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The behaviour of non-woven fabric filters in subdrainage applications

Das verhalten von Filtervliesen in unterirdischen Entwaesserungen

Dieses Referat diskutiert Laborversuche in das Verhalten von Stoff und herkömmlichen Kiesfiltern wobeieine Drainage in eine Richtung vorausgesetzt wird. Das Forschungsprogram bestätigte, dass für die Reihe von getesteten Filters aus Fliesstoffen ihr Filterverhalten gleich oder besser als herkömmliche kiesfilter war. Von gesammelten Testwerten und von praktischen Erkenntnissen ist anzunehmen, dass drei Grundanforderungen existieren, die von eined Stofffilter erfüllt werden mussen; es muss einer rohrartigen Durchbruch von Erde verhindern, es muss durchlässig genug sein um einen Aufbau von Wasserdruck innerhalt der geschützten Erde zu verhindern und es muss ausreichende physikalische Eigenschaften besitzen um Installationsbeshadigungen durch schlechtes Behandeln zu widerstehen und immer fest bleiben und funktionieren für die geplante Lebenszeit des Drainagesystems. Die ersten zwei dieser Anforderungen sind Kalkulierbar.

INTRODUCTION

The need for drainage systems within civil engineering structures has been long recognised. It is necessary to prevent structural failure during or after construction to control both surface water flow and subsurface water flow (seepage). Seepage, which is the saturated flow of water through soil, not only influences the moisture conditions within a soil but also can create adverse hydrostatic pressures causing instability within the soil. Properly designed subdrainage systems are used to prevent infiltration or seepage into a soil mass or to improve existing conditions within an unstable soil. The general requirements for drains are that they have a long life, do not clog and are not disrupted by subsidence.

The correct functioning of granular filters requires the fulfilment of two divergent criteria:-

1 The particle size grading should be such as to prevent movement of soil particles. The pore spaces in the aggregate filter should be small enough to prevent movement of fines into or through the filter. If excessive migration of soil particles was allowed into the filter the flow of water through the filter could be restricted. Migration of soil particles, however, could leave cavities in the protected soil producing unstable conditions. This phenomenon is known as piping.

2 The filter particle size grading has to be such to permit removal of water from the soil mass. Pore spaces therefore have to be large enough to permit seepage flow without any development of hydrostatic pressure within the soil mass, which can cause unstable conditions.

Terzaghi (1) was the first to formulate design criteria and he assumed the eighty five per cent size of the soil (D_{85S}) represented the larger particles and that fifteen per cent of the filter (D_{15F}) was a measure of its pore size. Terzaghi stated if $D_{15F} \leqslant 5xD_{85S}$ the soil would not work into the filter and if $D_{15F} \geqslant 5xD_{15S}$ the filter would have adequate permeability. Accordingly the filter envelope can be produced by multiplying the D_{85S} and D_{15S} by 5 and drawing grading curves parallel to the base soil grading curve. This approach of Terzaghi proved to be simplistic and since these general filter rules were produced several investigators have carried out research into a variety of base soils and aggregate filters. Perhaps the best known is the United States Waterways Experimental Station (2), which differentiates between uniformly graded soils and well graded soils.

The design of conventional single layer graded aggregate filters produces a system which is inefficient and uneconomic. The cost benefit of various drainage systems has been investigated by Cedergren (3). Based on the assumption that drainage costs are related to the water removal potential of the drainage system then single layer graded filters are extremely expensive. The layered drain concept consists of granular material with small particle size adjacent to soil mass, thus acting as a filter and a coarser large particle granular material towards the centre of a drain or the upper layer of a blanket drain, thus providing a zone of high hydraulic conductivity. The limitations with this type of construction however are in the difficulty and additional expense of placing layers of different materials.

The advantages of fabrics for controlling filtration at the soil/drainage media interface was reported by Barrett (4). Early installations incorporated fabrics in coastal and river protection schemes where they replaced graded filter layers. In this use however the fabrics were subjected to severe changes in pressure head due to wave action and were subject to two way flow situation. Such conditions are not comparable with true drainage applications where one way laminar flow and low hydraulic gradients predominate.

