PREFABRICATED VERTICAL PVC DRAINAGE SYSTEM FOR CONSTRUCTION OF EMBANKMENT ON COMPRESSIBLE SOFT SOIL

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PREFACE

This report is based on detailed literature survey, field experience and technical appraisal of methodologies available. The views expressed are subject to modification from time to time in the light of future developments on the subject. The views do not represent the views of Ministry of Railways (Railway Board) Government of India.

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(Nand Kishore)
Executive Director/Geo-tech Engg.
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1.0 INTRODUCTION

The soil behaviour on Indian Railways differs from region to region. In the northern part of country where soil, in general, is alluvial type, no problem is faced in construction of embankment for a new line. However, southern part of country consists mainly of black cotton, laterite soil and very soft marine clay generally close to coastal areas, as such, construction of new embankment is fraught with plethora of problems. Soft marine clay soils are characterised by low shear strength, high compressibility and low bearing capacity. In such situations sub-soil needs strengthening, therefore, special measures are to be taken before constructing the embankment on marine clays.

On account of poor permeability of clayey soil, the dissipation of pore water pressure is very slow and primary consolidation takes a long time to complete. To shorten the consolidation time, consolidation process is accelerated by means of vertical drainage. Prefabricated vertical drains are artificially created drainage paths, can be installed by several methods and can have a variety of physical characteristics. The vertical drains can reduce settlements from years to months. Due to this reason, most settlement occurs during construction phase itself, and post-construction settlements are reduced to bare minimum.

2.0 CONSTRUCTION PROBLEMS ON SOFT COMPRESSIBLE SOILS

In case of highly compressible saturated soft clay, imposition of load generates excess pore water pressure in soft layer. This excess pore water pressure is initially borne by water molecules existing within the soft layer. Initial excess pore pressure in the water is equal to the applied external pressure on the soil. Slowly and slowly, as water oozes out of pore space depending upon permeability of soil, excess pore water pressure dissipates and the load gets transferred to soil grains. With the passage of time, excess pore water pressure decreases and correspondingly, the effective stresses in the layer increases. After
a very long time the excess hydrostatic pressure becomes zero and the entire consolidation pressure becomes an effective stress transmitted from grain to grain of the soil.

As a result, soft soil gets compressed and the consolidation process continues over a long period of time unless measures are taken for quick dissipation of excess pore water pressure. Throughout this process, the foundation of structure would settle until the complete consolidation takes place. By this time, irreparable damage to structure occurs.

Because of low permeability and poor drainage characteristics of soft soil, it becomes essential to drain out pore water before construction begins, otherwise the added weight of new structure will cause water to squeeze out for a long period of time. Moreover, due to high compressibility of these soils, the consolidation settlements are of a very high order and from structural safety point of view, it would be better if major portion of this consolidation settlement takes place before/during construction phase itself.

![Fig. 1 Consolidation without vertical drains](image-url)
3.0 CONSOLIDATION METHODOLOGY

For constructing any structure, it is necessary to accelerate the process of consolidation. To achieve this, the following methods are generally adopted-

i) Preloading
ii) Stage Construction
iii) Vertical Sand Drains
iv) Prefabricated Vertical Drains
v) Vacuum Assisted Consolidation

The choice of method depends upon the importance of structure, applied loading, site conditions and time period available for construction etc. Therefore, it is important to select the appropriate method for a given situation.

3.1 Pre-loading

Pre-loading refers to the process of compressing sub-soil under applied vertical stress prior to placement of final construction load. If the temporary applied load exceeds the final loading, the amount in excess is referred to as surcharge. When a preload is rapidly applied to a saturated soft clay deposit, the resulting settlement can be divided into three components, namely immediate settlement, primary consolidation, and secondary consolidation. In field condition, the settlement behaviour is more complex.

The relative importance and magnitude of each type of settlement depends on many factors such as: the soil type, compressibility characteristics, stress history, magnitude, rate of loading and relationship between area of loading & thickness of compressible soil. Generally, the primary consolidation settlement predominates and in many cases, it is the only consideration in the preload design.
3.2 Stage Construction

In stage construction, construction of embankment takes place in stages and the total height of embankment is constructed in parts. After constructing the embankment up to certain height, it is left over for a pre-determined period so as to allow consolidation to take place and then second stage of construction is done and so on up to the required height. Increase in shear strength of the sub-soil soft strata after each stage of loading due to consolidation of embankment is taken advantage of.

