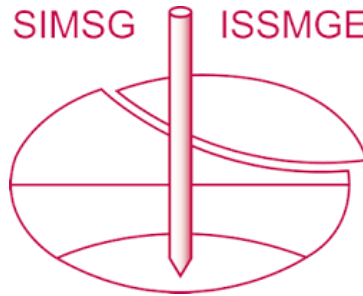


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Long-term effects in drainage systems of slopes

Les effets à long terme dans les systèmes de drainage des pentes

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SYNOPSIS

Percolated and, therefore, instable slopes are often effectively stabilized by dewatering measures. For this purpose vertical and horizontal drainage systems are installed alternately. The seeping water is mostly drained off by perforated pipes which are covered with pervious material. The whole system has to work for a great number of years, but the discharge capacity of the pipes and the surrounding filter can be substantially reduced by mechanical, hydraulic, biological and chemical processes. These processes are summarized under the term "ageing" and their effects depend on the soil as well as the water conditions. The results of two field investigations serve as examples. At the planning stage, possible damage and unavoidable ageing processes forecasting have to be taken into consideration more than in the past. The drainage systems must always be designed taking the possibilities of checking and flushing into consideration.

INTRODUCTION AND GENERAL ASPECTS

Natural slopes generally show under the changing atmospheric conditions, which they are exposed to in course of time, a stability factor, which - at least for a time - amounts to about 1. The angle of inclination, which arises with this kind of slope, mainly depends on the soil properties as well as the water conditions in the subsoil.

In the course of constructive measures on natural slopes - for example cuts or embankments for traffic lines, material adjustments made when taking measures for reparcelling agricultural land or also changes in the stress conditions by putting a dam into operation - the natural equilibrium is disturbed and in many cases deteriorated.

If these changed statical conditions or additional loads are not considered, more or less sudden slides or also creeping slope movements may occur, the results of which may under certain circumstances be considerable, sometimes even disastrous.

The geotechnical engineer is thus required to arrange his planning so as to make such events improbable. An important fact here is that natural slopes become part of the constructive measures by means of these measures. This is why these slopes themselves assume the character of engineering buildings, which must generally have stability reserves in the form of a calculated safety factor greater than 1: depending on the type of land, the required standard, the existing circumstances etc. for example $F_s = 1.3$ or 1.5.

In addition to the flattening (i.e. the "trivial solution") and supporting banks at suitable points the following methods for stabilizing unsafe slopes can be taken into consideration:

- the construction of supporting structures (walls), mostly designed with anchors,
- the (more or less extensive) dowelling of the sliding surfaces in question,
- the construction of drainage installations for the neutralization of a substantial part of the driving forces.

The first two measures mentioned involve the installation of constructive elements. For this purpose structural members made from steel and/or concrete are used, about which one has an idea of the durability and stability from the experience in engineering and geotechnical practice (cp. e.g. Sembenelli 1988). Anchor systems for example are constructed, checked and controlled as "permanent anchors" following special regulations and standards. In recent investigations thoughts have been made about the "life span" or duration to use, where there are slope movements due to creeping soils, where dowelling is mainly applied (Schwarz 1987, Lipmann 1988).

Similar considerations for drainage systems, of which the reliability and durability are undoubtedly just as important, are far less usual, although such systems are subjected to ageing to a greater or lesser extent, as is well known. Not only does the selection of the materials (especially the types of drain pipes) and the technique of laying them often take place without adequate regard to the possibility of causing damage during installation, but also the construction and the designing of the systems in many cases do not consider the requirements of an inspection with a television probe, subsequent supervision and the servicing. In addition a life span of many decades is automatically expected from these constructive elements, which substantially affect the stability. One is tempted to say that no constructive

engineer would ever carry out tasks, which can later be checked, with the optimism, or even the affordability, which evidently are sometimes to be found in some fields of geotechnique, where the conditions of construction moreover are particularly difficult.

In an attempt to inspect a great number of drainage systems, which are installed in unstable slopes or embankment dams as securing elements with regard to the condition of the tubes after installation or to ageing, we have found practically no system in a proper condition.

This remarkable result, especially in its extent - despite previous doubts -, seems to us to be a sufficient reason, to discuss some of the problems of the reliability and durability of drainage systems in this paper. Some of the following statements may seem to the reader to be obvious and therefore perhaps trivial. Geotechnical practice in this field appears to disprove this in many cases.

REASONS FOR THE AGEING OF DRAINAGE SYSTEMS

The first danger for drainage systems consists in faulty installation and in overloading immediately after installation. The relevant risks are not really part of what we call ageing, but should be mentioned beforehand, because they are an extraordinarily frequent reason for damage. Fortunately the technique of inspection with a television probe has been developed so far in the meantime that final checks before opening up the system are usual. This way it is also possible to recognize early damage very easily.

