Paper 2.01

DRAIN ENVELOPE MATERIALS IN CANADA

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Summary

Envelope materials have always been used with problem soils in Canada. Originally this was grass sod, straw or tar paper. About 1957 thin synthetic envelope materials became available and field and laboratory tests were conducted periodically to evaluate their use. The results of these tests have been printed. No failures have been reported in the field where envelope materials have been properly applied. In 1977 about 10% of all drain pipe installed used an envelope. The material is a polyester knitted fabric sock.

Introduction

Drains were installed in Canada by trenching machines for nearly half a century prior to 1950. There were few reported cases of drain failure due to silting. Only the land where drainage could be achieved easily was drained at this time, usually with wheel-type trenching machines. Fields only were drained, not entire farms.

The following decade was transitional. Farming began to change. Corn for both grain and silage replaced much of the small grains, hay and pasture. Table 1 shows the huge increase in corn production in Ontario. Corn demands good soil drainage. There was also a change from dairying to cash cropping.

TABLE 1. Area of land used to produce corn, Ontario, Canada

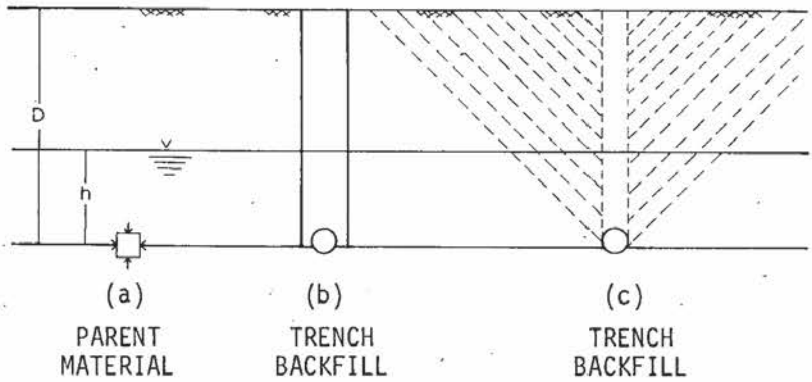
Year	Grain corn (ha)	Fodder corn (ha)	Total (ha)
1950	113,805	138,510	252.315
1955	228,825	110,970	339,795
1960	182,250	114,210	296,460
1965	299,700	170,100	469,800
1970	445,500	228,825	674,325
1975	575,100	295,650	870,750
1977	652,050	350,330	1,002,380

By 1970 the drainage industry was also undergoing a corresponding change to cope with the demand for improved farm drainage. The introduction of faster chain-type and plow-type drainage machines, corrugated plastic drainage tubing, laser grade control, and synthetic envelope materials all occurred in a five-year period. Contractors could not wait until researchers examined the problems, and many of the problems are not yet solved.

Typical field situation

Drains are usually installed at a depth of 0.7 to 1.0 m in Ontario. Failure of drains due to silting is a frequent problem with non-cohesive soils, and in areas with a high water table at the time of installation (spring or late fall, for example). A wheel or chain type trencher mills the soil producing irreversible structural changes to any existing soil structure. When using standard methods of backfilling with wet soil into a wet trench, the density of the backfill is about 15% less than that of the parent material. Irwin (1971) showed that when a plow-type drainage machine is used to place drain tubing, the soil density above the drain tubing is also about 15% less than the parent material (see Fig.1).

Critical hydraulic gradient is the gradient at which the buoyant weight of a volume element is balanced by the vertical component of the body force due to water flow into the drain. No erosion is assumed to take place until the gradient is exceeded by the vertical component of the exit gradient at the drain. Failure can take two forms - erosion through grain migration of a



(a)	(b)	
1.55	1.25	dry bulk density (ρ_d) g/cm^3
1.97	1.78	wet bulk density (ρ) g/cm^3
0.71	1.12	void ratio (e)
27.00	42.00	water content (e) %
0.96	0.78	critical gradient (i_c)

Fig.1. Soil cross-section illustrating

(a) a soil element at the base level of a drain
(b) drain installed by trenching machine, and
(c) drain installed by drainage plow.

