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LINKING WATER RETENTION CURVES OF POROUS MEDIA TO PORE SIZE DISTRIBUTION CURVES BY A STOCHASTIC MODELLING TECHNIQUE

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I N H O U D

1. ABSTRACT

Air/water exchange phenomena in a porous medium as evoked by stepwise suction changes, imposed to the water in the pores, are simulated. The modelling technique is based on Poiseuille's Law which links capillary rise to pore diameter and suction. The modelling domain is a vertically oriented, two-dimensional cross-section through the porous medium, containing a maximum number of 24 200 pores. The nature of the model is stochastic in the sense that pore diameters are generated from an input pore size distribution using a pseudo-random generator.

Model results indicate that the shape of the simulated water retention curve is dependent on air entry boundary conditions. The suction increase, required to drain a pre-determined percentage of the entire sample pore space, will be larger when the sample/air interface area is increased, leading to a 'steeper' water retention curve.

Upon re-wetting the modelling domain by a suction decrease, airpockets develop at random spots. As a consequence, the simulated wetting curve corresponds to a lower pore water content than the water retention curve at the same suction (hysteresis).

Model results show a systematic discrepancy between pore size distribution curve and water retention curve. Future research is aimed at the computation of pore size distributions from water retention curves, that can easily be determined.

2. PROBLEM IDENTIFICATION

Soil particle invasion into subsurface drain pipes often forms a real problem, notably in unstable, fine-sandy soils. In order to counteract this process, filter materials are used. Properties of filters are largely determined by their spatial and size distribution of the pores. Knowledge of this distribution is therefore a prerequisite in any filter design procedure.

Pore size distribution curves of filters are often derived from water retention curve data by converting suctions into equivalent pore diameters using Poiseuille's Law. The 'retention curve method' is widely used because it is implemented easily. Pore size distribution curves, however, derived unequivocally from water retention curves of filters, are erroneous in that the latter curves are dependent on sample dimensions, where pore size distributions are not (STUYT, 1982). For the purpose of characterizing pore size distributions of drainage filter materials it was felt necessary to develop a technique to convert a water retention curve, easily determined in a laboratory setup, into a pore size distribution. As a first step, a computer simulation model was developed which allows for studying air/water exchange phenomena in a coarse porous medium (pore sizes ranging from 10 to 1000 μm) caused by suction changes in the water in the pores of the medium.

3. MODELLING CONCEPT

A porous medium, e.g. a soil or a filter, may be quite homogeneous if considered macroscopically, but is quite heterogeneous if considered microscopically. The variation in geometry of the elements (e.g. particles or fibres and pores) cannot be described mathematically in a non-ambiguous manner. The uncertainty evolving from this variability causes a corresponding data scatter in experimental results, e.g. a water retention curve, or in the results of a stochastic simulation model. Data sets, acquired by running such a model several times with the same input data, lead to probability-density functions of the data in these sets reflecting the variability of the results due to the heterogeneity of the porous medium. Because of the inability to describe the pore geometry of a porous medium analytically a stochastic modelling technique was applied.

In a laboratory set-up, water retention curves are determined on disc-shape filter samples. The modelling domain applied here is a vertical cross-section or plane through such a filter sample (figure 1).

