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# Review on " Effect of Smear on Consolidation by Radial Seepage Flow Using PVD"

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## ABSTRACT

*The installation of vertical drains with a mandrel causes significant disturbance of the subsoil surrounding the mandrel, resulting in a smear zone. The smear zone affects the consolidation of the soil. This paper presents a new analytical solution for the consolidation analysis of soil with a vertical drain. this zone retards the horizontal consolidation of soft clays in the vicinity of PVD. The characteristics of the smear zone, such as its extent and hydraulic conductivity remain discrepant among investigators. This study attempts to determine the extent of the smear zone and to measure the hydraulic conductivity of the smear zone directly by laboratory tests.*

**KEY WORDS:** ***Vertical drain, Consolidation, Smear zone, Permeability***

## INTRODUCTION

The rapid development and associated urbanization have compelled engineers to construct earth structures, including major highways, over soft clay deposits of low bearing capacity coupled with excessive settlement characteristics. Restricted space, tight construction schedules, environmental and safety issues, maintenance costs and the longevity of earth structures have continued to demand innovation in the design and construction of essential infrastructure on soft clays. For innovative design constructions on extremely soft foundation medium, it is required to increase the strength of the soil.

Thus use of appropriate geosynthetic materials offers the possibility to solve or drastically reduce the severity of problems. Even though there are a variety of soil improvement techniques available to stabilize the soft ground, the application of preloading with prefabricated vertical drains is still regarded as one of the classical and popular methods in practice.

Geosynthetic is mainly used for Ground Improvement Techniques. As to resolve this problem and ensure serviceability, pre-compression or preloading with prefabricated vertical drains are usually selected as the soft ground improvement method attributed to its cost-effective factor.

## WHAT ARE VERTICAL DRAINS

Vertical drains are positioned vertically through the ground, generally made of coarse granular material, particularly Sand. Generally Vertical drains are used for the acceleration of the rate of consolidation of the clay layer. Installation of vertical drains can be achieved in a various ways depending upon the type of drain to be installed and the nature of the ground. The installation of vertical drains in the field causes significant remolding of the subsoil, especially in the immediate vicinity of the mandrel. The permeability of the clay layer is greatly reduced due to the reorientation of the soil particles. This phenomenon is known as the "smear". Reduction in the permeability takes place due to this effect and proper functioning of the drain is not achieved.

Classical solutions Barron 1948; Hansbo 1981; Indraratna and Redana 1997 have considered the influence of the smear zone with an idealized two-zone model, where the smear zone is the disturbed region in the immediate vicinity of the drain, and the outer zone is the intact undisturbed region.