Typical values are $D = 0.8$ m, $h = 0.5$ m, particle density = 2.65 g/cm^3, and others as tabled above.

small volume due to flow concentration into the drain pipe, or, the bulk heave of a large volume such as the trench bottom which may put the drain off grade. Heave without boiling results in an increase in void ratio and consequent increase in permeability and possible failure through boiling. Schmidbauer (1950) found that bulk heave occurred if a sand contained more than 10% by mass of grains finer than 40 μm, and if the hydraulic gradient was sufficient to induce failure.

The total stress, σ, at the base of the drain for the example in Fig.1 (a) is:

$$\sigma = \bar{\sigma} + u$$

where u is the neutral stress equal to $\rho_w h$ and $\bar{\sigma}$, the effective stress equal to the mass of soil and water above the drains base. The total stress can be called the surcharge. Surcharge gives the soil a confining strength which may reduce soil instability.

When the effective stress equals zero a quick condition exists in the soil. This situation is particularly common with fine sands of uniform particle size in a loose or open state of packing.

Small amounts of clay or silt give the soil cohesive properties which adds to its strength. Cohesion may range for the effective stress condition to about 2000 kg/m^2 which exceeds hydrodynamic seepage forces. The pressure of cohesion reduces soil instability. The plasticity index of a soil should be determined to evaluate this important soil property.

The critical hydraulic gradient, i_c, for the unconfined condition is:

$$i_c = \frac{G - 1}{1 + e}$$

where G is the particle density of the solid material and e is the void ratio. This term is independant of the soil hydraulic conductivity, velocity of flow and particle diameter. For sand with a particle density of 2.65 and a void ratio of 0.65 the critical hydraulic gradient is unity. The general equation for instability at a subsurface drain is:

$$i_c = \frac{G - 1}{1 + e} + \text{surcharge} + \text{cohesion}$$

The hydraulic conductivity, k, is related to void ratio, e, thus:

$$k = c_v \, m_v \, \gamma_w = c_v \frac{a}{1 + e} \gamma_w$$

where

c_v is the coefficient of consolidation

m_v is the coefficient of compressibility

a is the coefficient of volume compressibility

After installation of a drain the backfill is very loose (Fig.1b), or the parent material is loosened by the drainage plow (Fig.1c), creating a higher void ratio and bulk volumetric change above the base of the drain.

Darcy's law governs the flow to the drain. Assuming the hydraulic gradient to be unity and unchanged in the intitial stages after drain installation the higher void ratio permits a higher hydraulic conductivity. The increased velocity of flow detaches soil particles and carries them into the drain. This was observed by Hore and Tiwari (1962) who determined that the soil entering the drain came from the backfill and not the parent material. Tests at Guelph showed that soil will move into unprotected drains with heads as low as 25 mm.

Synthetic envelope materials

When properly installed, most synthetic envelope materials used in Canada adequately perform the functions of passing water into the drain while excluding sand.

A glass fibre filter with parallel reinforcement (manufactured by L.O.F. Glass Fibers Co., Toledo, Ohio) was used in Ohio in 1956. About 1957, the same product was marketed in Canada by Globe Glass Saturaters, Petrolia, Ontario. The material tore easily, and in 1959 "Tile Guard S-110" with random reinforcement was introduced. The cost was 5¢/m. It was marketed in rolls of 365 m. The rolls were attached to the sand box of the trenching machine and mechanically placed above and below the drain pipe. Tile Guard is an inert lime borosilicate glass filament held together with phenol-formaldehyde binding agent.

"Durant type 204" was marketed at the same time for use as a stable base under the drain pipe in unstable soils. It is a glass fibre reinforced material saturated with bitumen. The price was 3¢/m.

About 30,000 m/yr of these products were used in Canada from 1957. They were satisfactory as long as the contractor took care to wrap the pipe adequately. Polyethylene sheet underlay was often substituted for Duramat. However, these products proved to be difficult to adapt to the plow-type machine they ruptured if the plow stopped and then started again. "Tile Guard PG-90" was introduced to overcome this problem. High rate machine operation made the application of this form of protection difficult and some failures occurred where the upper and lower rolls failed to meet properly. Tile Guard has remained the standard product where clay drain pipe is used.