3.3 Vertical Sand Drains

When the time required for consolidation is less, sand drains are employed to eliminate deleterious differential settlements or to acquire sufficient additional shear strength. Sand drains are vertical columns of sand or other pervious material inserted through compressible stratum at sufficiently close spacing so that the longest horizontal drainage path is less than the longest vertical path. The rate of drainage can be increased by application of vertical sand drains in the embankment/sub-soil. Thus the drains serve to hasten the consolidation process.

Fig. 2 Effect on consolidation with /without vertical drains
There are two categories of installation methods, namely: displacement and non-displacement types. In the **displacement type**, a closed end mandrel is driven or pushed into the soft ground with resulting displacements in both vertical and lateral directions. The **non-displacement type** installation requires drilling the hole by means of power auger or water jets and is considered to have less disturbing effects on soft clay. Casagrande & Poulos opined that driven sand drains are harmful in soft and sensitive clays due to the disturbance in driving the drains causing the reduction of shear strength and horizontal permeability. However, Akagi (1979) asserted that the mere installation of the sand drains alone results in the consolidation of the soft clay because of the large stresses induced during the installation. Thus, high excess pore pressure is generated and after its subsequent dissipation, a gain in strength is achieved.

A sand blanket is placed over the top of the sand drains to connect the same. To accelerate the drainage, a surcharge load is placed on the sand blanket. The surcharge is generally in the form of dumped soil. Due to surcharge load, the pore water pressure increases in the embankment. The drainage occurs in the vertical and horizontal directions. The sand drains accelerate the process of dissipation of excess pore water pressure. Sand drains tend to act as weak piles and reduce the stresses in the clay. However, these are ineffective in controlling the secondary consolidation for highly plastic and organic soils. Sand drains may get distorted & dislocated during process of consolidation, thereafter, they may not remain effective.

### 3.4 Prefabricated Vertical Drains (PVD)

Prefabricated vertical PVC drain can be defined as any prefabricated material or product consisting of a synthetic filter jacket surrounding a plastic core. Because of their shape, they are also known as **band** or **wick** drains. They are manufactured in rolls of 200-300 m and are inserted into ground to required depths using special drain stitcher rigs. Generally, installation takes place up to
full depth of compressible soils. PVDs have replaced conventional sand drains for soil consolidation due to their easy & speedy installation and unlike sand drains, they act as a integral unit during the process of consolidation.

![Prefabricated PVC wick drain](image)

**Fig. 3: Prefabricated PVC wick drain**

### 3.5 Vacuum Assisted Consolidation

Vacuum Assisted Consolidation is a new technology with the aim to replace the standard preloading technique. Instead of increasing the effective stress in the soil mass by increasing the total stress with a conventional surcharge, a negative pressure preloads the soil by reducing the pore pressure while maintaining a constant total stress. This technique mainly consists of placing an airtight membrane over the soft cohesive soil to consolidate and create a vacuum underneath it by pumping. The major advantages offered by this technique compared to the classical preloading technique are :--

i) No risk of short term circular slip failure because of no increment of total stress.

ii) Increase of shearing resistance in the upper fill during pumping, thus stability is increased against failure. Hence, embankment preload can be combined with this technique.
4.0 PREFABRICATED VERTICAL PVC DRAINAGE

4.1 Historical background

The concept of drainage through vertical drains was initially developed in 1920s. The property of sand being more permeable than clayey/silty soil was utilized by creating sand columns in lesser permeable soils as these sand columns functioned as drains. The first pre-fabricated vertical drain (wick) was developed by Walter Kjellman in 1940s. It consisted of few channels imprinted into a stiff card board core. Drains using a synthetic drainage core with longitudinal channels or grooves enveloped in a paper or non-woven filter were introduced in early 1970s after further development in wick drains.