Later Healey et al (5) Calhoun (6) and Pivovar (7) all used fabrics in one way laminar flow filtrations situations. Fabric screens provided the filter and permitted relaxation of the aggregate design criteria, hence the infill only formed the one function namely hydraulic conductivity.

Utilisation of fabrics to protect highly permeable drainage media has the advantages advocated by Cedergren in his multi layer drain concept without the installation difficulties.

A fabric screen can be thought as the part of the overall soil/drainage system which initiates the formation of a filter cake in the upstream soil therefore allowing the use of a highly permeable drainage media. The creation of the filter cake is dependent on the size and number of migrating soil particles and on the hydraulic conductivity of the screen. The fabric construction affects this filter cake formation, the relevant physical properties being pore size distribution, the percentage open area and the thickness.

Migration of front ranked soil particles through the fabric pores is followed by movement further away from the screen as large particles adjacent to the screen reorientate. The movement diminishes as the distance from the screen increases. When the distance is such that no movement takes place the soil is in its natural condition. The filter cake layer adjacent to the fabric screen has a higher porosity and hence seepage velocity will be greater in this region. This process is known as 'self induced filtration'.

Other factors governing the fabric filter operation are the soil properties, drainage media grading and the fluid flow conditions.

FILTRATION TEST PROGRAMMES

The test programmes were run to study a wide range of soil types and melded fabric types over a range of hydraulic gradients and at different confining pressures. The test programme at ICI was continued for a longer duration to confirm the shorter term trends observed at the Universities of Strathclyde (8) and Tennessee (9).

The type of soil used at Strathclyde and at ICI laboratories was a West Highland Moraine with 50% of its particle size in the silt range and all passing the BS 1377 No 25 sieve. The permeability of the soil was 1×10^{-7} m/sec. The Tennessee study was intended to observe a wider range of soil types. In order to do this a base soil of Unified Classification SC of plus No 100 US sieve was used to which finer fractions of various soils were added to produce a wide range of silt and clay soils.

The fabrics in all three studies were all spun bonded hetrofil melded products of 70, 140 and 280 gm weight. The range of pore size distribution is shown in Fig 1. Permeability values are indicated in Table 1.

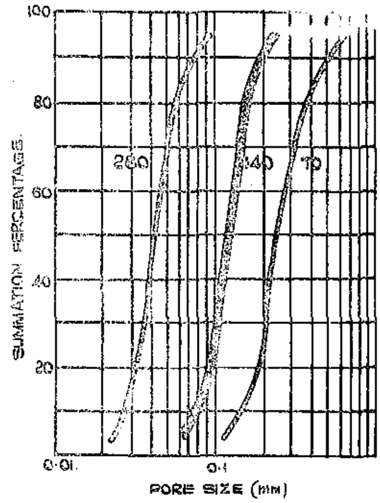

Fig 1 Pore Size Distribution of T70, T140 and T280 Fabrics

FABRIC	PERMEABILITY (x 10^{-3} m/sec)
T70	3.22
T140	1.67
T280	0.72

TABLE 1

The permeameter used in the three studies varied slightly in detail but consisted of an upper and lower section bolted together through a flange. The filter fabric was held in position at the flanged joint. The lower section of the permeameter contained the single size drainage media when a fabric filter was being used, or the conventional granular filter when their performance was being compared. Soil was positioned in the upper section of the permeameters. Variable water head devices were used to produce a hydraulic gradient through the system. Fig 2 illustrates the apparatus used at the University of Tennessee. The Strathclyde permeameters had an internal hydraulic jack to impose different confining pressures on the system.

Flow rates were measured for each test together with manometer readings until equilibrium conditions were reached. Soil loss measurements were taken to determine soil loss from the total system as a result of piping and also soil loss due to clogging in the filter.