In 1973 the Big O Drain Tile Company, Hensall, Ontario, installed a small knitting machine to produce a sock for pre-wrapped plastic drain pipe. At the same time they marketed Drain-O-Guard, the Cerex spun-bonded nylon sock patented by Advanced Drainage Systems, Inc., in the U.S.A. Cerex was satisfactory as a filter but was hard to get into the ground without tearing. Each roll was delivered in a plastic bag for protection. The cost of the envelope was 23¢/m. In 1975, the Big O Drain Tile Co. started to manufacture nylon knit sock which was more resistant to abrasion and damage in transport and in field handling. In late 1973, other manufacturers adopted Remay polyester (14 g/m^2) and continued to increase its thickness. When 36 g/m^2 proved unsatisfactory, these companies also changed to a knitted sock. A knitted sock is now the standard form of protection for most of the plastic drainage pipe used in Canada. The contractor does not charge extra for installation of this type of pre-wrapped pipe. The cost of the envelope is 26.2¢/m in addition to the 56¢/m for 100 mm pipe.

In 1977 about 10% of all corrugated plastic drainage tubing was shipped with a pre-wrapped envelope. Some contractors will use this on 40% of their work.

Problem soils

The soils in Ontario and Quebec which tend to cause silting of drains were developed from deltaic medium to fine sands and silts deposited on a till plain. The topography is nearly level. The pervious upper sand strata over an impervious clay layer typically at 1 to 2 m depth contributes to a naturally waterlogged condition. Until recently, suitable drainage outlets were not available for many of these areas.

Complete information on these problem soils is not available. Fig.2 shows the range of the grain size distributions for these problem soils. Most drain failures occur when significant proportions of the soil grain sizes are between 50 to 120 μm in diameter.

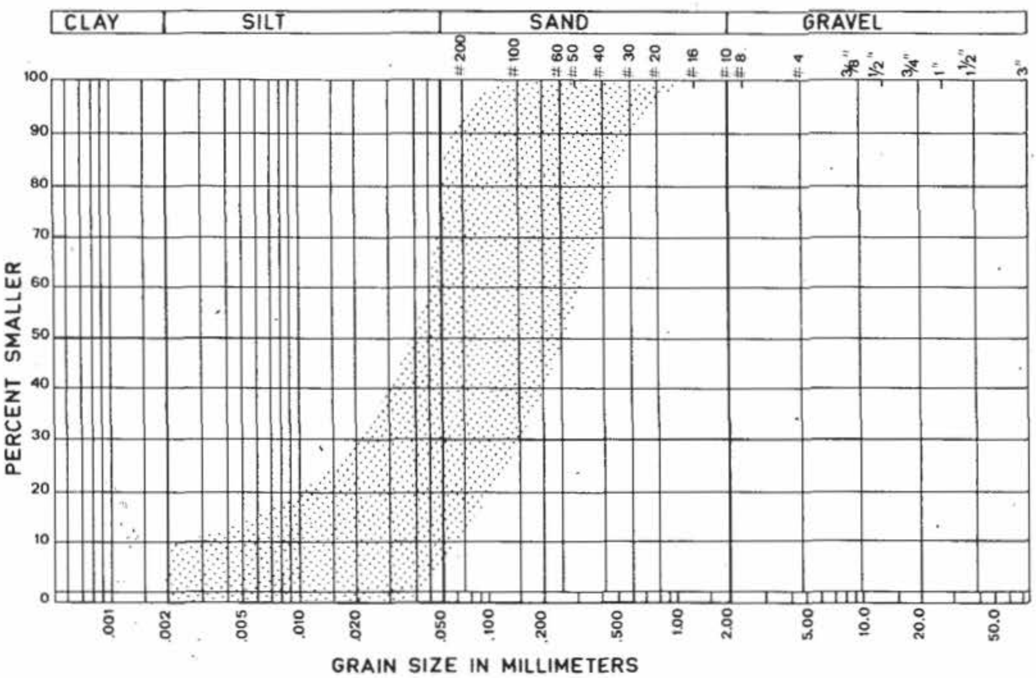


Fig.2. Range of grain size distribution for problem soils.