4.2 Necessity of Vertical PVC Drains

Soil stabilization using vertical wick drains is applied in areas with compressible and water saturated soils such as clay and silty clays. These soils are...
characterized by a very weak soil skeleton and a large pore space, usually filled with water (pore water). When a load such as a railway embankment is placed on soft compressible soils, increase in load results in an increase of pore water pressure and in impermeable soils, this water dissipates very slowly, gradually flowing from the stressed zone. At the same time, increased pore pressure may cause instability and slip plane failures may occur. Also, significant soil settlements may occur which can create serious problem. Risk of instability affects the safe rate of fill placement during construction. To increase the rate of consolidation process, flow path needs to be shortened so that pore water is released quickly.

![Consolidation with vertical drains](image)

**Fig. 5** Consolidation with vertical drains

A large amount of consolidation is usually experienced in swamp deposits, hence extremely flexible PVC drains should be used. In addition to flexibility, continual functioning of PVC drains is very important.
4.3 **Components of Vertical PVC Drains**

There are two components of pre-fabricated PVC drain namely, core and filter jacket. By combining the features of both core and filter jacket, pre-fabricated PVC drain system provides effective, fast and reliable performance for soil improvement.

**Core**

It is also called drain body which is a unique, corrugated, flexible and made of polypropylene specifically designed to provide high discharge capacity, high tensile and compressive strength.

**Filter jacket**

It is strong and durable non-woven, thermically bonded polypropylene fabric wrapped around the core. The fabric is of random texture having high tensile strength, high permeability and effective filtering properties. It acts as a filter to allow passage of ground water into the drain core while eliminating movement of soil particles and preventing piping. It also serves as an outer skin to maintain the cross sectional shape and hydraulic capacity of the core channels.

4.4 **Principle of Vertical PVC Drains**

The vertical PVC drains are often employed on site, which consists of fine grained, saturated soils having poor drainage properties. If the soil is not strengthened in advance, the added weight of a new structure will cause water to squeeze out over time. The soil will compress or settle as water is removed. It is critical that all excess water be removed from the soil before construction begins. This will increase the bearing strength of the soil and allow it to support the weight of the new structure. However, fine grained, compressible soils have a low permeability and therefore, take a very long time to consolidate. This problem can be overcome by installing prefabricated vertical PVC drains, which
provide a shorter and easier drainage path through which the water can escape. The same degree of consolidation may be achieved with or without drains. Vertical drains simply reduce the settlement time required to complete the consolidation. The close drain spacing will cause the faster rate of settlement. A fill or surcharge is placed on the site to trigger the movement of pore water. The increased pore water pressure caused by the fill exerts a force or gradient which moves the water to the nearest drain and up to the drainage layer at the surface of the site, under the fill. Once the desired consolidation has been achieved, construction can continue. A site can be ready in just a matter of months with PVC drains while it may take several years or even decades, if drains are not used.

### 4.5 Characteristics of Vertical PVC Drains

a) Ability to permit pore water in the soil to seep into the drain.
b) A means by which the collected pore water can be transmitted along the length of the drain.
c) The jacket material consists of non-woven polyester or polypropylene geotextiles that function as a physical barrier separating the flow channel from the surrounding soft clay soils and a filter to limit the passage of fine particles into the core to prevent clogging. The plastic core serves two vital functions, namely: to support the filter jacket and to provide longitudinal flow paths along drain even at large lateral pressure.

Presently there are many firms which manufacture pre-fabricated drains for various conditions of sub soil and applied loading. An indicative list of some manufacturers is given in Annexure-I. The principle behind the use of pre-fabricated drains is similar. Each of these products have different designs, shapes, physical properties, usage and the design methodology etc.
4.6 Performance of Vertical PVC Drains

During the consolidation process, the vertical drains are subjected to both tensile and compressive forces as the soil shifts and settles. Lateral soil displacements can cause certain drains to elongate beyond their rupture point. Vertical soil compression (settlements) has been shown in the following figure to cause some drains to pinch off, as they experience folding and buckling of the core. This can severely affect the ability of the drains to function as intended.

Drain performance under both conditions must be considered when selecting a vertical drain. Drain failure can seriously jeopardize the project’s construction schedule and structural stability.

![Fig. 6 Drain deformation during consolidation](image)

4.7 Advantages of Vertical PVC Drain System

There are following advantages of using PVC drain system –

- Minimum disturbance to the soil layers during installation.
- High water discharge capacity.
- Customized cores and filters to suit the various soil conditions.
- High compressive strength core prevents the collapse of the flow path.
- Proven performance under different soil conditions.
- Fast and easy installation.
- Deep installation exceeding 40 m in depth.
- The unique and flexible core will not pinch off or flatten during the consolidation process.

