Stabilization and prevention of water triggered landslides

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Preface

The big majority of the water triggered landslides could happen at the areas, where permeable (*sand, gravel*), semi permeable (*fine sand, silt*), semi watertight (*sand or silt with high clay content*) and watertight (*clay*) soil layers had been settled above each other as a sandwich-like soil structure in a light slope (*over 4-5%*) to deeper valleys, rivers, lakes, or see.

These types of landslides had been triggered by the significant rise of the groundwater level, and therefore by the dramatic changes in the subsurface stream of the groundwater.

In several cases the sliding soil volume is so enormous (sometimes several hundred-thousands m³) that is it nearly impossible to stop it with engineering structures (or if is it possible, the costs are extremely high).

With more than 15 years of design and construction activity on this field we have realized, that the possible best solution could be to extinguish the main reason, the increasing piezometric pressure in the non mobilized soil volume. We have several well proven references how to stop the already sliding soil volume and how to prevent the further landslides.

In this lecture I'm intending to give you a general view on the water triggered landslide phenomenon, a proposal for the stabilization and prevention of these types of landslides. Finally, I would like to share our experience with you how to use the deep drilled drainage systems as a perfect tool to minimize the water table in the non mobilized soil volume.

General description of the water triggered landslide phenomenon

In normal cases there is a **balance between the groundwater quantity** streaming in water permeable soil layer(s) between watertight or semi-watertight layers in the earlier mentioned sandwich-like soil structure **and the water transport capacity** of this permeable layer(s) being in not completely saturated condition. In this case the whole area is in stabile condition, in safe situation. (Fig. 1., Fig.2.)

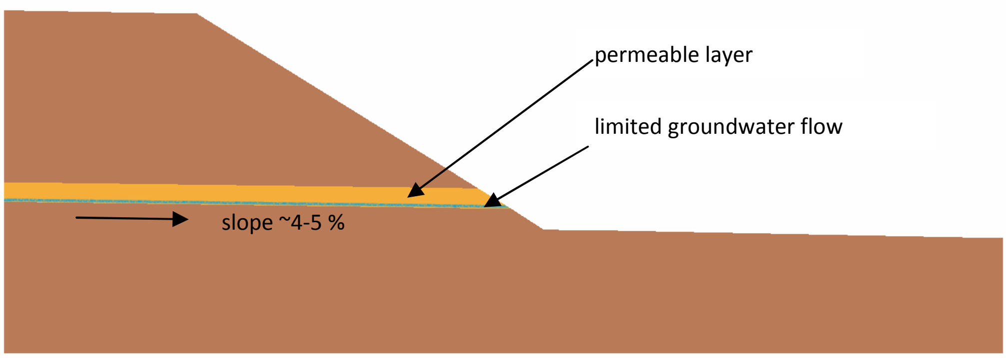

Fig. 1. Sketch of an embankment cross section with one permeable layer

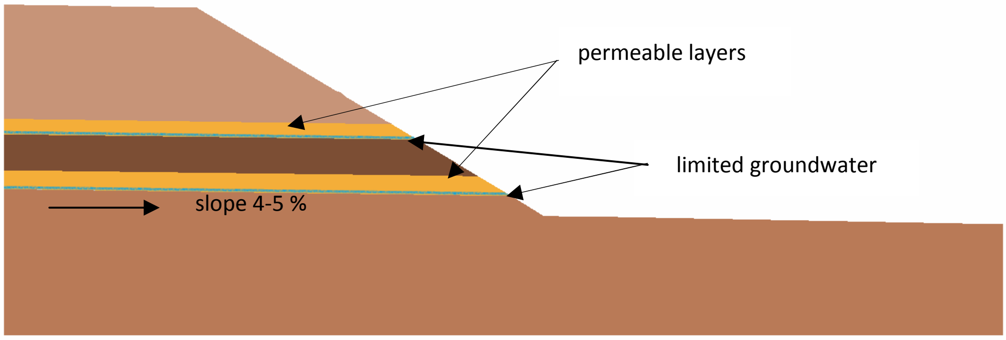

Fig. 2. Sketch of an embankment cross section with more permeable layers

In case of the quantity of the streaming groundwater rises dramatically *(because of very high precipitation, leaking septic tanks, reservoirs, freshwater and sewage pipelines in the background water collector area, etc.)*, or the water transport capacity of the permeable layer(s) - between two watertight or semi watertight soil layers - is falling significantly *(e.g.: any kind of blockage at the discharge area)* the earlier streaming balance will not exist anymore, therefore there is no more stabile condition and safe situation in the area. (Fig.3.)

