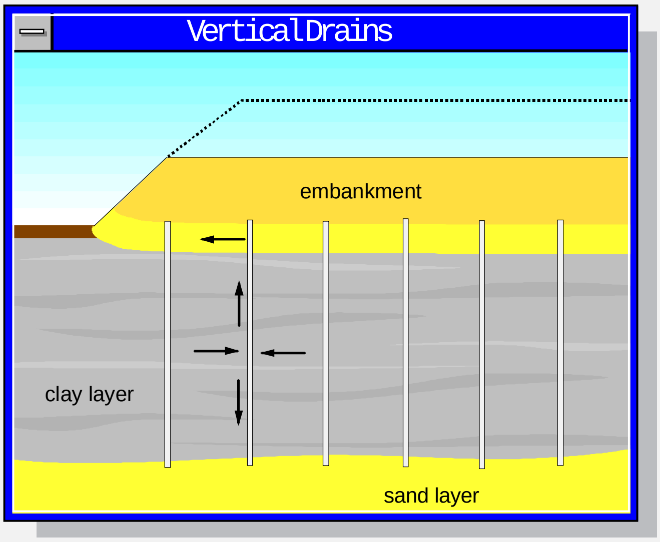


Soil stabilization with vertical drains is used on compressible, saturated soils, like clay and peat. These soils are characterized by a soft structure and a big pore capacity, normally filled with water (pore water). When a heavy load, like an embankment or a dike, is placed on top of clay or peat soils, settlements could occur due to the compressibility of the soil. These settlements could create serious construction problems.

The load created by the surcharge is initially carried by the porewater. However, when soil is not very permeable, water pressure will decrease gradually because the porewater is only able to flow away very slowly.

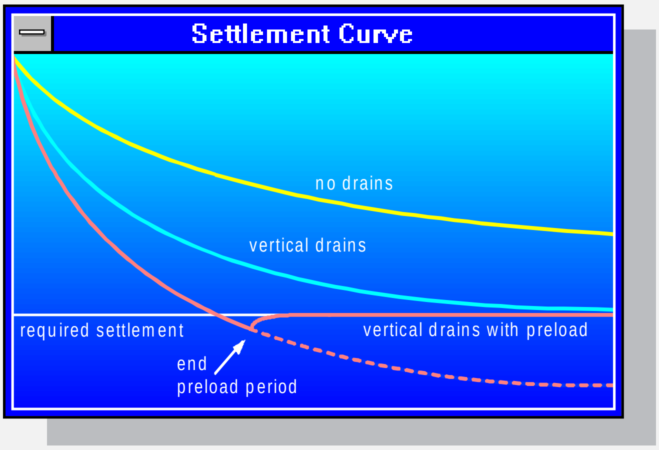
Increased water pressure can create instability of the subsoil, which in turn can create slip planes. This instability can decrease the rate of fill placement. A vertical drainage system enhances a quicker construction of the embankment without a risk of landslides.

To increase the settlement process and the reduction of water pressure, it is necessary to decrease the flow path of the porewater. This can be achieved by installing evenly spaced vertical drains. The presence of this drainage system enables the pressurized water to flow horizontally towards the nearest drain, and escape freely. By using vertical drains, the period of consolidation can be reduced from an average time of decades to only six months, or even a shorter period.



By applying surcharghe or a vacuum system, it is possible to accelerate consolidation even further

Adjoining graph explains this method. The upper curve shows the settlement of the load without using vertical drainage. The blue curve shows the effect of vertical drainage application and the red curve shows the progress of settlement when a temporary load is removed after reaching the desired settlement.

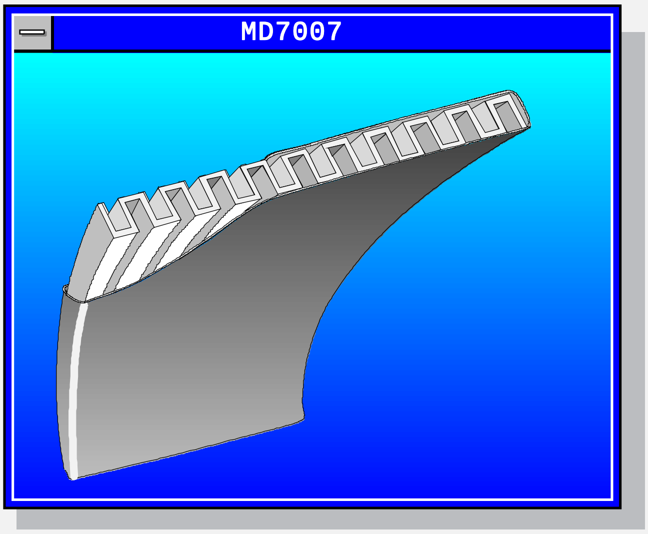


Soil improvement by means of vertical drains has been used in many civil engineering projects. Some of the applications are shown in:

* Construction of embankments for roads, railways, airports and dikes
* Land reclamation
* Construction of ports
* Residential and industrial areas
* Preloading of storage and landfill depots.

2.2 MEBRADRAIN

Mebradrain® consists of a prefabricated strip which is very suitable for water transportation. The flexible core is manufactured of a highquality polypropylene. Both sides have grooves, through which water can flow unimpeded. The core is wrapped in a strong and durable geotextile filter fabric with excellent filtration properties, allowing free access of porewater into the drain. At the same time, this filter prevents piping of fines from adjacent soils without clogging.



The drains is manufactured in a width of 100 mm, a size accepted as standard worldwide. Mebradrain° is available in 3 types:

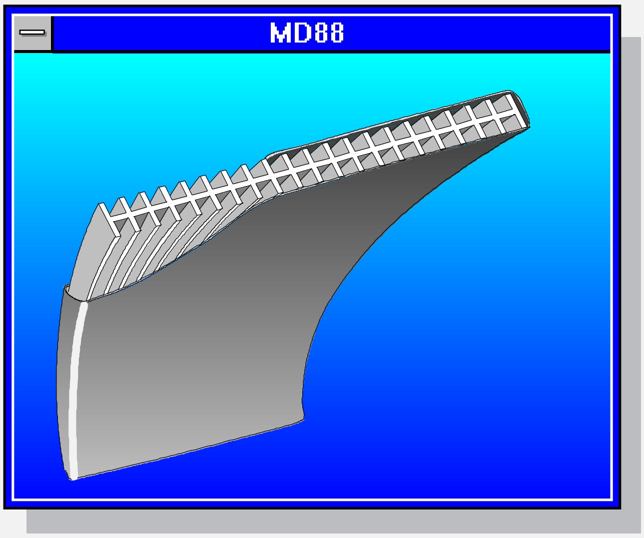
MD88 / 7007

which is a drain type with high discharge capacity, suitable for depths upto 25 meters;

MD88M

is a drain suitable for depth up to 50 m.

Both types are available with a filter that can be adjusted to specific soil conditions. Mebradrain has grown into one of the most used drainage systems in the world, and the multiple applications of Mebradrain in lots of projects throughout the world proves that customers have confidence in our product. By the end of 2002, a total of over 500 million meters of Mebradrain had been installed worldwide.

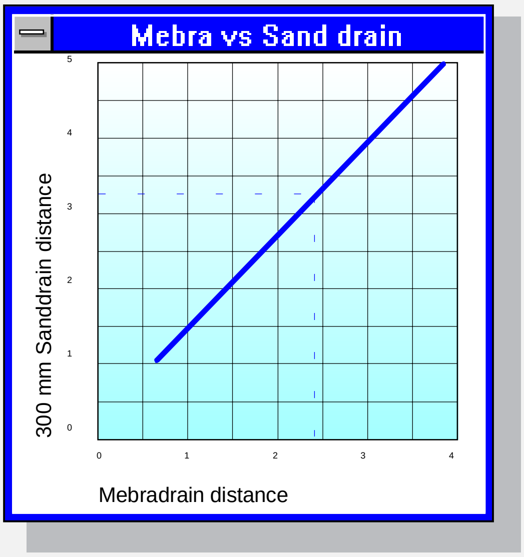


Advantages of the Mebradrain system:

* The least possible disturbance of soil layers
* A guaranteed water discharge
* The possibility of adapting the core and the filter to specific soil conditions
* The high installation rate; 4,000 to 8,000 m' per day/unit
* The adaptable spacing, thus enabling a very short period of consolidation
* No water requirement for installation
* Drain installation possible to depths exceeding 50 meters
* Easy control of installation.

2.3 Sanddrains

The core of the Mebradrain guarantees a higher vertical discharge capacity than a sanddrain with a diameter of 300 mm. Assuming that the equivalent diameter of a 100 mm synthetic drain amounts to 65 mm, a comparison between both drain distances can be made by using the Barron formula. Adjoining graph shows that, theoretically, approx. twice as many drains should have to be used in order to result into a similar progress in settlement. Because of the considerably lower price of synthetic drains, this system is ultimately much more cost-effective than sanddrains.



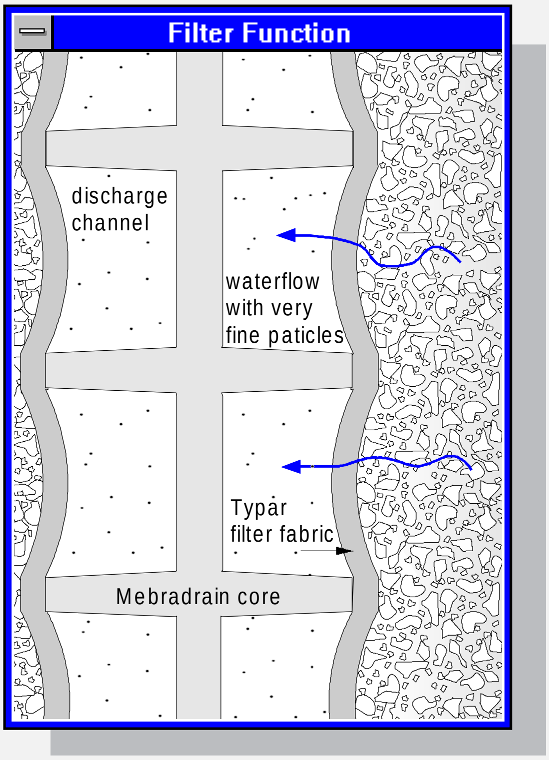
2.4 Filter Fabric

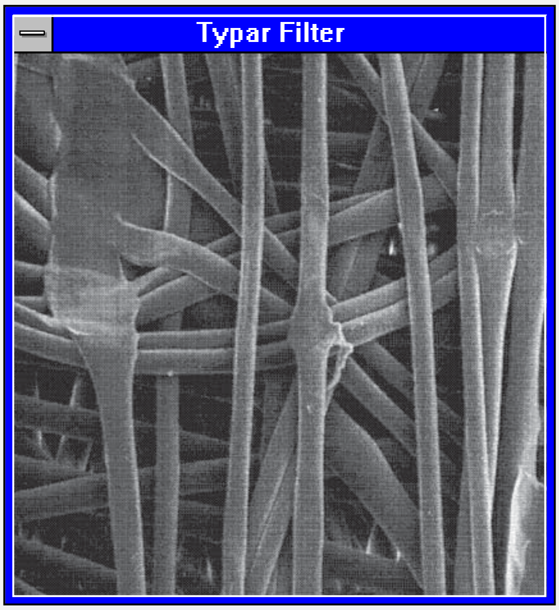
The filter jacket has an important function. It consists of thermically bonded polypropylene fabric of a random texture.