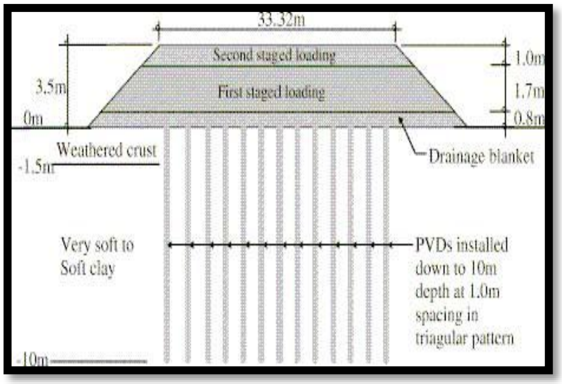

Fig: 1 PVD installed to reduce the drainage path

## HISTORICAL BACKGROUND AND PROGRESS

According to Holtz et al. (1991), the American engineer D.J. Moran first proposed the use of sand drains as a means for deep stabilization in 1925. Following this, the first practical sand drain installation were constructed in California a few years later. In the last 20 years, a large number of prefabricated drains have appeared on the market. Till 1970, most of the drains used were vertical sand drains, mainly using close-ended mandrels, which produced a large smear zone. In 1950, jetted sand drains came into use in Netherlands, but it had problems of additional costs of large jetting pumps and difficulties in driving out large quantities of water. First use of smaller diameter band-shaped cardboard wicks was by KJELLMAN (1970). In Sweden in the mid to late 1930's, Kjellman began experiments and obtained patents on the first prototype of a prefabricated drain made entirely of cardboard. It was soon discovered that the prefabricated drains were subject to undesirable rapid deterioration, particularly near the top of the drained clay layers. Even with these difficulties, Kjellmall wick drains have been used occasionally in both Europe and Japan during the past 50 years (Holtz et al., 1991). However, until the early 1970s, the vast majority of vertical drains installed in the world were sand drains. In 1971, Wager improved on the Kjellman wick by using a grooved plastic polyethylene core in place of the cardboard. This drain was called Geodrain and the first models utilized Kraft paper filters. Later models were provided with non woven textile filters (Holtz et al., 1991). Recent trends are inclined to the use of Prefabricated Vertical Drains (PVD) using man-made fabrics like Polyethylene, Polyvinyl chloride, Polyester & Polypropylenes and the latest trend is to use the PVD having starch based plastic cores, or otherwise the use of Electro-Conductive PVD

## CHARACTERISTICS OF PVD

A prefabricated vertical drain can be defined as any prefabricated material or product consisting of synthetic filter jacket surrounding a plastic core having the following characteristics:

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.

The jacket material consists of non-woven polyester or polypropylene geotextiles or synthetic paper that function as 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 the drain even at large lateral pressures. Typical prefabricated drain products are shown in Fig. 3.

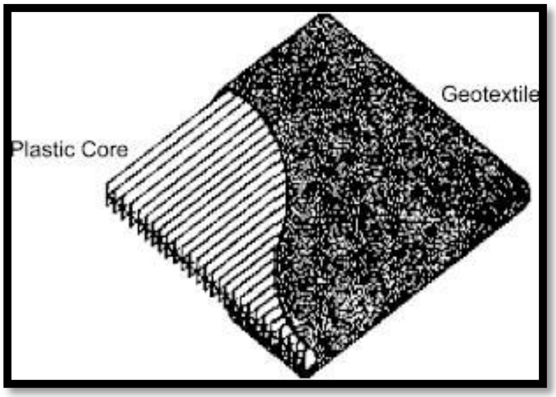

Fig. 2 Component of PVD

Fig.3.Typical prefabricated drain products

## INSTALLATION METHODS OF VERTICAL DRAINS

Vertical Drains can be used in low permeability soils (clays, silts) and can significantly increase the rate of consolidation. Prefabricated Vertical Drains consist of a flexible plastic core (flat or cylindrical in shape) wrapped in a spun-bond filter fabric and can be installed to depths of more than 50 m. Depending on the type and nature of the soils to be treated, it is also possible to install sand or stone drains.

1. PVD are installed by pushing a hollow steel mandrel which houses the wick drain material itself. The mandrel is driven into the ground by a mast attached to an excavator. 2
2. At the base of the mandrel, the wick material is looped through a steel anchor which holds the drain securely in place. Once the required depth or refusal is reached, the mandrel is extracted while the drain stays anchored at depth. Once the mandrel has been fully extracted from the ground, the drain is cut about 15 to 20 cm above the working platform.
3. To be able to push the mandrel into the ground, the tip resistance of the soils ( particularly, the working platform made of draining granular material as well as any geotextiles layer should not exceed about 5 MPa. In the case of very stiff soils, the mandrel may be vibrated or hammered into the ground or predrilling might be required

## SMEAR ZONE

The installation of PVDs requires the use of a steel mandrel, which firmly clamps the drain during its insertion into the ground. Accompanying the mandrel is an anchor plate fixed to the bottom of the drain, which serves to prevent soil from entering the drain and to keep the drain in place upon removing the mandrel. Below is a simple diagram of the anchoring system.