As far as the actual ageing processes are concerned, the following symptoms should be described:

Mechanical influences (cp. fig. 1, 2)



Figure 1: Broken stoneware pipe

- Rupture or deformation of the pipe section as a result of static overload,
- Deformation of the pipe section due to creeping effects of the pipe material (influence of the temperatures of the surrounding area and the water led off),

- Rupture or deformation of the pipe section as a result of soil movements in the surrounding of the pipe line.

Hydraulic influences (cp. fig. 3)

- Damming up and sedimentation from the tailwater (outlet),
- Clogging of the drain pipe openings,
- Siltation of the pipe section.

Biological influences (cp. fig. 4)

- Clogging with biological phlegm,
- Ingrowing roots.

Chemical influences (cp. fig. 5)

- Corrosion of the pipe material,
- Iron hydroxide deposit,
- Sinter deposit

The kinds of ageing mentioned above may appear - depending on the circumstances - individually or combined. Each of them however reduces or even neutralizes the hydraulic intake or discharge capacity of the drain pipes concerned.

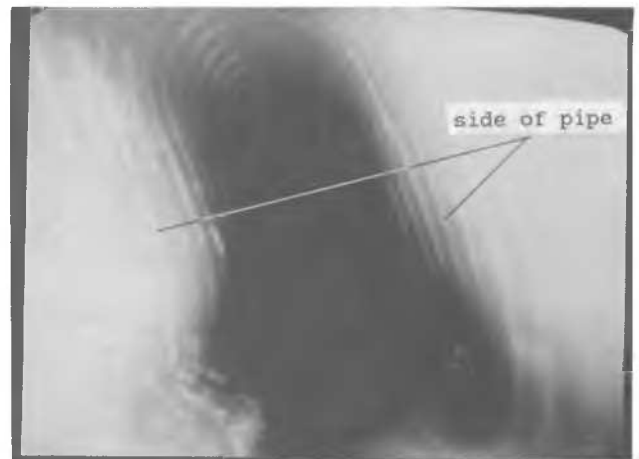


Figure 2: Deformed plastic drain tube



Figure 3: Gravel and sand sediments in a slope drainage system



Figure 4: Ingrowing of roots in a drain pipe



Figure 5: Removed drain pipe with sinter deposits

Following this, two cases of slope stabilization by means of drainage measures are described to derive some basic rules for the design of drainage systems with the help of these examples.

TWO EXAMPLES

In the examples, comparatively small dewatering measures, which had become necessary as a result of measures taken for land reparcelling in viniculture areas in South-Western Germany are involved. Here large soil movements were carried out without any concern whatsoever regarding the danger of landslides - especially in wet seasons - and without careful dewatering of temporary springs. Consequently continuous or periodical slope movements arose, which subsequently had to be stopped, in the areas concerned.

Depending on the circumstances, different techniques for slope dewatering are taken into consideration: transversal or longitudinal deep drainage trenches as well as more or less horizontal dewater-

ring drillings. Details of the different techniques and the question of the hydraulic system are not described here. In both of these cases the drainage systems were in the form of drainage trenches, one with the technique of excavating a ditch, the other with close vertical large-scale drillings (cp. Bley 1976).

The investigations of the condition of the drainage systems took place within the scope of the more comprehensive study mentioned above about ageing processes in drainage systems of dams and slopes.

Example A

The ground-plan of the system in case A, which was carried out in 1981/82, is to be found in figure 6. The applied sections of the pipes are between $\phi = 80$ and 500 mm.

