21 Subsurface Drainage Systems

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21.1 Introduction

This chapter is about the implementation of subsurface drainage systems – an implementation that should result in a long-lasting system, functioning according to the design. This means that the subject matter is mainly of a practical nature.

Subsurface drainage aims at controlling the watertable – a control that can be achieved by tubewell drainage, open drains, or subsurface drains (pipe drains or mole drains). This chapter, after comparing open drains and pipe drains (Section 21.2), will focus on pipe drains, briefly discussing mole drains at the end (Section 21.9).

There are three main phases in the implementation of pipe drainage systems: its design, installation, and operation and maintenance. These three subjects form the core of this chapter; they will be treated in Sections 21.3, 21.4, and 21.5, respectively. The theory of subsurface flow to drains has been discussed in previous chapters (e.g. Chapters 7 and 8), but not the hydraulics of drainage pipes nor the flow conditions in the vicinity of a drain pipe. These two subjects will be treated in Sections 21.6 and 21.7. They deal with drain-line performance, as opposed to the more general concern for system performance in most drainage theory. A section on the testing of pipe drainage (Section 21.8) is included, and, as already stated, Section 21.9, on mole drainage, completes this chapter.

21.2 Types of Subsurface Drainage Systems

If one has decided to install a subsurface drainage system, one has to make a subsequent choice between tubewell drainage, or open, pipe, and mole drains. Tubewell drainage (Chapter 22) and mole drainage (Section 21.9) are applied only in very specific conditions. Moreover, mole drainage is mainly aimed at a rapid removal of excess surface water, rather than at controlling the watertable.

The usual choice is therefore between open drains and pipe drains. This choice has to be made at two levels: for field drains and for collectors. If the field drains are to be pipes, there are still two options for the collectors:
- Open drains, so that we have a 'singular pipe-drain system';
- Pipe drains, so that we have a 'composite pipe-drain system'.

Open drains have the advantage that they can receive overland flow directly, but the disadvantages often outweigh the advantages. The main disadvantages are a loss of land, interference with the irrigation system, the splitting-up of the land into small

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parcels, which hampers (mechanized) farming operations, and a maintenance burden. Nevertheless, there are cases where open drains are used exclusively. Some examples are:

- As a temporary measure in unripened alluvial soils of newly reclaimed lake bottoms or coastal land:
  Initially, these soils are virtually impermeable and the open drains initiate an aeration process which causes the development of soil structure and hence an increase in hydraulic conductivity (Chapter 13). After a few years, the open drains are replaced by pipe drains;
- In peat soils:
  To avoid undue subsidence, only shallow watertables are desired, say about 0.5 m below the land surface. This can be maintained by a network of narrowly-spaced open drains. As far as is possible, oxidation of the top soil is then prevented. An approximately similar principle applies to acid sulphate soils to prevent the oxidation (and thus acidification) of deeper soil layers;
- In very saline land under a monoculture of rice:
  A network of open drains provides the required surface drainage, and a limited additional subsurface drainage is needed for salinity control. This subsurface drainage component can often be achieved by giving the open drains some extra depth; to install pipe drains would be grossly overdone.

Combined Surface and Subsurface Drainage Systems

Combined systems of surface and subsurface drainage may be appropriate in particular situations, as was discussed in Chapter 20.5.1. A few examples are:

- A soil profile with a layer of low permeability below the rootzone, but good permeability at drain depth:
  This is a profile that can be found in alluvial soils throughout the world. After heavy rain, a perched watertable forms in the rootzone, and cannot be lowered rapidly enough without some form of surface drainage. Subsurface drainage subsequently draws down the watertable to a normal depth. An alternative solution may be to break up the impeding layer by subsoiling, especially if the impeding layer is less than about 0.3 m thick;
- Areas with deep frost penetration and snow cover during winter:
  When the snow melts and the topsoil thaws, but soil at some depth is still frozen, a perched watertable will form and will damage a crop of winter grain. The same measures as in the previous example are required here;
- Irrigated land in arid and semi-arid regions, where the cropping pattern includes rice in rotation with 'dry-foot' crops (e.g. as in the Nile Delta in Egypt):
  Subsurface drainage is needed for salinity control of the dry-foot crops, whereas surface drainage is needed to evacuate the standing water from the rice fields (e.g. before harvest);
- Areas with occasional high-intensity rainfall that causes water ponding on the land surface, even if a subsurface drainage system is present:
  The ponded water could be removed by the subsurface drainage, but this would either take too long or require very narrow drain spacings. In such circumstances, it would be more efficient to remove the ponded water by surface drainage.