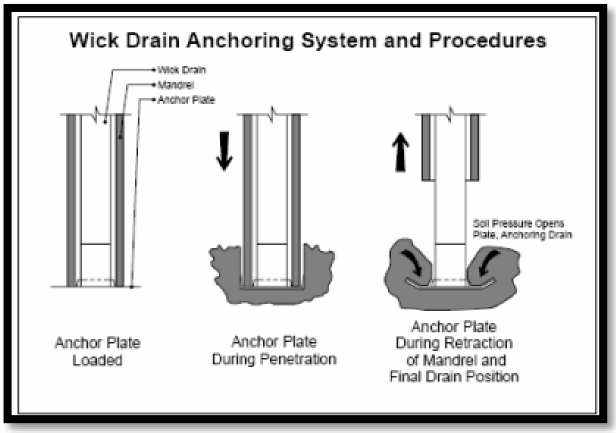

Fig: 4. Drain, Mandrel and Anchor Plate

As the mandrel is pushed downward and upon its removal once the drain is in place, it disturbs the soil surrounding the drain producing shear strains and displacement that decrease its hydraulic conductivity.

Minimizing the mandrel cross sectional area will reduce potential for soil displacement and disturbance. It may be suitable to taper the mandrel tip, as long as the stiffness is not sacrificed. For soil profiles with many different layers, large kh/kv ratios, the laying may enhance horizontal permeability. It is possible to retard the lateral seepage of pore water into the drains by smearing of pervious and less pervious layers. Static pushing is preferred to drive or vibrating the mandrel in sensitive soil, but may cause buckling or wobbling of the mandrel. An idealization of the mandrel disturbance area is shown in Figure 5.

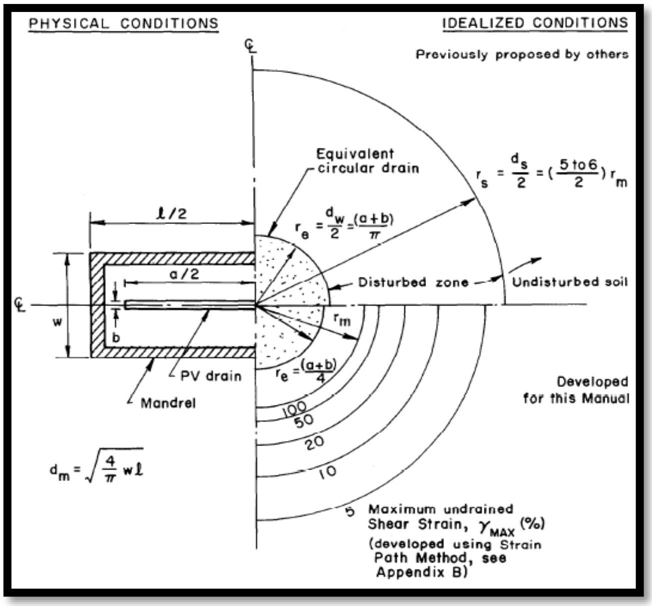

Fig.5. Idealization of the mandrel disturbance area

## APPROXIMATION OF THE DISTURBED ZONE AROUND THE MANDREL

Although there have been numerous studies conducted to assess properties of the smear zone including range, shape, and effect on hydraulic conductivity, there is no precise consensus among researchers. Nevertheless, some generalities are listed below: The larger the mandrel, the larger the smear zone. The shape of the mandrel affects the shape of the smear zone.
Square/Circular Mandrel – Square/Circular Smear Zone
Rectangular Mandrel – Ellipsoidal Smear Zone
The outer boundary of the Smear Zone has been found to range from 4-18 times the equivalent mandrel radius.
The overlap of smear zones from adjacent drains complicates smear zone calculations further.

## SMEAR EFFECTS AND DISTURBANCES

The effect of various thicknesses of smear was first considered by Barron (1948). Barron assumed the analysis for the ratio of permeability in the undisturbed and smear zones was 10.

Barron showed that if the thickness of the smear zone was 1/6th of the drain radius, the time to achieve a particular degree of consolidation would be increased by about 20%. If the thickness of the smear zone was increased to twice the drained radius, then the effect would be approximately to double the consolidation time

Cassagrande and Poulos (1969) concluded that the permeability of the smear zone could be considerably less than the 1/10th of that of the undisturbed soil, and possibly as little as 1/1000.

