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Design and performance of materials for subsurface drainage systems in agriculture

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ABSTRACT

During the second half of the 20th century, numerous land drainage systems using new materials for the drain channels that often function inadequately due to biochemical and mechanical clogging, were developed. The design of drainpipes and envelope materials used for these land drainage systems was based on both theoretical and experimental investigations. This contribution reviews the simultaneous development of theory and practical experience in Europe and North America. The results of the effect of perforation shape and pattern in drainpipes and of envelope materials on drainage performance are summarized and the latest design criteria of granular materials and synthetic envelopes presented. Theoretical investigations are associated with field data on the performance of drainage materials. A thorough knowledge, not only of the flow conditions, but also of the physical soil properties in the vicinity of the drains is imperative for a correct interpretation of field data. This contribution represents the main features on drainpipes and envelope materials, and the physical soil processes that occur in the vicinity of the drain. It gives an overview of the research work done referring to numerous publications where relevant and detailed information can be found.

1. Introduction

This paper is concerned with conditions in the immediate vicinity of subsurface pipe drains, which is traversed by vast quantities of ground water. Conditions around drains have to satisfy the conflicting requirements for favourable water flow rates and the retention of soil particles. The compatibility of these functions has been the subject of many research projects. The impact of physical processes of groundwater flow, occurring in the vicinity of pipe drains, such as the development of internal erosion channels (macropores) or the internal soil and/or envelope clogging is often quantified by the 'entrance resistance'. Cavelaars (1967), however, introduced the concept of 'approach-flow resistance' for the flow in the vicinity of the pipe drains because, strictly speaking, the entrance resistance accounts only for the additional head loss caused by convergence of groundwater flow towards the gaps and perforations in commonly used drains. This entrance resistance is not included in conventional, analytical drain spacing equations. These equations consider only so-called 'ideal' drains that are imaginary pipes with a completely permeable wall. However, real drains have a wall that is not completely permeable so that there is an additional resistance for water on its way towards the drain. For radial flow, the entrance resistance is the difference between the total radial flow resistance to a real drain and the radial flow resistance to an ideal drain of the same

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diameter. The entrance resistance also can be obtained from any other situation where the flow resistance to an ideal drain can be expressed analytically (e.g., ponded water). The gradual replacement of clay tiles by plastic pipes has prompted a search for the design parameters that determine their entrance resistances in terms of pipe diameter, perforation pattern, and the design parameters of an envelope.

Envelope materials, which are commonly used to prevent soil particle invasion in drain pipes, may substantially reduce the entrance resistance. The search for reliable envelope materials for subsurface pipe drains was supported by both fundamental research and also pragmatic empirical field research. The latter was imperative because in many countries such as Belgium, Germany, France and The Netherlands, a very large number of subsurface drainage systems were being installed. The popular organic substances that were used initially as envelope materials performed very well, but became scarce and expensive so that new and affordable alternatives were gradually proposed.

In The Netherlands, the Governmental Service for Land and Water Use, which was responsible for many reparcellation projects, gave high priority to field trials of new, promising envelope materials. In these field research projects, the prewrapped drain pipe and the soil surrounding it were considered as a 'black box' in terms of the physical processes that were associated with the discharge of groundwater. These processes, and their impact on the functioning of the drain, were only roughly addressed so that the conceptualization of the physical processes near the drain into a simple model was limited to the description of the effects of these processes. The assumed impact of the groundwater flow, such as the development of clogged areas (with reduced hydraulic conductivities) near the drain was described in terms of entrance resistance and approach flow resistance. The underlying processes were considered too complex to be monitored.

Given the inherent complexity of soil–envelope interactions due to water flow near subsurface pipe drains, Dierickx (1980) used a simplified, analogue model for both the hydraulic conditions and the movement of soil particles near such drains. For the hydraulic component, he developed an electrolytic model (Fig. 1), simulating radial flow towards a drain, to study the effect of openings and surrounds of various permeabilities on the performance of field drainage pipes.

