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Performance of Composite and Monolithic Prefabricated Vertical Drains

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ABSTRAK

Dengan bertambahnya penggunaan saliran tegak pemprabikin dalam merawat tanah-tanah liat lembut, berbagai jenis saliran telah muncul di Malaysia. Saliran-saliran ini terdiri daripada saliran rencam (dengan pembalut geotekstil) dan juga saliran monolit (tanpa pembalut geoteksil). Beberapa jurutera beranggapan bahawa kesemua jenis saliran berfungsi dengan baik. Namun, beberapa kajian kes yang telah dijalankan menunjukkan terdapat beberapa saliran yang tidak berfungsi dengan cekap. Oleh yang demikian kajian diperlukan untuk mengenalpasti saliran yang tidak sesuai ataupun saliran yang tidak berfungsi dengan baik. Kertas kerja ini memperihalkan berbagai ujian yang telah dijalankan ke atas dua jenis saliran (iaitu saliran rencam dan saliran monolit) untuk mengkaji prestasi saliran-saliran tersebut apabila terkena tekanan sisi. Keputusan yang diperolehi menunjukkan pentingnya teras saliran dibaluti dengan sarung turas (geotekstil). Kajian ini juga menunjukkan bahawa jenis pembalut geotekstil memberi kesan terhadap prestasi saliran. Geotekstil tenun yang agak kaku menunjukkan prestasi terbaik.

ABSTRACT

With the increasing use of prefabricated vertical drains in the improvement of soft clay there are many types of these drains, both composite (with geotextile wrapping) and monolithic (without geotextile wrapping), available in Malaysia. Some engineers have the impression that all drains perform satisfactorily. However, case studies have shown that there are cases where vertical drains failed to function. Therefore, there is a need to identify the drains which are not suitable or do not perform satisfactorily. This paper describes the various tests that have been carried out on two types of drain (i.e. one composite and one monolithic) to study their performance under lateral pressure. Test results show the importance of having a filter sleeve around the drain core. They also indicate that the type of geotextile wrapping affects the performance of the drain. A relatively stiff woven geotextile seems to be the most favourable.

INTRODUCTION

Consolidation settlement of highly compressible cohesive soils often creates serious problems in foundation engineering. The consolidation process is governed by the rate of excess pore pressure dissipation which is dependent on the coefficient of consolidation, Cv and the thickness of the soil layer. The time required to achieve complete primary consolidation may be considerable for a thick layer of soil with a low value of Cv. To reduce the time of consolidation on such soils, preloading in combination with vertical drains has been found to be effective (Stamatopoulus and Kotzias 1985). The preload, often in the form of an embankment, causes consolidation due to excess pore pressure in the clay between the drains. The pore water can escape horizontally towards the drains and flow along the drains to a drainage blanket or a permeable layer above or below the soil layer. The rate of consolidation is increased because the shortest drainage path is reduced as vertical drains are placed at relatively close spacing (0.8 - 3m). Furthermore, the value of Ch in most sedimented cohesive soils is 2-5 times higher than Cv, especially if there are continuous sand and silt seams.

The conventional type of vertical drain is the sand drain. They were first installed in the USA during the 1930s. The diameter of sand drains ranges from 18cm to 30 cm. However, there are some difficulties associated with sand drains. Firstly, the soil may be considerably disturbed during installation especially if the displacement method, where a closed-end tube is driven into the soil, is used. Necking of the drain may occur, which could reduce the effective diameter. There is also the possibility of discontinuity in the drain if excessive settlement and lateral movement occur. Furthermore, suitable sand may not be easily available.

The first prefabricated drain, the Kjellman Cardboard Wick, was introduced in 1937 (Kjellman 1948). It was a band-shaped drain, 3.5 mm thick by 100 mm wide, made from 3 layers of cardboard; two outer layers serving as a filter and a middle layer forming 10 longitudinal flow channels. Subsequently, many types of prefabricated band-shaped drain were developed and prefabricated drains have now largely replaced sand drains. Many of the difficulties associated with sand drains were eliminated with the prefabricated drain.

Prefabricated vertical drains often consist of a profiled plastic core wrapped in geotextile filter fabric (composite). There are also unwrapped vertical drains (monolithic drains). These are inserted into the ground with the help of a mandrel, sometimes to a depth of 30 - 40 metres. At this depth, the lateral pressure on the drain may close the drainage paths along the plastic core so much so that the flow of water is inhibited. This problem may be aggravated with time because the geotextile and the core are likely to be clogged up by the clay particles and the plastic core may deform further with time. This is because of the filter extensibility and creep of the core and filter under lateral soil stress. As noted by Holtz *et al.* (1987) very few long-term tests have been carried out on prefabricated drains especially when confined in soil.