In the case of an 18 in. (457 mm) dia. driven casing, a typical size for main sand drain installations, the thickness of the remolded zone would be about 90 mm. The effect of such a thick smear zone of greatly reduced permeability would be to negate any potential beneficial effects of such a drain. Cassagrande's and Poulos (1969) concluded that drains installed by displacement methods were generally uneconomic and failed to produce any beneficial effects in many cases. A controversy generally arises in cases where the band-drains installed by displacement methods produced good results. In such a case, it is necessary to examine the effect of area of the soil/drain interface after installation of the drain. The modern band-drains are generally 100 mm in width, about 4mm thick, and are installed using a lance about 140mm wide by 30 to 40mm thick. This produces a smeared zone about 10mm thick would be expected along the wall of the hole made by the lance

After a period of time, the smear zone would lie against the filter layer of the drain McGown and Sweetland (1973) and Marks (1975) showed that a fabric filter initially allows the finer soil particle to pass through the filter, i.e. piping occurs. As these smaller particles pass through the fabric, a bridging network of the larger soil particles builds up adjacent to the drain, thus forming a natural graded filter within the soil, the thickness of which was found to be several millimeters.

The effect of the piping is to remove the clay particles from the smeared zone immediately adjacent to the drain. Too large a pore size will permit continuous piping of the soil leading eventually to a significant loss of ground, and clogging of the drain if the upward velocity of the water is less than the settling velocity of the heavier particles. Too small a pore size will produce a finer soil filter than desired. This will not only reduce the thickness of the soil filter and therefore restrict the amount of smear removed, but will also a produce a soil filter of low permeability, significantly effecting the efficiency of the drain installation Field and laboratory experience by the fabric manufacturers has shown that the optimum filter for drains used in clayey soils has an average pore size of about 10-20µm methods were generally uneconomic and failed to produce any beneficial effects Although there are numerous variations in installation equipment for vertical drains, most of the equipment has fairly common features, some of which can directly influence the drain performance. The installation rigs are usually track-mounted boom cranes. The mandrel protects the drain during installation and creates the space for the drain by displacing the soil during the penetration. The mandrel is penetrated into the subsoil using either static or vibratory force. The drain installation results in shear strains and displacement of the soil surrounding the drain. An example of soil movements produced in Bangkok clay as a result of the installation of displacement sand drains is given in Fig. 4.15. The shearing is accompanied by increases in total stress and pore pressure.

The installation results in disturbance to the soil around the drain. The disturbance is most dependent on the mandrel size and shape, soil macro fabric, and installation procedure. The mandrel cross-section should be minimized, while at the same time, adequate stiffness of the mandrel is required.

## CASE STUDY- I

Bergado et al. (1991), from a full scale test embankment performance, obtained faster settlement rate in the small mandrel area than in the large mandrel area indicating lesser smeared zone in the former than the latter. For design purposes, it has been evaluated by Jamiolkowski et al. (1981) that the diameter of disturbed zone, $d_s$, can be related to the cross-sectional dimension of the mandrel as follows:

$$d_s = \frac{(5-6)d_m}{2}$$

Where, $d_m$ is the diameter of a circle with an area equal to the cross-sectional area of the mandrel. At this diameter, the theoretical shear strain is approximately 5 % as shown in Fig. 6. Hansbo (1987) recommended the following expression based on the results of Holtz and Holms (1973) and Akagi (1979):

$$d_s = 2d_m$$

This relationship has been verified in the reconstituted soft Bangkok clay by Bergado et al. (1991) using a specially designed laboratory drain testing apparatus (Fig. 8) as plotted in Fig. 9. Thus, the influence of smear increases with increasing drain diameter for sand drain or mandrel diameter for prefabricated drains (Hansbo, 1981). The time-settlement relationships obtained from full scale field test embankment (Bergado et al. 1991) is shown in Fig. 10 for small mandrel area together with the settlement prediction. The performance of PVD is well predicted with smear effect taken into consideration using $k_h/k_v = 10$ and
$d_s = 2d_m$. (Bergado et al. 1993b).