Contrary to fabrics with a straight passage through which soil particles can flow freely, the Mebradrain filter ensures a coiling passage, enabling it to limit the movement of soil particles and to prevent clogging.
In general, a filter is required that prevents clogging by soil particles but is sufficiently permeable. The Mebradrain filter structure meets both requirements. When compressible subsoil contains permeable soil in horizontal layers, pressurized pore water will flow onto these layers and thus to the nearest drain. So as to make the best possible use of these permeable layers, permeability of the filter needs to be at least as high as the permeability of the soil.
The Mebradrain filter has a relatively high permeability, enhancing an effective passage in layered soils.
Other important criteria a filter should meet, are:

* Great mechanical strength
* High resistance to bacteria and microorganisms
* Durability against acids and solvents
* Negligible loss of strength over a prolonged period
* Minor creep under heavy compression.

Mebradrain© has been tested extensively on all of these aspects, and has been adapted to the relevant requirements.





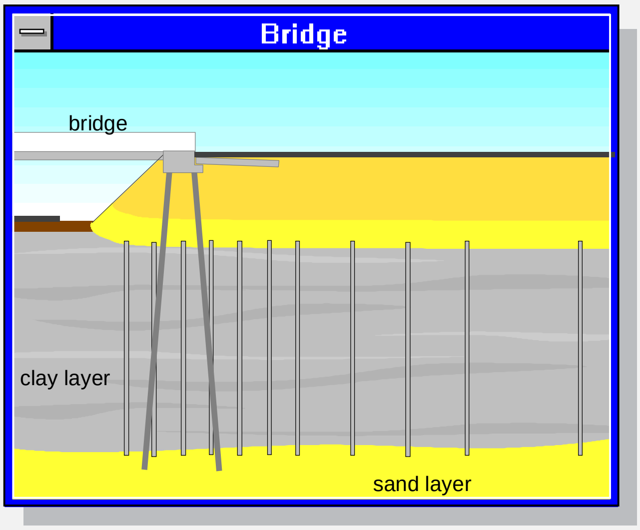
2.5 Quality control

Stringent quality control is maintained during all stages of the manufacturing process of Mebradrain. As to raw materials, only those manufactured under quality control according to the NEN 9000 standard are used.
Drain geometry, quality of welding and weight of filter jacket and core are checked continuously during manufacture. In addition, laboratory tests on below mentioned characteristics are executed in accordance with a set schedule:

* Core size
* Weight of core and filter jacket
* Tensile strength of the drain
* Discharge capacity of the drain
* Permeability of the filter
* Pore size of the filter.

3. APPLICATIONS

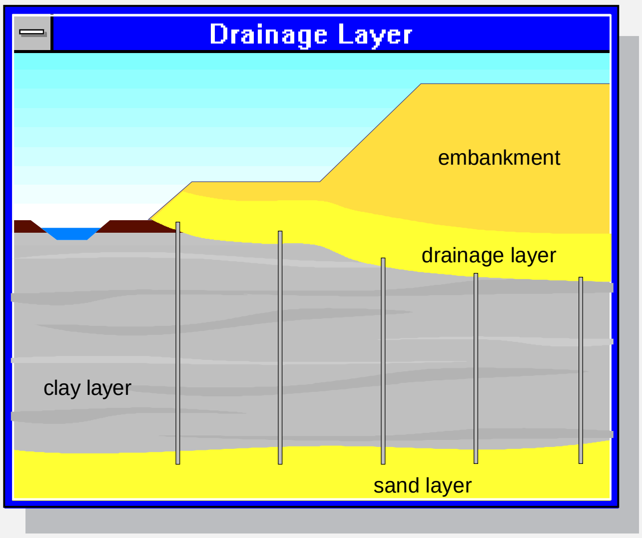
3.1 Consolidation



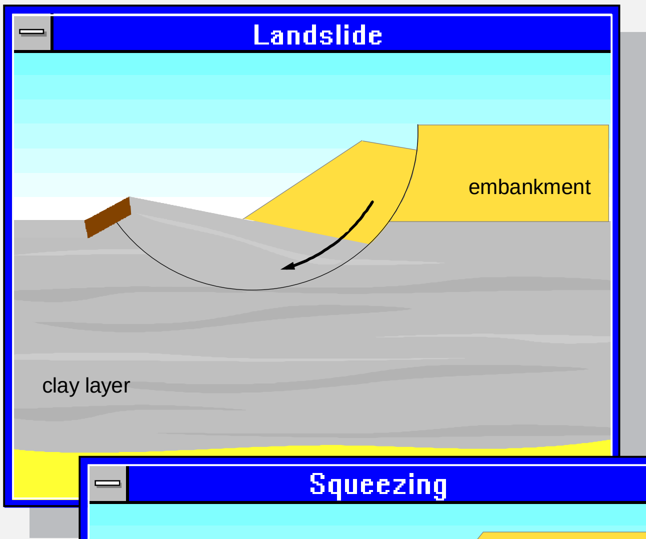
The Mebradrain system has many purposes. The most common application is the consolidation of compressible soil. Highways, airstrips, harbours and railways have to be built as fast as possible, while at the same time maintenance costs have to be kept to a minimum. Uneven settlements and settlement differences are unacceptable as they hinder traffic.

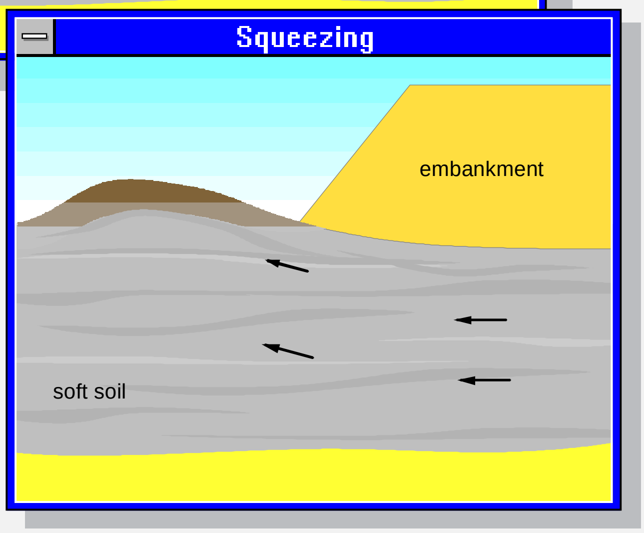
By using the Mebradrain system, 95% of the settlement can be realized in a short time. Settlements at a later stage, caused by the secondary effect can, however, not be achieved by using vertical drainage. These settlements can be accelerated by using a preload.

To guarantee an optimum use of Mebradrain, the pore water should flow freely. In some cases a permeable sand layer is present beneath the compressible layers, thus serving as a discharge layer. Commonly, however, in absence of this layer, the drain will discharge at the surface. In order to minimize resistance, a permeable layer of sand or gravel is placed, if necessary combined with a horizontal drainage system. This layer ensures that the pressurized water will flow freely, after which a less permeable layer of surcharge can be placed



Oil tanks and ore depots are often founded directly on the subsoil, even in areas where soils are very compressible. Because of the great fluctuation in weight, a dynamic stress is created which influences the settlement and stability. Tanks tend to sink into the soft subsoil, and specialized companies lift the tanks to their original position and apply a layer of sand below the tanks. This method is costly and vertical drainage, combined with a temporary surcharge, can materialize even settlement in a short period. Vertical drainage beneath oil tanks or other environmentally unsafe constructions should never reach the deeper permeable layers, to avoid future spreading of any pollution.





3.2 Stability

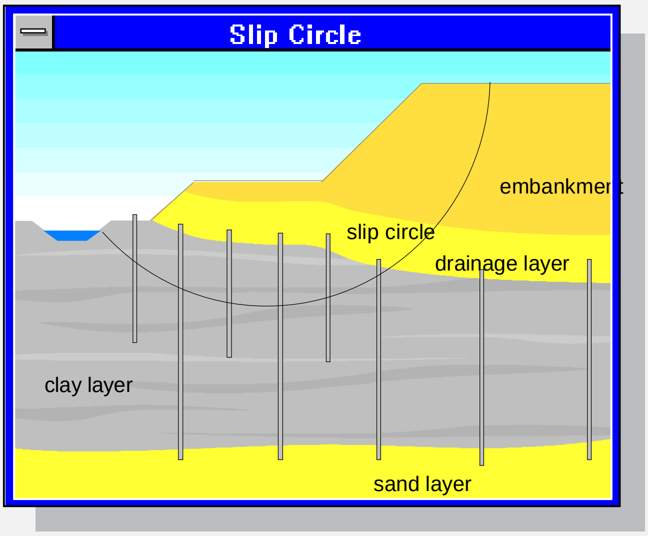
Apart from expediting consolidation, a vertical drainage system can be a good support in maintaining the stability of an embankment during and after execution. Instability of the subsoil can manifest itself in two ways:

* Sliding of the slope, whereby part of the dike slides downwards along a slip circle;
* Squeezing of the soft soil below the embankment. The slope remains intact, but the land level next to the embankment is raised and additional settlements occur.

An increase in water pressure causes instability of the subsoil. This insufficiently mobilizes shear stress. The equilibrium can be restored in several ways:

* Slower filling-up rate
* Placing of a supporting shoulder (contrafill)
* Vertical drains
* Combination of above possibilities.

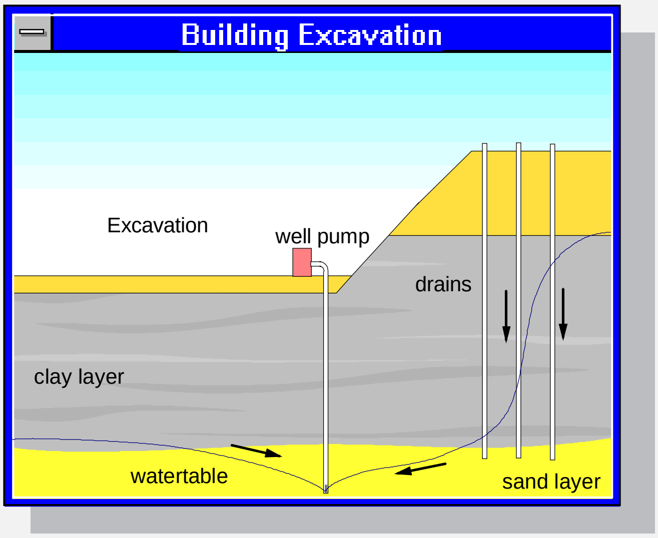
For a certain situation, the equilibrium can be calculated by use of the slip surface calculation according to the generally applied Bishop method. Sliding can be prevented by calculating the maximum allowable excess pore pressure and by checking this with pore pressure gauges during fillingup. Design can be controlled by applying shorter drain distances in those areas where instability may occur.