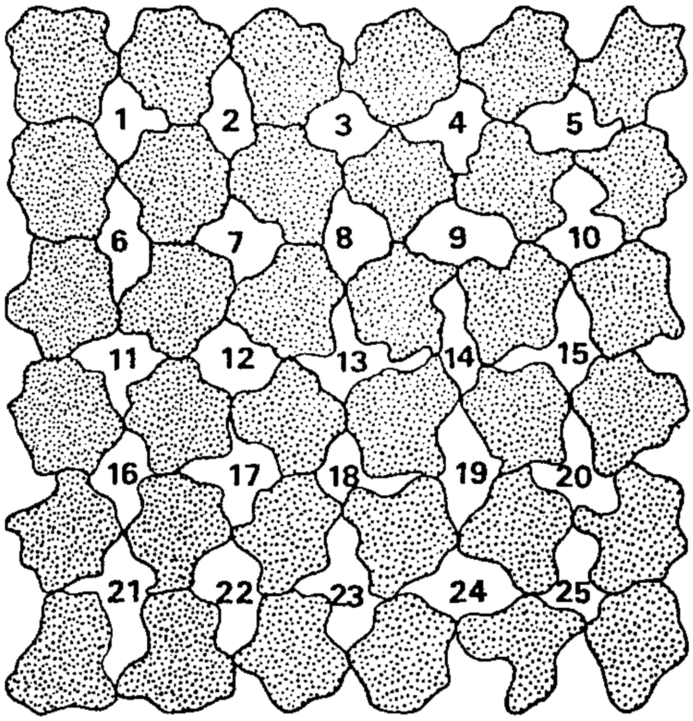

Fig. 1. Schematic representation of the modelling domain: a vertical cross-section through a porous (in this case: granular) medium

The pores in the filter, numbered 1 to 25, are shown separately in figure 2. The pore shape variability is large, but the model does not take into account the pore shape. All pores are considered to have a cylindrical shape, and their diameters are considered equal to the generated pore diameters. All pores have equal length (unity).

In reality (three dimensions) each pore may be connected to adjacent pores in many directions. In the model, pores are thought to be connected to adjacent pores in horizontal, diagonal and vertical directions only (figure 3).

Parallel to the modelling domain a second, also vertically oriented, cross-section through the porous medium has been defined. Pore diamaters in this adjacent cross-section are generated similarly to those in the modelling domain. In addition to the connections between pores in the modelling domain as described above, facing pores in both cross-sections are considered to be mutually connected. Water exchange with the modelling domain is possible via the pores at the bottom end.

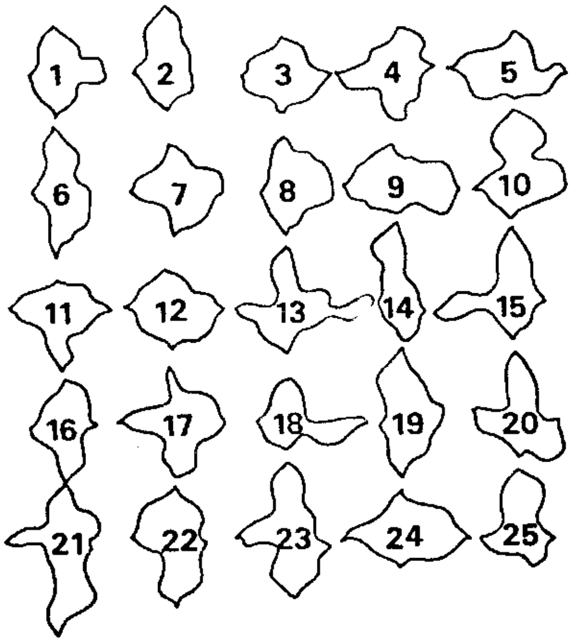

Fig. 2. The pores in the modelling domain or filter cross-section

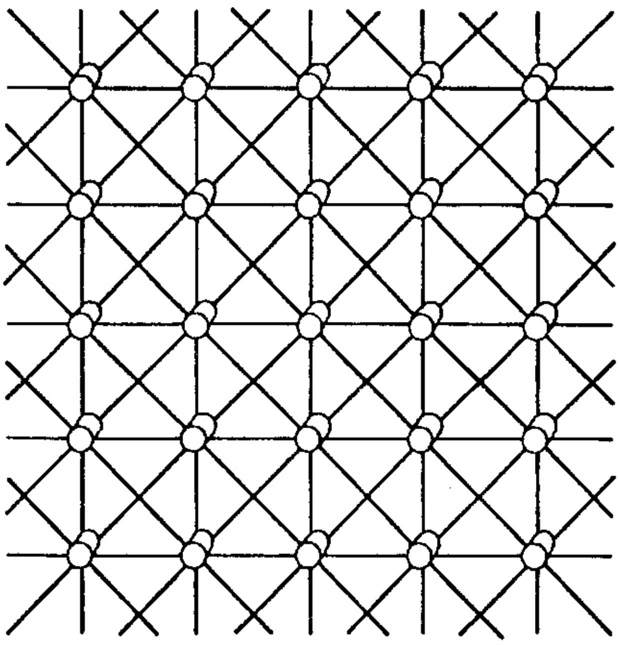

Fig. 3. Connections between pores in the modelling domain

Air exchange is possible via the pores located at the upper side, via the pores in the second cross-section, and also via the pores at the vertical edges (optional).

