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DEFINITION OF THE DRAINAGE FILTER PROBLEM

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Tasks of a filter around an underground drainage filter

It is common to consider the following

1. Retention of soil particles that may enter the drainage pipe and cause its clogging. For some sensitive structures it is important to prevent settlements due to soil transportation by drainage water.

2. Increasing the effective permeable diameter of the drainage pipe. This is done in two ways

   a. By actually increasing the permeable diameter reducing the radial resistance by the logarithmic ratio of the original diameter D_o and the enlarged one D_f so that the decreased resistance is by

   $$\frac{\ln D_f/R}{\ln D_o/R} \cong \frac{\Delta/D_o}{\ln D_o/R} \tag{1}$$

   where R is some equivalent distance of the radial resistance part of the flow and Δ is $D_f - D_o$. The denominator has a value of 4 - 5 clearly a 50% increase in D_o gives only about 10% reduction in radial resistance.

   b. The second form of reducing the radial resistance is by increasing the effective perforation of the drainage pipe almost to infinity. The local contraction of streamlines towards pipe perforation is over a distance which is of the same order of

magnitude as the distance between perforation holes. KIRKHAM and SCHWAB (1950, 1951).
Here the effect is different for corrugated plastic pipes where the filter bridges over the corrugation and can form a continuous finely perforated surface even when very thin. Without the corrugations the filter must have a certain thickness to allow for easy latteral flow towards holes in the pipe's circumference.

3. Integration of cracks root holes and other permeable elements in the ground. The larger the perimeter of the filter the larger is the probability of such integration.

4. Junction of latterals and main pipes.

5. Short circuiting partially clogged drains letting the water bypass the clogged part.

6. Increasing the hydraulic conveyance capacity of the pipe.

The main uses are the first two. Under present prices of pipes and filters it will not pay to increase diameter by a thick filter. Rather it is cheaper to increase the pipe itself.
The cost price of meter drainage increases with the diameter whether by a larger pipe or a thicker filter. Both from a hydraulic point of view and from the point of view of performance probability there exists an alternative of installing a denser drainage system. There must be an optimum which is difficult to calculate. Nevertheless there is a trade-off between pipe effective diameter and other improvements and it is therefore quite questionable. The proper minimum diameter seems to be determined by maintenance requirements and higher diameters by hydraulic conveyance requirements.
Thus we are left with two main uses of the filter.

1. Holding back of soil grains.

2. Approaching an ideal continuous perforation.

Materials tried for filters

Numerous materials have been tried as filters. For the following a simple classification will be

1. Gravel
   These were used more than any other filter and usually with success. They are rather expensive, almost doubling the price of underground drainage.
   The gravel filters have all the advantages of bulky filters. In some heavy soils they are absolutely essential. This is because the drain must be layed below the plough layer while the soil at this depth tends to be absolutely impermeable.

2. Artificial aggregates produced from soil (DIERICKX ET AL).
   The aggregates have been produced by using portland cement, lime asphalt emulsions and polime resins of various kinds. It is easy to show that the cheapest among these would be with portland cement or lime. Still at about 5% level by weight to produce the aggregate the ratio of 1/20 between the cost of aggregate per ton and cement per ton is roughly the break even point. In most cases artificial aggregates will not be economical as were substitutes for gravel filters.
   Artificial aggregates may have some merits if used in a smaller quantity around the drainage pipe by some special technique. It may also become interesting when gravel are rare and expensive or when they cannot prevent effectively soil particle transport.

3. Fibrous filters
   These were made of natural materials such as coconut fibers or peat and synthetic materials or felt like or actual cloth. There exist many examples of glass plastics and other fibers. The main experience with such filters can be summarised as follows.

   a. Fine filters clog by clay accumulation on its surface and possibly by deposition of organic matter and chemicals.

b. Thin coarse filters do not fulfil their taks as they let particles of silt to enter the drain which will easily settle and will not be washed out.

c. Thick and coarse filters have worked well.

There is no proved explanation for this experience. However an attempt may be made here.

Why thick and coarse filters work

The theory of detachement of soil particles has been formulated and demonstrated elsewhere (ZASLAVSKY, KASSIFF, 1965).

Particles smaller than the filter's hole leave the soil. Larger particles remain behind. This process may continue until the soil stabilizes and an inverted natural soil filter forms gradually, changing from coarse to fine grains.
If the filter is too coarse and conditions fit, the erosive process may continue almost without a chance for stabilization. If the filter is thin and fine all the small particles will be stopped at one thin surface and practically clog it. However with a thicker filter the fine particles leaving the soil into the filter will be stopped somewhere in the filter. Each particle will be stopped at some other filter's depth. The probability of filling up the filter completely over a continuous surface and thus clogging it is minimal. The inverted natural soil filter has an opportunity to develop. It then stabilizes the soil against further erosion while somewhat increasing the effective thickness of the filter.