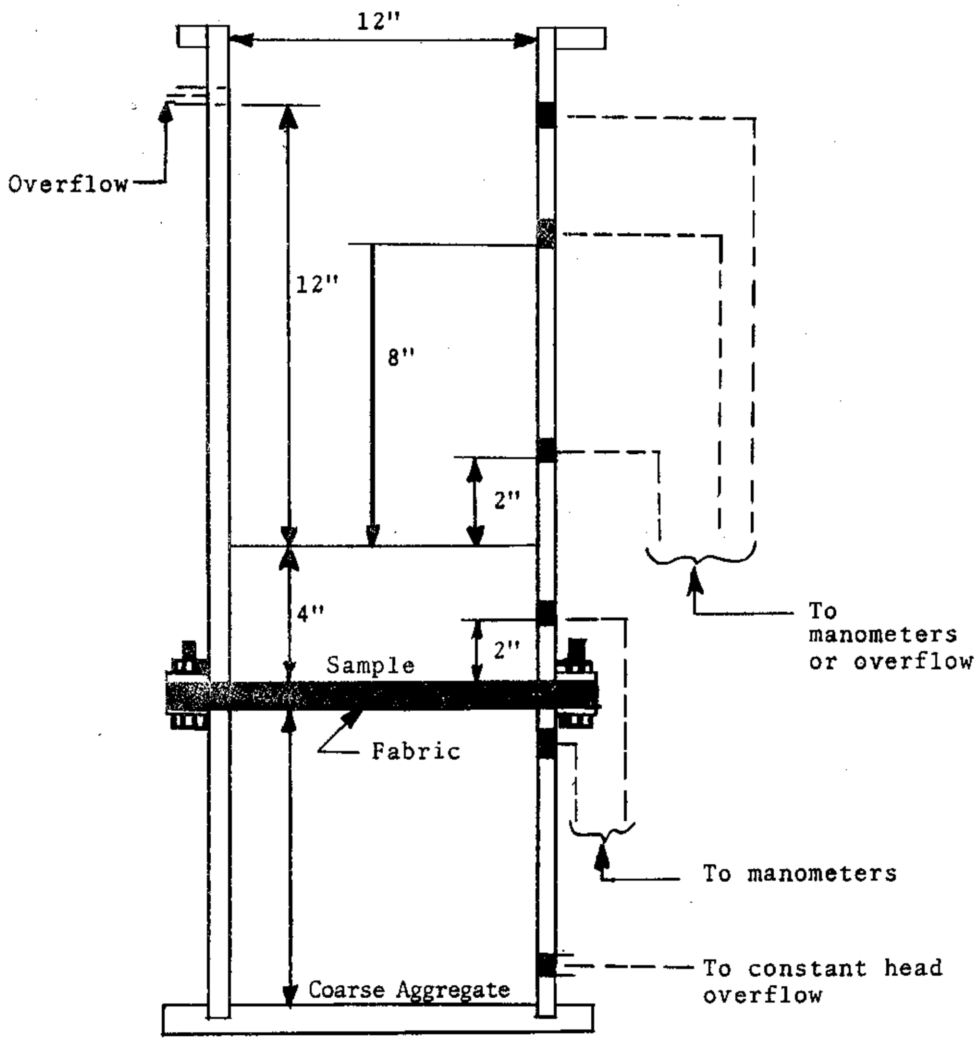

Fig 2 Laboratory Permeameter

DISCUSSION OF RESULTS

All soils tested with fabric filters exhibited a characteristic s-shaped permeability versus log-time curve. These curves indicated that, within the first few days of flow, the permeability of the system remained relatively constant; however, the log-time curves did not portray slight reductions in permeability during the first few minutes of flow, which were attributed to induced filtration and clogging of the fabric by particles immediately adjacent to the filter. These changes in permeability were insignificant relative to the overall behaviour of the system.

It was observed that after an initial period of filtration, steady flow conditions were attained, indicating that soil particles were induced to migrate through the fabric screen and initiating the formation of an upstream filter cake in the soil mass and adjacent to the screen.

Equilibrium permeability conditions were achieved at approximately 600 hours (Fig 3). Extended testing to periods up to 3000 hours (Fig 4) suggest that this type of filter fabric can be used in static drainage conditions without fear of blinding.

The permeability at filter cake - fabric interface depends upon the correlation between particle size distribution of the soil and the characteristics of the fabric. These consist of the pore size distribution, percentage open area, and the thickness of the fabric.

The experimental results indicate that the fabric filters performed at least as efficiently as conventional granular filters under steady flow seepage conditions.

