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Long-Term Material Performance Prediction Of Rockfill Dams Exposed To Aggressive Solution

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Abstract*: The rockfill dams, usually use in huge hydraulic geotechnical, exposures to water and aggressive solutions such as: seawater, acid mining drainage. In particular, the mechanical properties of rockfill dams is depended on volumetric deformation. However, the volumetric deformation of rockfill dams depends on as well as the contact solutions inducing different chemical reaction. The chemical reaction leads to the modifications of rockfill dams mechanical behaviour such as irreversible settlements. The modifications evolve over the time. To relatively predict the chemical degradation rockfill dams, the geochemical modelling is used to simulate chemical reactions between heterogeneous particles or different mineral of rockfill dams. The model can predict relatively the long-term material performance of rockfill dams exposure to different environment such as acid mining drainage and seawater.

Keywords*: Rockfill dams, Volumetric deformation, seawater, acid mining drainage, Geochemical model.

I. Introduction

In response to climate change, mitigation of sea level rises as well as saline intrusion, many dams including rockfill dams are newly built. However, according to Silvestre's study [1], hydroelectric dams or the construction of hydraulic reservoirs as dams, dykes and embankments including rockfill dams are undergone irreversible settlements although the construction is within the limit of design bearing capacity. Volumetric deformations over time can cause the irreversible settlements. One of the main causes of the volumetric deformation is the weathering of the mineral components of the dam. Indeed, the main material that makes up the dam: rocks, soil and stabilized materials such as: cement, pozzolan, etc…are porous media. The media exposures to aqueous solutions such as seawater, polluted water, acid mining drainage. Thanks to pore networks and tortuosity, the solutions contact with the minerals, inducing chemical reaction such as modification pH of pore solution, dissolution/precipitation. That leads to volumetric modification. However, each dam has different mineral composition, as well as the solution with different chemical composition. In fact, current design standards do not take into account the settlements caused by these chemical reactions. Therefore, in order to explain more about the cause, a geochemical model is proposed to use in this paper. First, some principal equations of the model are presented, geochemical model is applied to simulate the weathering process of an rockfill dams with mineral composition from the study of Xu et al. [2]. At the same time, assuming that the rockfill dams is exposed to acid mining drainage solution [3] and seawater [4]. Some results of the model and discussion will be presented in third section.

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II. Modelling Approach

A. Transport equations

Without convection phenomena, the ion transport is governed by diffusion in a saturated environment. Therefore, in one dimension the principle of transport equation can be written [5], [6]:

$$\frac{\partial M_j}{\partial t} = -\frac{\partial J_j}{\partial x} + q_j \qquad (1)$$

M_j, J_j and x are the molar accumulation of species j in the aqueous phase (mol.m^{-3} of material), the flux of species j in solution (mol.m^{-2}.s^{-1}) and the distance of diffusion (m), respectively. The q_j source or sink of species j (mol.m^{-3}.s^{-1}). In porous media, considering the ionic interactions are taken into account in the source term, the flux of a species j, J_j, can be described by the first Fick's law:

$$J_j = -D_e \frac{\partial C_j}{\partial x} \qquad (2)$$

D_e effective diffusion coefficient of species j (m^2 ·s^{-1})

B. Thermodynamic equilibrium

The interaction between the ionic species and the mineral species leads to precipitation/dissolution of minerals. The principle thermodynamic equilibrium is described in Xu et al. [5], Vu et al. [7]. Thermodynamic database includes these parameters, the thermodynamic database THERMODDEM of Blanc et al [8] is applied in this paper.

C. Kinetic control

A requirement of chemical reaction under kinetic constraints is necessary. The kinetic laws of mineral dissolution/precipitation is used in this study, given by Lasaga et al. [9] .The rate expression is functions of the primary species:

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$$r_n = f(C_1, C_2, \ldots, C_{N_c}) = \pm k_n A_{ms,n} \left|1 - \Omega_n^{\theta}\right|^{\eta} \quad (3)$$
n=1,..,Nq

Where positive values of r indicate dissolution and negative values precipitation, k is the rate constant ($mol.m^{-2}.s^{-1}$). A_{ms} is the specific reactive surface area ($m^2.g^{-1}$), Ω is the mineral saturation ratio defined in (eq. 2). The parameters θ, η can be determined from experiments, they are usually taken equal to one due to lack of measurement. q is the number of minerals under kinetic constraints. The kinetic parameter of cement hydrated was extracted from Baur et al. [10].