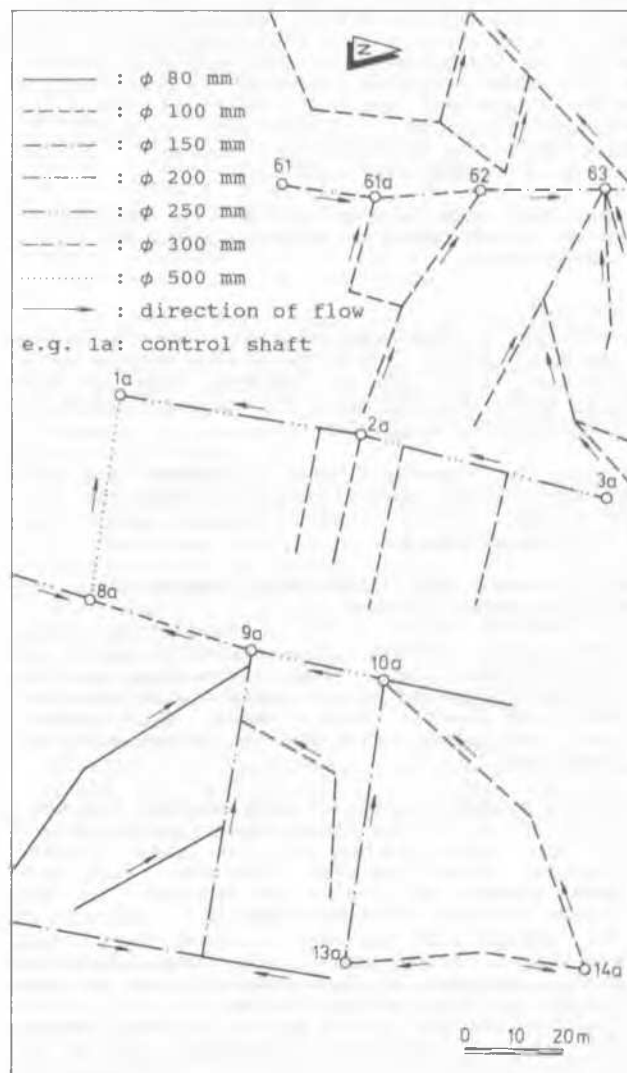


Figure 6: Drainage systems of example A

Even in figure 6 serious planning faults, which mainly concern the difficulties in inspection, are to be seen:

- Many of the applied sections of the pipe are too small for an inspection even with the smallest TV-probes.
- The distances between two neighbouring control shafts are too long for an optical inspection.
- Bends in the pipe line without control shafts make an inspection with the TV-probe impossible.

The optical inspection therefore had to be restricted to small accessible sections of the whole system. In most parts of the pipes material, which had been carried into the system through the shafts and then deposited, could be found. The reason was that the trough beyond the sealing of the shaft for catching coarse material and dirt, had not been cleaned for a number of years.

The material-intake had not been hardened by chemical precipitation, which had been expected to be in the form of sinter, because of the very high calcium content in the seeping water. This was due to the presence of the very high content of free carbon dioxide (surplus) in the seeping water. Therefore the deposits found could be removed by flushing. It was only possible to clean the system by flushing, however, in the areas with larger pipe sections.

Altogether this system has to be criticized because of the unsuitable planning and the lack of maintenance.

Example B

In contrast to the example above, here we have a system, which, with the choice of the pipe diameters ($\phi = 150$ mm) and the line of the pipes, meets the standards for making inspection and maintenance possible.

As can be seen in figure 7, there are two separate sliding areas (working sectors) in the same slope, with a distance between each other of only about 180 m.

Here interesting differences concerning the behaviour were observed:

- In working sector 1 (BA 1) immediately after completion intense sinter deposits could be found in the pipes, which since then require frequent flushing of the whole system (in the beginning several times a year). Our inspection took place after one of these cleaning campaigns.

Figure 8 shows plates of lime, which had been found in one of the lines. These plates formed on the plain bottom of the pipe (tunnel profile) after the last flushing, and have been pushed on top of one another in the course of this flushing campaign.

- The analysis of the water yielded very high contents of calcium- and magnesium-ions (total hardness of the water $\approx 33^\circ\text{dH}$) in the absence of free carbon-dioxide.
- The observations in the second working sector (BA 2) were completely different. Almost no sinter deposits could be found, and the water analysis showed no appreciable contents of calcium- and magnesium-ions (total hardness $\approx 11^\circ\text{dH}$) worth mentioning.

From this example of slope dewatering measures, it can be seen that it is necessary to ascertain

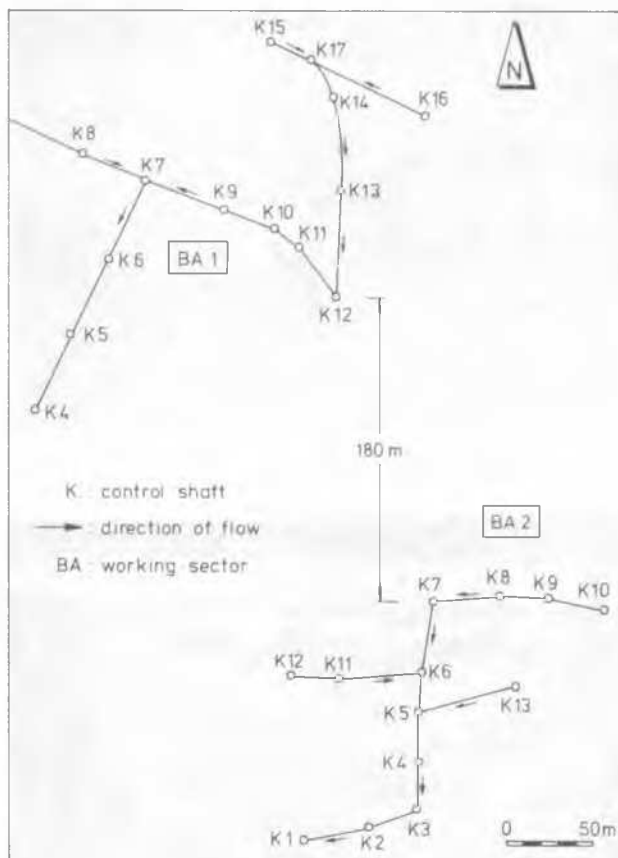


Figure 7: Drainage system of the example B



Figure 8: Plates of lime, which are stacked up during flushing

in advance the danger of intense sinter deposits with the help of water analyses and observations of the surrounding conditions. Regular flushing of the pipes with high-energy jets of water is not only a matter of expense, but is also an additional burden for the technical system.