The permeability values for aggregate and fabric filter systems were found to be essentially the same for comparable soils.

For the range of silt-sand soil it was found that the 140 g and 280 g fabrics were almost identical in performance, but the 70 g fabric proved a more efficient filter than conventional granular filters.

The amount of soil found to be trapped in the fabric (ie, clogging) was approximately equal for all soil types tested

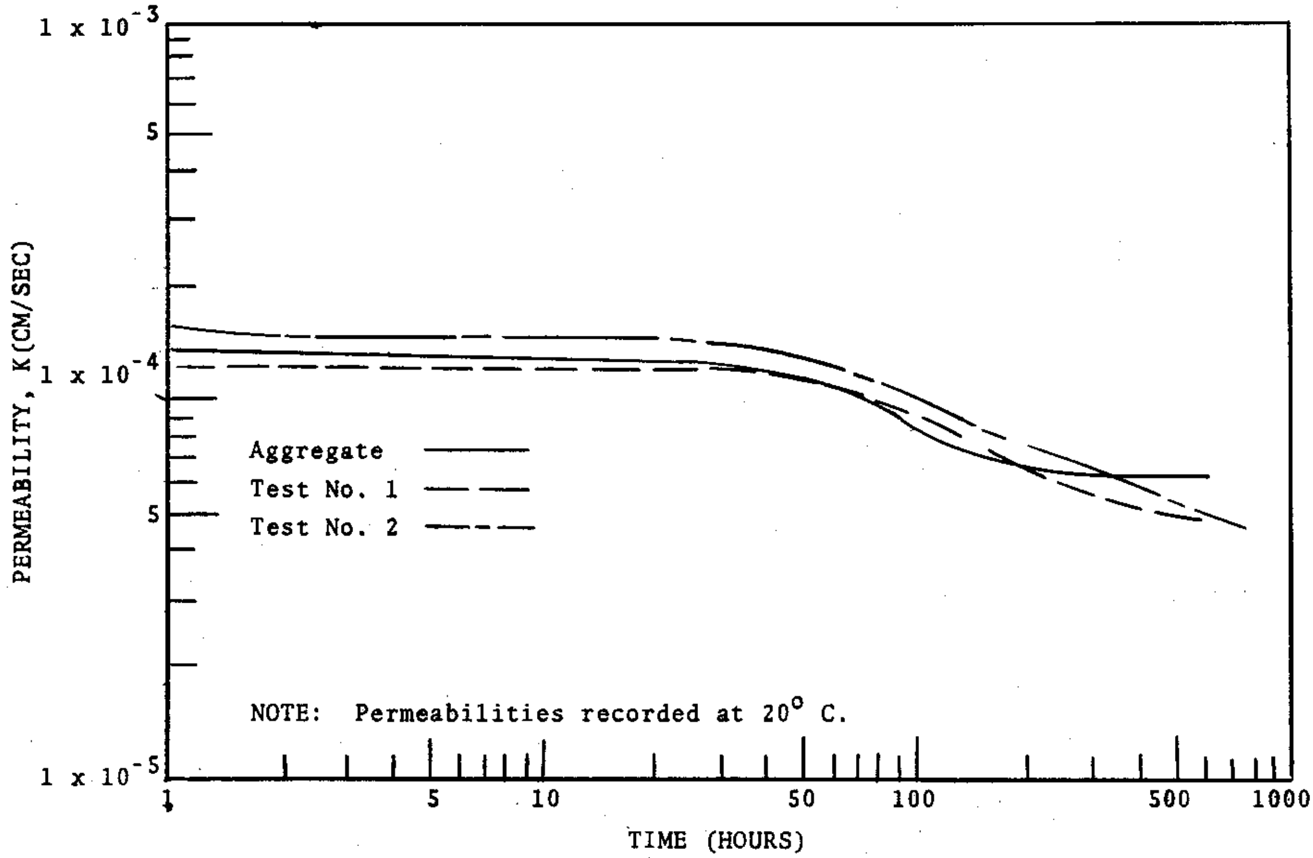