3.3 Dewatering

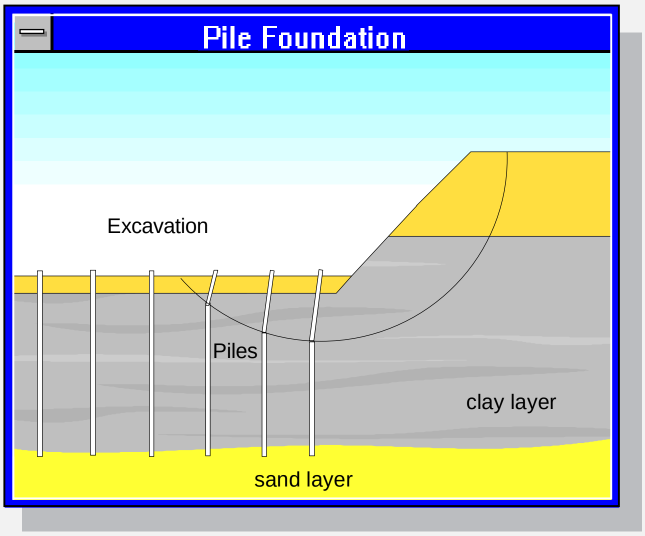
Mebradrain has been used in various projects as a dewatering medium. In Germany, Mebradrain° has been used extensively as a horizontal drainage system on concrete motorways. Horizontal drains are installed beneath the joints to prevent damage to the foundation caused by any leakages.
Another common application is the dewatering of the topsoil in those places where a lower groundwater level is present in the lower discharging layers. The surface water is drained off vertically to this layer through the drains. No drainage channels or other drainage systems are required to lower the groundwater level.
A larger surface remains available for building purposes, which is of special importance to industrial areas.

Deep building pits are often drained with a well system on the upper level of the slope. However, when the soil has a layered structure, making it impossible for the groundwater to leak down vertically, the groundwater will flow out on the slopes, with all its consequences.
A vertical drainage system around the building pit ensures groundwater at all levels to be drained off downwards without any obstacles.
Moreover, the water pressure is spread over a larger triangle towards the pit, thus improving stability. A lowering of the groundwater level at the active side of the piling of sheet-piling tubs can contribute to an optimum sheet-piling profile.



3.4 Pile foundation

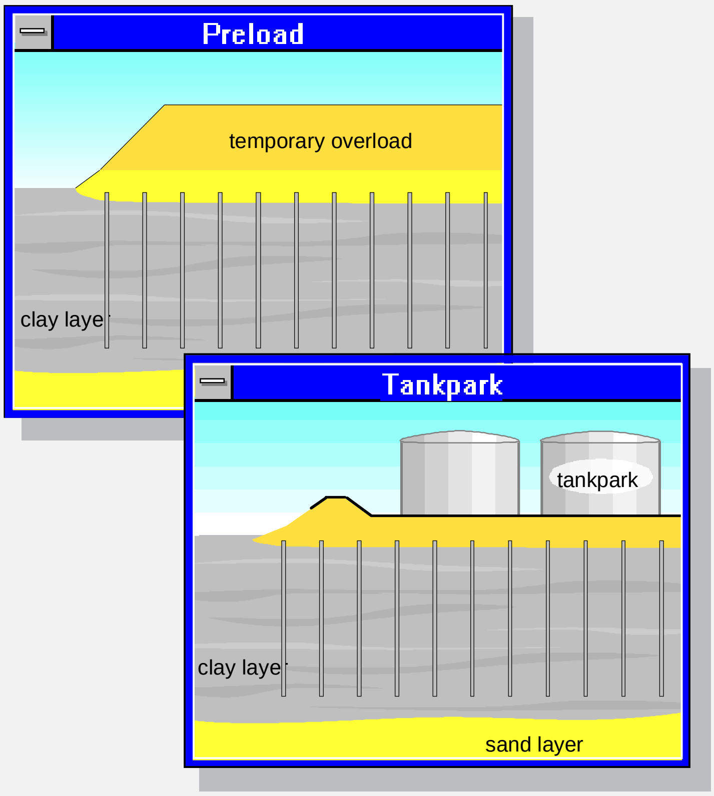
Groundwater pressure can increase considerably as a result of piledriving. Usually, this does not affect the stability of the subsoil. However, when piledriving occurs in an excavation, it can lead to such instability that the pile foundation can collapse. A vertical drainage system in the excavation, or simply installing drains whilst piledriving, can prevent many problems. Piles are burdened by settlements, resulting in the loss of carrying capacity (negative adhesion and/or inadmissible bending).



It is therefore advisable that a surcharge, possibly combined with vertical drainage, is present before piledriving starts. Especially near slopes, great forces can be exerted on the piles with all its consequences. In the past, many expensive pile constructions, which could have been saved by using a relatively inexpensive drainage system, were lost due to the above mentioned causes.

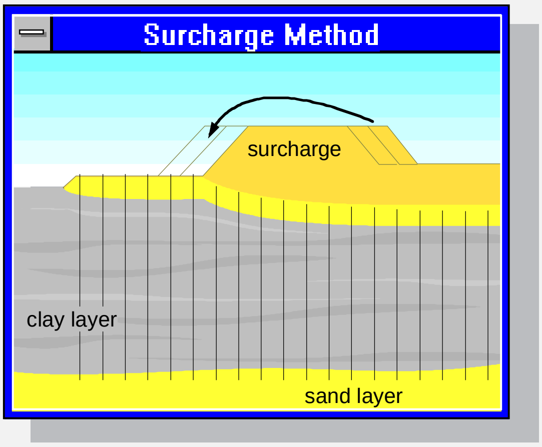
3.5 Preload

There are numerous methods, when combined with wick drains, which can speed up consolidation. These methods do not only shorten the consolidation time, but can also help in areas where a substantial primary settlement is expected. Primary settlements can be accelerated with the use of vertical wick drains. Settlement occurs when the soil is compressed. Compression takes place logarithmically and is independent of the existing pore pressure. With a preload by means of a surcharge or a vacuum drain, the resulting secondary settlement can be realized in a short time. By removing the preload, the original balance of the soil will return.



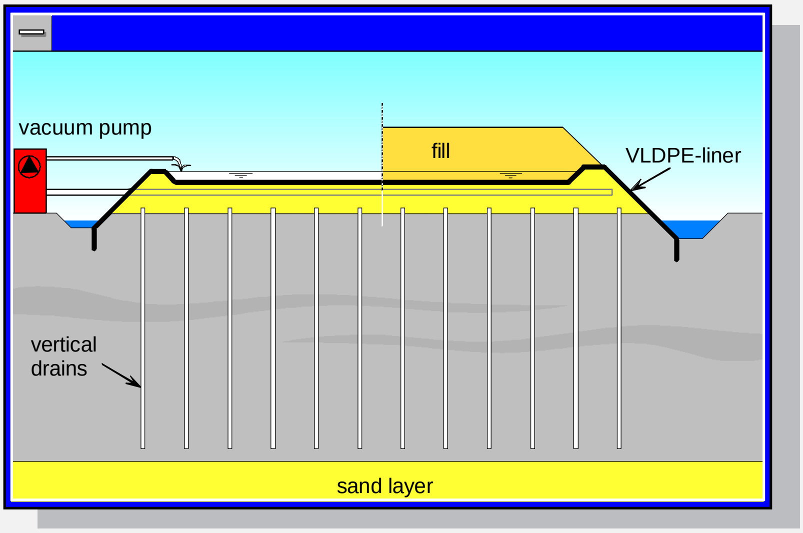
3.5.1. Surcharge

A surcharge is often applied in those places where long-term settlements have to be avoided, such as where embankments change into constructions which are supported by a pile foundation. A good example of aforesaid is where embankments join viaducts. Sometimes the additionally required amount of surcharge can be used at a later stage in other places in the embankment.
However, when the entire surface of an area has to be treated with a surcharge, the following is done. On one side a considerable surcharge is started off with. After some time, this will be excavated and dumped on a still untreated area. The required amount of additional surcharge depends on the consolidation period and rate of filling-up. During progress of the work, additional surcharge material has to be supplied regularly in order to set off settlements.
This method works well when widening motorways which, themselves, are not apt to settlements anymore as they are founded on a sand cunette. Preloading by means of surcharge is not always possible, as instability may occur. In this case vacuum consolidation can offer the solution.



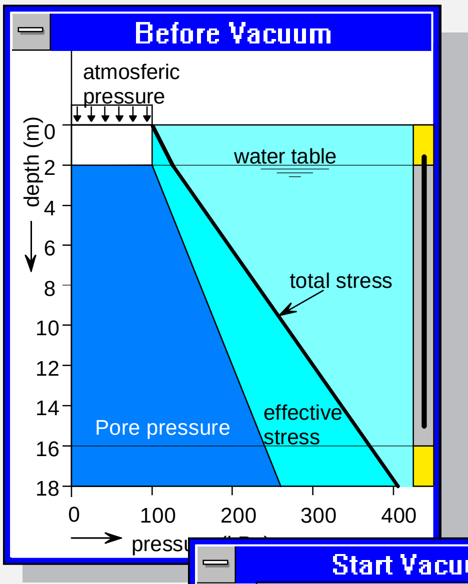
3.5.2. Vacuum consolidation

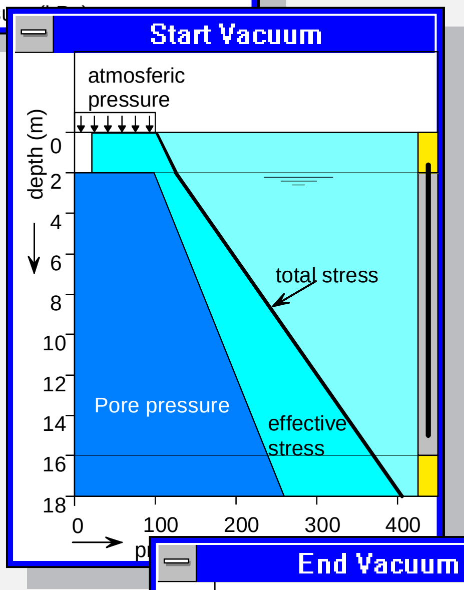
Apart from applying a surcharge, consolidation time can also be considerably shortened by means of vacuum consolidation. This form of soil improvement uses atmospheric pressure. An important advantage of this method could be that instability of the subsoil is avoided, as no increase of the sliding stress at the rim of the embankment occurs. Theoretically, a surcharge of 100 kPa can be achieved by using vacuum consolidation. In practice, a value of 60 kPA to 80 kPA, which equals a sand layer of a maximum of 5 meters thick, can be achieved due to air and water leakage and the restriction of pump system applied.