Scope of Investigation

The design of a vertical drain system is generally based on theoretical solutions in which the drains are assumed to be functioning as an ideal well, i.e. water collected from surrounding soil is allowed to flow freely along the drain to the drainage blanket. However, such ideal conditions rarely exist in practice. Hansbo (1981) has shown that the resistance of the central core can have an important effect on the consolidation process of a vertically drained soil, particularly for greater drain lengths. Well resistance has been recognized by researchers and has been incorporated in theoretical solutions to radial drainage (Barron 1948; Yoshikuni and Nakanodo 1974; Hansbo 1981). The effect of well resistance is quantified by a parameter called discharge capacity, qw. It is defined as the rate of discharge of a drain, Q, under a unit hydraulic gradient, i.

i.e. $qw = Q/i$

With the increasing supply of different types of prefabricated drains, it is necessary to ensure only drains with adequate discharge capacity are used. The discharge capacity is dependent on a number of factors such as the volume of the core available for flow and the effect on lateral earth pressure of that volume, folding and crimping of the drain due to large settlement.

Because of extensibility and the creep of both the core and filter under lateral stress, the discharge capacity of the drain could decrease with time. The extent of the reduction depends on the stress level, duration of stress and the rigidity of the core and the filter, and the geometric shape of the core. For monolithic drains (without a filter sleeve) soil particles can easily be pushed into the core.

In an effort to study the suitability of several soil improvement methods on soft clay the Malaysian Highway Authority constructed several trial embankments between 1986 and 1989. Four common types of vertical drains have been installed underneath some of the embankments. Two of those types of drains have been used as test samples in this investigation. They are Flodrain (composite) and Desol (monolithic).

MATERIALS AND METHODS

An apparatus, as shown in *Fig. 1,* was designed for the above purpose. It has a similar working principle to the Delft Discharge Test (Hansbo 1983; Oostveen 1986). It is a rectangular frame, consisting of four channel sections welded on top of a 6 mm thick mild steel base plate. A 105mm × 10mm slot is cut on two channel sections, one opposite the other, to accommodate the vertical drains. Two perspex tanks are attached to the frame. The inlet tank is 800mm high, with five overflow points at different heights to provide hydraulic gradients of 0.1, 0.25, 0.5, 1.0 and 1.5 respectively across the drain to be tested. The

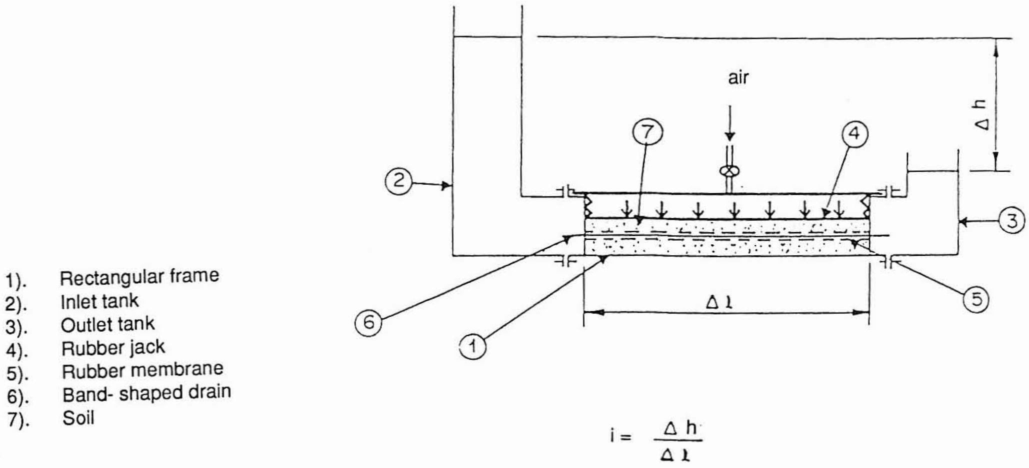
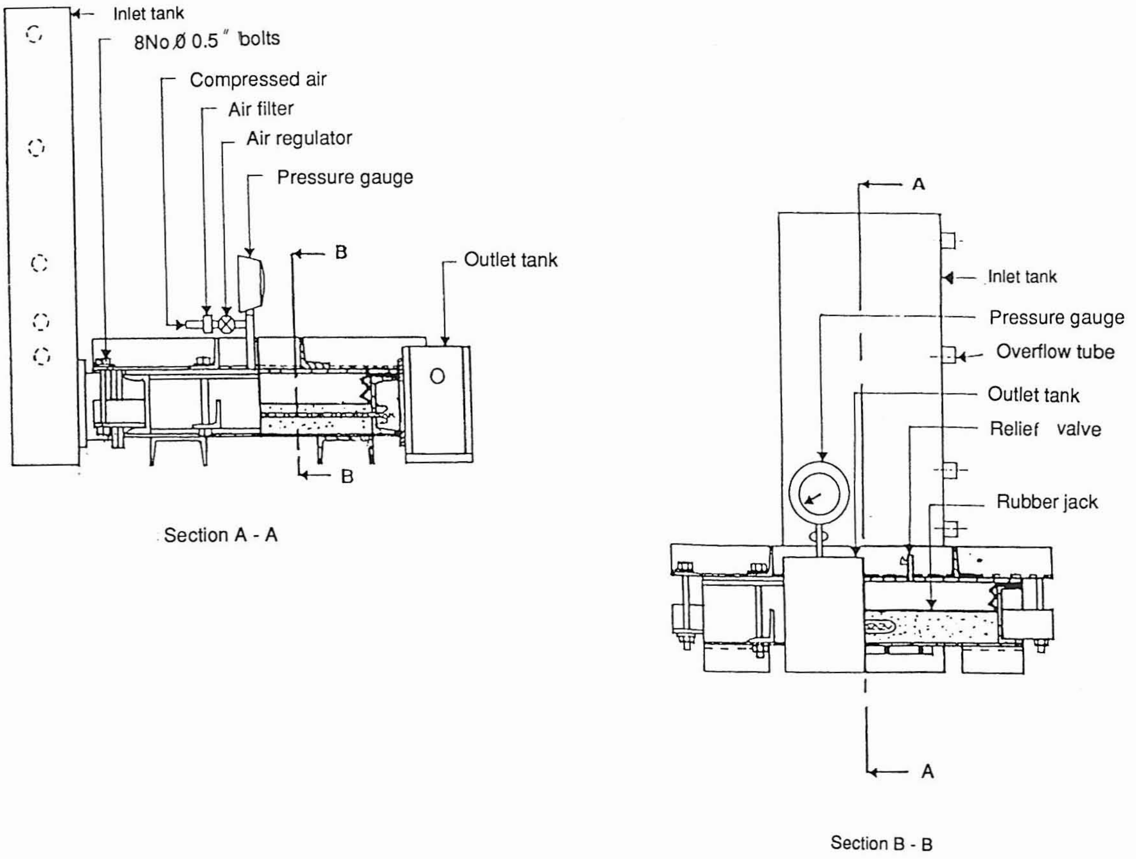


