Laboratory Testing of Vertical Drains

Essais en Laboratoire des Drains Verticaux

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SYNOPSIS A view is given on the most important properties of prefabricated vertical drains. The apparatus used for measuring these properties in the laboratory are explained, in particular the Enka drain tester. Results are presented of investigations into the discharge capacity, prolonged exposure to pressure, and the filtering properties. Some considerations deal with the relation between the circumstances in the laboratory and in the field. Conclusions are drawn, especially about the filter behaviour of drains.

1. INTRODUCTION

In practice one simple demand can be made on a vertical drain: During its required lifetime the drain must function in agreement with the capacity anticipated and calculated. When settlement is completed in the required period, the drains obviously are good.

The problem now is: what can be predicted about the "good behaviour" in practice?
Probably the present generation of drains, synthetic, prefabricated, bandshaped, lends itself more easily to laboratory investigations than the former generation, the sand drains.
But nevertheless these drains, too, present some problems in testing the functioning in the laboratory.

The function of prefabricated drains can be subdivided as follows:

- discharge capacity (under lateral pressure), both initially and during prolonged use.
- filter function.
- tensile strength.

This paper will not go into the tensile strength. Strength measurements are easy to perform, and the requirements (although not defined sharply) can be met adequately.

The compressibility in soil, and thereby the discharge capacity of drains, is a different matter. Some years ago questions arose about the suitability of Colbond KF 650 drains (a fully non-woven type) as to the rate of discharge under high lateral pressures. For some applications these questions probably were justified, so Enka started the development of an improved drain, with increased discharge capacity. Simultaneously an apparatus was designed by which the functioning of this new core/skin drain could be measured. The so-called drain tester and the testing procedures used are described in section 2.

In the drain tester also the behaviour under long-term pressures could be investigated. For simultaneous measurement of more samples nevertheless a different arrangement was used.
This too is described in 2. Furthermore the drain tester was found to be rather useful for testing the behaviour of a drain in combination with soil. This item however is complicated, as somehow a compromise has to be found between the two contradictory requirements:

- All soil particles should be retained outside the drain.
- All the excess pore water should enter the drain without any pressure losses.

Our view on this compromise is expressed partly in section 3 (Results, considerations) and partly in the conclusions.
Many questions about the functioning of drains in practice have yet to be answered before definite laboratory testing methods can be proposed.

2. APPARATUS AND TESTING METHODS USED

2.1. The Enka drain tester.

A scheme of the drain tester developed and built by Enka Research is given in Fig. 1.

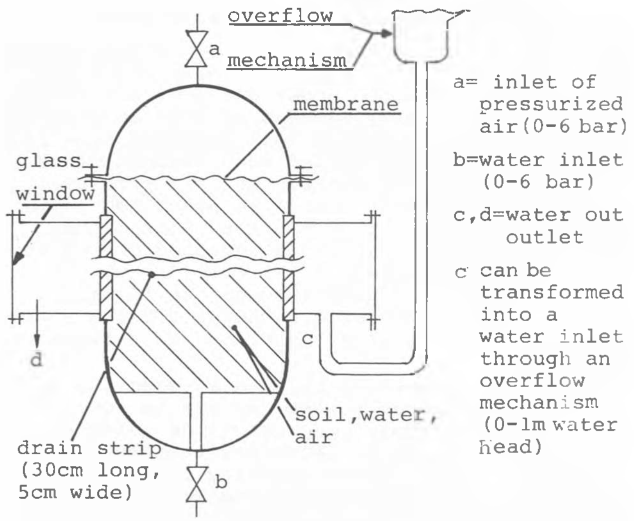

Fig. 1 Scheme of Enka drain tester.