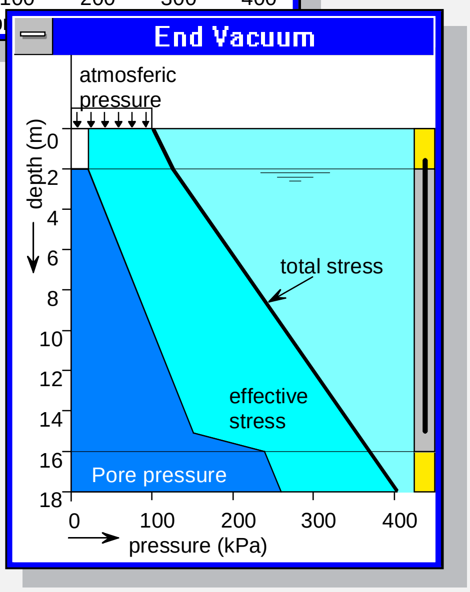


Vacuum consolidation is created as follows:

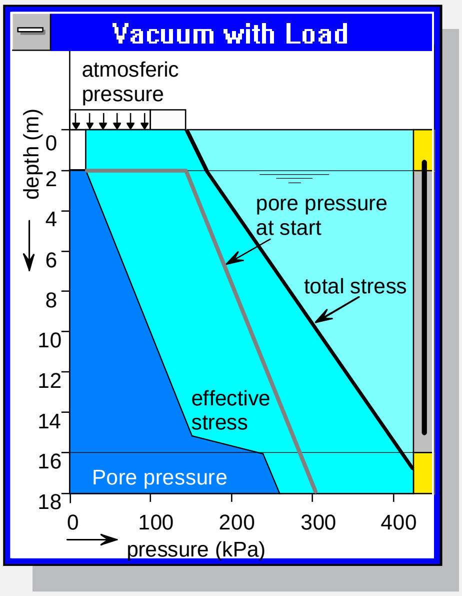
A sand layer of at least 50 cm thick is applied onto the site to be consolidated. From this layer Mebradrain® is installed up to a depth of max. 1 m above the deeper sand layers. The vertical drainage should definitely not run into the permeable discharging layers, as too large a flow of water will occur, preventing the formation of a vacuum. In the sand layer, horizontal drains are installed on an interval of 5 m, and are connected to a vacuum pump. A well pump which pumps both water and air makes it possible to realize a vacuum of 70 kPa to 95 kPa.
The site is covered with a flexible, 1 mm thick VLDC-liner which is dug in on the sides, so that no flow of water and/or air is possible from the sides. The liner should be placed and sealed with the necessary care and follow settlement without tearing. In a number of projects, unskilled execution of the liner construction has led to disappointing results.
VLDC liners (Conductive Very Low Density liners), however, can be tested on air tightness with the spark test so that pinholes can be localized before the vacuum is applied. The liner construction has to be placed in accordance with the guidelines as formulated for the execution of lining constructions at landfills. The seams have to be carried out with a double seam, accommodated with a test channel. It is recommended to build a dike around the site and to pump emerging groundwater onto the liner. The permeability of any perforations is thus considerably reduced and stepping on the liner, which could cause damage, is prevented. The required pump capacity strongly depends on the amount of affluent air and/or water.







Lowering of the groundwater level outside the site could lead to sucking in of air through the soil. Excess water therefore has to be drained off to a ditch which keeps the groundwater at level along the side. An extensive system of vacuum, water pressure gauges and clinometers should record the proper working of the system. These gauges should preferably be readable by the side of the area so that they can be checked easily.



When water pressure drops in the horizontal and vertical drains after applying the vacuum, only an increase in the effective stress occurs in the subsoil. An increase in water pressure, as it occurs in the traditional methods of filling-up, does not take place. In principle, stability problems therefore do not occur and the vacuum load can immediately be increased to its maximum value.
Squeezing out of soil from the embankment is prevented. A vacuum load, in principle, completely neutralizes these movements. Condition is that the liner is not removed after termination of the consolidation period and that measures are taken to secure the vacuum pump by means of emergency power units.
After all, falling out of drainage could cause instability of the embankment.

Applications:

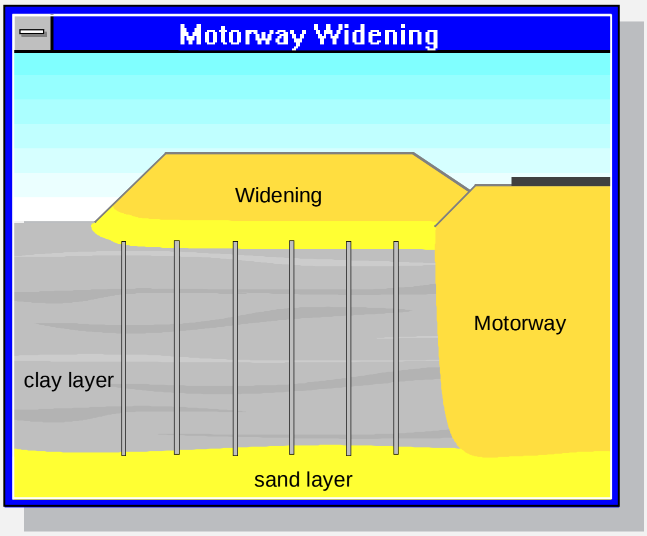
* Soil improvement in those places where both primary and secondary settlements could cause future problems, e.g. near bridges and other connections between embankments and pile supported constructions.

* Embankments which have to be executed within a very short period of time and where stability of the subsoil is an impeding factor.

* Road widenings where settlement differences are undesirable.

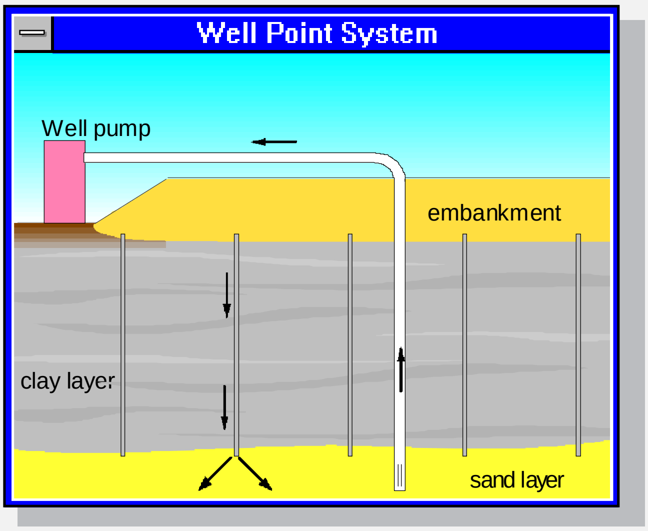
* At sludge basins. When fast dewatering of the sludge is required to increase the capacity of the depot.

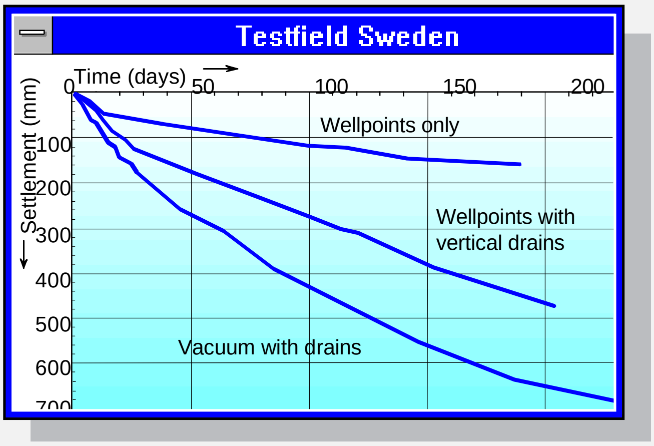
* Preload for tanks



3.5.3. Deep well point system

A third method of expediting consolidation is placing a well point system in the deeper soil layers. This reduces the ascent in the drain to zero, causing a larger potential difference with the surrounding soil. This leads to faster consolidation than without a deep well point system. Adjoining graph shows the results of a testfield in Sweden where the settlements of three comparable sections were provided with vertical drainage, well points and vacuum load.





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Consolidation of clay using vacuum method and wellpoint system in combination with vertical drains, B.A. Torstensson.
Vacuumconsolidatie, KIVI (Vacuum consolidation).

3.6. Environmental technique

3.6.1. Landfills

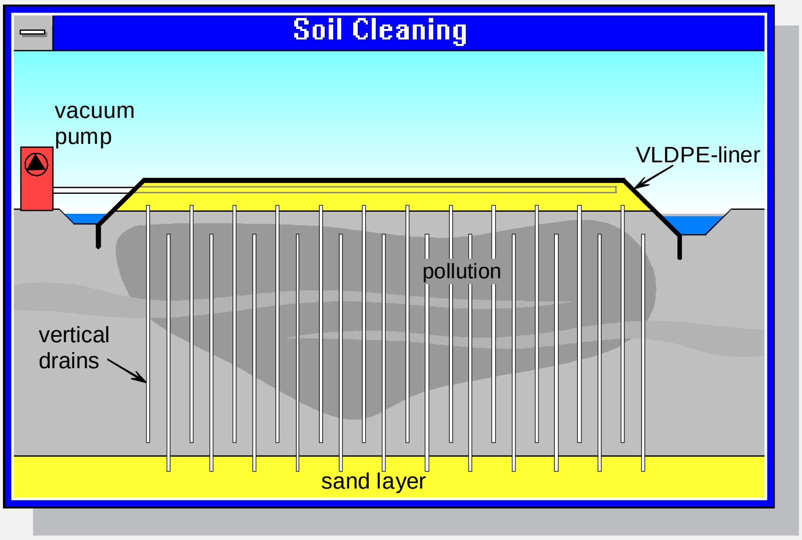
Landfills are often filled to a great height. This creates huge loads on the subsoil and therefore large settlements. This could jeopardize the quality of the bottom liner. Both mineral seals and liners can give way as a result of irregular settlements and thus lose their function, with all its consequences.
A vertical draining system combined with a preload can prematurely enforce a large part of the settlements, so that large loads on the bottom seal fail to occur at a later stage. After completion of the preload system, the drains should be sealed off or removed to preclude pollution of the subsoil during any calamities.

3.6.2. Sludge depots

Polluted harbour mud, process sludge from water treatment plants, industries or mines have to be stored in isolated depots. This kind of mud has a particularly high water content which takes up a large part of the available, expensive, storage space.
With the Mebradrain system, either combined with a preload or with a vacuum system, the capacity of such depots can be extended considerably. Using special equipment, drains can be installed from the sludge surface into the drainage layer on top of the liner sealing. By draining off this drainage layer, accelerated settlement of the sludge occurs. Depending on the type of sludge storage, capacity can be extended by 50%.

3.6.3. Soil cleaning

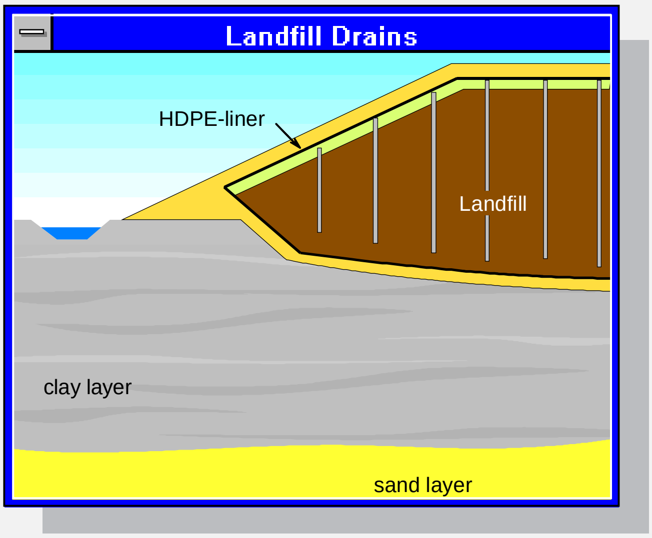
One of the least expensive methods of cleaning soil is the in situ rinsing method: a vertical drainage system in which every other drain is connected to the deeper sand layer and every other to the applied drainage layer. The whole system is then connected to a vacuum system. The deep groundwater is sucked up through the drains, finds its way through the polluted soil and continues its way via the adjoining drain to the surface, where the groundwater is cleaned with a mobile cleaner. Mebradrain is made of polypropylene, a material with excellent resistance to a large number of chemicals.