Fig. 1 (a): Schematic diagram of test apparatus



Section A - A

Section B - B

Fig. 1 (b): Assembly drawing of test apparatus

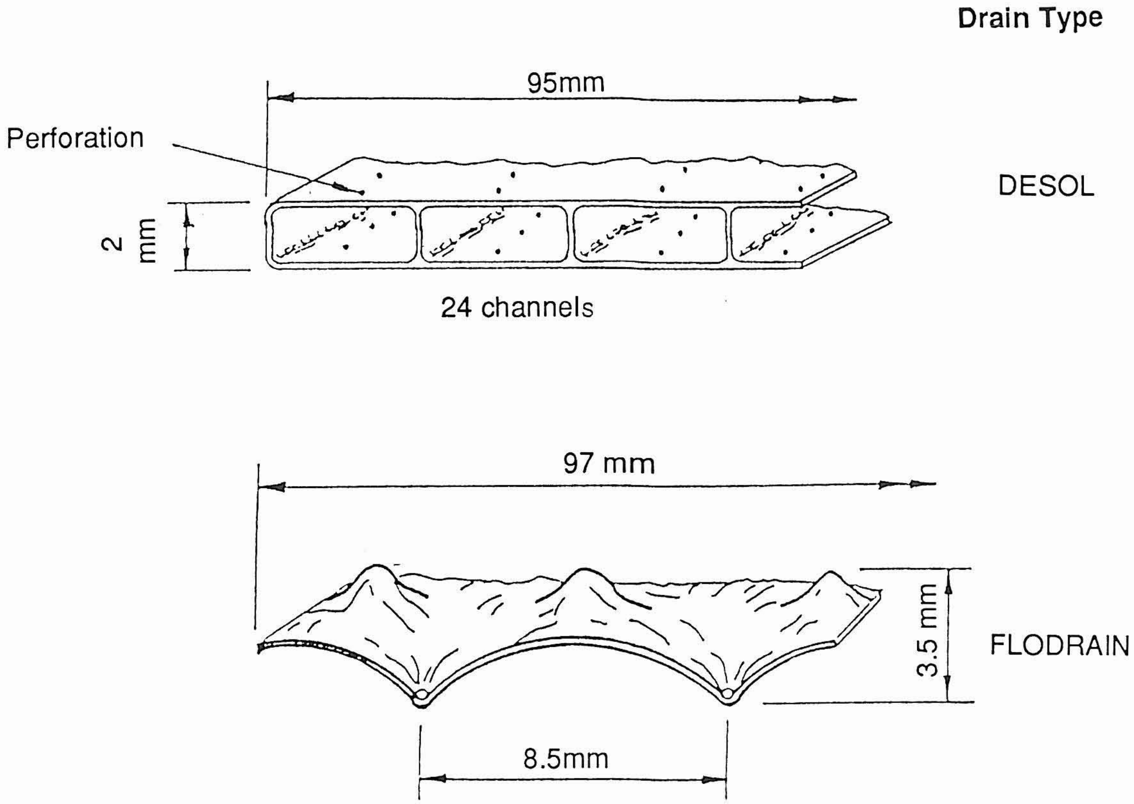


Fig. 2: The geometrical shape of drain cores

outlet tank is comparatively lower with only one overflow tube where the outflow water can be collected. Both the tanks are removable to facilitate the installation of the drains.