The pressure vessel consists of stainless steel, and has an inner diameter of 0,30m; the admissible inner pressure is 6 bar. The drain strip usually is 5cm wide. Depending on the drain construction this width can simply be cut from a wider drain, or be prepared specially. The former method is suitable for fully nonwoven drains or other drains with separate channels. When the core does not form separate channels - as in the case of the Colbond CX 1000 drain where the channels are interconnected over the full length - the core is cut separately, and the filter jacket is closed in the original manner.

The sealings on both ends of the drain strip are metal plates provided with a hot melt glue.

The slack rubber membrane, used when the vessel is filled with soil, provides air tightness even after consolidation of the soil. Two pore pressure cells can be built into the soil for which special connections are provided in the wall of the vessel.

2.2. Procedure for testing the discharge capacity.

The drain strip is provided with a thin polyethylene film, before the hot melt sealings are fitted. The vessel is filled either with water or just with air. Both have the advantage over soil that the pressure near the drain is controlled instantaneously. The advantage of air over water is that a possible leakage in the polyethylene cover or in the connection with the sealings becomes visible immediately, whereas water would cause misreadings (temporarily, because a leakage will always be detected after the completion of a test). After the lateral pressure has been set (normally 0.5, 1, 2 or 3 bar) the hydraulic gradient over the drain is adjusted by the overflow mechanism connected with c. Air in the drain can be removed by vacuum at d. The discharge capacity of the drain as a function of lateral pressure and hydraulic gradient is obtained by measuring the water output at d per unit of time. Normally the temperature is 20°C; the water is demineralized and deaerated.

2.3. Procedure for testing filter function and discharge capacity of soiled drains.

The drain strip as such is fitted to the sealings. The vessel is filled with the soil, which is carefully distributed under and over the drain, air enclosures being avoided as much as possible. Up to now only artificial soil mixtures have been used, consisting of graded sand, standardized clay (Limburg T) and water. The air pressure over the membrane is increased stepwise, normally to 3 bar in 30 minutes. During the pressure build-up, water is squeezed out of the soil through the drain.

Clay particles that pass through the filter jacket during the test are caught simultaneously with the water leaving the drain, as a function of time.

The test can either be terminated when the excess pore pressure becomes zero, or can be continued infinitely by supplying pressurized water to the soil by connection b. When the test has been finished, the discharge capacity of the drain - now in the soiled state - can be measured separately according to the procedure described in 2.2.

2.4. Test arrangement for prolonged exposure.

The drain tester permits the mounting of one specimen only. For testing the behaviour of several drains at the same time over longer periods under high lateral pressure in wet condition, a different arrangement has been used. A scheme is given in Fig. 2.

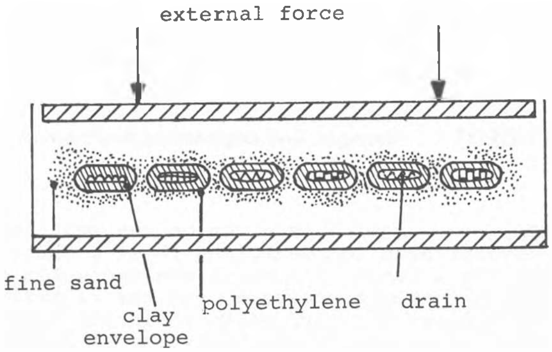

Fig. 2 Arrangement for testing during prolonged exposure.

Each drain strip is provided with a wet clay envelope, again packed in a polyethylene film. Six samples are laid side by side in a fine sand bed, under water. The upper load is supplied by a compression tester, and adjusted to cause a normal stress of 2 bar. By adjusting a hydraulic gradient over each drain, the rate of discharge will indicate the state of the drain.