Fig 3 Curves for Aggregate and Fabric Filters with S-25 Soil

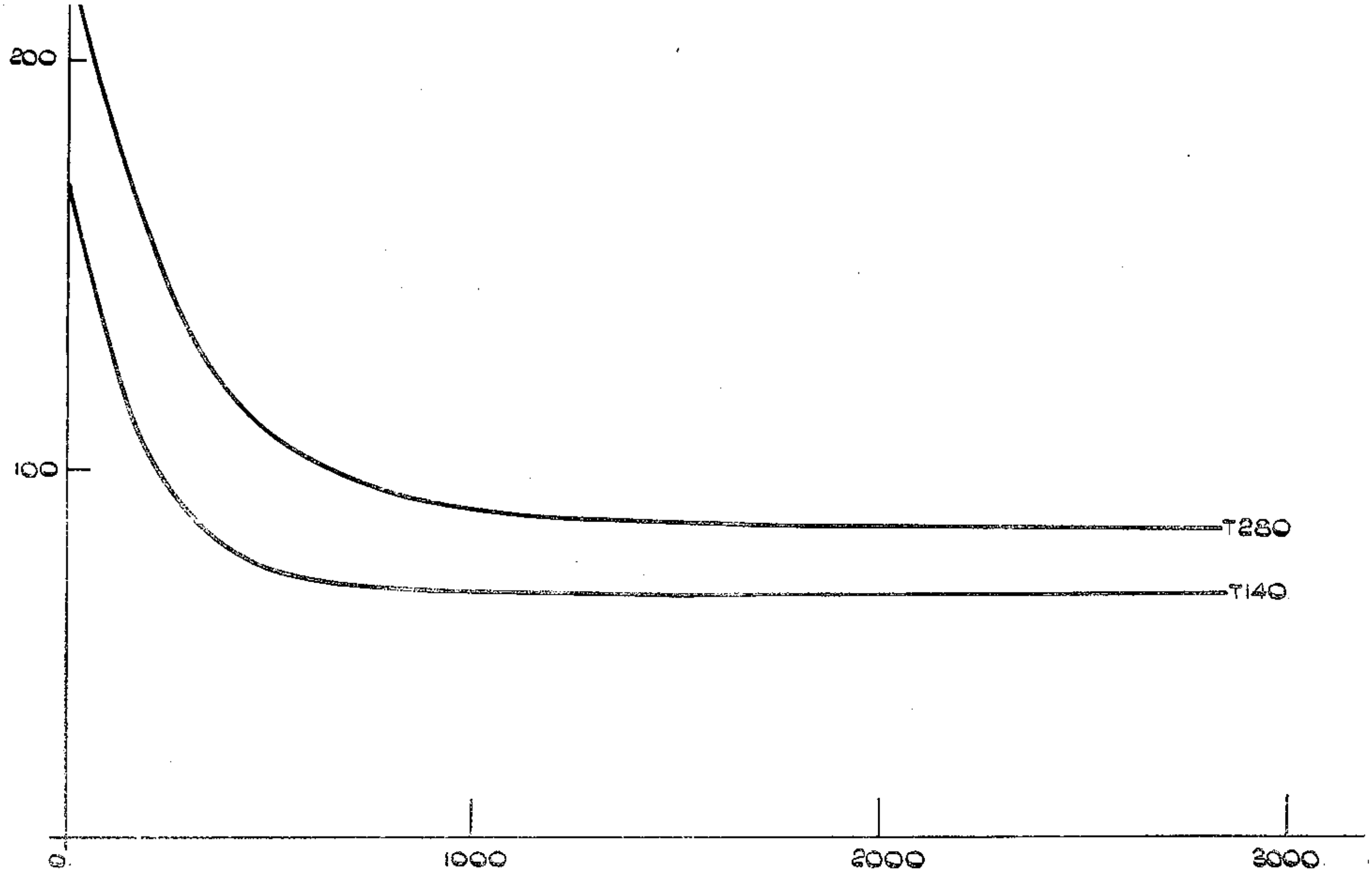

Fig 4 Long Term Permeability Curve for West Highland Moraine

but the total soil loss during filtration was found to decrease significantly with increase in plasticity of the soils. As clogging has shown to be aimost constant this means that piping decreased as plasticity increased. The soil loss data indicates that large amounts of soil can be carried into the aggregate filter producing clogging and thus affecting the performance.