For simulation and investigation of soil–particle interactions, he developed a reproducible test in a cylindrical flow model – a so-called permeameter – in which the flow towards a plain or wrapped drain pipe was simulated by a one-dimensional upward flow towards a flat piece of drain pipe wall either protected with an envelope material or not. Tests were performed with increasing hydraulic gradients within a gradient range representative for hydraulic gradients developing near the drain in field circumstances. Combining the results from both models, crucial envelope properties were elucidated and quantified. The most relevant design parameter for a drain envelope was found to be O_{90} or the opening size for which 90% of the pores are smaller and therefore called the 'effective opening size'. This parameter was developed for geotextiles earlier (Ogink, 1975).

Subsequently, between 1980 and 1990, Stuyt (1992) conducted a joint field and laboratory research project using a video camera and a CAT-scanner to elucidate approach flow conditions near subsurface drains and the clogging of envelope materials. This project also included the use of analogue flow models, similar to the work by Dierickx. While the findings made with the electrolytic model and the CAT-scanner have substantially enhanced our knowledge of drainage materials, they were not very relevant for practical application. Application criteria were largely derived from results emerging from field investigations, supported by findings made with analogue laboratory flow models (Stuyt and Willardson, 1999).

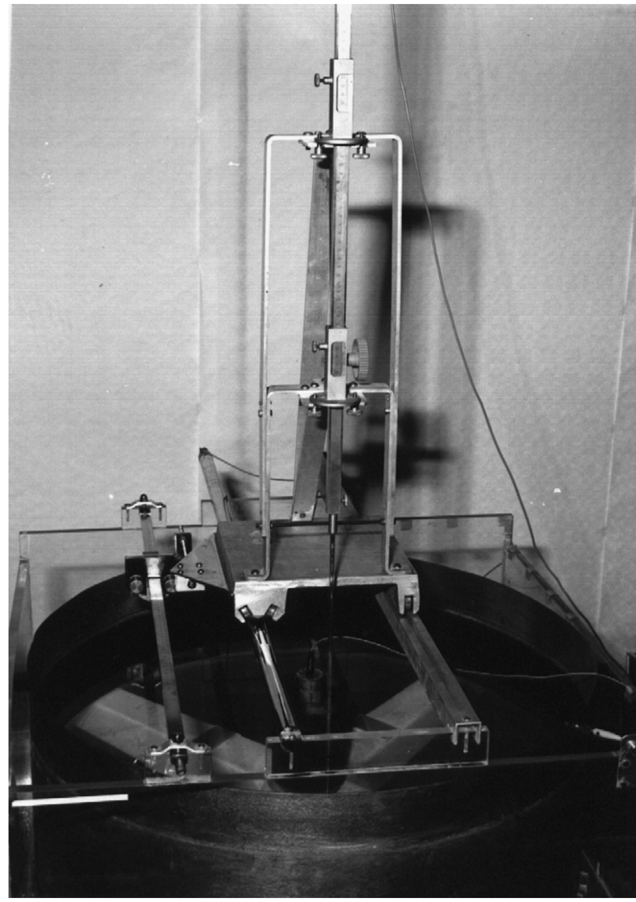

Fig. 1 – Electrolytic model, developed by Dierickx (1980) to validate mathematical solutions for entrance resistances of (wrapped) subsurface drains.

2. Hydraulic properties of (wrapped) subsurface drains

2.1. *Entrance resistance and effective radius of drain pipes*

The research on the effect of perforations in a pipe wall on discharge rates started at the end of the 19th century with the investigation of the performance of pumping wells consisting of well screens with discontinuous longitudinal slits. However, the formula of Forchheimer (1898), based on experimental data, and the formulae of Rother (1904) and Kooper (1914), for which the supposed boundary conditions differ widely from reality, are hardly applicable.