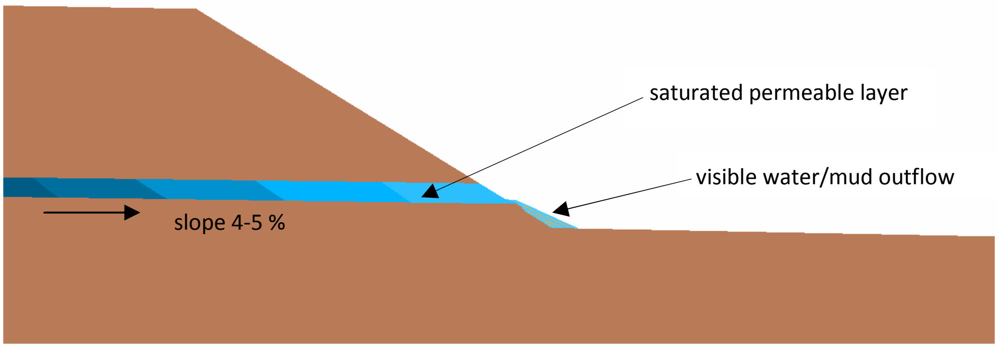

Fig. 3. Sketch of an embankment cross section with a totally saturated permeable layer

The permeable layer(s) came on completely saturated condition, the geotechnical characteristics decline and the vertical load bearing capacity of these layers fall significantly close to the discharge area. Because of the less vertical load bearing capacity of the completely saturated permeable soil layer(s) these layer(s) will be compressed. A certain volume of soil will be fallen down by a closely vertical shared surface with a small step (several cm-s only) at the first downfall. With this downfall the thickness of the permeable layer(s) will be reduced as well. (Fig.4.)

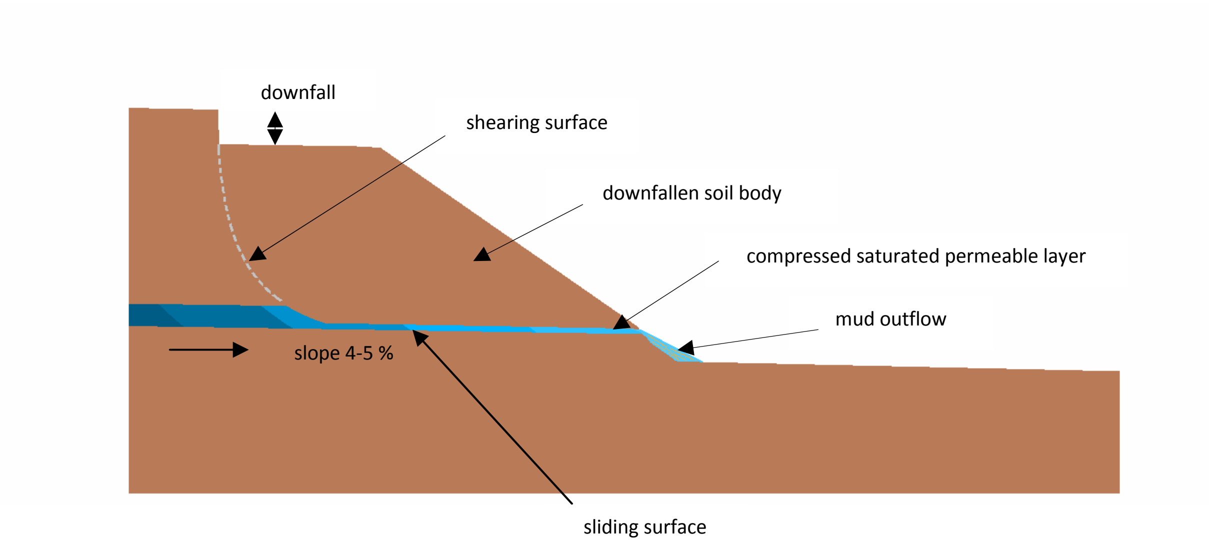

Fig. 4. Sketch of an embankment cross section showing the first downfall above a totally saturated permeable layer

Behind the already downfallen soil body the groundwater table will rise because of the increasing difference between the constant water supply from the background water collector area and the reduced water discharge capacity of the already compressed permeable layer under the downfallen soil body. *(We have realized several times crossing the nearly vertical shearing surface zone with the horizontal drain line drilling, that in this zone the soil is very loose and completely saturated. Crossing this zone a sudden strong water flow could be realized. This means, that in this zone a real hydrostatic pressure could be formed.)* With the rising groundwater table and hydrostatic pressure the active horizontal sliding forces are increasing as well. (Fig.5., Fig.6.)