5.0 DESIGN CONSIDERATIONS OF PVC DRAINS:

5.1 DIFFERENT CRITERIA

To investigate whether a vertical drainage is required and, if so, what sort of design is needed, a number of criteria need to be applied, namely:

I. Stability criterion
II. Settlement criterion
III. Cost criterion

Stability criterion

The stability during and immediately after filling needs to be ensured. This can be achieved by formulating a design criterion connected with the degree of consolidation, which must be attained before the next fill layer is started. When quantifying this criterion, the basis used for a given fill phase involves analysis of the least stable soil stratum.

Settlement criterion

A pre-established settlement needs to be achieved within a certain period following completion of a fill layer.
Cost criterion

If the time schedule is not very tight, a cost analysis can be used to investigate whether, in the event of no vertical drainage being used, early investment in the sand structure and annual loss of interest during a number of years, compensate for the costs of a prefabricated vertical drainage system. However, the possibility of drainage system malfunction also needs to be taken into account. Actual design of a prefabricated vertical drainage system covers working out which type of drain to use including the diameter or width, drain length and relative drain spacing. The choice of drain length is often governed, not only by the thickness of the strongly compressible soil layer, but also by considerations of a geohydrological and/or environmental nature.

5.2 Patterns and spacing of PVC drains

Vertical wick drains are usually placed in a square/triangular configuration, as shown below, the pattern size (Ds) being converted into the equivalent drainage spacing (D) determined from the diameter of the ground cylinders around a drain. The relationship between D and Ds is as follows:

D = 1.13 x Ds for a square pattern
D = 1.05 x Ds for a triangular pattern

![Fig. 7 Equivalent drain spacing](image_url)
The drain spacing may be varied to optimise the design. Closer drain spacing decreases consolidation time but increases installation costs. In the design process, it may also be necessary to consider such factors as the smear zone and drain characteristics such as well-resistance; however, these factors theoretically influence the average degree of consolidation. Generally 1-3 metres centre to centre spacing is adopted.

The smear zone surrounding the drains is generated by the soil disturbance from the installation of the PVD. The degree of disturbance depends on the size and shape of the mandrel used to install the drains, soil macro-fabric and the installation procedure (whether driven, pushed or vibrated). The mandrel cross section should be minimized, while at the same time, it must have adequate stiffness. Hansbo recommended that the diameter of the smear zone be assumed as \( d_s = 2d_w \).

Finally, the material characteristic of the prefabricated drains must be appropriately considered. The information required includes:

a) the discharge capacity of the drain considering lateral stress, possible drain folding or kinking;
b) transverse permeability of the filter sleeve;
c) mechanical properties;
d) durability of the proposed drains.

In the figure give below,
L=Length of drain when drainage occurs at one end only
Z=Distance from drainage end of the drain
\( q_w \)=Discharge capacity of drain at hydraulic gradient of unity
\( d_s \)=Dia. of disturb zone around the drain
\( d_w \)=Equivalent dia. of the drain
De=Dia. of the equivalent soil cylinder
5.3 Selection of drain type

The primary concerns in the selection of the type of prefabricated drain for a particular project include: equivalent dia., discharge capacity, filter jacket characteristics and permeability and material strength, flexibility and durability. The theory of consolidation with radial drainage assumes that the soil is drained by a vertical drain with circular cross-section. The equivalent diameter of a prefabricated PVC drain is defined as the diameter of a circular drain which has the same theoretical radial drainage performance as the pre-fabricated PVC drain. For design purposes, the following expression given by Hansbo can be used:

\[ d_w = \frac{2(a+b)}{\pi} \]

For use in practice, Rixner suggested based on finite element studies, the equivalent diameter as:
\[ d_w = \frac{a + b}{2} \]

Where ‘a’ is the width of a pre-fabricated PVC drain cross-section and ‘b’ is the thickness of pre-fabricated PVC drain cross-section. The relative sizes of these equivalent diameters are compared to the pre-fabricated PVC drain cross-section in figure:

**Fig. 9 Equivalent diameter of PV drain**

For common prefabricated drains, equivalent diameter of the drain \( d_w \) ranges from 50-75 mm. It is generally inappropriate to use a drain with an equivalent diameter of less than 50 mm. Typical values of the discharge capacity, \( q_w \), are function of lateral confining pressures. Generally, the selected drain should have a vertical discharge capacity of at least 100 m³/ year measured under a gradient of one while confined to maximum in situ effective horizontal stress.