During depletion, the drainage of a pore is a conditional event, depending on:

- the pore diameter in relation to the current suction. According to Poiseuille's Law, only pores having an effective diameter (μm) equal to or exceeding (29.6/suct) are drainable, where 'suct' is the water suction (m);
- the presence of air in at least one adjacent pore. If the diameter of the mutually connected pore in the adjacent cross-section exceeds the diameter of the pore concerned, the pore in the adjacent cross-section is assumed to contain air, increasing the number of potential air-exchange paths;
- the existence of at least one continuous water outlet path to the bottom end of the section.

During water uptake, the saturation of a pore is a conditional event, depending on:

- the pore diameter in relation to the current suction. Only pores having an effective diameter (μm) equal to or smaller than (29.6/suct) can be saturated, where 'suct' is the water suction (m);
- the presence of water in at least one adjacent pore, provided that a continuous water inlet path exists to the bottom of the section;
- the existence of at least one continuous air outlet path to the upper end (optional: vertical edges) of the sample. If the diameter of the mutually connected pore in the adjacent cross-section exceeds the diameter of the pore concerned, the pore in the adjacent cross-section is assumed to contain air, increasing the number of potential air-exchange paths.

At each suction change, the above water/air exchange boundary conditions are checked for each pore individually in a predetermined sequence. The entire modelling domain is scanned several times in vertical and horizontal directions at each suction change, allowing for the simulation of complicated air/water breakthrough patterns. The model is run on a VAX 11/750 computer.

4. RESULTS

The model was run to study influence of height and diameter of a sample on the shape of the water retention curve. For all model runs, a log-normal pore size distribution curve, having a mode of 70 μm was used as an input.

On studying the effect of different sample dimensions, that is, varying air exchange boundary conditions, four different sample diameters were considered (110, 220, 330 and 440 pores) and five sample heights (11, 22, 33, 44 and 55 pores).

Starting from a suction at wich 5% of the total pore space was drained, the required suction increase to drain the sample to 80% of the total pore space was computed. No repetitions of the computations were made.

In figure 4, the influence of the sample height is shown, for two cases: air-permeable sample edges (dotted line) and air-tight edges (continuous line). Both curves indicate that the required suction increase is smaller when the sample height increases, leading to a less steep water retention curve. This is caused by the decreasing sample/air interface area, relative to the total number of pores. A smaller interface area causes a more sudden air breakthrough in the sample. If the vertical edges of the sample are also air-permeable, the water retention curve will be generally steeper, due to relatively larger air entry area.

In figure 5, the effect of the sample diameter is shown. The required suction increase is slightly larger with increasing sample diameter, when the vertical edges of the sample are air-tight. If these edges are air-permeable, there is no significant trend.

In figure 6, the model output following an attempt to simulate hysteresis is shown. Here, an initially saturated sample was drained, and re-wetted subsequently due to a decrease of the water suction in the pores. The hysteresis-phenomenon can be fully ascribed to the development of air-pockets in the sample, and the so-called 'ink-bottle' effect. The air-pockets are caused by the cut-off of potential air-evacuation paths by pores which were saturated at higher suctions, that is, earlier in the re-wetting simulation run. The air-pockets are shown in figure 7.

