Soil & Tillage Research 146 (2015) 66–78

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

# Quantification of mechanical strength and sliding stability of an artificial water catchment (Chicken Creek)

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ARTICLE INFO

*Article history:*
Received 6 December 2013
Received in revised form 25 May 2014
Accepted 31 May 2014

*Keywords:*
Shear strength
Slope stability
Soil creep
Hydraulic conductivity
Anisotropy

ABSTRACT

Natural shear forces due to gravity along inclined terrain surfaces are controlled by the inclination of the terrain, material composition and its mechanical properties, stratification and hydraulic stress states. Both shear forces and shear strength under a given inclination of the terrain surface strongly depend on the interaction between mechanical and hydraulic stresses. These internal conditions as well as the interactions between these various components are fundamentals in all nonplanar regions under arable, forest or grassland management and they dominate also under various geoscientific aims. Generally, soil creep is a slow soil movement downslope under gravity. It can occur even on gentle slopes when the shear forces exceed the shear strength of the soil. Deposited material on slopes is more sensitive to such movements than well-developed soils due to the absence of a pronounced soil structure, site and management dependent hydraulic properties and functions, which results in low soil strength.

We applied the described measurements and the modelling approaches to investigate and to analyse the stability of an artificially constructed water catchment (Chicken Creek) in the mining district of Cottbus/Germany, where glacial sand was deposited above a clay layer with an inclination of about 3.5%. At the lower part of the catchment, an impermeable barrier (clay wall) was positioned transversally to the main slope. Mechanical and hydraulic parameters of the soil layers were determined on soil samples taken from the field site. The measured values were inserted as input parameters for the finite element model (Plaxis 2D) to simulate soil movements and their effect on the stability of the catchment. The obtained results showed that the kind of construction negatively affected the physical low soil strength (low pre-compression stress) although the bulk density was very high (1.7–1.9 g/cm$^3$ for the sandy material). Hydraulic conductivity revealed a significant anisotropy with higher hydraulic conductivity values in the horizontal direction. Furthermore, finite element results showed that the design of the newly formed landscape remains weak concerning mass movements too. The high water table in the sandy material in conjunction with low soil strength enhances the downslope movement and increases the shear stress near the clay wall at the lower end of the slope, which finally results in soil creep processes.

These results also proof that such geotechnical and modelling approach is also suitable to validate or to predict mass movements and the internal processes responsible for these internal mass erosion.



## 1. Introduction

Soils are characterized as rigid media, if neither mechanical, hydraulic, thermal, nor chemical processes as well as the combinations of any or all of these aspects results in changes of the existing soil properties and functions.

If however, such coupled processes exceed the internal soil strength, strain, creep or internal soil deformation occur and result in a newly reached dynamic equilibrium. One of the deformation components is the mass movement which describes the movement of material downslope under the influence of gravitational forces (Fitzsimons, 2001) and which is amongst others, also intensified by the processes of liquefaction coinciding with reduced shear strength or smaller effective stresses. Movement of soil mass on slopes occurs primarily when gravity forces exceed the shear resistance (shear strength). The velocity at which the soil mass moves downslope can range from seconds in case of

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http://dx.doi.org/10.1016/j.still.2014.05.013
0167-1987/

catastrophic rockfalls and flow events, to slow creep that occurs over hundreds or thousands of years. Generally, all slow movements are defined as creep movements irrespective of the cause and the nature of this movement. According to the general soil mechanics, such lateral mass movement will only stop if the surface is planar at all locations.

Creep movements on slopes can be therefore defined as a slow progress of downslope movement of soil or rock debris with lapse of time (fraction of mm/year) due to natural processes molding the earth's relief, they are imperceptible except for observation of long duration and are common on all unconsolidated slopes (Feda, 1991; Fitzsimons, 2001; Sharpe, 1938; Shimokawa, 1980).

The factors affecting downslope creep movements occur either permanently or episodically. Permanent creep occurs, depending on both the slope and material as well as on the inclination and height of the slope, petrographic composition and physical properties of the material, which is valid not only for geotechnical but also for all kinds of land use management (Hammouri et al., 2008; Lewis, 1974). Thus, permanent changes of these factors can result in continuous creep movements of slopes if at the toe of the slope, the abutment has been removed or if chemical and physical weathering of the soil properties occur. Shimokawa (1980) states, that the landslide displacement and slope stability of cohesive soils correlates with the creep deformation and creep strength behavior. Van den Ham et al. (2009) indicate that in geotechnics creep movement poses a threat to infrastructure and buildings on or below the slope and, furthermore, represents an initial stage of active landslides or earth flows with an even more detrimental impact. Therefore, it is necessary to be able to predict creep displacements on slopes as well as their velocities and evolution over time (Van den Ham et al., 2009). Apart from material properties effects, changes in climatic and hydrologic conditions are the most important triggers of episodic factors affecting downslope creep movements. Especially volume changes due to changes in temperature and/or water content affect movements of the soil downslope. An often ignored aspect is the interaction of pore water and its binding forces, as increasing pore water pressure decreases the internal strength of the soil (effective stress) and, therefore, decreases the stress needed for soil deformation while negative pore water pressure increases soil strength. If, in addition the interflow at the boundary between the permeable and less permeable layers or along shear zones is prevented, enhanced sliding occurs due to positive pore water pressure (Lewis, 1974). The theoretical background of this is defined in the effective stress equation first described by Terzaghi and Jelinek (1954). Positive pore water pressure reduces the effective stresses at a given total stress and vice versa by drying.