The drain to be tested was cut to a length of 480mm. It was then inserted into a rubber membrane before being pushed through the slot. This membrane is necessary to prevent the seepage of water from the drain to the surrounding soil. Otherwise, the flow rate measured at the outlet tank would not be the actual discharge capacity of the drain. The membrane was surrounded with soil which was then subjected to lateral pressure provided by compressed air via a rubber jack. The air pressure in the jack can be adjusted by means of a regulator. In some of the series of tests carried out the drains were enclosed in clay before being surrounded with the rubber membrane, i.e. the drains were in contact with the clay, to see the effect of squeezing of clay particles into the drain core. Five different pressures were applied in the tests ranging from 70 kPa with an increment of 70 kPa.

At the beginning of each test, i.e. after applying an initial pressure of 70 kPa, the outlet tank was connected to a vacuum pump via the outlet tube to draw out any trapped air inside the drain as the water was flowing from the inlet tank towards the outlet tank.

The water level was at first maintained at i = 1.5. The flow rate was taken when a steady flow had been established, which was measured by recording the time required to collect 1000 ml of water at the outlet tank. At least two readings were taken to obtain the average while the pressure and the hydraulic head were maintained. The hydraulic head was reduced to the next value such that i = 1.0 with the pressure at 70 kPa. Flow rate was again measured with the same procedures as above. The test was then repeated for i = 0.5, 0.25 and 0.1 at the same pressure. Then the pressure was raised to 140 kPa. The flow rates were obtained at i = 0.1, 0.25, 0.5, 1.0 and 1.5. This procedure was then repeated for pressures 210, 280 and 350 kPa.

The geometric shapes of the drains are shown in *Fig. 2.* Desol is a monolithic drain and is made of polyolefine. Each strip consists of 24 rows of channels with tiny perforations on the wall (24500 holes/linear metre, diameter 0.2mm). Flodrain is a composite drain, i.e. consists of a core and a filter sleeve, and is made of polyethylene. Each core consists of studs arranged on a flat plane. The usual filter sleeve is Terram T1000. To derive information on the effect of clogging (not clogging of geotextiles) on the discharged capacity of the drain, a series of tests was carried out whereby clay was used in direct contact with the geotextiles.

The effect of different types of geotextiles on the discharge capacity was investigated by wrapping the composite drain with five different types of geotextiles, i.e. Terram T1000, Fibertex F2B, Fibertex G100, Typar TP3407 and Bidim U14. Descriptions of the geotextiles are given in Table 1.

TABLE 1
Types of geotextiles

Fibertex F2B	:	Non-woven needle-punched thermally-bonded polypropylene geotextile
Fibertex G100	:	Non-woven needle-punched thermally-bonded polypropylene geotextile
Terram T1000	:	Non-woven thermally-bonded geotextile produced from continuous filament
Typar TP3407	:	Spun-bonded fabric consisting of a uniform sheet of preferentially oriented continuous filament of 100 % isostatic polypropylene manufactured by integrated process of fibre spinning and bonding
Bidim U12	:	Fabric made from continuous filament polyester fibres that are spun and then mechanically entangled by needle punching.

RESULTS AND DISCUSSION

In every test, the flow rates of a prefabricated band-shaped drain specimen at the prescribed conditions were determined and the results are presented as discharge capacity using equation 1. Since the discharge capacity is dependent on several factors as discussed previously, the conditions under which the test was carried out are stated.

The credibility of the test results depends on the ability to reproduce the results under similar test conditions. For every test series at least one repeat test was carried out for each drain specimen.