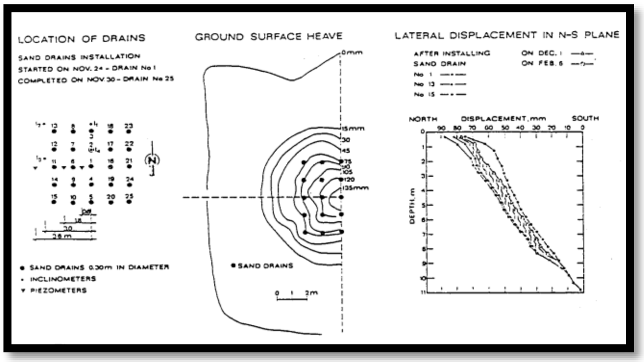

Fig: 6. Ground movements during and after installation of driven Sand Drains in Soft Bangkok Clay (Akagi, 1981)

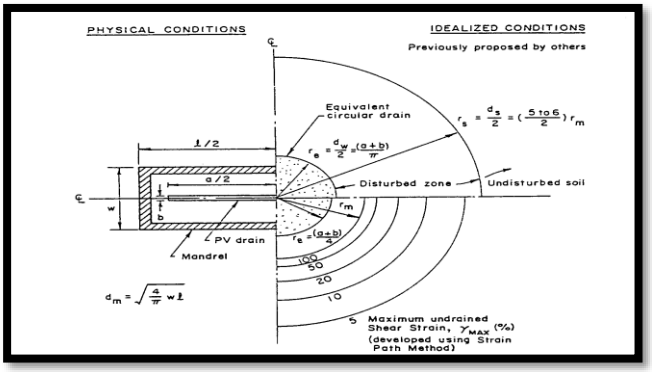

Fig.7. Approximation of Disturbed Zone Around the Mandrel (Rixner et al. 1986)

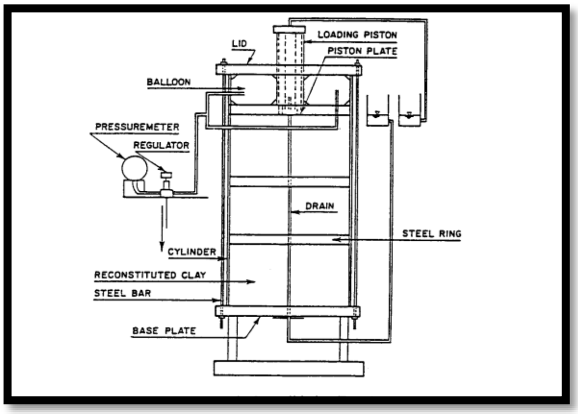

Fig.8. Schematic of Large Scale Consolidation Test Apparatus **(Bergado et al. 1991)**

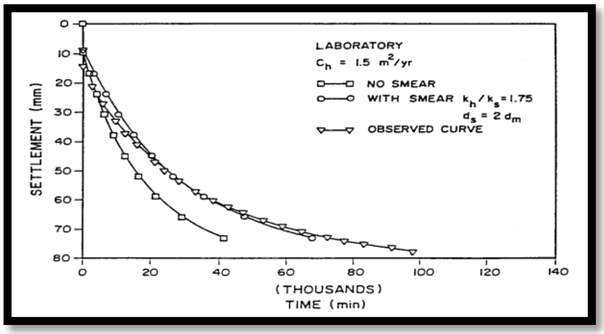

Fig: 9. Effects of Smear on Rate of Settlement **(Bergado et al. 1991)**

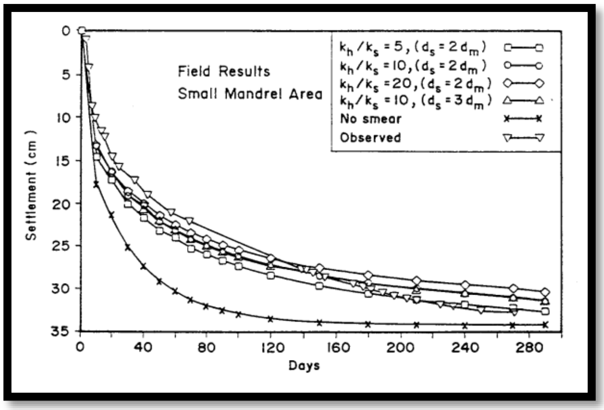

Fig.10 Observed and Predicted Time- Settlement Relationship from Full Scale Field Test **(Bergado et al. 1993)**