21.3 Design of Pipe Drainage Systems

21.3.1 Detailed Project Design

Pipe drainage projects can vary widely in scope and size. A project may be a single farm, or it may cover many thousands of hectares. In this chapter, we shall assume a comprehensive large-scale project, because it offers a suitable setting to discuss all the relevant aspects. In Chapter 18, the train of events in such a comprehensive project was reviewed: from its first conception, through the final acceptance of works by the project authorities, to its operation, management, and maintenance.

The implementation of a drainage project draws heavily upon the post-authorization (or detailed design) study – the result of which is laid down in the tender documents in the form of maps, drawings, lists, tables, and written specifications. This is the stage when the technical design of the pipe drainage system is detailed. It may therefore be useful to list the main items that are to be specified in such a detailed design, and the documents that have to be prepared for it. These are:

- The layout of the drainage network, showing:
  - The alignment of all major drains (collectors and mains), indicated with a clear and consistent numbering system (Chapter 19);
  - Field drains are usually not indicated individually. Instead, in a given block, only the first and last drains are drawn; spacing and depth are indicated in writing;
- Open drains:
  - Dimensions (in cross-sections);
  - Bed level and slopes (elevations with respect to a well-defined benchmark): on longitudinal profiles, or, sometimes, in tables;
  - Water levels at design discharge: longitudinal profiles or tables;
- Pipe drains:
  - Spacing and depth of field drains, indicated on map;
  - Diameters and slopes, elevation of outlet;
  - For collectors: longitudinal profiles and/or tables;
- Materials and structures:
  - For pipe drains: pipes, envelope materials, connections between field drains and collectors, outlets;
  - For open drains: bridges, culverts.

The specifications relate to:

- Technical specifications: dimensions, elevations (drawings);
- Quality requirements;
- Construction specifications: for certain items, it might be necessary to specify working methods (as will be discussed in Section 21.4).

Against the above background, this section presents an overview of the materials and structures used in pipe drainage systems. It then goes on to discuss the design of field and collector drains, and the layout of drainage systems.

More details are given in e.g. Schultz (1990), Framji et al. (1987), and Smedema and Rycroft (1983).

21.3.2 Pipes

The materials used in the manufacture of drain pipes are clay, concrete, and plastics. Important criteria for pipe quality and for selecting the most suitable type of pipe are resistance to mechanical and chemical damage, longevity, and costs.

Mechanical damage and chemical deterioration may occur during transport and handling, or after the pipe has been installed. In addition, the lifetime of the pipes should not be unduly shortened by a deterioration in mechanical or chemical properties in the course of time. The costs are the total costs for purchase, transport, handling, and installation.

Clay Tiles

Clay tiles used to be the predominant type of drain pipes in Europe, from the first introduction of pipe drainage (before 1850), to about 1960-1970. These clay tiles had common diameters of 0.05 to 0.15 m, and came in lengths of 0.30 to 0.33 m. Their ends were either straight or had a collar, with a less-than-perfect fit so that the water could enter through the joints. The chemical stability and longevity of good-quality pipes are excellent (think of archaeological pottery finds!).

Criteria for testing the quality of clay pipes are: shape (they should be straight, with straight-cut ends), absence of fissures and cracks (which can be judged by the sound when the pipe is hit), and mechanical strength (breaking strength).

The manufacture of good-quality pipes requires considerable skill and a fairly large well-equipped production unit.