3.6.4. Degassing

Various gasses arise during decomposition of organic refuse in rubbish dumps. This dump gas mainly consists of methane (60%) and carbon dioxide (39%). The gas flows out slowly and is often flared out with a complex pipe system to prevent corrosion of the top cover of the dump.

Degassing can be expedited in a relatively inexpensive way with a vertical drainage system. Settlements in dumps are realized within a short period of time, enabling covering of the dump at an early stage. The vertical drain is connected to a gas flare system which is placed below the top seal of the dump. A second advantage of a vertical drainage system is the discharge of percolate to the drainage pipes at the bottom of the dump. B adly permeable horizontal layers are often formed in dumps. These layers prevent the perco late from draining downwards, so that it will flow out on the slopes. Vertical drains form a free passage for vertical transportation.
Both core and filter of Mebradrain are made of polypropylene, a material with excellent chemical resistance. During the installation procedure, the installation equipment should be prevented from damaging the liner. A minimum distance of 2 meters should be kept between the end of the lance and the seal.



4. Requirements

The requirements a prefab drain should meet, largely depend on the following circumstances:

* Size of the settlement
* Consolidation period
* Drain length
* Size of the embankment
* Method of installation.

The required discharge capacity for pore water must be guaranteed at all times to ensure the best possible settlement progress. In the Netherlands, the requirements for prefab drains are summarized in a Classification schedule drawn up by the work group "Vertical drainage" of the C.R.O.W. (the Dutch Centre for the issuance of rules and regulations and investigation in civil engineering). As to vertical drainage, C.R.O.W. formulated the following requirements.

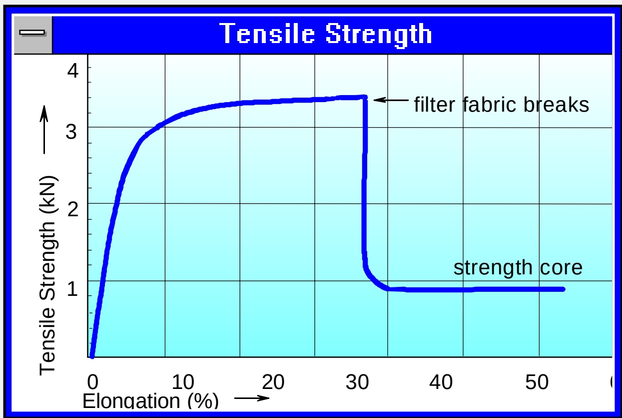
4.1 Drain strength

During installation high forces can occur in the strip drains. Especially when a vibrator is used to install the drains, large accelerations during free fall of the mandrel have to be transferred to the drain roll. This creates large forces that have to be absorbed by the elongation and strength of the drain.
The diameter of the transportation rolls is of great importance, too. In the past, paper filters were used that teared up, while the core stayed intact. These failures could not be detected because the drain was not visible during installation. The limited elongation of the filter paper did not allow for large forces in the drain.
Therefore, the following mechanical requirements were specified:

Elongation drain	e_d	$\geq$ 2%
Strength drain	F_d	$\geq$ 0.5 kN
Elong. filter 0,5 kN	$e_{0.5kN}$	$\geq$ 10%

For the guide rolls in the installation rig, the following requirement was set:

diameter transportation rolls > 150 mm



4.2 Filter strength

During the consolidation process, the filter fabric may not be pressed into the discharge channels and therefore has to retain its original strength under wet conditions. As the load in the fabric strongly depends on the configuration of the core, it is very difficult to set a uniform requirement for filter strength. Therefore, the filter strength is related to the discharge test. During this test the filter may not fail at a maximum cell pressure of 300 kN/m2. Moreover, the filter should be wrapped tightly around the core to prevent penetration of the filter into the channels.
To prevent damaging of the filter fabric during installation, the following requirement is proposed:

Tensiler strength filter $F_f > 6$ *kN/m*

4.3. Flow capacity of prefab drains

When calculating vertical drainage systems, the resistance in the drain is taken as zero. The flow capacity is determined by the free volume of the drain. The free volume is influenced by the compression of the core and the depression of the filter in the channels as a result of the horizontal soil pressure. Depending on the length of the drain, the filling speed, the compression and the ultimate load, the discharge capacity of a prefab drain (q_w) generally has to meet the following requirements:

Drain length < 10 m and no stability problems:

$$q_{w(straight)} > 10x10^{-6}\ m^3/s = 315\ m^3/yr$$
$$q_{w(buckeld)} > 7.5x10^{-6}\ m^3/s = 236\ m^3/yr$$

Drain length > 10 m and/or stability problems:

$$q_{w(straight)} > 50x10^{-6}\ m^3/s = 1575\ m^3/yr$$
$$q_{w(buckled)} > 32.5x10^{-6}\ m^3/s = 1183\ m^3/yr$$

The discharge capacity of prefab drains is determined in accordance with the method as described in chapter "Lab tests" of this paper.

Buckled Drain

4.4. Permeability of the filter

Pore water should be enabled to enter the drain without too much resistance. Tests with filters are always carried out with clean water and a clean filter. Nowadays, permittivity is usually considered as the calculating value for permeability ($\Upsilon = k_f/d_f$). However, as a result of the flowing out of soil particles, the filter will silt up fast, lowering permittivity by a factor 1000. Permittivity of the filter must therefore be a factor 1000 larger than most permeable soil types in which vertical drainage is applied.
The filter criterion will then be:

$$\Upsilon > 5 x 10^{-3} /s$$

Permittivity is determined in conformity with the NEN 5167 standard.

4.5. Pore size

Soil particles carried along should not clog the filter or be deposited in the discharge channels of the drains. As a filter criterion, it could be supposed that:

$$O_{90} < 2 \times D_{90}$$

In which O_{90} indicates that 90% of the particles of a certain size are stopped, and D_{90} indicates that 90% of the soil particles are smaller than the given size.

For most non-erodible soils, the criterion could be adhered to that:

$$O_{90} < 160\ \mu m$$

For erodable clay and silts soils such as harbour mud, a denser filter is required. In that case the criterion is taken that:

$$O_{90} < 80\ \mu m$$

The pore size of a filter is determined in conformity with NEN 5168.

4.6. Summary

Adjoining table gives a summary of the requirements set to a simple drain, applying to class I, and a drain classified within the most superior class, class 111. Geotechnics Holland by have tailored the properties of all its drains to the classification schedule, thus guaranteeing the proper working of the drain.

Wick Drain Requirements

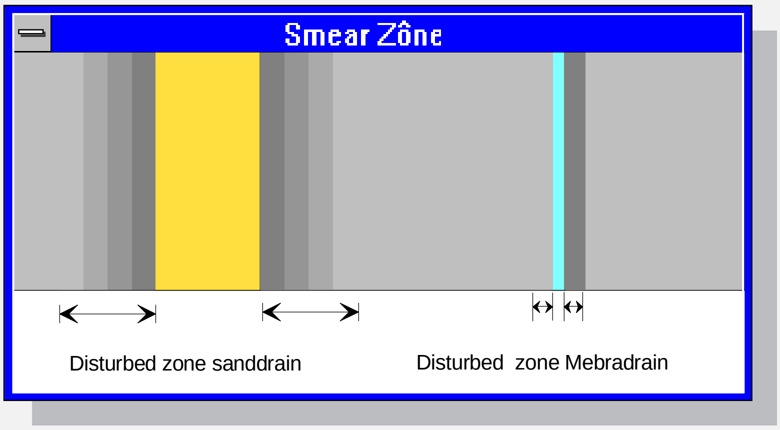
Test	Symbol	Req.	Unit
Strength drain:			
Elongation filter	e_f	>2	%
Tensile str. drain	F_f	>0.5	kN
Elongation at 0.5 kN	$e_{0.5}$	<10	%
Discharge capacity:			
Straight (300 kPa)	q_w	$>50\times10^{-6}$	m^3/s
Buckled (200 kPa)	q_w	$>32.5\times10^{-6}$	m^3/s
Filter properties:			
Permittivitty	Y	$>5\times10^{-3}$	s^{-1}
Pore size	O_{90}	<80	µm

References:
Systematic quality control of vertical drainage W.F.J. de Jager, J.P. Oostveen, 4th Int.Conf. on Geosynthetics, The Hague 1990.

5. Installation

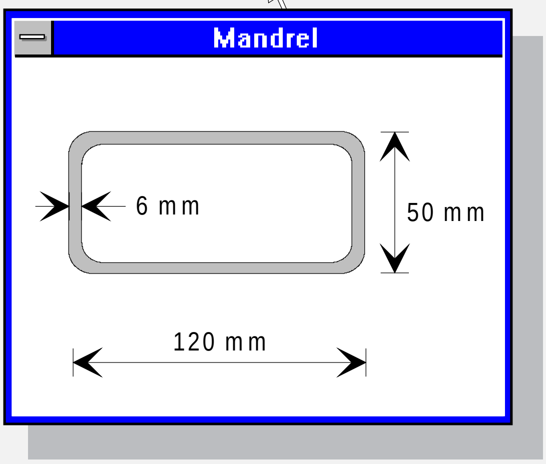
5.1. General

In order to prevent damage to and smearing of the drain, a rectangled steel pipe is used to install the prefab drain. The size of this mandrel is minimal, in order to prevent resistance during installation and to avoid disturbance of the subsoil. In the course of time, numerous different types of machines have been constructed to move the mandrel up and down as quickly as possible.
In general, these machines, the so-called drain stitchers, can be divided into two groups: the static machines, pushing the mandrel into the soil, and
the dynamic machines, vibrating the mandrel into the soil. Testing for the effect of both systems has taught us that the method of insertion has no influence on the ultimate effect of the drain. The pros and cons of these systems are dealt with in the following chapters. Depending on the insertion system, the subsoil and the circumstances, daily production can range from 1,000 to 10,000 m. The effect of the insertion depth on production is shown in adjoining graph. As installation costs cover at least 50% of the total costs, very short or very long drains are found to be, relatively, considerably more expensive. Moreover, the price of an accessory anchor plate for short drains is a major expense factor.



5.2. Pushing

There is a great variety of machines that push installation mandrels into the soil. The first used machines pulled a diamond-shaped, as regards sectional view, mandrel through transportation rolls. The rather weak insertion pipe had to be supported along the entire length. Later on, stitchers were designed which pulled the mandrel into the soil using a steel cable, driven by a hydraulic winch or ram. Here, too, facilities are required to restrict buckling length. Besides these, machines were developed that pushed the mandrel downwards by direct drive.