Alternative approaches to drainage filter

It would be economical to use thin and coarse filters. However such filters would be effective only if in the soil there would be large enough particles or aggregates that will form the inverted soil filter with little silting into the drainage pipe.
Alternatively a finer filter could have been used if there would be no free fines in the soil.

The above may be achieved where the soil has stable aggregates. This is really the experience in many clay soils with high cohesion and stable aggregates when practically no filter is necessary for the prevention of clogging.

The use of a soil conditioner can be tried. Differing from the approach of producing a bulk of soil aggregates around the pipe we wish only to treat a relatively thin layer around the drain. Alternatively we can formulate our problem in eliminating from the soil particles smaller than some 50 - 100 microns in size.

In other words the requirement is not to produce large aggregates but to prevent clogging of fine filters or failure of coarse thin filters.

Preliminary experiments

In the following there are typical results in the use of 'Lima' soil conditioner on various soils. Clearly it increases the effective aggregate diameter and can practically eliminate any fines in the clay fraction and the finer silt fraction.
This soil conditioner is water soluble before it is adsorbed on the soil. The soil is stabilized practically as soon as it comes in contact with the 'Lima' solution.
Therefore it has been thought that the filter can be soaked with a soil conditioner solution and the soil that will come in contact with the filter will become stabilized. In other words the soil immediately in contact with the filter will have no fine loose particles.
A special permeameter has been built to try this concept. A thin and relatively coarse filter that permitted soil particles to pass through, became effective after the treatment which involved soaking with 5% 'Lima' solution. It still has to be shown that there is no appreciable clogging by clay accumulation at the outer filter surface.

Further work

A program has been drawn for a series of experiments with specially designed erosionmeters where the outflow hydraulic gradients at which soil detachement starts is observed. It is possible to install standard sieves of hole diameter D_s. The important measurement is j (D_s) (the outflow gradient as a function of the hole diameter) for each soil (ZASLAVSKY, KASSIFF, 1965).
The method of application of the soil conditioner should be studied in coordination with drainage machine builders. Contact in that respect have been made with Steenbergen B. V. It is possible to spray soil aggregates at different stages of the drainage installation.

APPENDIX I

Typical test results with a soil stabilizer

1 . Typical results of wet sieving after treatment with various stabilizing agents (The different enumerated stabilizers are precoarsers of 'Lima').

Table 1

The soil: Loess of Northern Negev: Clay 38%, Silt 49%, Sand 13%. Tests marked with $^{\Delta}$ have been done on a different loess, 30% Clay, 59% Silt and 11% Sand.

% of stabilizer by weight	0.025		0.050		0.075		0.100		0.200	
	% stable aggregates by weight									
Type of stabilizer	larg. than 0.25	larg. than 0.1	larg. than 0.25	larg. than 0.1	larg. than 0.25	larg. than 0.1	larg. than 0.25	larg. than 0.1	larg. than 0.25	larg. than 0.1
1	2	3	4	5	6	7	8	9	10	11
Water alone	14.8	36.2								
Krikium	19.5	39.2	21.6	42.3	23.4	44.7	28.1	49.3	32.1	53.4
Cat flock			38.5	49.5	45.0	56.9	47.5	61.2	51.0	74.9
Russian Lignosulfonate			17.3	40.1			20.2	44.5	22.6	46.2
Lignosulfonate	0.25%		0.50%		0.75%		1.0%		2.0%	
Norling II da	22.4	38.1	27.8	43.9	39.0	52.4	39.6	54.0	55.1	67.8
Lignosulfonate	0.25%		0.50%		0.75%		1.0%		2.0%	
Norling 41							46.1	59.2	57.0	69.2
Lignosulfonate							1.0%		2.0%	
Serla Sol N							24.2	41.6	35.9	50.9
Lignosulfonate							1.0%		2.0%	
W 88 C							33.4	48.6	36.2	51.1
Portland cement			0.50%				1.0%		2.0%	
			27.5	48.6			32.5	55.0	42.5	66.6
Stabilizer 16			25.5	49.5	35.3	60.3	34.7	60.1	42.1	64.5
Stabilizer 15							55.6	77.2	58.3	76.5
Stabilizer 1			22.2	47.2	29.5	54.7	28.1	54.1	45.1	65.4
Stabilizer 30			29.8	58.1			43.6	66.0	59.7	80.3
Stabilizer 29			21.7	39.8			30.9	61.6	66.4	86.5
Stabilizer 31 a							50.3	70.0		
Stabilizer 31 b							50.2	68.8		
Stabilizer 35							45.3	64.6	50.7	69.2
Stabilizer 41$^{\Delta}$	31.1	54.3	44.6	68.5	47.4	67.0	53.5	73.1		
Stab. 41 after spray drying$^{\Delta}$							67.9	81.9		
Stabilizer 42	31.4	50.8	47.1	65.8	55.2	72.3	60.0	74.5		
Stab. 42 after spray drying$^{\Delta}$							57.0	75.6		
Stab. 43 after spray drying							61.0	78.2		