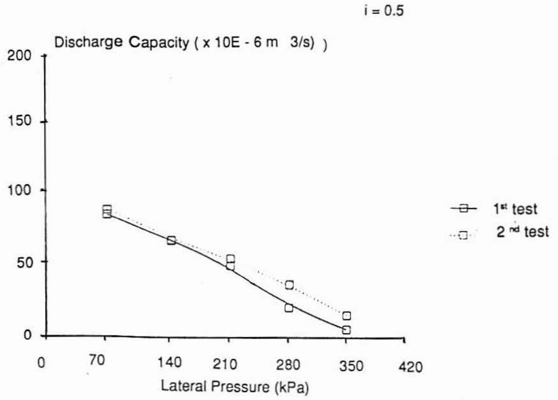


Fig. 3(a): Typical repeatability test results on Flodrain

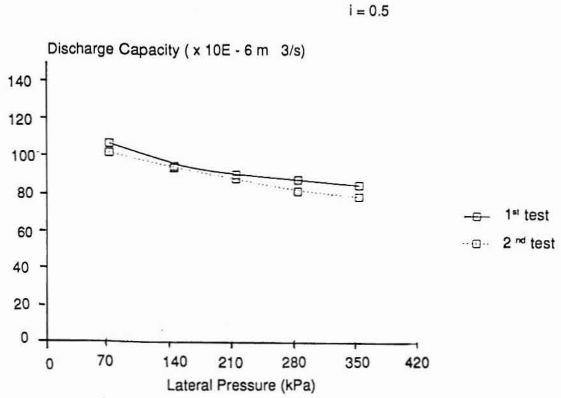


Fig. 3(b): Typical repeatability test results on Desol

Fig. 3 examines the repeatability of free drain tests. It shows typical results of tests on Flodrain. The results show good agreement at all values of lateral pressure considered.

From the above plot, it is oberved that measuring the discharge capacity using the test apparatus is reproducible under the same laboratory-controlled conditions.

Fig. 4 and *5* show the typical variation between discharge capacities and the lateral pressures at different hydraulic gradients for Desol and Flodrain respectively. In these tests the drains were not in direct contact with soft clay, i.e. they were not enclosed in the soft clay before being surrounded by rubber membranes. They are, therefore, called 'free drains'. The figures show that the discharge capacities of the drains decrease with increasing magnitude of lateral pressure and hydraulic gradient, although to varying degrees. This is due to the compressibility of the core and more importantly the filter sleeve being pressed into the flow channels of the core resulting in further reduction of effective flow area. The discharge capacity is also influenced by the hydraulic gradient across the drain specimen. The higher the hydraulic gradient, the lower is the discharge capacity. This is due to loss of flow energy as a result of turbulent flow occurring at high hydraulic gradient.

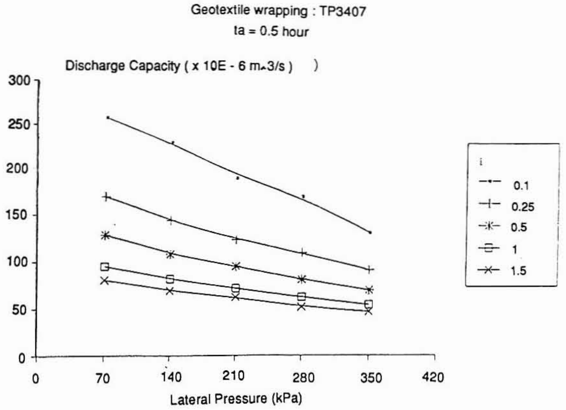


Fig. 4: Typical relationships between discharge capacity and lateral pressure (Flodrain).

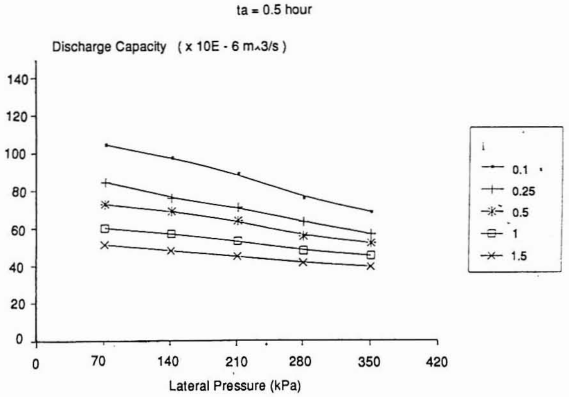


Fig. 5: Typical relationships between discharge capacity and lateral pressure (Desol).

Fig. 6 shows the variation between discharge capacities and the lateral pressures at i (hydraulic gradient) = 0.5, ('free drains'). The Flodrain drain samples were wrapped with five different types of geotextiles. At all hydraulic gradients and lateral pressures considered, Flodrain wrapped with Typar TP3407 gave the highest value of discharge capacity. This is due to relatively high stiffness of the geotextile which provides a better support against soil pressure. The core with Bidin U14 wrapping produced the least discharge capacity due to its fluffy structure that interfered with the flow paths as well as its relatively low level of stiffness.

