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Ettringite Swelling in the Treatment of Sulfate-Containing Soils Used as Subgrade for Road Constructions

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Abstract

In earthworks and road construction, several cases of damage caused by the formation of the mineral ettringite are known. If soils with natural sulfate content were treated with calcium-based binders, the binder may react under certain conditions with sulfate ions to cause the mineral ettringite. Ettringite has a very high crystal water content and is therefore highly voluminous and lightweight. Due to this increase in volume, the mineral reaction may cause uplift damage. Although factors are known for this mineral reaction in the soil, quantitative testing methods and standardized prevention strategies are currently not yet available. The aim of this study is to develop the basis for a practical test specification. With the help of adequate research and testing, in the future it should be possible to avoid damage cases. First, a literature study was conducted. It became clear that the mineral content, the water supply, the chemical environment, the temperature, the pore structure and the overburden pressure in the soil are key factors. In the second step, comprehensive powder-swelling-tests have been carried out on different materials. There is a relation between the sulfate content and the volumetric expansion due to ettringite formation. Critical sulfate contents are strongly dependent on the soil and can be influenced by the choice of the binder. It could be confirmed that treatment with burnt lime caused more heaving under the same boundary conditions, than the use of cement binder.

Indications to evaluate the risk of ettringite swelling were developed for engineering practice and recommendations for test methods are proposed.

Keywords: ettringite swelling, sulfate swelling, sulfate soil, risk assessment, test methods

1 Introduction

The objective of soil treatment is to increase the strength of the soil and to decrease its sensitivity to frost in order to make it permanently resistant to the stresses caused by traffic and environmental influences. In spite of positive experiences and prescribed execution of measurements for soil treatments with calcium based binders in road construction, it has become repeatedly to cases of damage caused by the formation of the mineral ettringite. Because of the binder treatment, silicates and alumi-

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nates of the clay fraction in the soil are released. The sulfates in the pore water react with the liberated aluminates and the free calcium from the binder. This results in the formation of minerals from the group of ettringite. With a share of about 46 percent by weight, ettringite is one of the minerals with the highest crystal water content and is therefore relatively voluminous and has a low density. Although factors for the reaction of sulfate-induced heave in soil are known, quantitative testing methods and standard prevention strategies are currently not available.

The aim of the research project 'Parameters for risk assessment of ettringite swelling in sulfate soils', sponsored by the Federal Highway Research Institute (German: BASt), was to develop a practical procedure as a basis for test specifications (Moormann et al, 2014). For the risk assessment of ettringite-induced swelling in the binder treatment of sulfate-containing soil, parameters and standard values must be defined. As a result, a relationship between the sulfate content in the soil and the volumetric expansion due to ettringite formation was noted. Furthermore, it was investigated that a ground treatment with burnt lime under the same boundary conditions caused more heaving, as the use of cement binder. Upon completion of the research project at the University of Stuttgart, another project was launched, in which the influence of the binder content was examined.

2 Influencing Factors

A number of known boundary conditions must be satisfied so that it can come to the formation of ettringite.

Mineral content: The availability of certain minerals has an essential influence on whether and to what extent the swelling reaction can occur. The critical sulfate content depends on the percentage, type and distribution of clay minerals in the soil. In soils with low clay content (< 10%), relatively high sulfate contents (> 10,000 ppm) are necessary for swelling-induced heave. The critical sulfate content of the soil decreases with increasing clay content. Kaolinitic soils (non-swellable) have a larger stock of aluminates than smectitic soils (swellable). Therefore the kaolinitic soils have, under the same conditions, a higher potential for damaging ettringite formation. The amount of the chemical compounds is not the deciding factor, but their distribution and availability in the soil and the size of the reactive surfaces of certain minerals. In the German literature (inter alia (Witt, 2012)), sulfate levels of 3000 ppm are considered as potentially harmful, but the risk potential is low. A high risk exists from a sulfate content greater than 8000 ppm. These limits (Witt, 2012) are also found in the technical rule of the Texas department of Transportation (2005). The lower limit of 3000 ppm is also confirmed by Mitchell & Dermatas (1992). Little et al. (2010) and Petry & Little (1992) indicate that even a sulfate content of 2000 ppm is potentially harmful. Hunter (1988) determined a limit of 10000 ppm, from which there is a high risk. Tidwell & McCallister (1997) noted that there is significant heave when using lime as binder with a higher sulfate content of 12000 ppm.

Amount of water: As a prerequisite for the ettringite formation, the sulfates must dissolve, which needs sufficient water.

Chemical environment / alkalinity: Ettringite precipitates only under alkaline (high pH) conditions. The addition of binding agents to the soil results in a sharp increase in alkalinity. At pH > 10.5 aluminate and silicate ions from the clay minerals of the soil are released up to a large amount and then they are available for the formation reaction (Witt, 2012). In soil stabilization with calcium-based binders, the required alkaline environment is realized.

Temperature: The soil temperature has a strong influence on the reaction mechanism. The ettringite formation takes place in particular between 15°C and 20°C. Thaumasite crystallizes at temperatures below 10°C (Witt, 2012).

Pore structure of the soil: The pore structure of the soil affects the swelling reaction. A continuous pore system favors the convective transport of sulfate solutions through the soil matrix. The damaging