### 5.4 Discharge capacity of drains

The discharge capacity, \( q_w \), of PVDs varies considerably depending upon how the drain is made, its installed length, and whether the drain is folded because of large settlements. The length is important because \( q_w \) decreases with increasing lateral pressure, which causes the filter sleeve to squeeze into the drain core channels and reduce the cross sectional area of the channels. Folding of the drain
also reduces the area available for flow in the core. Analytical and experimental studies indicate that well resistance has little or no influence on consolidation rates of PVD installations, even for long drains as long as \( q_w \) is at least 100 to 150 m\(^3\)s\(^{-1}\).

The transverse hydraulic conductivity of the PVD depends on the characteristics of the geo-textiles filter surrounding the drain. Durability depends on the particular polymers used to make the drain and their resistance to the chemical and biological environment at the site.

6.0 INSTALLATION METHOD

A vertical drainage system can be installed in order to accelerate the consolidation process and help to improve discharge of excess pore pressure in the sub soil. In this way, a stable situation is reached more quickly, thus shortening the filling time dramatically. At the same time, the settlement process is accelerated to such an extent that earthwork finishing off processes can be started earlier. All of this results in a substantially shorter construction time which may be important both economically and socially.

The installation of vertical PVC drains is usually done with the aid of a dragline fitted with tams along which the lance can move up and down vertically. The length of drain to be installed determines the minimum length both of the equipment and of the lance. The drains are wrapped around a coil which is placed in a housing in the rig. From there, the drain passes over a travel roller until it feeds into the top of the rig and then via a second travel roller through the lance downwards. Beneath the lance, a small anchor plate is secured to the drain. The lance is then installed to the desired depth either by vibration or with the help of a static pressure and tensioner. Any solid layer encountered can be pre-jetted. The anchor plate ensures that the drain, once to depth, remains at that depth whilst the lance is being withdrawn. The drain is then clipped off above ground level,
after which the entire procedure can be repeated all over again at the next drain location. Depending upon soil conditions, the length & width of the drain strip, an output of 2000 to 6000 linear m per eight hour work day per rig can be achieved.

Sequence of vertical drainage wick installation

All vertical drainage wicks will go to maximum allowable/anchorable depths or until refusal as per following method:

a) Thread the vertical drainage wick off the wick roll/spool, up the wick tube, and over the top wick roller and down through the mandrel.

b) Place the drainage wick through or around the anchoring device and tuck the loose end of the wick up into the mandrel about 6 to 8 inches (150 to 200 mm). Pull the drainage wick’s excess slack tight through the mandrel and vertical drainage wick tube by reversing the vertical drainage wick roll by hand. By reversing the vertical drainage wick spool or wick roll, the anchoring device will retract up tight against the bottom tip of the mandrel. This will prevent dirt or mud from entering the mandrel during the insertion of the mandrel into the ground.
c) Move the machine/mandrel to the specified vertical drainage wick location and insert the mandrel with anchoring device in place using static force (and/or vibratory force if necessary) into the ground to the desired depth.

d) Extract the mandrel, leaving the anchoring device and the completed or installed vertical drainage wick in place, uncontaminated and the proper depth.

e) Cut the vertical drainage wick off the contract-specified length above the working surface.

f) Check the vertical drainage wick installation machine mast to make sure it is plumb. Use hydraulic controls to correct if not within specification.

Fig. 11 Installation of drain.