2. Typical results for clay soil Nes Amim-Israel by wet sieving

	0.5% Lima	no treatment
larger than 2 mm	37.6 %	6.5
1 - 2 mm	32.7 %	15.5
0.5 - 1 mm	18.5 %	35.8
0.25 - 0.5 mm	6.38 %	21.9
larger than 0.25 mm	95.44 %	81.6
0.1 - 0.25 mm	4.93 %	14.7
larger than 0.1 mm	100.4 %	90.2
average weight diameter mm	1.24	0.575

3. Experiments with stabilized Loess with 0.1% Lima was conducted with two types aggregates 0.84 - 2 mm and 0.42 - 0.84 mm. In both cases there was no obvious settlement of the aggregates in the permeameter after wetting while there was 10% settlement in the stabilized soil.
The respective permeabilities to air were related to permeability with water (k_a/k_w)

Aggregate seize				instability
0.84 - 2 mm	untreated	(k_a/k_w)	=	675 - 386
0.84 - 2 mm	stabilized	(k_a/k_w)	=	110 - 29
0.42 - 0.84 mm	untreated	(k_a/k_w)	=	64 - 40
0.42 - 0.84 mm	stabilized	(k_a/k_w)	=	27 - 16

Clearly the stabilized soil maintains hydraulic conductivity that can be 2.5 - 12 times larger than the untreated soil.

APPENDIX II

Stability of Soil Fragments Against Seepage Forces

II. 1 Piping of Non-cohesive Material

Consider a soil surface making an angle α with the horizon or slope $m = \tan\alpha$ (Figure 1). Consider also a unit vector normal to the soil surface and pointing out of the soil. A flux

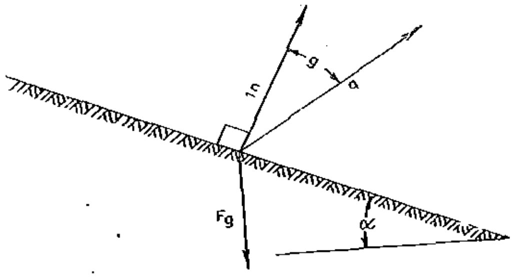

Fig. 1 Outflow seepage from sloping surface
q - water flux vector
F_g - submerged weight of soil fraction
g - vanishes in isotropic soil with equipotential soil surface

vector q makes an angle with this unit vector. Assuming moderate head differences in the water above the soil surface, equipotentials will be parallel to the soil surface. (This will not be the case with a thin water layer flowing downhill called seepage force). The hydraulic gradients will be orthogonal to the soil surface. Thus, any angle ρ between $\underline{q}$ and $\underline{1n}$, the normal unit vector, will be only in anisotropic soil. For the sake of simplicity, only the isotropic and orthogonal case will be treated. The general case is then straightforward.

The net submerged weight of a particle (for the total volume including pores) $\underline{F}_g$ is as follows:

$$\underline{F}_g = -(1-n)(\gamma s - \gamma w)\, V\, \underline{1\ z} \qquad \text{II. 1}$$

γ_s is the unit weight of the pore-free solid material, γ_w the unit weight of soil solution, V volume of the soil fragment, $\underline{1z}$ unit vector in an upward direction, n is the porosity, z elevation.

The component normal to the soil surface (direction of $\underline{1n}$) is

$$F_{gn} = |F_g| \cos\alpha = -(1-n)(\gamma s - \gamma w)\, V \cos\alpha \qquad \text{II. 2}$$

The seepage force (assuming orthogonality) is

$$F_{sn} = V\,\gamma w\ \operatorname{grad}\phi \qquad \phi = p/\gamma + z \qquad \text{II. 3}$$

Thus, a flow, out of the soil, has a positive flux q and a negative gradient grad ϕ, and, F_{gn} is positive. Combining F_{gn} of equation II. 2 and F_{sn} of equation II. 3 the total active force is

$$F_a = - V \left[\gamma \,\text{grad}\, \phi + (1 - n)\,(\gamma_s - \gamma_w) \cos \alpha \right] \qquad \text{II. 4}$$