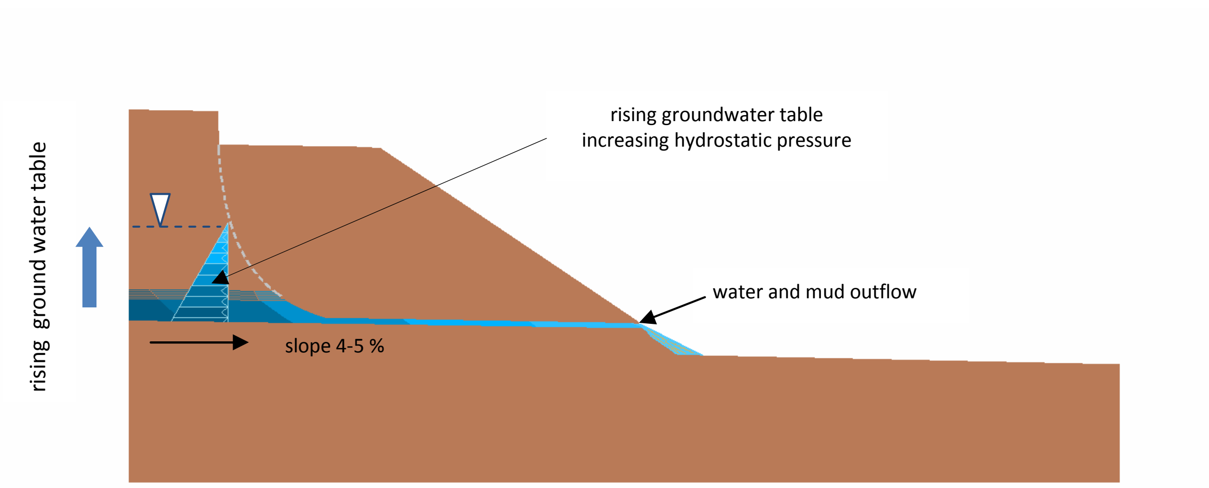

Fig. 5. Sketch of an embankment cross section showing the rising groundwater table and increasing hydrostatic pressure behind the first downfall above a totally saturated permeable layer

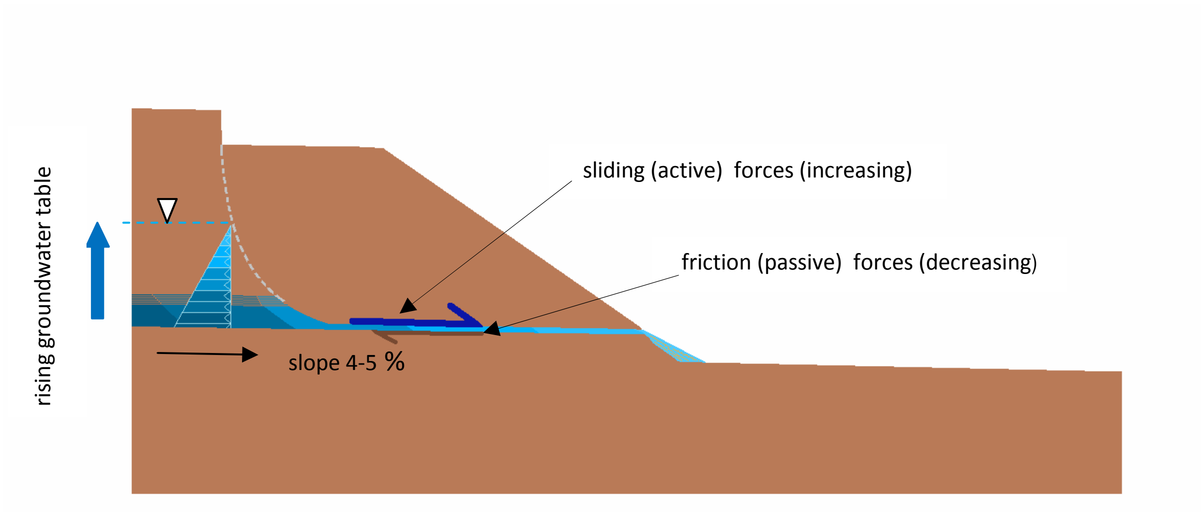

Fig. 6. Sketch of an embankment cross section showing the increasing active sliding forces and the decreasing passive friction forces.