Splicing vertical drainage wick

Vertical drainage wick is supplied on wick rolls. Each wick roll will hold about 1000 ft. of drain or 305 m. Once the wick roll is used off, a splice is necessary to add the next wick roll. To splice, cut the end of the previous wick roll at an angle and stuff it inside the end of the new wick roll. Then staple them both together as shown in figure.
7.0 VARIOUS AVAILABLE VARIETIES

There are a large varieties of PVC drains available in the market. Based on literature survey and information available from other sources, a few of them have been described below:

7.1 ALIDRAIN

ALIDRAIN is specially designed to ensure that adequate discharge capacities are maintained at all times, even under the most severe conditions. It is a pre fabricated band-shaped drain, consisting of a polyethylene core embossed with offset alternating rows of high and low studs and wrapped in a filter material. The core is perforated and designed in such a way as to allow free flow of water in all directions (vertical, horizontal and diagonal) along and across the core.

The product specifications are as follows:
<table>
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<th>S.No</th>
<th>Specifications</th>
<th>Value</th>
<th>Test method</th>
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<tbody>
<tr>
<td>1.</td>
<td>Drain Composite</td>
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<td>1.1</td>
<td>Discharge Capacity (Confining Pressure)</td>
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<td>1.1.1</td>
<td>Straight (240 kPa)</td>
<td>2.0 X 10^-2 l/s</td>
<td>ASTM-D 4716 (Note 1)</td>
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<tr>
<td>1.1.2</td>
<td>Kinked (240 kPa)</td>
<td>1.6 X 10^-2 l/s</td>
<td>ASTM-D 4716 (Note 2)</td>
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<td>Note 1: Flow measurement taken at i = 1.0 in a confining medium of closed-cell neoprene: straight. Note 2: Flow measurement taken at i = 1.0 in a confining medium of closed-cell Neoprene “Z” folded (interior angles &lt;15”)</td>
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<tr>
<td>1.2</td>
<td>Tensile Properties (Full width test)</td>
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<tr>
<td>1.2.1</td>
<td>Tensile strength</td>
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<td>1.2.2</td>
<td>Elongation at break</td>
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<td>1.2.3</td>
<td>Elongation at 1 KN</td>
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<td>Dimensions:</td>
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<td>1.3.2</td>
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<td>2.3</td>
<td>Strength:</td>
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<td>Tensile Strength at break</td>
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<td>Elongation at break</td>
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<td>2.3.3</td>
<td>Trapezoidal tear</td>
<td>240 N</td>
<td>ASTM - D 4533</td>
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<td>3.</td>
<td>Core: (Full width Test)</td>
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### 7.2 STRIP DRAIN

STRIP DRAIN is geo-composites pavement edge drain. It combines a thermoformed polymer core and geo-textile polymer fabric warp and was developed to provide an effective economical alternative to complex aggregate drain and filter system. This combination offers efficient soil filtration, high flow capacity, high compression resistance and long term durability – all in one pre-fabricated, pre-engineered easy to install product. Strip drain geo-composite pavement edged drains can economically meet the drainage needs of embankment while providing long-term durability comparable to more expensive aggregate/trench systems. Strip drain geo-composite pavement edge drains are available with full complements of fittings. End outlets of discharging the drain at the end of a run and a side outlet fittings maximize flow efficiency and system performance. The snap lock coupling ensures a positive connection between rolls of drain. This provides a high resistance to joint pull- apart and planer alignment to ensure efficient flow characteristics and soil tight connections. End outlet and side outlet fittings are moulded with nominal 10 cm diameter plastic pipe outlet stubs for easy connection of the under drain to the outlet pipe.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Property</th>
<th>Strip drain 75</th>
<th>Test Methods</th>
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<td>1.1</td>
<td>Composition</td>
<td>High density polyethylene</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Thickness</td>
<td>.75 inch</td>
<td>ASTM D 5199</td>
</tr>
<tr>
<td>1.3</td>
<td>Compressive strength @ maximum 10% deflection</td>
<td>5,760 psf</td>
<td>ASTM D 1621</td>
</tr>
<tr>
<td>1.4</td>
<td>Flow capacity (geo-textile-)</td>
<td>12 Gal/Mic Ft width</td>
<td>ASTM D 4716</td>
</tr>
</tbody>
</table>