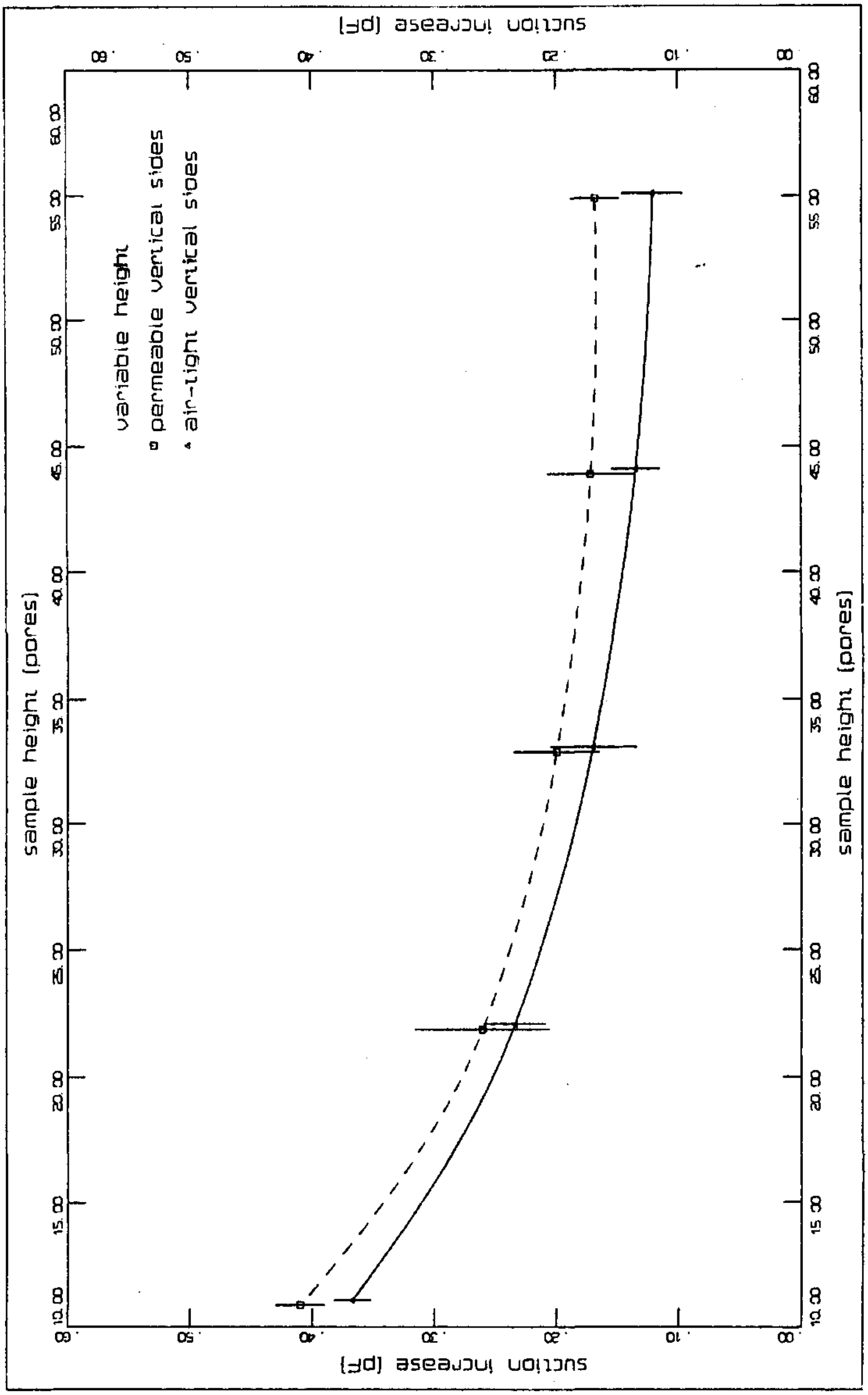

Fig. 4. The influence of the sample height on the required water suction increase, needed to drain a predetermined percentage of the entire pore space