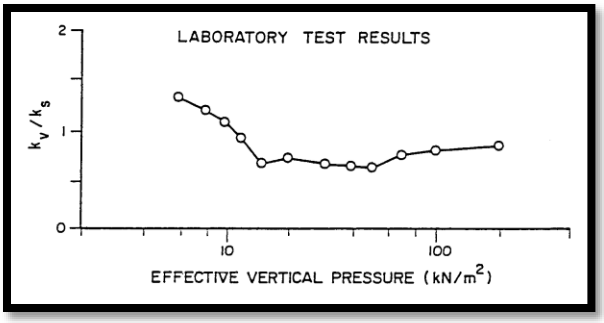

Fig.11. **Kv/Ks Values with Effective Pressure (Bergado et al. 1991)**

## CASE STUDY II

Atsuo Onoue carried a field study of consolidation by vertical drains taking well resistance and smear into consideration. The results obtained were as follows:

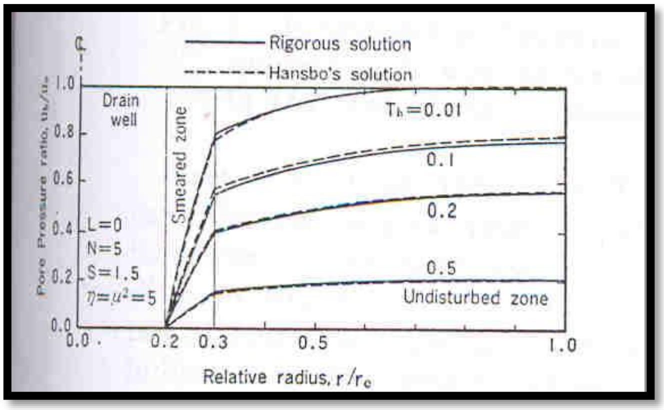

Fig:12. **Distribution of pore pressure ratio with smear without well resistance**

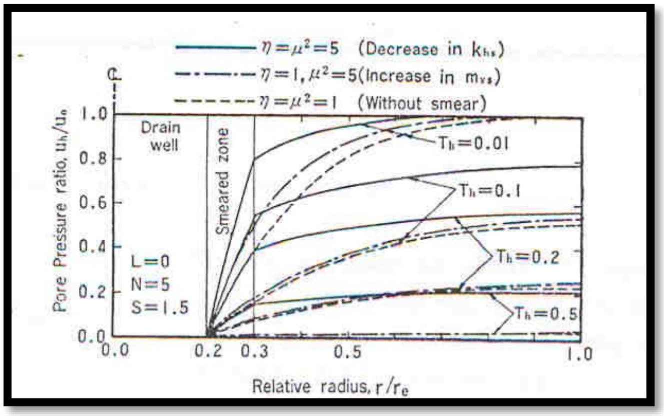

Fig: 13. **Distribution of pore pressure ratio in the presence and absence of smear**

## CONCLUSION

- Vertical drains are generally used in cases where the compression of the soil is dominated by primary consolidation.
- Vertical drains accelerate the rate of consolidation and the rate of settlement.
- It leads to the considerable reduction in the construction and maintenance costs.
- Smear effects are generally caused during the installation of the drains by displacement methods such as driving and washing.
- It can be overcome by the proper selection of the drain filter fabric and the size of the lance.
- Generally surcharge loading eg. preloading, heavy tamping etc. can be used in along with the sand drains for better improvement of the compressible soils.
- Installation of mandrel leads to an extensive zone of disturbance, and considerable increase of pore water pressure, thus more attention is to be given to the equipment and installation procedure.
- Spacing, diameter and depth of the vertical drains have a considerable effect on the design of the drains against smear.

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