Last mentioned type of machines include the roller stitcher, which uses rubber or steel wheels to move the mandrel downwards, or the rack stitcher, which has a rack welded onto the mandrel which is driven by a geared hydromotor. The latter type restricts the buckle length to 1 m so that the mandrel does not require any support and the stitcher can be manufactured as a lighter type.

The installation principle is described as follows.

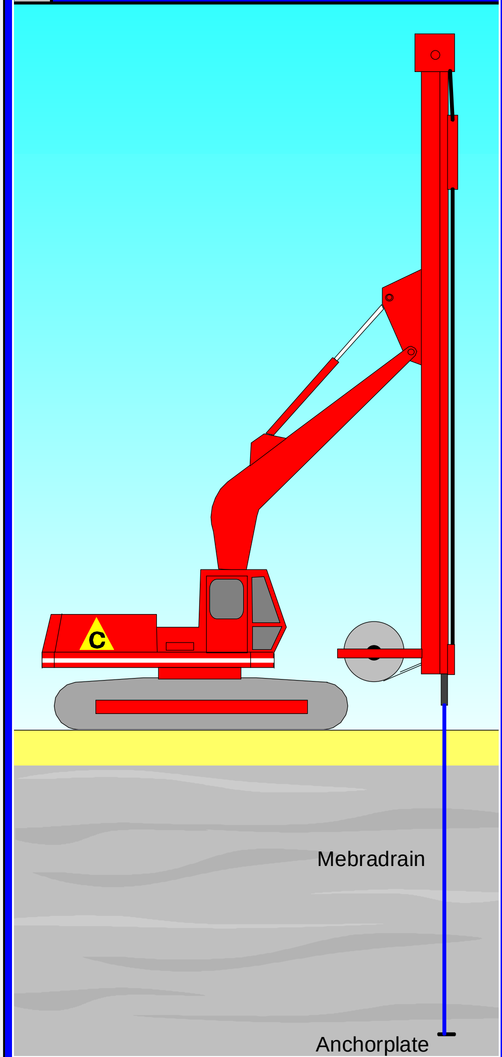
1. The tip of a roll of strip drain, fitted to the side of the stitcher, is guided into the stitcher, runs over a transportation roll and is led down into the mandrel. At the bottom of the mandrel, the drain is provided with an anchor plate which is pulled against the bottom of the mandrel.

2. The mandrel is pushed into the soil with a power ranging from 50 kN to 200 kN. As soon as the required depth has been reached, it is immediately pulled back up to prevent the soft soil from being pressed into the mandrel. Because of the cohesive working of the soil, the anchor plate to which the drain is attached remains in the soil.

3. As soon as the bottom of the mandrel is pulled up, the drain is cut off, after which another anchor plate is fitted. The stitcher is moved to the next insertion point and the cycle is to be repeated.

Rolls of drainage material can be sealed together by sliding the drain ends into each other and affixing them by stapling. This makes a continuous process possible. The drain stitcher must always remain vertically. Any deviation from the vertical position could cause deviations in the drain pattern at greater depth, resulting in disturbances in the consolidation process.

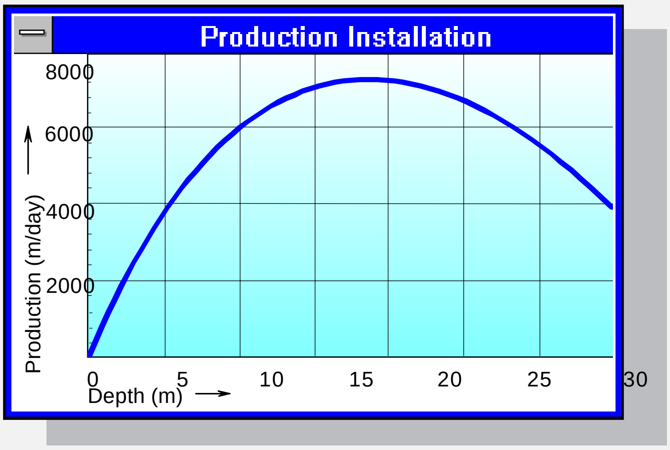
Cofra Drain Stitcher



5.3. Vibrating

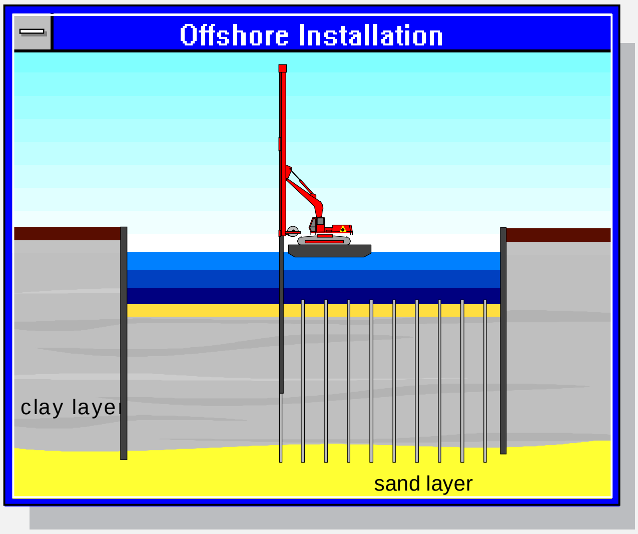
Vibrators are also available in several forms. The vibrator can be placed both centrically and eccentrically on the mandrel. Hydraulic and electric mandrels can be applied and high-frequency mandrels, too, are used more and more often. Electric mandrels, however, have the disadvantage that the frequent turning on and off of the mandrel

An advantage of the application of vibrators is that harder soil layers can be penetrated. A disadvantage, however, is that the drain can be damaged when the mandrel suddenly drops into a soft layer and the drain roll cannot follow the acceleration. The drain will then be overstressed, which may cause tearing of the filter. This often remains unnoticed as the drain is largely out of sight. In addition, the installation capacity is low while insertion costs are high. All this has added to the fact that vibrators are used less and less frequently.
A new development is the application of a vibrating needle in the tip of a mandrel, by means of which hard layers can be penetrated. The insertion procedure for vibrators is the same as for pushing stitchers.



5.4. Offshore operation

These days a lot of vertical drainage work is installed from the water. As the solution for lack of space, old ports or inlets are more and more often filled up to create new land. A pontoon with a stitcher is used as operating platform. The pontoon's position is controlled so as to create continuous drain patterns. Contrary to installation on land, the drains are cut off at length in advance and inserted into the mandrel from the bottom. This has the advantage that the drain can be installed from the insertion depth up to the bottom of the harbour. The drains need not be cut off under water and no long ends will float in the water. Using special equipment, it is possible to install drains in sludge depots. Then, instead of using a pontoon, the stitcher is fitted with large floating caterpillars, enabling the machine to move about across the sludge.



5.5. Predrilling

Hard surface layers are usually predrilled. Compact gravel or sand is often used as a drainage layer. The vehicles transporting this material drive across the drainage layer, thus increasing compactness. Predrilling with an auger or pre-injection is usually less expensive than prolonged vibrating with a drain stitcher. Predrilling prevents any delay in installation.

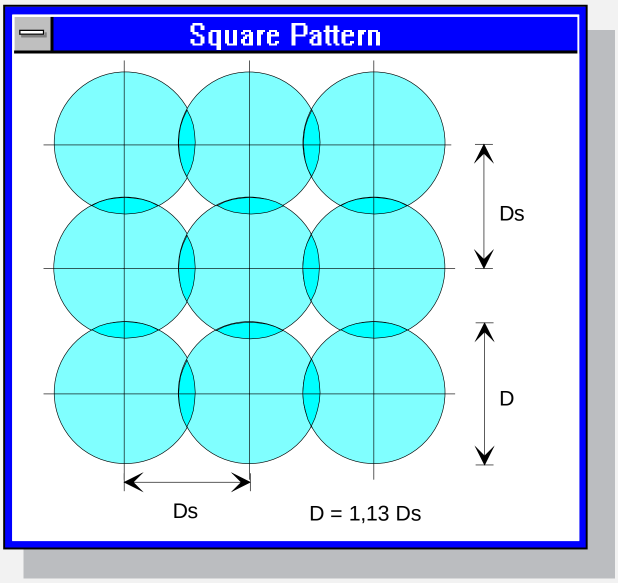
6. Calculation method

The principle of vertical drainage is relatively simple. The theoretical description of the operating mechanism is complex. The drain distance is generally calculated by use of undermentioned Barron formula.

$$C_h = D^2/8t\,[\,\ln D/d - ¾ + ¼(d/D)^2\,]\,\ln (1-U)^{-1} \quad (2)$$

in which:

- t = consolidation time (s)
- C_h = consolidation coefficient for horizontal flow (m^2/s)
- d = drain diameter (m)
- D = diameter of the drain's influence zone (m)
- U = average degree of consolidation at horizontal flow

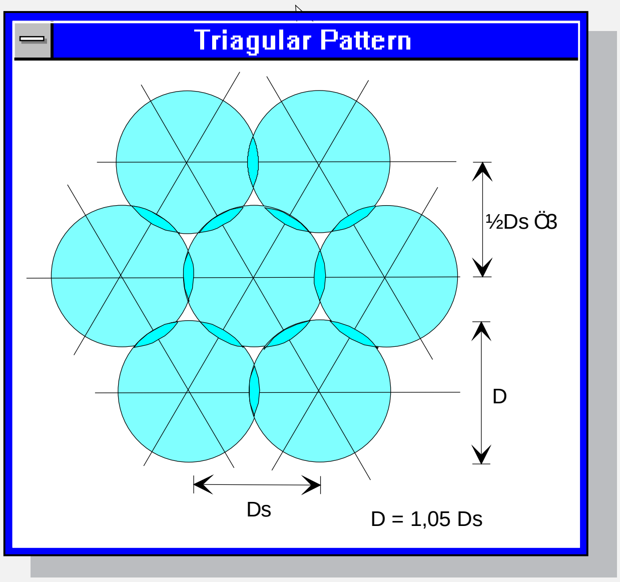


The C_h value is derived from laboratory tests on soil samples. Taylor's Vt-method is applied most often for compression tests. The C_h value is derived from the C_v value found in this test. For clay soil C_h = 1 to 4 C_v . In general, drains are installed in a triangular pattern. The diameter of the influence zone (D) in the formula (2), however, is based on the existence of a base cylinder. For a triangular pattern, the drain distance to be adhered to is therefore 1.05. For a square pattern this is 1.13 times smaller than D.

In the formula, the drain diameter (d) is considered as being a circular drain. The equivalent diameter of the Mebradrain is theoretically d = circumference/p. With a width of 100 mm and a thickness of 3 mm this means a d of 65 mm. Wick drain runoff, however, is negatively influenced as compared to runoff to a circular drain. In general, a value of 50 mm is therefore taken as drain diameter.