Fabric variances investigated in this study produced very little change in behaviour of the fabric filter system. Variations in fabric characteristics were not sufficient to overshadow variations in soil characteristics.

The permeability of the fabric filter drainage system at zero confining pressure is higher than at higher pressures of 5 and 15 psi (34.5 and 103.5 KN/m^2) although no difference was observed in performance between pressures of 5 and 15.

The range of melded fabrics tested were found to perform satisfactorily under a wide range of soil grain size distributions for soilspossessing liquid limit values of less than 40 per cent and plasticity index values less than 15 per cent.

SUMMARY AND CONCLUSIONS

The research programmes confirmed that for the range of melded fabric filters tested their filter performance was equal to or better than conventional aggregate filters.

From the data collected and from practical considerations there are three basic requirements that must be met by a fabric filter criteria used in subsurface drainage applications, and are as follows:

1 It must prevent the migration of protected soil through the filter media (piping requirement).
2 Be more permeable than the soil protected, thus allowing for the rapid removal of moisture without a build up of hydrostatic pressures. (Permeability requirement).
3 To have sufficient physical properties to withstand abuse during installation without damage and also to remain permanent and perform for the duration or life of the drain system. (Structural integrity).

It can be concluded therefore that the range of fabrics tested met the piping and permeability requirement for the range of protected soils tested (Fig 5). Experience of drainage installations has shown that these fabrics also successfully meet the structural integrity criteria.

Atterberg has suggested that the average pore size of a soil mass is:- $0.2\,D_{10}$
Now Terzaghi's piping requirement is that

$$D_{15F} \leqslant 5D_{85S}$$

$$\therefore 0.2D_{15F} \leqslant D_{85S}$$

now D_{10} is less than D_{15} for a graded filter, therefore it follows

$$0.2D_{10F} \leqslant D_{85S} \qquad \therefore Pav_F \leqslant D_{85S}$$

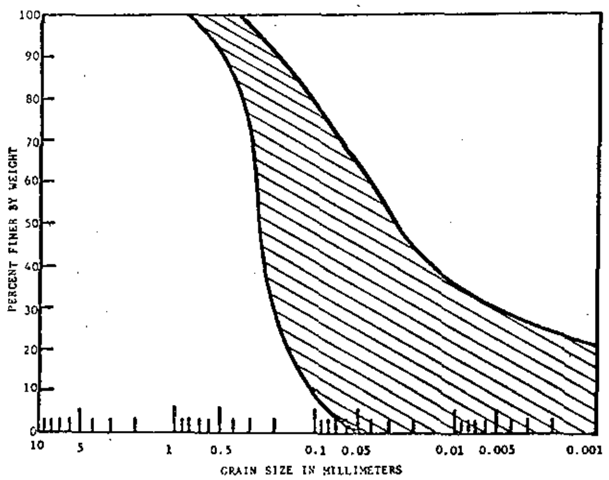

Fig 5 Range of grain size distribution for which fabric performed satisfactorily

The D_{85} of the soils used in the Tennessee investigation was 0.2 - 0.5 mm and the Pav for the 70, 140 and 280 gm fabrics are 0.25, 0.125 and 0.04 mm respectively. Therefore except for the 70 weight product with the finest soil the criteria that $Pav_F \leqslant D_{85S}$ was met.

The Strathclyde work highlighted that the 70 gm product was the most efficient filter. In fact the Pav for T70 is 0.25 mm and the D_{85} of the West Highland Moraine is 0.25 mm. Therefore again this piping criteria has been met for all the fabrics tested against West Highland Moraine.

Terzaghi suggests also that for adequate permeability that D_{15} filter $> 5D_{15}$ soil to ensure that the soil is adequately drained. The permeability tests with both fabric filters and aggregate filters show both systems to be similar. It would seem reasonable therefore to have a permeability criteria for a fabric filter of:-

$$K_{filter} > 5K\ soil,$$

5 being a reasonable safety margin.

A typical figure of K_{filter} being in the order of 10^{-3} cm/sec. The range of melded fabrics tested meet this requirement.

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