As soon as the active horizontal sliding forces exceed the passive friction forces on the sliding surface *(sliding surface: in this case the interface between upper permeable and lower watertight or semi watertight layers)* the downfallen soil body starts to move, to slide down on the sliding surface (we call this phenomenon as **landslide**). (Fig.7.)

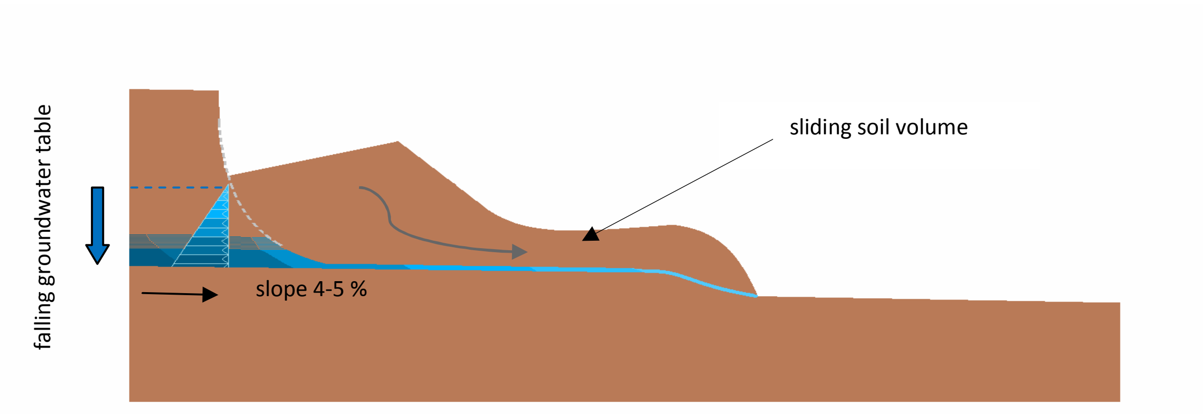

Fig. 7. Sketch of an embankment cross section showing the landslide phenomenon

The sliding movement will continue till the horizontal sliding forces will be reduced by the falling groundwater level (*with the sliding a certain quantity of collected groundwater will be discharged through the movement -sliding- surface, the groundwater level behind the movement -shearing- surface will fall down as well*) to the level of friction forces on the sliding surface. This sliding movement will continue till the sliding soil volume could reach a temporary balanced situation. (Fig.8.)

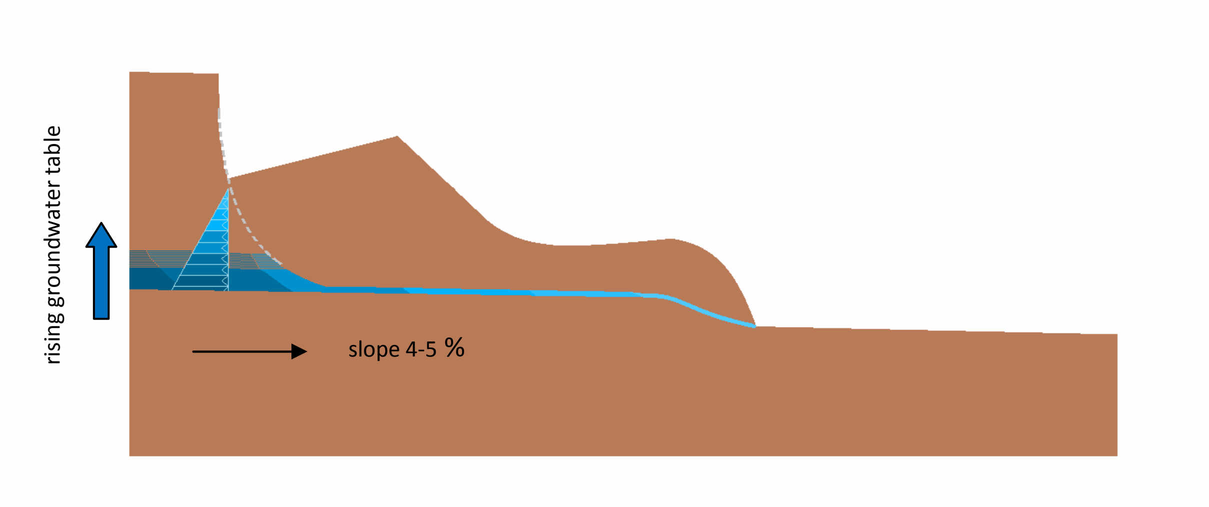

Fig. 8. Sketch of an embankment cross section showing temporary balanced situation with rising (again) groundwater table

The sliding / balanced situation with the movements will be repeated (see Fig. 9.) till the next shearing surface could be formed and the whole process will start again.

