Coupled hydro-chemo-mechanical modelling of a foundation heave due to gypsum crystal growth

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ABSTRACT

The Pont de Candí viaduct, which belongs to the high-speed train connection Madrid-Barcelona, experienced recently a sustained heave at high rates ranging from 5 to 10 mm/month after the end of its construction [1]. The bridge pillars are founded on a group 3x3 large diameter bored piles, 20 m long on average. The piles of the central pillars are socketed on a hard Eocene Tertiary claystone with certain content in gypsum and anhydrite. Deep extensometers showed the heave of the bridge was a result of expansions developing below the tip of the piles, in a layer 12-15 m thick.

Gypsum crystal growth in open discontinuities pushes the rock mass apart and generates the swelling behaviour observed in the active layer. Gypsum crystals precipitate from supersaturated groundwater. Supersaturation of water in calcium sulphate with respect to gypsum is achieved because the solubility of anhydrite is higher than the solubility of gypsum. This swelling phenomenon has been also observed under the invert of Lilla tunnel, excavated in an Eocene sulphated claystone formation [2] next to Pont de Candí bridge and also in other tunnels excavated in Triassic claystone formations containing sulphate species in Central Europe.

The swelling phenomena have been modelled within a general framework for coupled thermo-hydro-mechanical analysis for porous materials [3]. The presence of two soluble species (anhydrite and gypsum minerals) and one non soluble species (clay matrix and other non soluble minerals) has been taken into account in the formulations. The mass balance equation for the solid phase formulated defines the variation of porosity in time is a result of the volumetric strain rate induced by solid displacements, and of the volumetric rate of precipitated or dissolved mineral crystals. Two kinetic equations (one for each soluble mineral) have been formulated to describe the rate of precipitated or dissolved mass of anhydrite and gypsum crystals. The mass balance equation of water takes into account, in the source/sink term, that gypsum crystals incorporate water molecules in its crystalline structure when they precipitate. Strains induced by precipitation are considered as imposed "external" strains in the momentum balance equation of the medium. The deformations induced by precipitation of gypsum are calculated from the amount of precipitated volume of gypsum and from the prevailing stress acting on crystals. A solute mass conservation equation has also been formulated to keep track of calcium sulphate solute. These formulations have been included in the Finite Element program for coupled thermo-hydro-mechanical analysis in porous media CODE BRIGHT [4].

A column of foundation material of the central pillar of the bridge (P5) has been simulated. The flow conditions in the active layer have been reproduced. The fractured and high permeable sulphated claystone has been modelled as a porous material with a high porosity. The calculated response of the model seems to be consistent with heave records observed in a relatively long period (4 years). The model can also reproduce the effect of the construction of an embankment over the surface of the valley on the heave rate. A sensitivity analysis preformed provides an additional insight into the phenomena and shows the relevance of a few controlling parameters.

REFERENCES

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