Canadian research on envelope material

In 1957, a laboratory study was initiated by the senior author on the relative merits of seven types of protective materials used to overcome the problem of drain silting. This study was prompted by the silting-up of 16,000 m of drains on the Horticultural Experiment Station, Vineland, Ontario. Evaluated were blinding with top soil, Duramat cover, Tile Guard cover, Tile Guard above and below, Kraft impregnated building paper cover, No. 2 saturated tar paper cover, and straw cover. Tile Guard above and below provided a tenfold increase in flow and protection from silting compared to the other treatments.

In 1959, Hore and Tiwari (1962) tested the following treatments in the laboratory using Granby sandy loam: blinding with top soil, Tile Guard above and below the drain, Duramat above the drain, and Tile Guard above - Duramat below the drain. Rainfall on the backfill material followed by groundwater flow to the drain was simulated in 6 hour tests. Tile Guard above and below allowed maximum flow with minimum soil entry. Sand was transported into the drain by water draining from the backfill, not from the parent material.

In the fall of 1960, the authors commenced a 3.25 ha field experiment near Lancaster, Ontario, in Bainsville silt loam where drain failures had occurred. Five treatments (three replications) were evaluated: blinding with top soil, straw cover (3 kg/m), Tile Guard above and below, tar paper above, and Tile Guard above - Duramat below. The drains were 122 m long laid at a grade of 0.0017 with sediment sampling points at 30, 61 and 91 m from the outlet end. The hand installation of materials was less than ideal due to torn filters and some uncertainty of proper placement. However, statistical analyses of four samplings over an eight year period ranked the treatments in decreasing order of effectiveness as follows:

> Tile Guard above and below, Tile Guard above - Duramat below and straw cover (equally effective), blinding with top soil, and tar paper above. An additional analysis of variance involving "Linear Contrasts" showed that complete cover treatments were more effective than top cover treatments (tar paper and straw) and blinding with top soil.

In 1973 several additional materials were introduced by manufacturers and many problems developed such as tearing and general concern for effectiveness. The drag force was therefore determined by the senior author by pulling a known area of material over a wetted galvanized sheet of metal. The results are given in Table 2. The dry breaking strength of the Tile Guard S-110 was 470 N/m^2 but only 294 N/m^2 when wet. The material ruptured in the field under wet conditions.

TABLE 2. Physical drag force of envelope materials

Envelope material	Drag force (wet) N/m^2
Tile Guard, S-110	196
Tile Guard, PG-90	333
Globe Glass - nylon felt	314
Big O Nylon Weave 405 sock	stretched
Drain-O-Guard (Cerex)	461
Big O new sock	stretched

The above materials were also tested for effectiveness of filter action and for flow rate. The tests were made with a constant head permeameter fitted with a slotted plate. The slots were cut the same size as the perforations in commercial corrugated plastic tubing. Only very small quantities of soil passed through any filter; therefore each filter performed satisfactorily.

For the same hydraulic gradient, the flow rate through the soil and the soil plus filter was the same; therefore, the envelope materials did not affect the flow rate.

McKyes and Broughton (1974) found in the laboratory that full wrap glass fibre sheet and polyester weave sock filters provided superior performance to jute and hemp twine wrapped in the grooves of corrugated plastic drainage tubing. The latter treatments became plugged with fine sand resulting in unacceptable low flow rates after 10 to 20 days.

Rapp and Riaz (1975) in a laboratory study using a gravel filter and glass fibre filter material combinations similar to those studied by Hore & Tiwari (1962) verified that completely wrapped treatments other than the gravel filter provided the best protection. The gravel treatment provided the best flow characteristics but the poorest protection from siltation.