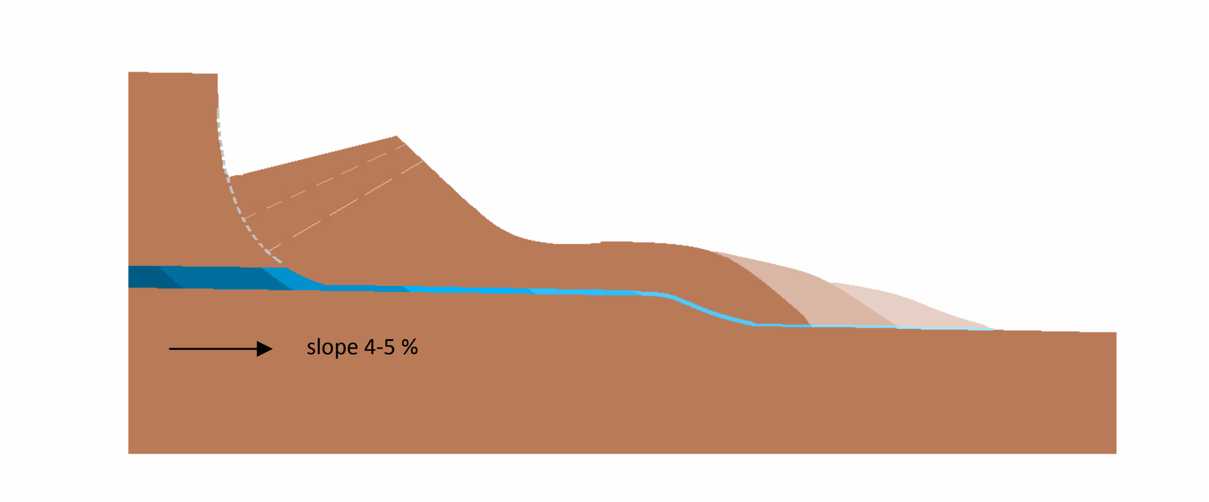

Fig. 9. Sketch of an embankment cross section showing the repeated sliding of the same soil volume

<u>Stabilization of landslide areas and prevention of water triggered landslides → a technical possibility</u>

The first step to solve the problem is to create a free outflow/discharge possibility for the groundwater volume collected behind the soil volume fallen dawn.

A deep and very long drilled drainage system laid by horizontal drilling technology into the permeable soil layer(s) behind the shearing surface *(the special drainage pipes used for these drainage lines - having widening slots to the centerline of the pipe - will create a natural filter body* *around these pipes with the inflow water stream)* can solve this problem in fine sand or silt soils as well. (Fig. 9.)

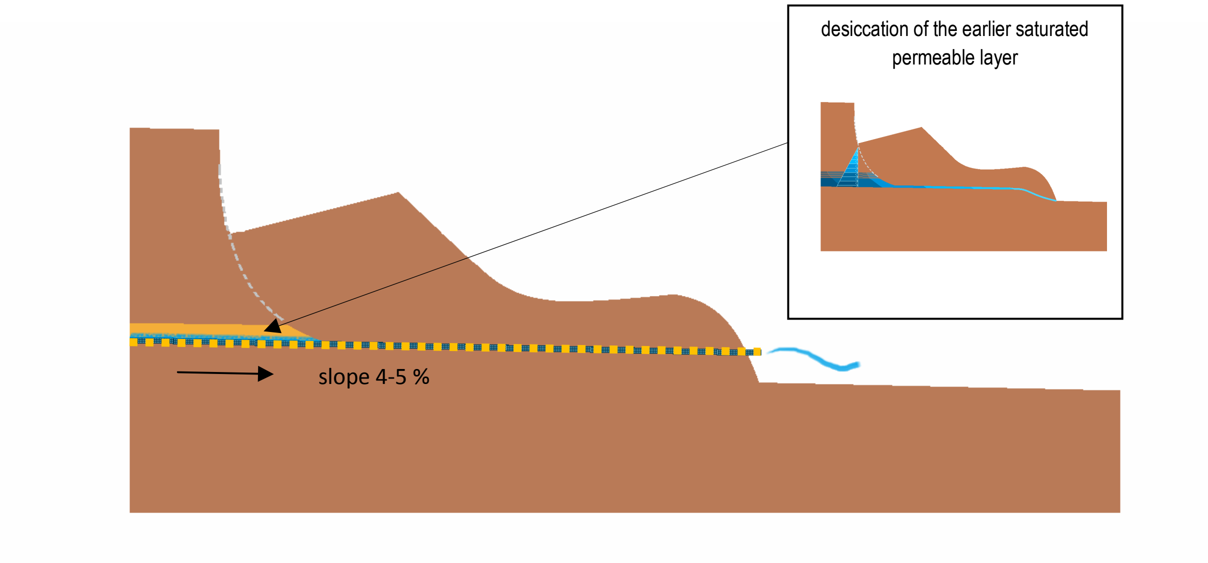

Fig. 9. Sketch of an embankment cross section showing the drilled drainage system in action