In a cohesionless soil this force must be positive to cause piping. In other words, the condition for piping is that

$$\frac{\gamma_w \left[\text{grad}\, \phi \quad 1 \quad n \right.}{(1 - n)\,(\gamma_s - \gamma_w) \quad \cos \alpha} > 1$$

This is a generalization of the commonly presented piping formula for horizontal soil surface (usually called boiling or quicksand). Several conclusions (almost trivial) may be drawn here.

a. An outward flow (grad $\phi < 0$) may cause piping. Infiltration (grad $\phi > 0$) is a stabilizing mechanism.

b. On a high slope ($\cos \alpha < 1$) the conditions are less stable against piping. Here the stability of a single aggregate is considered regardless of the possibility that the slope as a whole may become instable at α approaching the internal friction angle. It is realistic to consider larger values of a α only if there is an incoming seepage that acts as a stabilizer or if some other processes such as electro-osmosis are being used for stabilization.

c. Under the same gradients and cohesion, a compacted material (small n) will be more stable.

d. Any mechanism increasing the outward gradient or decreasing the inward gradient will decrease stability, against other forces such drag by flowing water, splashing by raindrops, earthquakes etc.

One of the more significant conclusions can be drawn by substituting grad $\emptyset$ in II. 5 by (q/k). The piping can occur by an extremely small flux of water if the conductivity is small. Furthermore grad $\emptyset$ may be large over an extremely small soil volume (cavitation point) and piping will occur with an extremely small water discharge. This is already in line with some observations.

II.2 Stability against piping in a cohesive soil

In equation II. 4 the gravity, floatation and seepage forces have been summed up. In the case that there is a net force F_a that tends to detach the particle from its place, there will develop an adhesive force F_c as a reaction. Let us assume the maximum average tensile stress T between aggregates and a contact area A (without any moments)

$$F_c = a\ t\ A \qquad \text{II. 6}$$

where a is some geometric coefficient and A a surface area of this soil fragment. The direction of F_c is always colinear and opposite to the net force in II. 4.

For a soil fragment to be unstable the criterion is now

$$- V \left[\gamma_w \text{ grad } \emptyset + (1 - n)(\gamma_s - \gamma_w) \cos\alpha \right. \ a\ T\ A \qquad \text{II. 7}$$

rearranging equation II. 7 and putting $(V/a\ A) = bD$ where D is an equivalent particle diameter and b a geometric coefficient one gets as a criterion for instability

$$- \frac{bD}{T} \left[\gamma_w \text{ grad } \emptyset + (1 - n)(\gamma_s - \gamma_w) \cos\alpha \right] > 1 \qquad \text{II. 8}$$

To somewhat simplify equation II. 8 we note an outward gradient by $j = -$ grad $\emptyset$. An aggregate will be unstable if

$$\frac{bD}{T} \left[\gamma_w j - (1 - n)(\gamma_s - \gamma_w) \cos\alpha \right] > 1 \qquad \text{II. 9}$$

If the outward flux q is known (assuming an isotropic equipotential soil surface) then in place of equation II. 9 one can write

$$\frac{bD}{T}\left[\gamma_w \frac{q}{K} - (1 - n)(\gamma_s - \gamma_w)\cos\alpha\right] > 1 \qquad \text{II. 10}$$

Many heavy soils may develop tensile strength of up to T = 0. 1 kg/cm and when compacted even as high as 1 kg/cm. For the following estimate, one can consider b as being round unity. Clearly

$$\frac{bD\gamma_w j}{T} > \frac{bD}{T}\left[wj - (1 - n)(\gamma_s - \gamma_w)\cos\alpha\right] \qquad \text{II. 11}$$

And therefore for highly cohesive soils the criterion for stability of a fragment against piping is

$$\frac{\gamma}{T} \quad D\gamma_w j < 1 \qquad \text{II. 12}$$

The neglected term here is $(1 - n)(\gamma_s - \gamma_w)\cos\alpha$. If T = 0. 1 kg/$cm^2$, then the product Dj must be of the order of 10^2. Clearly the neglected term which is at best of the order of a unity is negligible. It is interesting to note, that for the particle diameter D = 0. 1 cm, j must be of the order of 1000. This is what was actually found in experiments (ZASLAVSKY and KASSIFF, 1965). It explains why in cohesive soil, splashing by raindrops or free swelling and dispersion are necessary to produce appreciable erosion. The momentary outward gradients developed by a raindrop can be very high. A highly dispersed swollen clay has a lower T.

Evidently, large soil portions will be more easily washed out because of larger D and smaller T. This is really the experience in channels through cohesive soils where often large chunks of soil fall out from the bank into the water stream. However for larger soil portions the hydraulic gradients often cannot be maintained very high.

The action of a soil conditioner is in increasing the diameter or the cohesion for a given diameter.

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