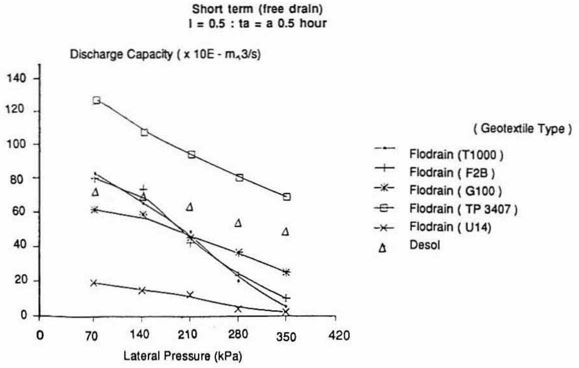


Fig. 6: Discharge capacity vs. lateral pressure

The effects of duration of loading on the discharge capacities of the drain specimens are shown in *Figs. 7 and 8*. Although the initial discharge capacities of Flodrain cores wrapped with geotextiles T1000, F2B and G100 are similar, the corresponding values after loading for 24 hours are different. Geotextile wrapping U14 still produces the lowest while TP3407 has the highest discharge capacity. Desol drain which has no wrapping is not significantly affected by duration of loading. These test results show that the discharge capacity of Flodrain is very dependent on the type of geotextile fabric and also highlight the importance of specifying the duration of loading when measuring the discharge capacity. Impressions of the studs were visible on all types of filter fabrics on the drain specimens after the tests.

From these results it can be seen that the filter fabric has an important effect on the discharge capacity of a vertical drain. Non-woven stiff fabric tends to give a higher discharge capacity than fluffy, flexible fabric. Nevertheless, the choice of filter fabric should not be governed by this factor alone. The filtering and retention functions of the filter sleeve are other important factors that need to be considered.

Fig. 9, 10 and *11* show the results of tests in which the drain specimens were in direct contact with soft clay (i.e. 'in clay' conditions). The test results and order of performance of the drains are not very different from those obtained in 'free

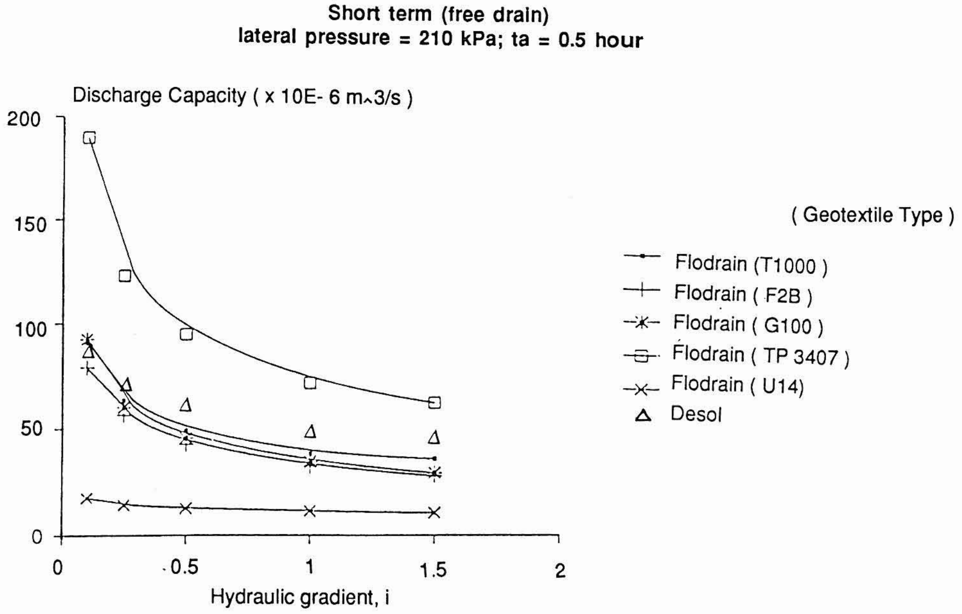


Fig. 7: Discharge capacity vs. hydraulic gradient, 0.5 hour after application of pressure