In case of several water permeable or semi permeable soil layer could be found in this sandwich-like soil structure, vertical filter columns *(filled with sand or fine gravel)* shall be constructed to collect the congested water from the upper layer(s) and direct to the deeper permeable layer in order to be drained later.

In case the reconstruction of the original soil surface form is required, the whole slipped soil volume shall be removed and a reinforced (*reinforcement with geosynthetics or hot galvanized wire mesh*) soil body as an invisible soil retaining wall shall be constructed. With the construction of this reinforced soil retaining wall the sliding surface developed during the soil movement shall be extinguished properly. (Fig.10.)

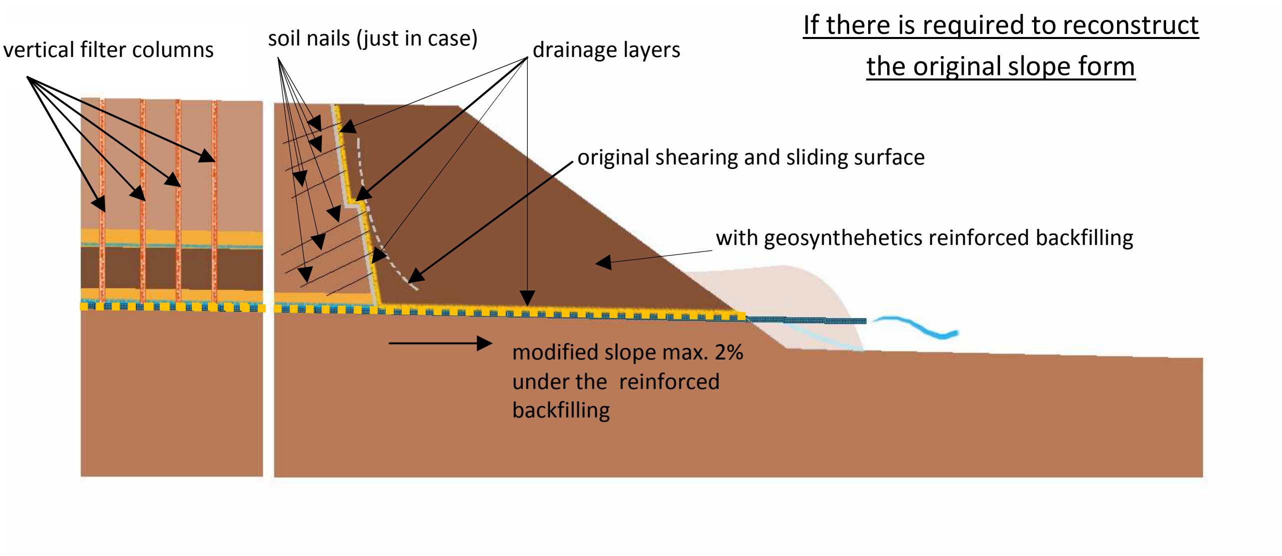

Fig. 10. Sketch of an embankment cross section showing the complete reconstruction in original embankment form

In case of there is no requirement to reconstruct the original soil surface the further slipping of the sliding soil volume could be stopped with the required safety with reinforced concrete pile system or soil anchors system as a special form of soil nailing. (Proper stability design work is required!!) The surface of the mobilized soil volume shall be formed in appropriate slope to prevent the further unnecessary infiltration of the precipitation. (Fig. 11.)