It would also seem to be desirable for the manufacturers of drain pipes to consider possible technical alternatives to high-pressure flushing under concerning chemical conditions in the water.

From the examples illustrated and the other systems investigated in the study, a number of principles and regulations can finally be ascertained, which, as mentioned above, may partly appear trivial. It is however necessary, to list them clearly, as our experiences have shown.

REGULATIONS FOR DRAINAGE SYSTEMS FOR THE STABILIZING OF SLOPES

Drainage systems are structures of possibly considerable importance. This is why the planning of such systems has to be carried out more carefully than seems to be the practice up to now. Thus the surrounding conditions should be recorded as exactly as possible; main points:

- soil samples
- drill logs (indications of groundwater levels)
- groundwater level progress lines
- precipitation progress lines
- chemical compound of the groundwater and/or the water in the slope
- static loads
- soil movements
- planting of the planned line of the pipes

With the help of the data gained for this purpose, the influences, which accelerate the ageing processes, can be minimized.

Mechanical influences:

- the effect of soil movements on the pipe can be avoided by symmetrical compaction and embedding of the pipe. Especially in slopes with existing movements, flexible types of pipes should preferably be used.
- When embedding the pipes it should be observed as to whether there is a possibility of load concentrations due to different degrees of rigidity in the soil surrounding the pipes.
- The requirement for the minimum covering, which allows the pipes to be passed over without danger (e.g. with heavy compactors), must be fulfilled exactly.
- Generally reduced material characteristics should be used for calculations, because of the long life span, which is demanded of the pipes.
- In Germany characteristic values for the static calculation are laid down in the "ATV Arbeitsblatt 127".

Hydraulic influences:

- The pipe openings must be adjusted to the surrounding material according to the filter rules.
- For hydraulic reasons the degree of perforation of the pipes should be as high as possible. If necessary a compromise is to be made with the static requirements.
- It is necessary to control and clean the shafts regularly, as often material enters into the pipes at these points.
- A sufficient hydraulic gradient in the pipe line must be ensured over the whole lifetime of the structure.

Biological influences:

- Any possible activity of plants and very small animals has to be prevented by a suitable covering.
- Ingrowing roots have to be prevented by ensuring that there is a sufficient distance to the surface. However, it should be noted that the length of roots may range from a few cm to meters. If necessary, no plants should be placed in the area surrounding the drain system.

Chemical influences:

- By choosing the pipe material according to the results of the water analysis made before, corrosion influences can be eliminated to a large extent.
- If there is any danger of iron hydroxide deposits, an attempt should be made to avoid these by reduction of air supply, e.g. with siphon installations.
- Sinter deposits can be influenced only little in this way. As far as technical measures for the facilitating of the flushing process, which is indispensable in these cases, are concerned, the manufacturers of the pipes should consider, how the adhesion of the precipitation products on the side of the pipes can be prevented. In unfavourable cases, systems, which allow a replacement of the pipes, could be advisable; such systems, however, are not yet available.

It is of the utmost importance, to construct the system so that it can be easily maintained:

- The ground-plan of the drainage system should be designed as simply as possible, in order to be able to clearly relate the discharge measurements to the other hydrological and hydrogeological data.
- The pipe diameters should not be less than 150 mm because of the necessary TV-probing and flushing.
- For the same reason the distance between two shafts should not exceed 50 m.
- At every branching there should be an inspection shaft, from where the servicing can be carried out.
- It should be made possible to measure the discharge in suitable shafts regularly and without any problems (e.g. by means of suitable pipes, etc.).
- At regular intervals, which depend on the respective circumstances, television probing should be carried out. An inspection plan should be made containing all important data of the section concerned.

CONCLUSIONS

Up to now it has not yet been sufficiently accepted that dewatering systems embedded in the subsoil are real buildings. Due to the lack of careful planning, many systems must be considered as inadequate with regard to the possibility of inspection as well as the condition of the pipes. However, many influences, which affect the hydraulic discharge of the pipes, could be eliminated or at least reduced with careful planning and this paper is intended to make a contribution towards this purpose.

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