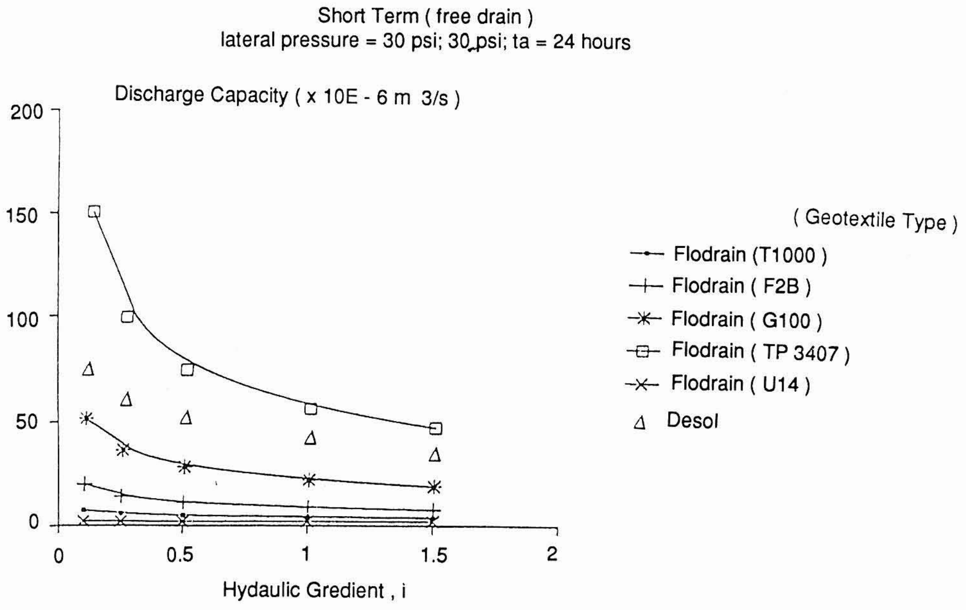


Fig. 8: Discharge capacity vs. hydraulic gradient, 24 hours after application of pressure

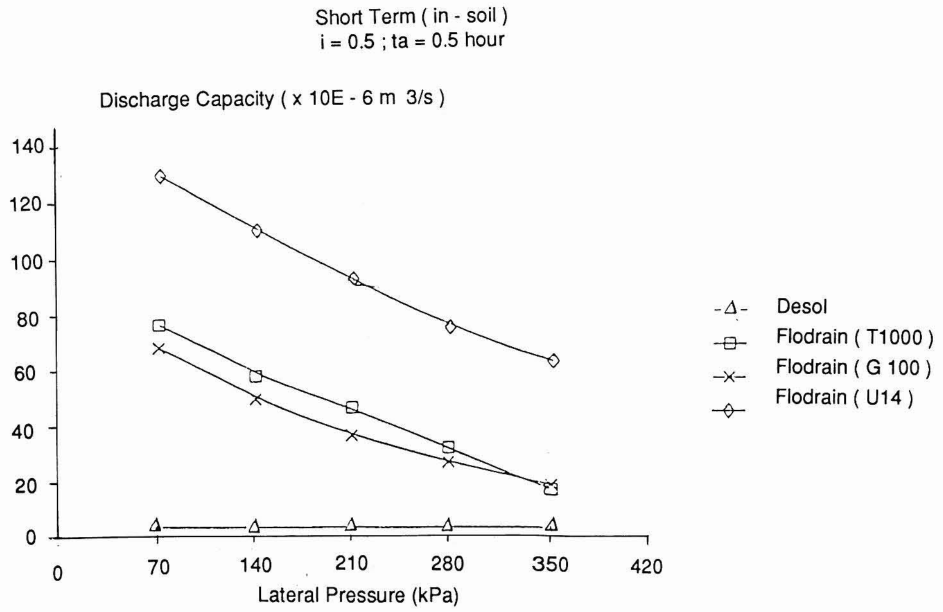


Fig. 9: Discharge capacity vs. lateral pressure

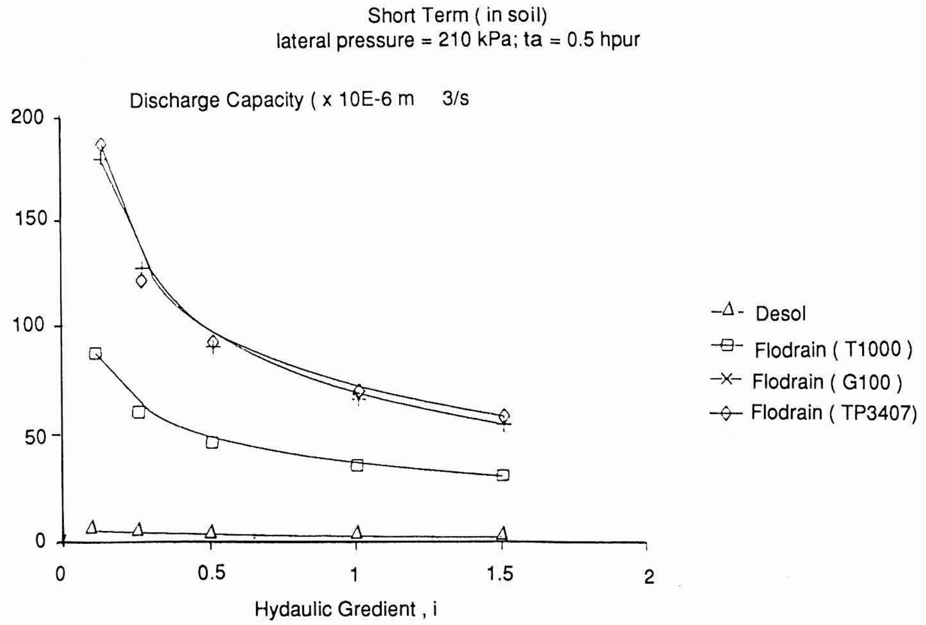


Fig. 10: Discharge capacity vs. hydraulic gradient, 0.5 hour after application of pressure