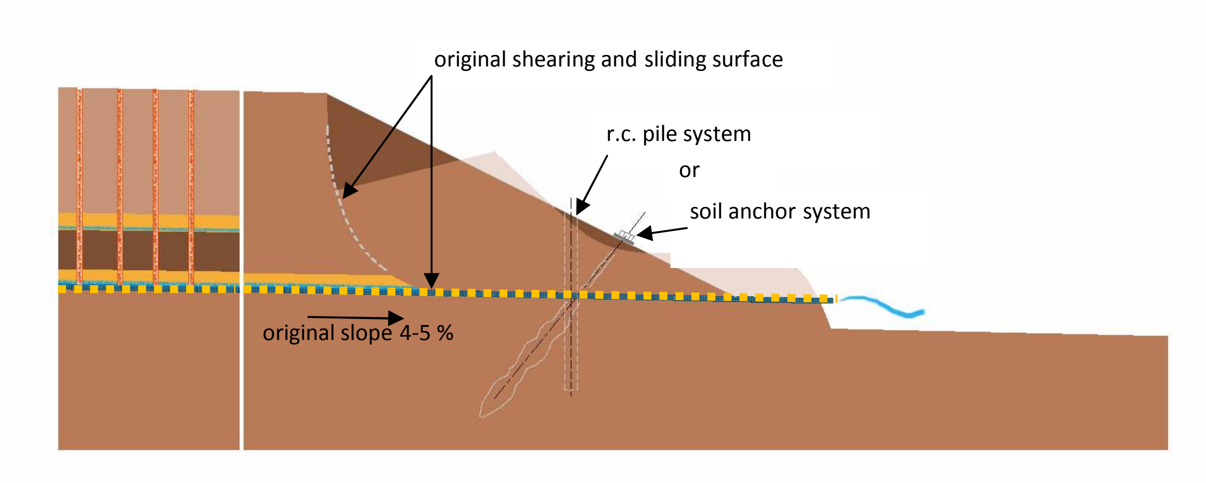

Fig. 11. Sketch of an embankment cross section with the deep drainage system showing simple slope leveling and r.c. pile or soil anchor systems to increase the safety against sliding

A deep drilled trial dewatering system at the landslide in Dunaújváros/ Táborállás (Hungary)

In October 2010 after a very intensive rainy period serious landslide had been occurred in Dunaújváros/Táborállás (Hungary). The Municipality of Dunaújváros - *getting information of several successful landslide stabilization at the neighboring cities based on deep drilled drainage system under nearly similar geotechnical conditions* - has decided to order a trial dewatering system based on a detailed geotechnical and geodesy survey for the better preparation of the stabilization design works.

The trial - *had been carried out in February/March 2011* – was very successful.

With 3 pieces of in average 100 m long deep - *just above the watertight clay layer* - drilled drainage pipe *(the depth below the surface was close to 18 m)* the water table in the non mobilized soil volume sunk with nearly 2 m in one month and the sliding speed of the mobilized soil body had been reduced dramatically – *from 30-50 cm/month to few cm/month* - in the same period.

On the general layout you can see the sliding cracks detected on the surface (continuous red line) with the possible extension (dotted red line), the position of the deep drilled K9, K10, K11 and K13 drainage pipes (continuous thin blue line) and the shallow drilled - partly in open trench laid - collector pipe (continuous thick blue line). (Fig. 12.)