Concrete Pipes

Concrete pipes were used as field drains in various countries, until, like clay tiles, they virtually became obsolete with the introduction of plastic pipes. In larger diameters, concrete pipes are still commonly used as collectors. Concrete pipes can be manufactured in comparatively simple (mobile) production units that can easily be erected in the project area. There is practically no limit to their diameter, although for large diameters (i.e. over 0.4 m), the concrete must be reinforced. Pipe ends are either straight, have a collar, or a spigot-and-groove. Water entry is almost exclusively through the joints between pipe sections. For larger diameters, openings at the joints may become rather large, which is why some manufacturers supply rubber sealing rings.

Possible drawbacks of concrete pipes are their susceptibility to acidity and sulphate, which may be present in the soil. This susceptibility can be reduced to some extent with the use of sulphate-resistant cement, and by producing to a high manufacturing standard, so that high-density concrete is formed, which seals off the concrete from attack by soil chemicals.

Plastic Pipes

The introduction of plastic pipes for drainage started around 1960. Initially, straight-walled smooth pipes were used. Around 1970, corrugated pipes were introduced, which soon replaced the smooth pipes.

The major advantages of plastic over clay or concrete are the much lower weight per metre of pipe, and the greater length of pipe (at least several metres). This makes transporting and handling the pipes a lot easier and cheaper, and it enables higher installation rates. A disadvantage is the pollution caused by the raw material (resin). Ex-factory prices of plastic pipes may be higher than for clay or concrete, but total costs may be lower because of a saving in the costs of transport, handling and installation.

The three predominant materials are polyvinyl chloride/PVC, high-density polyethylene/PE, and, to a minor extent, polypropylene/PP. When comparing PVC and PE, we find that the dark-coloured PE is more affected by high temperatures than the light-coloured PVC. Consequently, the risk of deformation of PE pipes is greater than for PVC pipes. On the other hand, PVC, being more sensitive to low temperatures, becomes brittle when exposed to temperatures below freezing point. In addition, PVC is more sensitive to ultra-violet radiation (sunshine), which may cause irreversible deterioration of mechanical properties (brittleness). PVC pipes should therefore not be stored in bright sunlight.

Plastic pipes, whether PVC, PE, or PP, are resistant to all chemicals that may occur in agricultural soils.

A comparison between corrugated and smooth plastic pipes may shed some light on the preference for corrugated pipes:
- Corrugated pipes have a greater resistance to outside pressure for the same amount of plastic material, or, conversely, a given strength can be achieved with less material. Since the cost of plastic pipe is approximately proportional to its weight, this means a lower cost;
- Corrugated pipes have a greater flexibility, so that they can be coiled and are easier to install. Corrugated pipe is virtually the only suitable type for trenchless drain installation;
- A small disadvantage of corrugated pipes, connected with the coiling, is that, after being unrolled on the drainage machine, the pipes have a tendency to 'spiral' in the trench (because of the 'plastic memory');
- Pipes with large corrugations (as a rule corresponding with larger diameters) have a comparatively high flow resistance and thus a reduced discharge capacity (Section 21.6). Certain special types are partly double-walled, so that they have a smooth inside wall (Figure 21.1). This provides considerable extra strength and, for equal diameter, a higher discharge capacity.

The outer diameter of corrugated plastic pipes ranges from 0.05 to 0.40 m. The height of the corrugations is between 5% of the pipe diameter (for small diameters) and 8% (for large diameters). Water enters through perforations in the bottom of the corrugations. These perforations are 0.6 to 2 mm long and 0.6 to 1 mm wide.

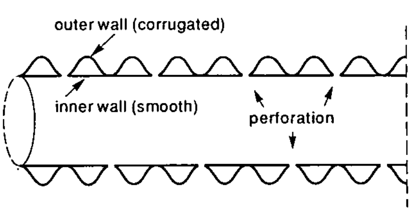

Figure 21.1 Double-walled corrugated plastic drain pipe