Broughton et al (1976) tested in the laboratory most commercially avai able materials in North America and showed that drainage rates decreased wit time; however, they recovered temporarily after a period of no flow, a condition frequently found in the field. They concluded that any full wrap material except coconut fibre would do a good job of excluding sand from a drain and permitting water to enter. These studies are being followed up by a field study of seven treatments installed in August 1976, in a Nicolet sand soil where unprotected drains have previously failed.

Pore size distribution of envelope materials have been determined by several techniques. Nelson (1960) used a dry sand sieve technique to measure the pore size distribution of thin envelopes. Miano (1977) used a Ballotinin ball technique. Suction methods have been adopted in The Netherlands for thick envelopes. Other methods in common use include that of mercury immersion (A.S.T.M., 1974). Most of the above techniques are laborious.

The Quantimet 720 has been used to determine pore size distributions of geological and soil materials (Ismail, 1975; Murphy, 1977). This instrument is an image analyzing computer and is used to measure in two dimensions the number and the area of voids in a thin section of material.

The drain envelope materials used in Canada are about 0.15 mm thick and can be assumed with reasonable accuracy to be two dimensional with respect to voids. Cerex spun nylon, Tile Guard S-110, Tile Guard PC-90, and a coarse and fine mesh nylon fabric sock as currently used with 100 mm corrugated plastic drainage pipe were analyzed in January 1978 by the Quantimet 720[1]. The results of these analysis are shown in Fig.3.

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[1] *The Quantimet 720 manufactured by Imanco, Royston, England was operated by Dr W.Petruk, Mineral Sciences Laboratory, Dept. of Energy, Mines and Resources, Ottawa, whose skilled assistance is gratefully acknowledged.*

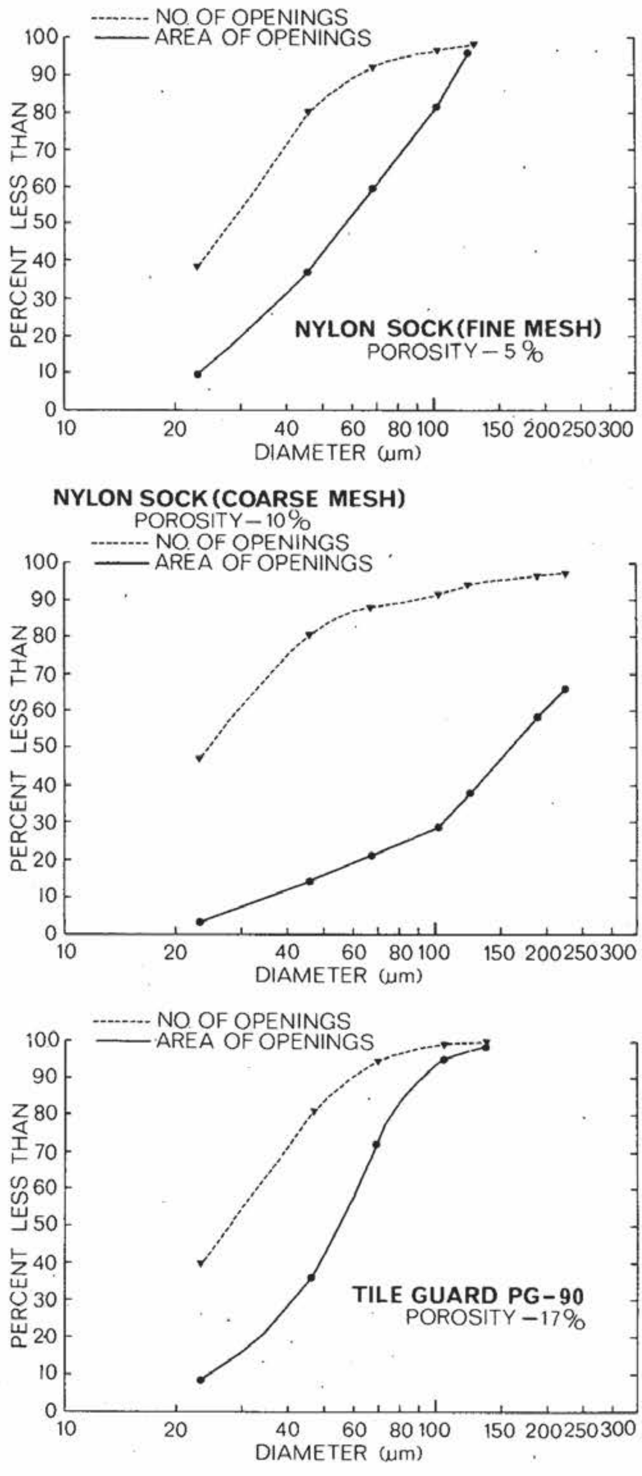
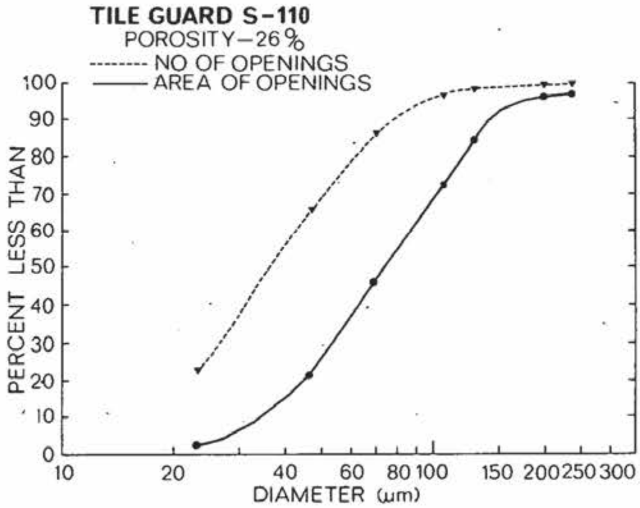