Moreover, shearing of the soil specimen under a given normal stress leads to its deformation and causes changes of the pore volume, the pore size distribution, as well as the cross-section and length for water flow. As a result, the hydraulic conductivity and the pore water pressure and/or matric potential change which in turn affect the stability of the soil (Nissen, 1999). Therefore, the destruction of the pore system and the related decrease of the hydraulic conductivity during creep movements on slopes lead to a further weakening of the soil due to an increase of pore water pressure and results finally in slope failure (Peth et al., 2010).

The possibility to predict slope creep or failure requires well-defined mechanical datasets as input parameters of a finite element approach (Alkasawneh et al., 2008). Despite a high number of studies, which are focused on simulating slope stability using finite element method, most of them investigate only the end stage of the slope (stable or not stable) indicated by the factor of safety. Only few studies have dealt with the simulation of the actual creep movement on slopes (e.g., Foriero et al., 1998; Jiaguan and Yahui, 2009; Ismail, 2012; van den Ham et al., 2009). One of the more complete computer programs is a 2D finite element model (Plaxis) which has already been used in many studies in order to simulate slope stability (e.g., Alkasawneh et al., 2008; Cheng et al., 2008). However, its use to simulate creep movement on slopes is so limited that literature dealing with it is seldom to find. Nevertheless, Plaxis proofed with high accuracy that the simulation of creep movement of the Leaning Tower of Pisa could be forecasted (Ismail, 2012).

The objective of this study is to investigate creep movement in the artificial water catchment (Chicken Creek) and to examine its stability in relation to a rising water level. Using the special design of the Chicken Creek and its defined boundary, this study will make

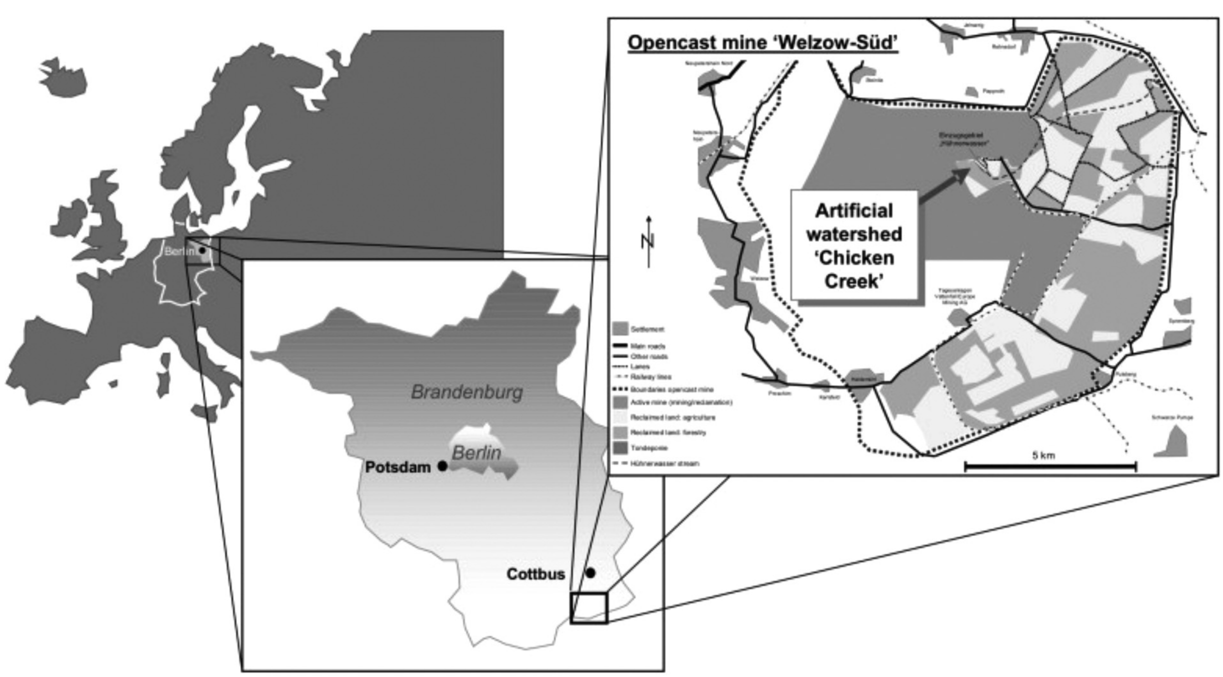


**Fig. 1.** Chicken Creek catchment in the open cast mine Welzow-Süd (State of Brandenburg, NE, Germany), adopted from Gerwin et al., 2009.