<p>| 3.1   | Tensile strength break          | 1300 N                          | ASTM - D 4595 |
| 3.2   | Elongation at break             | 20%                             | ASTM - D 4595 |</p>
<table>
<thead>
<tr>
<th></th>
<th>laminated core in soil environment) @ 10 psi, ( I = 1.0 )</th>
<th>(minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 Fungus resistance</td>
<td>No growth</td>
<td>ASTM G 21</td>
</tr>
<tr>
<td>1.6 Moisture absorption</td>
<td>&lt;0.5%</td>
<td>ASTM D 570</td>
</tr>
<tr>
<td>2. Geo-textile (minimum average roll values):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Grab tensile strength</td>
<td>95 lbs</td>
<td>ASTM D 4632</td>
</tr>
<tr>
<td>2.2 Grab elongation</td>
<td>50%</td>
<td>ASTM D 4632</td>
</tr>
<tr>
<td>2.3 Trapezoidal tear</td>
<td>40 lbs</td>
<td>ASTM D 4533</td>
</tr>
<tr>
<td>2.4 Mullen burst</td>
<td>170 psi</td>
<td>ASTM D 3786</td>
</tr>
<tr>
<td>2.5 Puncture</td>
<td>45 lbs</td>
<td>ASTM D 4833</td>
</tr>
<tr>
<td>2.6 A.O.S</td>
<td>70-100</td>
<td>ASTM D 4751</td>
</tr>
<tr>
<td>2.7 Water flow rate</td>
<td>180 Gal/Min/Sq.ft</td>
<td>ASTM D 4491</td>
</tr>
<tr>
<td>2.8 Coefficient of permeability</td>
<td>0.20 cm/sec</td>
<td>ASTM D 4491</td>
</tr>
<tr>
<td>3. Standard roll dimensions (nominal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1 Width</td>
<td>22” and 44”</td>
<td></td>
</tr>
<tr>
<td>3.2 Length</td>
<td>180’</td>
<td></td>
</tr>
<tr>
<td>3.3 Weight</td>
<td>145 lbs (44” X 180” Roll)</td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 13 Strip Drain](image-url)
7.3 **FLORA DRAIN:**

FLORA DRAIN has two components – a core, which serves as a water conduit, and geo-textile filter fabric, which allows water to pass into the core while restricting the movements of soil particles, which might clog the core. The Flora drain filter material uses a strong, tough, permeable woven filter fabric made from 100% yarns. The yarns are woven in twill or plane weave pattern to form a tough dimensionally stable fabric, having good tear and puncture resistance. It has a large number of openings with a range of opening sizes through its structure instead of a few openings of fixed size as in synthetic mono filament woven fabrics. The hairiness of the jute yarns used in weaving create a tortuous pathway resembling that of a well graded aggregate filter rather than a simple straight line exit for soil particles. Because of its unique structure, the filter fabric has both high permeability and the ability to restrict the movement of most soil particles, while allowing the very fine silts to flow into and out of the drain. The initial removal of very fine silts from the soil is beneficial because this leaves the larger particles to form a highly permeable soil network against the fabric. The soil network restricts the further movement of fine soil particles and helps to develop a graded filter. This soil filter effectively stops piping of soil and prevents other fine particles from entering the drain. The fabric filter being more permeable than the soil filter and the natural soil does not restrict the flow of water into the drain. The Flora drain consists of four yarns of coir laid parallel to each other separated by the stitch on the drain. The dimensionally stable core with good collapse resistance provides discharge passages for water flowing to the surface. The Flora drain is packed in rolls of 150 m or as per customers’ specification followed by wrapping with a polyethylene sheet and light jute fabric properly stitched and marked. Its various applications includes vertical drainage in embankment construction, under water consolidation, tank form foundation and material storage areas and land fill areas.
### Product Specification