Fig. 3. Pore size distribution by the Quantimet computer for five filter materials.



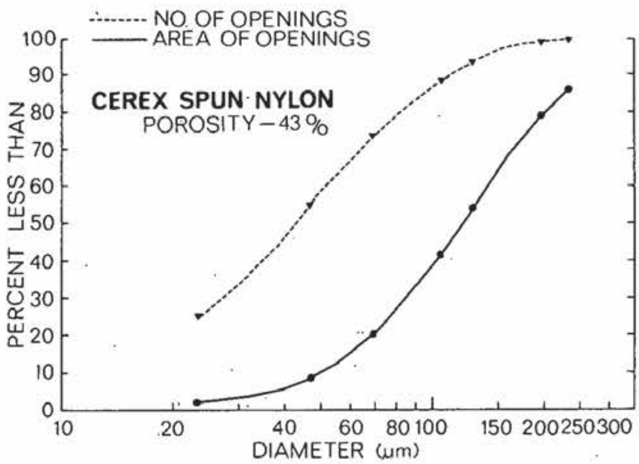


Fig.3. (cont.)

Figure 3 shows for each envelope material the relationship between percent less than and opening diameter as derived from the measured area of openings. It also shows percent less than, and the measured number of openings of different diameters. Total porosity for each material was also computed from the ratio of openings to the total area analyzed. The results of these analyses (Fig. 3) showed that these filters have a wide range in total porosity (5 to 43%) and a wide range in uniformity coefficients. The Uniformit Coefficient (D_{60}/D_{10}), based on area of openings, varied from 2.4 for Tile Guard PG-90 to 5.6 for the coarse mesh polyester sock. Both glass fibre products, Tile Guard PG-90 and S-110, had similar distribution characteristics, but the pore sizes of PG-90 were generally smaller. In all cases, the analyses based on the measured number of the various sized openings gave a finer pore size distribution than that based on the measured area of the openings.

Opinion and questions on the state of the art

The problem of drain silting is understood. The flow conditions which cause the movement of solid material is known. The physical properties of the soil can be measured. The physical properties of the envelope materials can also be measured. How do we put this information together to forecast in advance of construction which soils require protective envelopes? In cohesive soils, do envelopes cause drain failure?

An envelope adds 23% to the cost of a drainage system; therefore, envelopes should not be used unless required.

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