3. PERFORMANCE OF TESTS; CONSIDERATIONS;RESULTS.

3.1. Discharge capacity in relation to lateral pressure.

During the development of the CX 1000 drain a number of tests have been carried out according to the procedure described in 2.2. Although sometimes pressures up to 6 bar were used, normally the lateral pressure varied beteen 0.5 and 3 bar. This pressure range undoubtedly covers some needs for the future, though up to now we have not come across drain depths over 40m. Our goal was to obtain for the 10cm wide drain a discharge capacity of 10 litres per hour ($\approx 3.10^{-6}$ m^3/s), under any circumstances, which is about ten times the capacity of the KF 650 drain under high lateral pressure. At a working area of, say, 6 m^2 per drain, this capacity would allow a settlement of 4cm per day. This would be abundant for any drain application. The capacity is mainly determined by the open area of the drain, so partly by the initial volume of the core and ist compression resistance, and partly by the quality of the filter jacket that could be pressed into the core. As for the material, polyester was chosen, both for the filter jacket and for the core. The final values for the CX 1000 drain, 5cm wide, are presented in Fig. 3. (The discharge is given in the recommended units of m^3/s, a discharge of 10 l/h roughly corresponds to $2.8 \cdot 10^{-6}$ m^3/s).

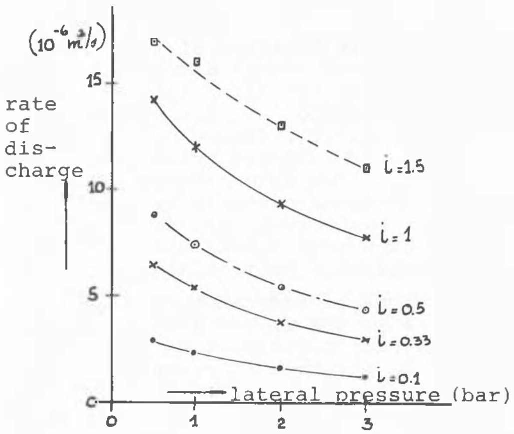

Fig. 3 Rate of discharge as a function of lateral pressure. parameter: hydraulic gradient i. Colbond CX 1000, 5cm wide.

Fig. 4 shows the influence of the modulus of the filter jacket on the discharge capacity of the drain. The two drains investigated have similar cores, but one is provided with a low-modulus fluffy non-woven, while the other has a high-modulus, firm non-woven. Other requirements concerning the filter quality will be dealt with in 3.4.

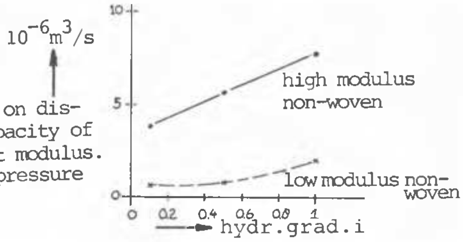

Fig.4 Influence on discharge capacity of the jacket modulus. (lateral pressure 3 bar).

3.2. Behaviour of drains under prolonged pressure in wet condition.

It is virtually impossible to check the condition of a drain installed in the field. When a drain stops working unexpectedly, the cause is difficult to trace. Not necessarily the drain itself is to be blamed, but there still exist doubts about the suitability of some materials used in drains. For that reason the test described in 2.4. was started to check the durability in mechanical behaviour of six drains, five of which had a core/jacket construction. The test had been set up for a period of one year, but had to terminated before schedule after three months. Two of the drains investigated had a non-woven polyester jacket, one an acetate rayon jacket, one acetate rayon jacket with polyester fibres, one a paper jacket, and one drain consisted of PVC. Some of the materials have a good reputation as on their resistance to rot or to degradation by conditions encountered in the soil. Others are known to be susceptible to degradation, or are likely to creep under prolonged tension. The lateral pressure used, viz. 2 bar, is severe but not unrealistic. As an intermediate check on the condition, once a week the discharge was measured, under a hydraulic gradient of 0.3. The results are given in Fig. 5. Nearly all the curves show a maximum. The reason was traced to air enclosures that could be removed.

During this (relatively short) test none of the drains failed or showed abrupt changes in rate of discharge. Some show a gradual decay, but probably apart from A, whose initial discharge is already very low, the discharge capacity for the others is more than sufficient. After the termination of the test, no drains, again with the exception of A, showed any clay inside.