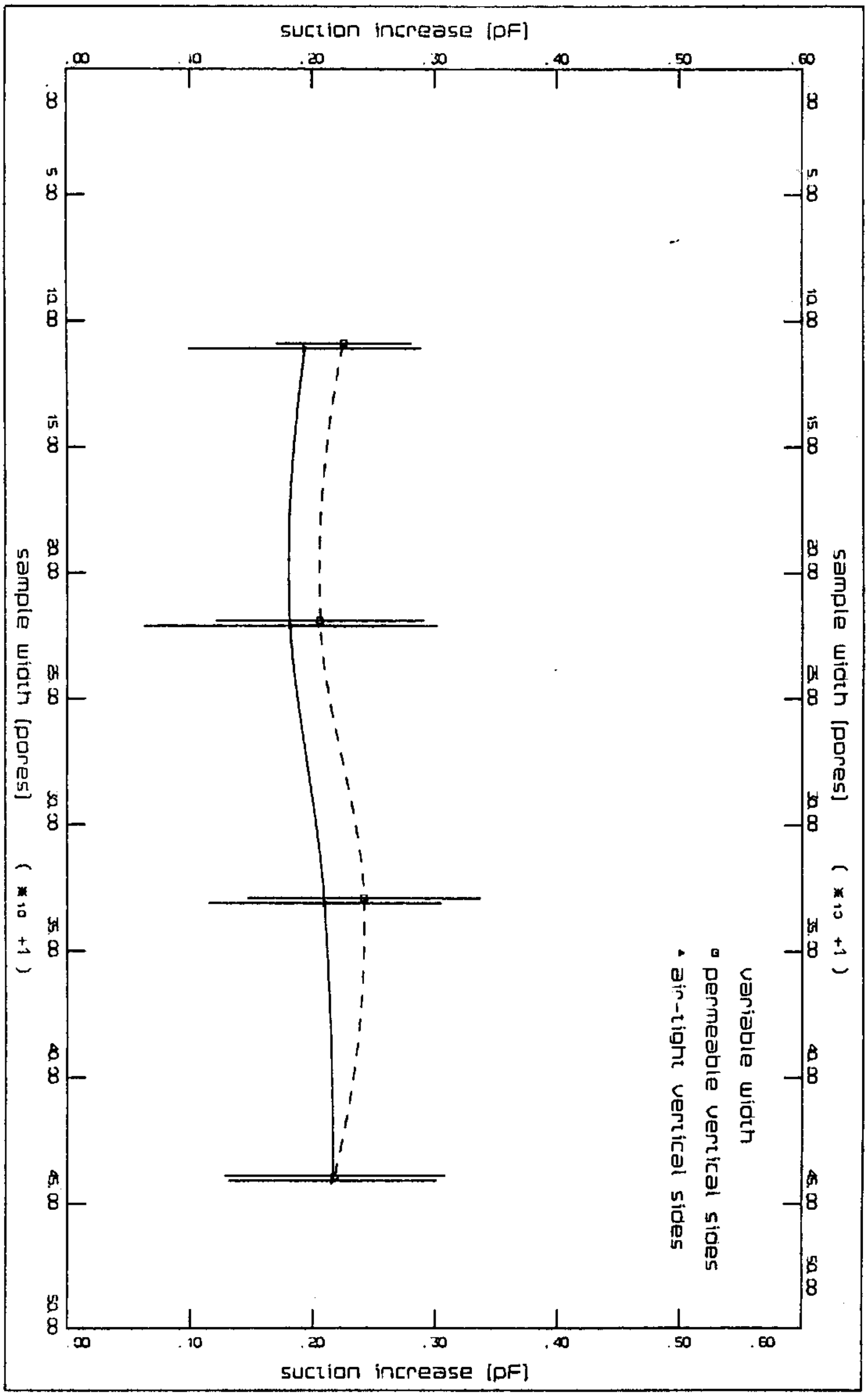

Fig. 5. The influence of the sample width or diameter on the required water suction increase, needed to drain a predetermined percentage of the entire pore space