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Item</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fabric</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Jute Fabric</td>
<td>D. W. plain weave</td>
</tr>
<tr>
<td>1.2</td>
<td>Grist (Warp* Weft)</td>
<td>10*28 lbs</td>
</tr>
<tr>
<td>1.3</td>
<td>Threads/dm (Ends* picks)</td>
<td>68*39</td>
</tr>
<tr>
<td>1.4</td>
<td>Width</td>
<td>88cm (44 cm strip* 2)</td>
</tr>
<tr>
<td>1.5</td>
<td>Weight</td>
<td>675 gm/sq.m</td>
</tr>
<tr>
<td>1.6</td>
<td>Tensile strength</td>
<td>Warp – 160 kg: Weft-180 kg (10*20)cm strip</td>
</tr>
<tr>
<td>2.</td>
<td>Core</td>
<td>Two ply coir yarn Sona King</td>
</tr>
<tr>
<td>3.</td>
<td>Product</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Width</td>
<td>8-10 cm</td>
</tr>
<tr>
<td>3.2</td>
<td>Thickness</td>
<td>8mm</td>
</tr>
<tr>
<td>3.3</td>
<td>Weight</td>
<td>150 g/m approx</td>
</tr>
<tr>
<td>3.4</td>
<td>Length</td>
<td>150m</td>
</tr>
<tr>
<td>3.5</td>
<td>No. of stitches/cm</td>
<td>6 to 8</td>
</tr>
<tr>
<td>3.6</td>
<td>Strength</td>
<td>45 KN</td>
</tr>
<tr>
<td>3.7</td>
<td>Pore size</td>
<td>300 microns</td>
</tr>
<tr>
<td>3.8</td>
<td>Discharge capacity</td>
<td>12 l/s at 50 Kpa</td>
</tr>
</tbody>
</table>

#### 7.4 FLEXI DRAIN

FLEXI DRAIN consists of a drain body, which is corrugated Flexi-drain core made of poly-propylene. It is specially designed to provide a high discharge capacity, high tensile and compressive strength. A filter jacket which is strong and durable non-woven polypropylene with high tensile strength, high permeability and effective filtering properties envelopes the core. It acts as a filter to allow passage of ground water into the drain core while eliminating...
movement of soil particles and preventing piping. It also serves as an outer skin to maintain the cross sectional shape and hydraulic capacity of the core channels. By combining both the features of unique cores and filter jacket, it gives effective, fast and reliable performance. The range of Flexi drain is available in a choice of filter fabric to suit various soil conditions and engineering practices.

7.5 MEBRA DRAINS

It is a prefabricated drain strip consisting of a polypropylene core extruded into a highly flexible configuration and designed to transmit a maximum water flow on both sides of the core. The core is wrapped with strong and durable non-woven polypropylene filter fabric selected for its excellent filtration properties. A vertical drainage system using Mebra Drain allows for a faster removal of excess pore water and at the same time decreases the risk of slip plane failure, with unrestricted fill placement. With the aid of Mebra Drain, the consolidation period can be significantly reduced.

Mebra Drain is available in two types: MD 7407, suitable for projects with low requirements like a maximum drain depth of 25 m and a compression ratio of 20%. and MD88/7007, suitable for all applications depth up to 80 m and a compression ratio of 50% are possible without loss of performance. Mebra Drain is subject to continuous quality control to ensure reliable performance.

7.6 SOLPAC DRAIN

This vertical prefabricated “wick” drain for soil consolidation includes 2 complementary components: a cusped core made with HDPE material, fully wrapped with a synthetic filter. The combination of these 2 components results in a reliable and high-performing drainage product. SOLPAC drain can bear deformation during soil consolidation with no risk of pinch-off. The hydraulic conductivity remains protected all along the consolidated phase. The core and
geo-textile, both are biologically inert and resist to any chemical agent commonly found in soil.

The wick drain SOLPAC range is available in two thickness:

- 4 mm for SOLPAC C400
- 6 mm for SOLPAC C600

8.0 CONCLUSION

Each and every project is unique due to its features, geographical locations and importance, hence while adopting one variety amongst various available alternatives, precautions should be kept in view. In addition, while deciding the method to be adopted for enhancing the process of consolidation, the economy aspect, time available for construction and availability of various material should be considered.

The need of the method depends upon the time frame for completion of project. If project is to be completed early; the stage construction cannot be employed. For such cases, the methods for quick consolidation of sub-soil have to be adopted using PVC vertical drainage system. In case, when no time constraint is there, installation of sand drains with stage construction after proper design can be adopted.
9.0 REFERENCES

5. Improvement Techniques of soft ground in subsiding and Low land Environment by D.T. Bergado, J.C. Chai, M.C. Alfaro & A.S. Balasubramanium.
6. Design and construction of earth structures both on and into highly compressible sub-soils of low bearing capacity – Building on soft soils by A. A. Balkema
7. Soil Improvement By Preloading, by Aris C. Stamatapoulos, Panagiotis C. Kotzias.

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Manufacturers of Prefabricated Vertical PVC Drain System

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