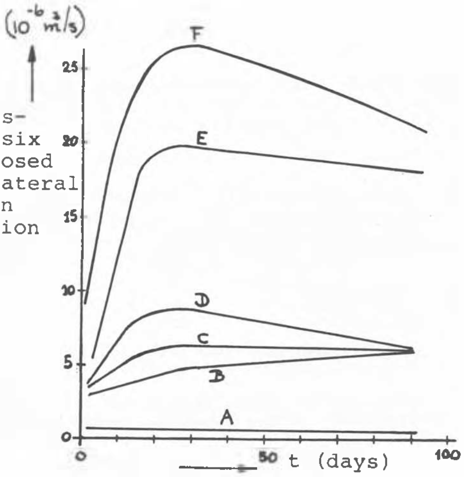

Fig. 5 Rate of discharge of six drains exposed to 2 bar lateral pressure in wet condition

3.3. Performance of filter tests; results

The drain tester is filled with the mixture of graded sand, silt, clay and water. The particle size distribution of 2 mixtures used is sketched in Fig. 6.

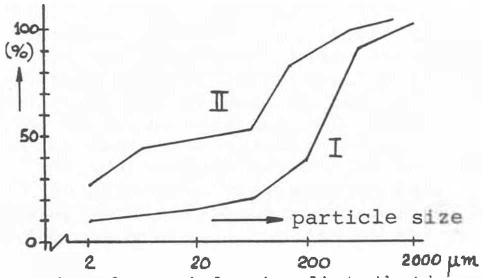

Fig. 6 Particle size distribution of 2 artificial soil mixtures

In soil type I, tests were carried out with drain types B,C and E (the code is identical whit that used in Fig. 5)
Fig. 7 presents the setting of the air pressure and the water pressure as a function of time.

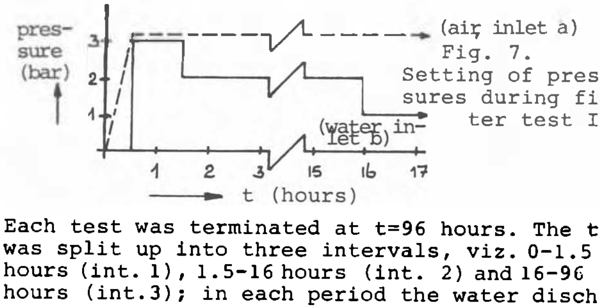

Fig. 7. Setting of pressures during filter test I.

Each test was terminated at t=96 hours. The time was split up into three intervals, viz. 0-1.5 hours (int. 1), 1.5-16 hours (int. 2) and 16-96 hours (int.3); in each period the water discharge and the amount of clay in the discharged water was measured, Pore pressures directly over the drain and 10 cm under the drain were read regularly. Results are presented in tabel I.

A similar test was performed with soil type II on drains A and C. The pressure settings were different and are presented in Fig. 8.

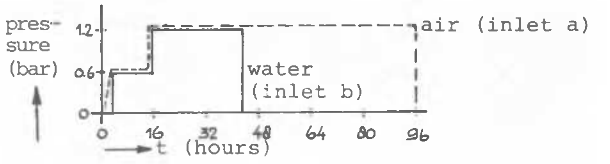

Fig. 8 Setting of pressures during filter test II.

The three time intervals now were chosen: 0-16 h (int.1), 16-44 h (int.2) and 44-96 h (int.3). The results are given in table II.

Table 1 Results of filter test I

type of drain:		A	C	E
Total amount of water discharged (10^{-6} m^3) during:	int. 1	300	1200	300
	int. 2	1600	4800	1450
	int. 3	2400	9600	3200
Total amount of clay discharged (g) during:	int. 1	35	110	3
	int. 2	10	10	1
	int. 3	0	0	0
Maximum pore pressure near the drain during test (bar)		2.0	1.4	2.4

The clay particles discharged are mainly < 2μ m, with only a few % between 2 and 5 μm.