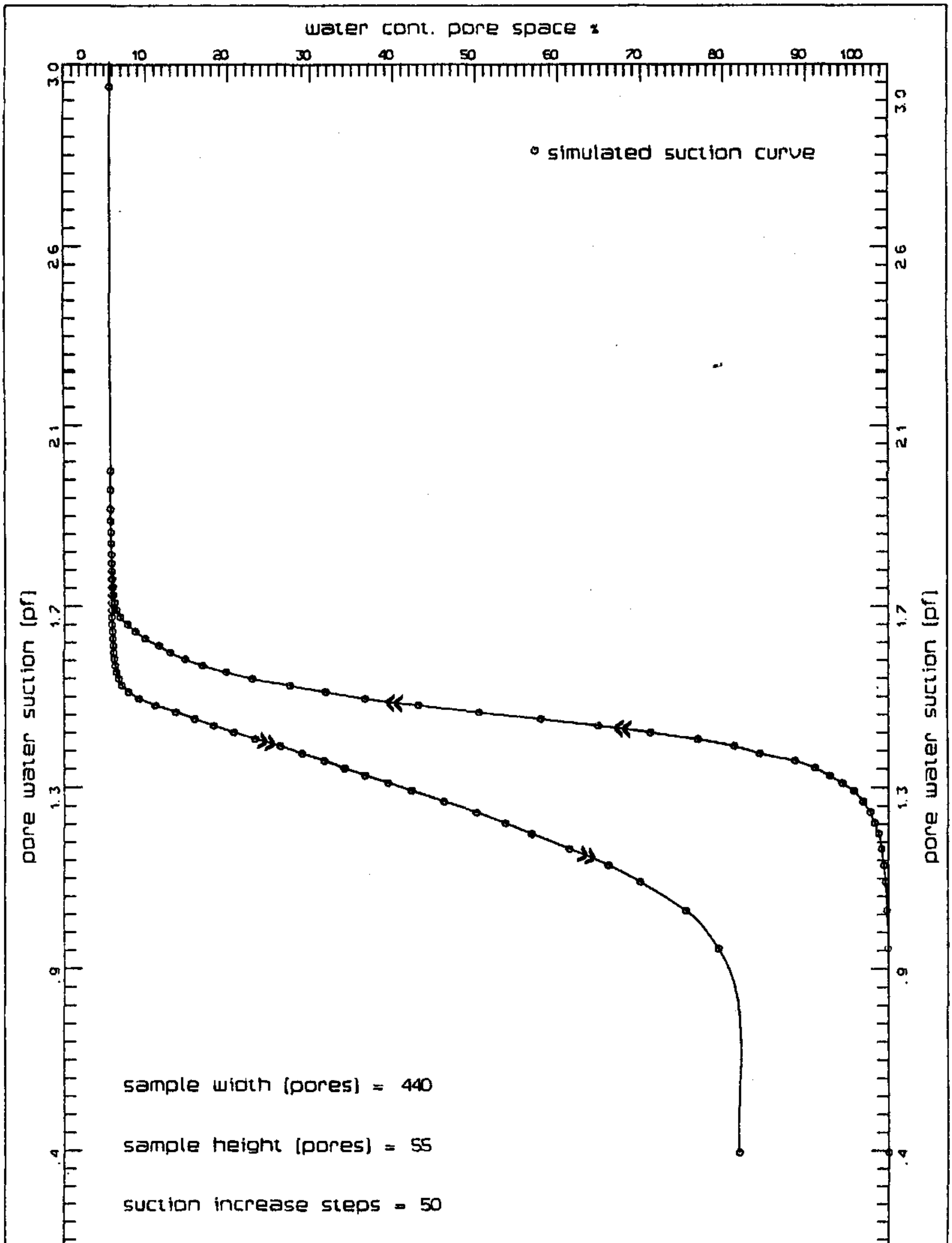

Fig. 6. The simulated water retention curve following a water suction increase and subsequent decrease (hysteresis)