The average degree of consolidation (U) is usually expressed in a percentage or a figure between 0 and 1. U = 0.9 = 90% consolidation. Experience shows that the drain distance is usually larger than 1 m. This means that $(d/D)^2$ for Mebradrain with a d of 0.05 is smaller than $2.5x\ 10^{-3} m^{-1}$ and will therefore hardly influence the result of the calculation. Therefore the simplified formula will suffice:

$$C_h = D^2/8t\,(\,\ln D/d - ¾\,)\,\ln (1-U)^{-1} \quad (3)$$



Apart from other data, this formula assumes that the drain discharge resistance is zero. Mebradrain, however, has a limited discharge capacity(q_w = 10^{-4} tot $10^{-5}$$m^3/s$) , which can considerably influence consolidation time, especially when long drains are used. According to the Hansbo theory, the discharge capacity can also be derived from the formula as follows:

$$C_h = D^2/8t\,[\ln D/d - ¾ + pz\,(2L-z)\,k_c/q_w]\,\ln(1-U)^{-1} \quad (4)$$

where:
z = distance to runoff point (m)
L = drain length for one-sided flow (m)
(half length for two sided flow)
k_c = soil permeability (m/s)
q_w = discharge capacity drain (m^3/s)

The discharge capacity (q_w) of Mebradrain is approx. 5 x 10^{-5} m^3/s, which is 10 times larger than a sanddrain with a diameter of 300 mm. Permeability of strongly compressible soil (k_c) ranges from 10^{-7} tot 10^{-11} m/s. Adjoining schedule shows the k-values and ratio k_c/q_w in order of size for different soil types. A q_w van 10^{-5} m^3/s is assumed here.
The discharge capacity of the drain will influence the progress of consolidation when the ratio is $k_c/q_w > 10^{-4}\,m^{-2}$. For Mebradrain this means that the consolidation process is influenced when soil types have a permeability > 10^{-9} m/s het consolidatieproces wordt beïnvloed.
Formula (4) makes it possible to determine consolidation for horizontal runoff at a certain depth z. The progress of the average consolidation over the thickness of a stratification equals the consolidation at a depth ranging from 0.3 to 0.5 l. When as average value z=0.41 is substituted in formula (4) the following formula is obtained.

$$C_h = D^2/8t\,[\ln D/d - ¾ + p.0{,}64L^2 k_c/q_w]\,\ln(1-U)^{-1}$$

An MSDOS calculating program is available for interested parties. This program is based on Barron's calculating theory and calculates the most economic drain distance. This program simultaneously calculates the average degree of consolidation for vertical and horizontal runoff. Also, using the Carrillo theory, the average degree of consolidation is calculated for the combined occurrence of vertical and horizontal flow.

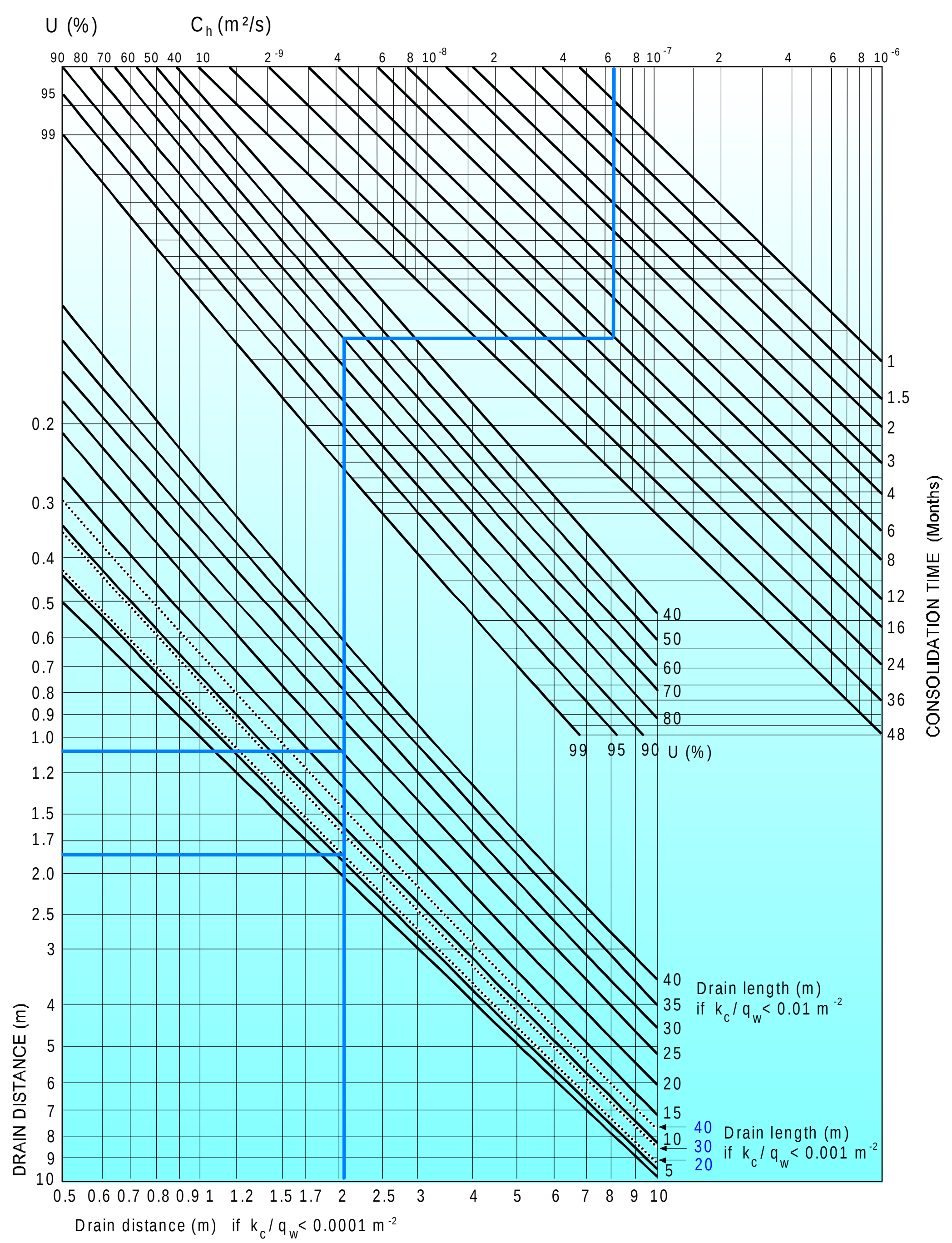
Soil Permeability

Soil type	k (m/s)	k_c/q_w (m^{-2})
Course sand	10^{-2} - 10^{-3}	1000 - 1000
Sand	10^{-3} - 10^{-4}	100 - 10
Fine sand	10^{-4} - 10^{-5}	10 - 1
Silty sand	10^{-5} - 10^{-6}	1 - 10^{-1}
Sandy silt	10^{-6} - 10^{-9}	10^{-1} - 10^{-4}
Peat	10^{-7} - 10^{-9}	10^{-2} - 10^{-4}
Clay	10^{-9} - 10^{-11}	10^{-4} - 10^{-6}

Formula (5) has been worked out in the graph below. The blue line gives an example of how the graph may be used.

The coefficient for horizontal flow can either be determined by compression tests of undisturbed soil samples in a laboratory, or by measurements in situ with a pressure probe as developed by
Torstensson in 1978.

Mebradrain Triangular Distance



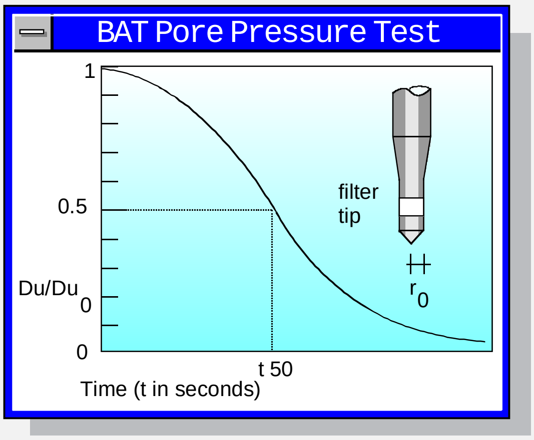
The probe is pushed down into the soil at a constant rate of penetration. The generated excess pore pressure, An, in the soil around the probe is continuously recorded. By stopping the penetration of the probe and recording the rate of pore pressure dissipation, the coefficient of consolidation C_h can be calculated. It is recommended to calculate the C_h at a dissipation level of 50%, i.e. $Du/Du_0 = 0.5$, in which:

Du = remaining excess pore pressure at time t
Du_0 = initial excess pore pressure

If the time needed for 50% dissipation of the excess pore pressure is denoted t_{50} then the C_h can be calculated from the following expression:

$$Ch = r_0^2/t_{50}$$

in which r_o = radius of the cylindrical filter. Back-calculated field values of Ch from various vertical drainage projects indicate a good correlation with the C_h-values calculated from pore pressure dissipation tests.

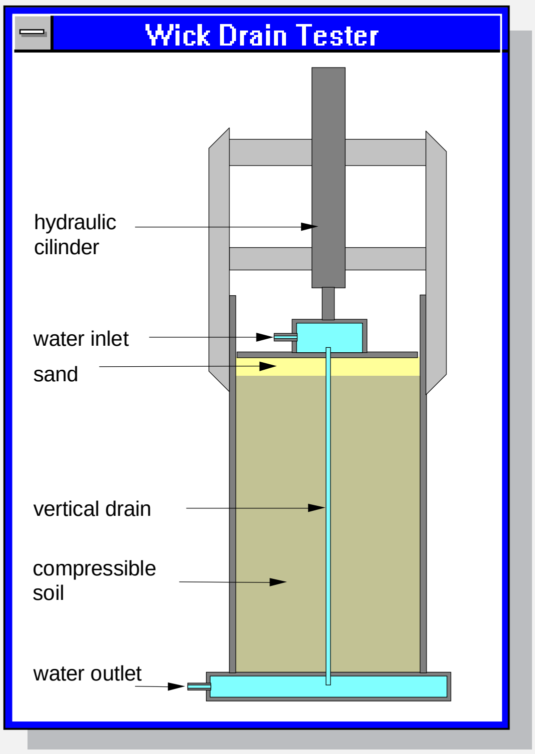


7. Laboratory tests

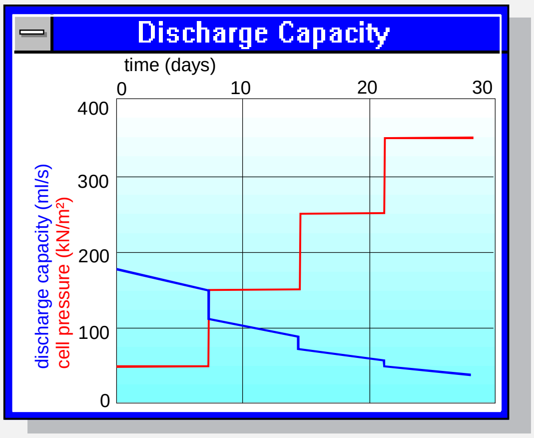
The properties and operation of Mebradrain° have been tested in independent laboratories. Reports are available from these tests, in which the discharge capacity of the drains were determined in both straight and buckled forms. In addition, an extensive report is available on test fields and realized projects.