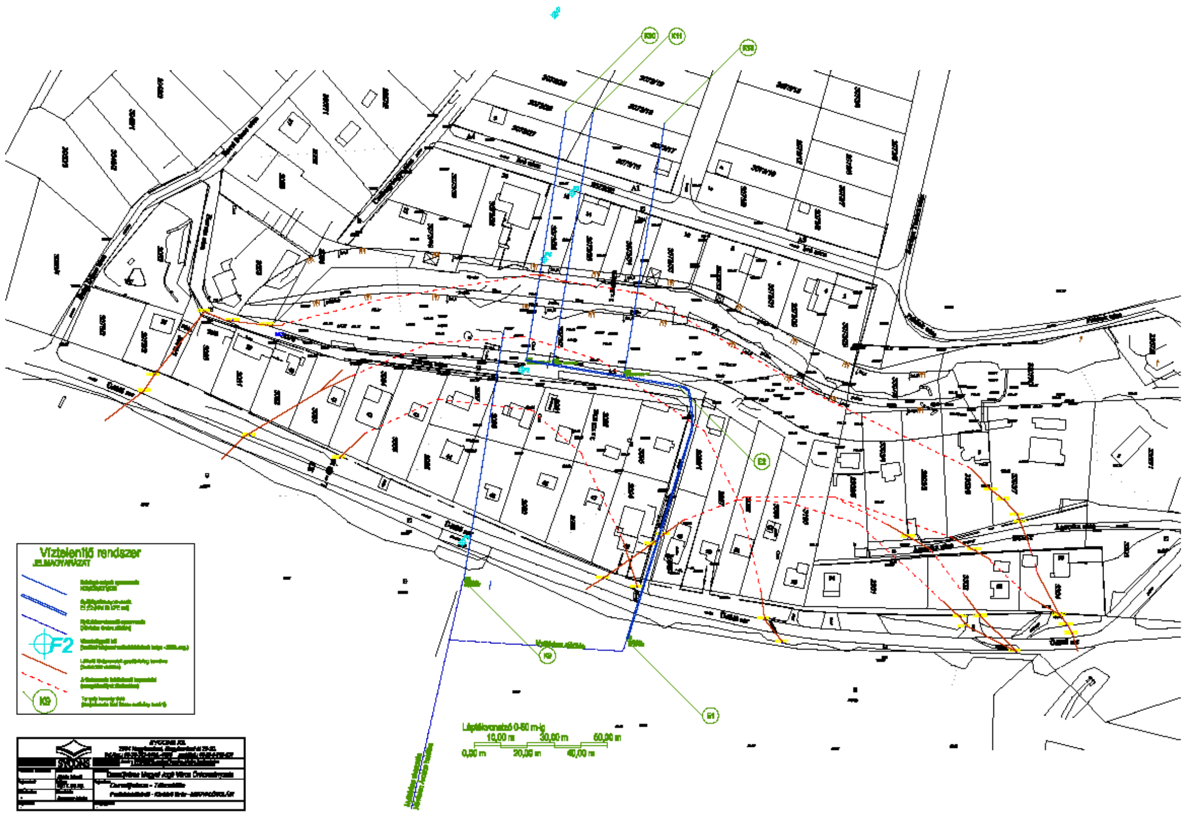

Fig. 12. General layout of the Dunaújváros/Táborállás (Hungary) deep drilled trial drainage system

The soil could be dewatered by these deep drilled drainage pipes was silty fine sand. (See Fig. 13.)

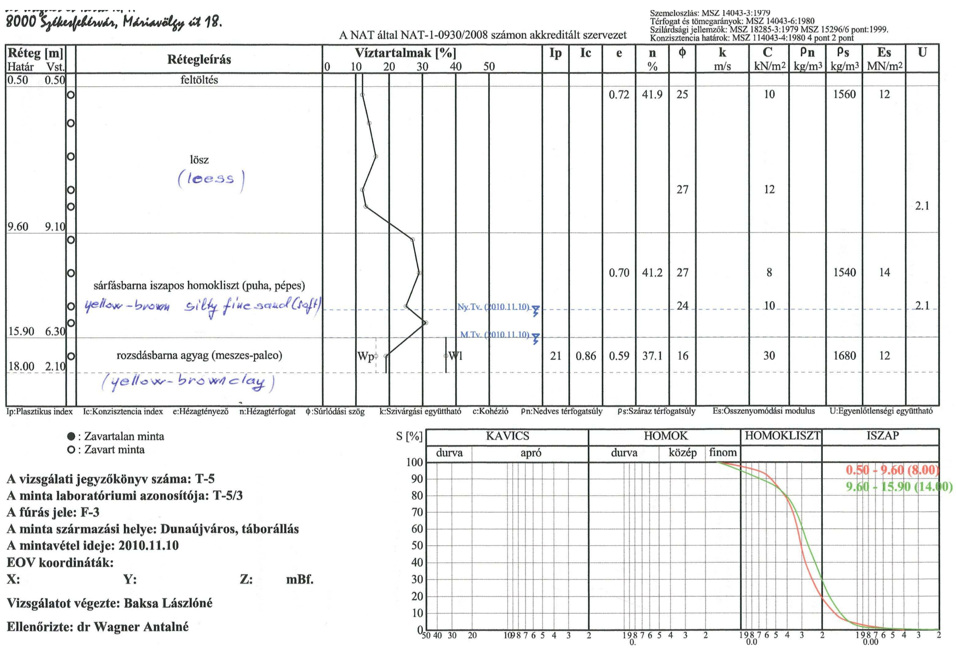

Fig. 13. Granulometry report on the soil layers showing especially the layer to be dewatered

Conclusion

The majority of the water triggered landslides in loessic soil environment could be stabilized and prevented by the significant lowering of the water table in the non mobilized soil area.

A perfect tool for this dewatering work is the deep drilled drainage system.

To increase the safety after the successful dewatering of the non mobilized soil area additional engineering structures could be applied such as:

- complete distinguishing the shearing/sliding surfaces + gravel drainage layers + geosynthetics reinforced soil embankment as a retaining wall
- "nailing" the mobilized soil body to the lower non mobilized watertight soil layers by r.c. pile or soil anchor system

The well positioned deep drilled drainage system is a quick, effective and very economical solution to stabilize of certain type of water triggered landslides and for prevention as well.

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