Table II Results of filter test II

type of drain:		A	C
Total amount of water discharged (10^{-6} m^3) during:	int. 1	110	400
	int. 2	240	480
	int. 3	560	720
Total amount of clay discharged		none	none

3.4. Considerations about filters for vertical drains.

In contrast with industrial filters, vertical drain filters do not permit cleaning. In the drain process it is irrelevant whether specific particles are retained as long as the drain keeps working; that means that neither the water intake is prevented by an impermeable cake just outside the filter and/or within the filter, nor the discharge is blocked somewhere. The core of a drain could be blocked by particles that pass the filter but cannot be carried along by the discharge flow.

In our opinion the formation of an impermeable filter cake at the drain surface by retaining all solid particles should be prevented. On the contrary, the surrounding soil should be kept as open as possible. This implies that the smallest particles, which are responsible for a low permeability of the soil, should be allowed to pass the filter and be taken along by the discharge flow. In this way in fact a natural filter zone is gradually built up around the drain. This should increase the effective equivalent diameter, so eventually more water will be discharged from the soil.

At the moment it is impossible to specify the maximum size of the particles that should be allowed to pass the filter. Too much is unknown about the behaviour of the soil and of particles floating in abundant water near a drain just after installation.
In the first period (hours, may be a day) after installation, when much water is discharged, the natural filterzone must be formed. Later on, when the rate of discharge decreases, and the risk of blocking could arise, the supply of small particles to the drain jacket stops naturally.
The results of filter test I support this theory. Draintype C (which as a matter of fact stands for the Colbond CX 1000 drain) discharges a total of 110 grams of clay in the first interval (1½ h) and only 10 in the second (14½ h). After that no clay is discharged at all. It can be calculated that 110 g particles < 2 μ m are originally present in a layer of about 1 cm thick around the drain. The readings of the pore pressure cell provided at abt. 5 mm over the drains, are lower when more small particles have been discharged (order:C-B-E) indicating a higher soil permeability.

Apart from the physical restraints imposed by the size of the pores in the filter jacket, the size of the particles that actually will pass depends on the filter velocity that is reached. In a quick filter test (Büchner funnel) with filter velocities around 0.1 m/s, a particle size up to 6 μ m passes the filter. In the filter test II, presented in table II, no particles passed through at all. Here the filter velocity is of the order of 10^{-7} m/s. In the latter test the amount of water discharged by the drain is controlled completely by the permeability of the soil. To demonstrate this fact the soil in the draintester was carefully replaced by medium sized sand, so that the clay adhering to the filter jacket was not disturbed. At a hydraulic gradient of 10 the drain yielded 50.10^{-6} m^3/s (180 l/h), corresponding to a filter velocity of the order of 2.10^{-3} m/s.
To prevent rapid clogging the structure of a filter is as important as the permeability to the finest particles. From filter experiences in hydraulic engineering (erosion control) and in water purification, it is known that "thick", three dimensional filters are less susceptible to clogging than thinner filters with the same water permeability. Hence probably needlepunched nonwovens should be prefered to heat bonded ones.

4. CONCLUSIONS

- Although the required discharge capacity varies widely for drain applications on the field, in general a discharge capacity of 10 l/h (2.8 10^{-6} m^3/s) will be adequate.
- The filter jacket of a drain should allow the passing of fine soil particles. In this way a natural filter around the drain can be formed, which increases the effective equivalent diameter of the drain.
- The fine particles enter the drain principally just after it has been installed, when the discharged flow is relatively large, so that the risk of blocking is negligible
- More knowledge should be gained about the hydraulic conditions around a vertical drain. More attention should be paid to the development of reliable methods and equipment for measuring e.g. inlet resistance or hydraulic gradients in the soil near a drain.