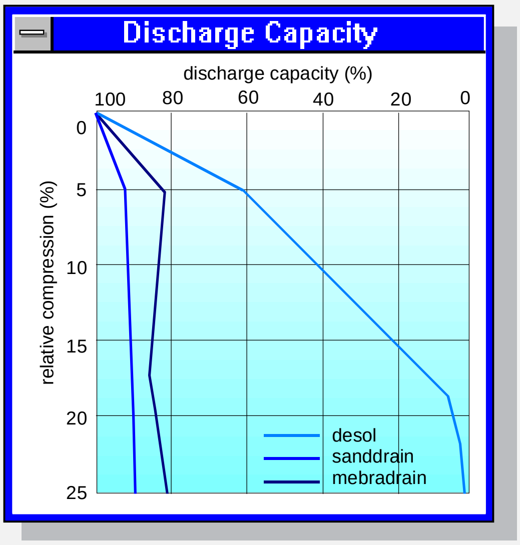
7.1. Compression tests

In order to get a practical insight in the behaviour of Mebradrain in compressible soil, a number of compression tests were carried out on different types of drains by using a test unit.
This tester consisted of six steel cylinders 0500 mm and 1200 mm high. A drain was tightened in the centre line, after which the cylinder was filled with a layer of soft soil and a layer of filtering sand on top. The bottom of the drain was clamped into the bottom plate.



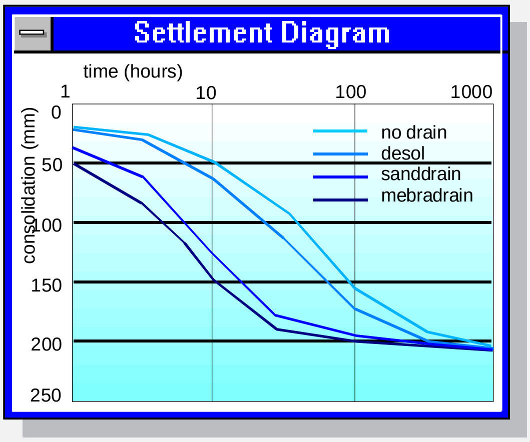
The top of the drain was conducted through a steel cover which could be loaded with a pressure of 70 kPa by means of a hydraulic cylinder. The air chambers at the bottom and top of the tester were used to measure head, flow rate and discharge resistance of the drain.
Tests were carried out on several types of vertical drains and a 50 mm sanddrain. The soft soil used consisted of soft clay, peat, or harbour mud. Depending on the soil type used, relative settlements were achieved of 25 to 50%. In adjoining settlement/time graph the result is shown of a test with peat. There is a considerable difference in the progress of settlements. One of the causes of retarded settlement when certain drains are used is the fact that the drains buckle as a result of vertical compression and largely lose their discharge capacity. In the adjacent graph this decline is shown graphically. The number of buckles in the drain strongly depend on its rigidity. Especially rigid drains such as Desol sharply buckle, blocking up the discharge channels entirely.





7.2. Discharge tests

The TU Delft (Technological University, Delft/ Holland) have developed a test in which a 300 mm long drain sample can be tested on discharge capacity in both straight and buckled forms. For this purpose the drain sample is wrapped into a thin latex liner and placed in a pressure tank. Practical circumstances can be simulated by varying the pressure in the tank and the flow rate. In order to also measure the effect of a prolonged load in the drain, the trial is extended over a period of 30 days, during which the load is raised step by step from 50, 150, 250 to 350 kPa. The test results are related to a water temperature of 20°C. Adjoining graph shows the result of this test on a Mebradrain type MD7007.



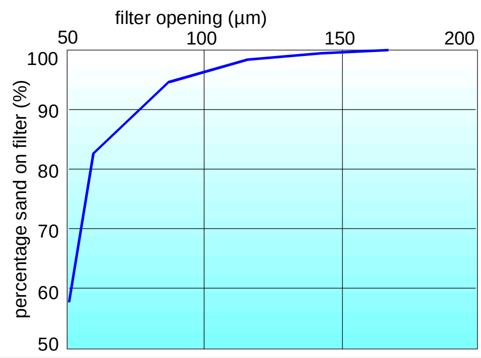
7.3. Pore size filter

The pore size of the filter is determined on the basis of NEN 5168. Dry soil, split up in fractions of the following sizes:

150 - 180 mm
125 - 150 mm
106 - 125 mm
75 - 106 mm
53 - 75 mm

is sieved through the filter, thus composing a grading diagram of particles slipping through the filter, thus composing a gradient diagram of particles slipping through the filter.
The size of those particles of which 90% remains behind on the filter is called 0_{90}. The grading diagram for the filter jacket of Mebradrain type MD88 is given in adjoining graph. This graph shows that the average 0_{90} of this jacket agrees with 76 gm.

Pore Size Opening



7.4. Permittivitty of the filter

The filter's permittivitty does not depend on filter thickness and is therefore more suitable to determine specific water permeability of the material. Permittivitty is water permeability/ filter thickness and is expressed in s^{-1}. (y = k/d). According to NEN 5167 permittivity of a filter cloth is related to the average value at a water temperature of 10°C and a filtration rate of 10 mm/s. The filter is subjected to a water stream at right angles with the filter surface. The supply is increased stepwise, during which the occurring fall Dh over the synthetic filter and the discharge output Q are measured. From the values found, the water permeability (k-value) is calculated in m/s.

7.5. Chemical resistance

Both the core and the jacket of Mebradrain° are manufactured of polypropylene (PP). This polymer has an excellent chemical resistance, comparable to HDPE. Adjoining table shows the resistance of PP at a temperature of 20°C. This high resistance to all kinds of chemicals makes Mebradrain highly suitable for environmental applications.

Chemical Resistance

Agent	Effect
<u>Acids</u>	
Acetic	none
Chromic	none
Hydrobromic	none
Hydrochloric	none
Sulfuric	none
Phosphoric	none
<u>Alkalis</u>	
Ammonia	none
Sodium hydroxide	none
Sodium hypochlorite	none
<u>Organic chemicals</u>	
Acetone	none
Benzene	moderate
Cyclohexanone	none
Ethanol	none
Ethylene Glycol	none
Dimethyl	none
Gasoline	considerable
Methylene chloride	considarable
Trichloorethene	considerable

8. Specifications

8.1 General

8.1.1. The relevant details of the soil investigations are stated in the appendix to the tender specification, or as the case may be are available for perusal in ...

8.1.2. Installation of vertical prefab drains takes place from a drainage layer of at least 0.5 m thick and with a course grading.

8.1.3. Vertical drains should be installed in accordance with the pattern shown in the drawing.

8.1.4. The maximum allowable deviation of the spot of installing a drain in relation to the set point is 0.15 m. The maximum allowable deviation of the vertical is 50:1, unless obstacles are present, such as overground power lines and foundation rests.

8.1.5. In those places where it is impossible to install a drain as a result of obstacles, another drain must be installed within a distance of 0.15 m.

8.1.6. Drains have to be installed up to the depth(s) shown in the drawing. Prefabricated drains are cut off at 0.15 m above the surface.

8.1.7. During installation it must be possible to read off the insertion depth on the machine.

8.1.8. A registration must be kept on which number, length and place of the drains and date of installation are noted.

8.1.9. The contractor should take it for granted that instrumentation of a total value of US$ ... is present at site. The contractor should see to it that the instrumentation to check the progress of consolidation is not damaged during execution of the work. Damage caused is repaired on notification by the board of directors for account of the contractor or, where appropriate, the contractor is fined to an amount of US$ ... for any equipment broken down through a fault of his.

8.2. PREFAB DRAINS

8.2.1. Prefab drains supplied under a recognized certification with quality mark in conformity with the class required for the work and inspected at the work by the board are considered to have been tested.

8.2.2. Prefab drains purchased from a producer who is not entitled to supply under a recognized certificate with quality mark in conformity with the class required for the work have to be supplied per relevant lot in accordance with a lot-qualification system. The supply of a lot in accordance with a lot-qualification system of a recognized inspection service must meet the following points:

* Type of inspection, not older than 6 months in conformity with the adjoining schedule, is in agreement with the class required for the work.

* During production and supply at site the quality of the drain is checked in accordance with the tests and frequencies shown in adjoining schedule.

* None of the results of these checks will exceed the allowable deviation mentioned in the schedule as compared to the average values fixed at the type of inspection. When the allowable deviation is exceeded, the entire manufactured or, where appropriate, supplied lot will be rejected.

Quality Control Scheme

aspects control schedule	type of inspection >		factory control	control on site	Allow. devia.
beproeving	Code	number of tests	1 sample per		
1 core geometry	EN ISO 9863	5	2.000m	10.000m	5%
2 core mass per metre	EN ISO 9864	5	2.000m	10.000m	10%
3 mass filter.	EN ISO 9864	5	2.000m	10.000m	25%
4 mass drain per metre	EN ISO 9864	5	2.000m	10.000m	25%
5 tensile test drain	EN ISO 10319	5	1.000km	—	25%
6 discharge test	CROW publ.	3	2.000km	—	25%
7 discharge test buckled	CROW publ.	3	2.000km	—	25%
8 permeability filter	EN ISO 12958	3	1.000km	—	25%
9 pore size filter	EN ISO 12956	3	1.000km	—	25%

8.2.3. The equipment and installation method require approval of the supervisor.

8.2.4. It is allowed to install the drain by means of vibrating or pushing. In consultation with the supervisor it is allowed to predrill or inject in hard layers.

8.2.5. The drain has to be anchored at the shown depth.
8.2.6. All material wasted during work has to be removed from the building site. Any sludge has to be discharged.

8.2.7. During storage the drainage material has to be sufficiently protected against any influence of weather.

9. Reference Projects

In the course of time Geotechnics Holland by have executed a large number of projects in all continents. A number of relevant projects is shown below:

'78 Ringweg Amsterdam	3.170.000 m
'81 Basrah Airport Iraq	3.200.000 m
'81 IJzererts opslag Lissabon	1.100.000 m
'83 Bintulu haven Maleisië	1.740.000 m
'84 Spoorweg Jijel Algerije	1.050.000 m
'84 Annacis brug Vancouver	1.420.000 m
'86 Bombay haven, India	2.000.000 m
'88 Kanaaltunnel Calais	2.200.000 m
'88 Estevan dam Canada	1.500.000 m
'89 Highway Subang Jaya	1.600.000 m
'90 Highway Turku Finland	925.000 m
'91 Bonny terminal Nigeria	1.270.000 m
'92 Osaka Airport Japan	1.500.000 m
'93 Spoorweg Thailand	6.000.000 m
'93 Madras haven, India	1.200.000 m
'99 Changi Airport	25.000.000 m
'00 Bangkok Airport	15.000.000 m
'01 Tuas View	20.000.000 m
'01 Pulau Tekong	26.000.000 m
'02 Airbus Hamburg	19.000.000 m
'02 Escravos Nigeria	5.500.000 m

10 Papers

Geotechnics Holland BV has the following papers available for interested parties:

1. Diemen, Test sections in Highway 1.
2. Samendrukkingsproef Rotterdams havenslib.
3. Typar filterproeven, Delft Hydraulics.
4. Standard Drain Discharge Test, TU Delft
5. Mebradrain® Test Report, Frobel USA
6. Verticale Drainage, CROW/TU Delft
7. Vervorming van kunststof drains, v.d. Griend