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On the swelling behaviour of weak rocks due to gypsum crystallization

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Abstract

The paper describes the case of an industrial pavement in Northern Italy, subjected to significant uplift (up to 0.2-0.4 m) due to the response of the rock mass below the concrete floor. The study included monitoring the pavement for a long period of time, the execution of a geotechnical investigation campaign and a number of X-ray diffraction analyses. The results of the investigation suggested that a strong correlation exists between the uplift of the pavement, the swelling behaviour of the material exposed by the excavation and the chemical process of gypsum crystallization.
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1. Introduction

The design of engineering structures interacting with rock masses needs to take into account the potential deformational behaviour of the rock mass under the induced state of stress. For most rock types various constitutive models can be used with confidence as long as there is no interaction between the rock-forming minerals and water.

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However, if water chemically interacts with the rock minerals the behaviour of the rock mass becomes more difficult to predict [1].

The swelling behaviour of sedimentary rocks has been extensively studied by many researchers and is generally most evident in deep underground excavations, such as tunnels and underground mining [2,3]. On the contrary, there are limited documented cases in the literature referring to shallow formations. In argillitic rocks, hydration of anhydrite ($CaSO_4$) and dehydration of gypsum ($CaSO_4 \cdot 2H_2O$) lead to alternating volume changes, posing serious engineering problems to human structures. Anhydrite in surface layers readily imbibes any available water and quickly converts into gypsum. The associated swelling is known to create pressure on the walls and heave in the floors of tunnels as well as uplift of foundations. As an example, the Vobarno tunnel in Italy, not far away from the site of the case study presented in this paper, was constructed through anhydrite and gypsum formations. Completed in 1931, it gave no trouble until 1940 when it suddenly began to crack and progressively heave, causing the concrete lining to disintegrate into rubble [4].

The paper presents a case study regarding an industrial pavement constructed in 2000 in Lumezzane (Brescia, Northern Italy), subjected to significant uplift (up to 0.2-0.4 m) between 2003 and 2008, due to the swelling of the foundation material. The study was conducted with a multidisciplinary approach that included either monitoring the pavement for a long period of time, or the execution of geotechnical investigations in situ and laboratory testing, and X-ray diffraction analyses to assess the mineralogical composition of the foundation materials.

2. Geochemical and engineering aspects of anhydrite/gypsum phase transition

Mineral transition between anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$) takes place according to the following reversible hydration-dehydration reaction (1):

$$CaSO_4 + 2 \cdot H_2O \leftrightarrow CaSO_4 \cdot 2H_2O \qquad (1)$$

Aside from the chemistry of the water, the chemical relation (1) is governed by temperature and pressure [1,5,6]. The hydration-dehydration reaction alters the crystalline structure of the resulting mineral; therefore estimates of volume changes associated with such mineral transition should be based on the molar volumes of gypsum, anhydrite and water [5]. Table 1 summarizes the theoretical assessments on the volume changes due to hydration and dehydration of calcium sulphate minerals for “open” and “closed” systems [1]. Open systems allow free exit/entry of water during hydration/dehydration, whereas a closed system is defined as an environment where water is trapped with the calcium sulphate minerals before and after the transition. In open systems, gypsification is associated with a volume increase of up to 63%, whereas dehydration of gypsum results in a volume decrease of up to 39%. The volume changes for closed systems take place in the opposite direction, so that anhydrite hydration results in a volume decrease of 9% and gypsum dehydration results in a volume increase of about 10% [5]. It must be noted that the above estimated volume changes are intended for complete mineral transition and provide the boundary values for hypothetical situations. Actual volume changes in the field are governed by many factors such as the in situ porosity, the homogeneity of composition and the nature of the system (the characteristics of the rock mass, the water regime). Volume change predictions for systems with partial water access and incomplete mineral transition are complex and, although they would fall between the boundary values, direct measurements are necessary to determine the engineering behaviour of local formations [5].

Table 1. Theoretical maximum volume changes in calcium sulphate minerals [1,5]

Volume	Open system		Closed system	
	hydration	dehydration	hydration	dehydration
Initial [cm^3]	V_A = 45.9	V_G = 74.7	V_A+2V_L = 45.9+36.2	V_G = 74.7
Final [cm^3]	V_G = 74.7	V_A = 45.9	V_G = 74.7	V_A+2V_L = 45.9+36.2
Change [(Final/Initial – 1)×100]	+62.8	-38.6	-9.0	+9.9

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