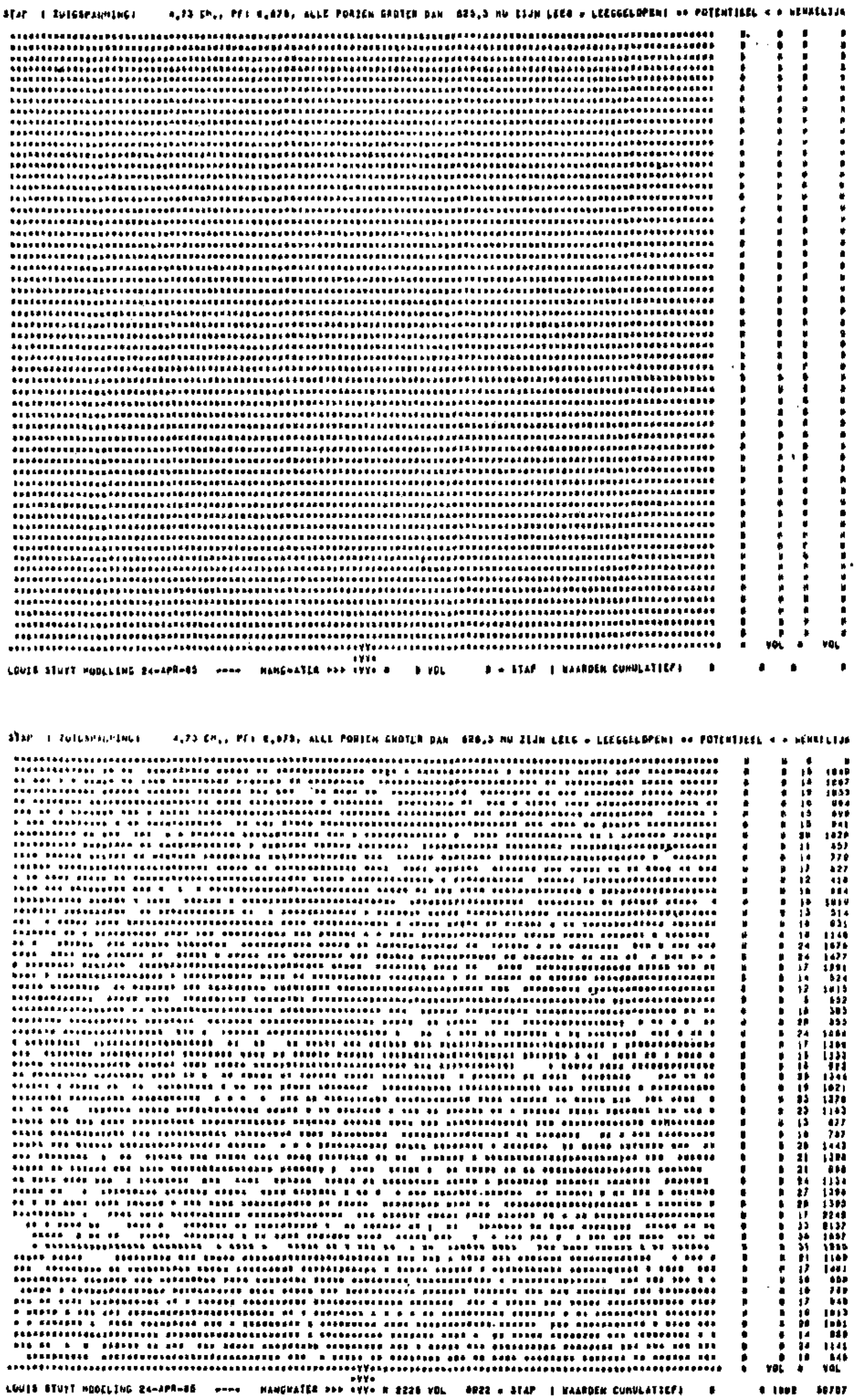

Fig. 7. The air-pockets, developed in the modelling domain after an attempt to simulated hysteresis (bottom), compared to a completely saturated sample at the beginning of the simulation (top)

5. CONCLUSIONS

A water retention curve, recorded on a filter- of soil sample, is dependent on the sample dimensions and the experimental set-up. The effect of the height of a sample on the recorded water retention curve appears to be more pronounced than that of the sample width. This result is a logical consequence of the fact that the relative decrease in sample/air interface area is correlated more strongly to an increase in the height of the sample than to an increase in the diameter, provided that the total number of pores remains constant. At present, these trends cannot yet be expressed in a more detailed numerical form, because the model has not been calibrated yet. Considering the discrepancy between the simulated water retention curves and the corresponding pore size distribution curves, the generally assumed relation between these two curves appears to be ill-defined, though close enough to further develop a technique to derive a pore size distribution curve from a recorded water retention curve, taking into account sample dimensions and interfaces. The provisional result of the simulation of hysteresis is encouraging and might increase our knowledge about this phenomenon.

REFERENCES

STUYT, L.C.P.M., 1982. 'Stochastische simulatie van de bepaling van een pF-curve van grofkorrelige materialen', Nota 1336, Instituut voor Cultuurtechniek en Waterhuishouding (ICW), Wageningen, Nederland.