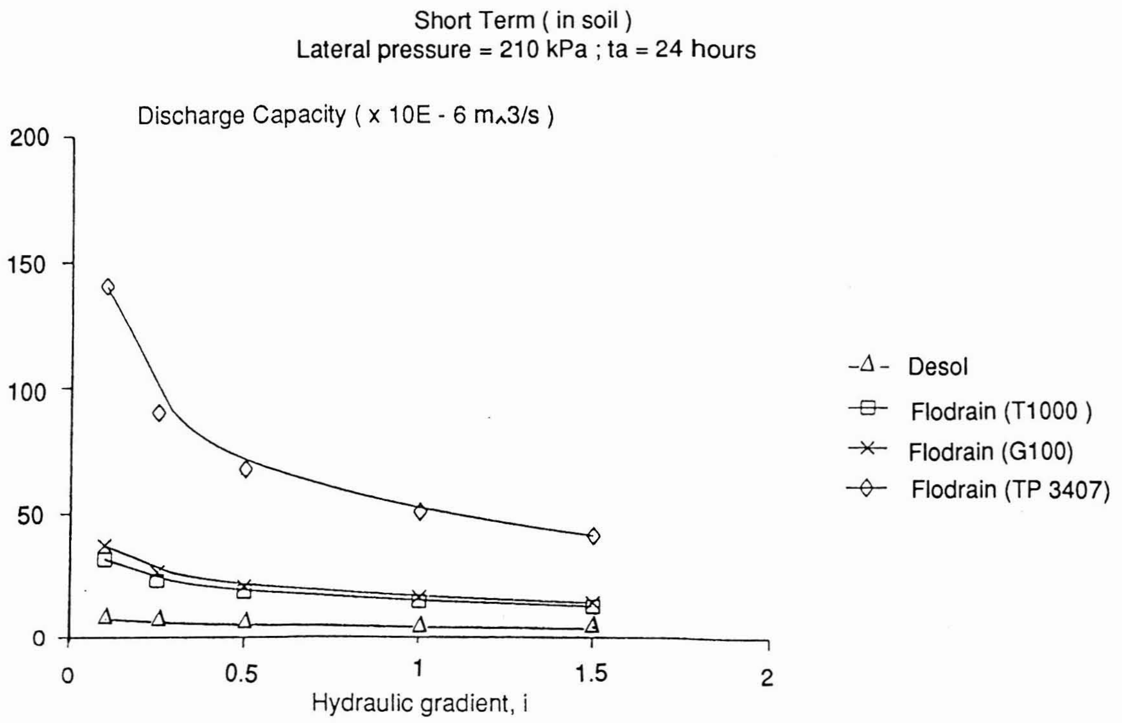


Fig. 11: Discharge capacity vs. hydraulic gradient, 24 hours after application of pressure

drain' condition, with the exception of Desol drain. Desol drain suffers a severe loss in discharge capacity if compared with its performance shown in *Fig. 6.* This is due to the intrusion of clay particles into the flow channels. The pore size on the walls of the drain is uniform and of diameter 0.2 mm which is even bigger than D100 of the soft clay surrounding it. All other drain specimens were not intruded by the clay. The experimental set-up does not give the true indication of the siltation process of the drain specimens because there is no direct flow of water from the surrounding soil into the drains. In the real situation or field conditions the effect of siltation may be even worse than what has been indicated by the above results. These test results indicate the importance of having a filter sleeve around vertical drains; the intrusion of soil particles cannot be prevented by just having small holes around the drains.

CONCLUSION

The following conclusions were drawn from the experimental work carried out in this study.

i) The discharge capacity of the prefabricated band-shaped vertical drain is influenced by the magnitude of the lateral pressure on the drains. The discharge capacity of all the drain types studied in this experiment decreases with increasing lateral pressure. The amount of reduction depends on the type of drain.

ii) The value of discharge capacity of a band-shaped vertical drain is dependent on the hydraulic gradient prevailing along the drain. Increasing the hydraulic gradient causes a reduction in discharge capacity because of the occurrence of turbulent flow. For the range of hydraulic gradient in this experiment (above 0.1), turbulent flow prevails and therefore the discharge capacity is not independent of hydraulic gradient. Since the actual hydraulic gradient in field conditions is difficult to determine the discharge capacity of a drain should be quoted for a range of hydraulic gradients.

iii) The type of filter sleeve is important as far as discharge capacity is concerned. However, it should be borne in mind that the suitability of a filter fabric should not be judged in the context of discharge capacity alone; it must also be tested for permeability and retention properties against the soil to be encountered in the site.

iv) The creep deformation of the plastic core and filter of band-shaped drains is significant to the long-term discharge capacity of the drains. Increasing the stress duration will decrease the discharge capacity.

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