D. Porosity changes

The mineral dissolution/precipitation inducts to change initial porosity. Therefore, the media accessible porosity is update at each time t according as follows [11]:

$$\phi = 1 - \sum_{m=1}^{nm} fr_m - fr_u \quad (4)$$

where *nm* is the number of minerals, *frm* is the volume fraction of mineral *m* in the rock ($V_{mineral}/V_{medium}$, including porosity), and *fru* is the volume fraction of non-reactive rock. As the *frm* of each mineral changes, the porosity is recalculated at each time step.

E. Model geometry

The ions ingress is undergone by diffusion phenomena, only thermodynamic equilibrium and kinetic control are considered in the investigation. Representation of numerical model is shown in the Fig. 1. The simulations are carried out in two cases of acid mining drainage solution with different pH.

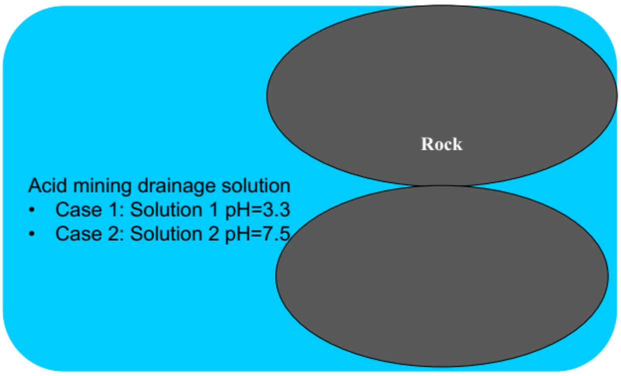

Fig. 1 Representation of numerical model

F. Required input data

Mineral composition of of the rockfill dams, is extracted from the work of Xu et al.[2] (cf. table 1). Initial accessible porosity of rock is equal to 0.08. Based on the results: effective diffusion coefficient over accessible porosity (cf. Fig. 2) of Luc et al. [12] about 7.10^{-13} ($m^2.s^{-1}$)

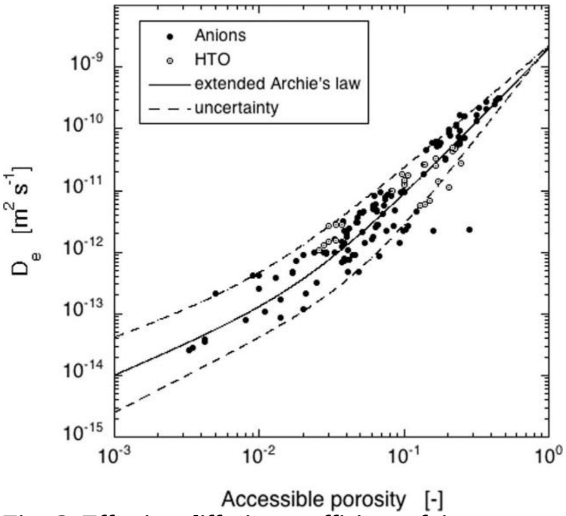

Fig. 2 Effective diffusion coefficient of ions over accessible porosity [12].

Table. 1 Mineralogical composition of rock [2].

Mineral	Formulation	Volume fraction of solid
Pyrite	FeS_2	0.090
Chalcopyrite	$CuFeS_2$	0.045
Magnetite	Fe_3O_4	0.045
Microline	$KAlSi_3O_8$	0.180
Albite	$NaAlSi_3O_8$	0.090
Anorthite	$Ca(Al2Si_2)O_8$	0.045
Annite	$KFe_3(AlSi_3)O_{10}(OH)_2$	0.045
Muscovite	$KAl_2(AlSi_3)O_{10}(OH)_2$	0.090
Anhydrite	$CaSO_4$	0.045

Ionic composition of acid mining drainage solution and seawater and is presented in the table 2 and 3, respectively.

Table. 2 Ionic composition of acid mining drainage [3].

Ionic	Concentration (mol/l)
Na+	0.020
K^+	0.001
Ca^{2+}	0.011
Mg^{2+}	0.012
HCO^{3-}	-
$SO4^{2-}$	0.091
Cl^-	0.001
pH	4.0

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Table. 3 Ionic composition of acid mining drainage [4].

Ionic	Concentration (mol/l)
Na+	0.4690
K^+	0.0121
Ca^{2+}	0.0103
Mg^{2+}	0.0528
HCO^{3-}	0.0021
$SO4^{2-}$	0.0282
Cl^-	0.5459
pH	8.0

III. RESULTS AND DISCUSSIONS

The numerical numerical are performed by Phreeqc code [6]. Evolution of mineral composition at the interface between rocks and aggressive solution (acid mining drainage solution and seawater) is shown in Fig. 3.

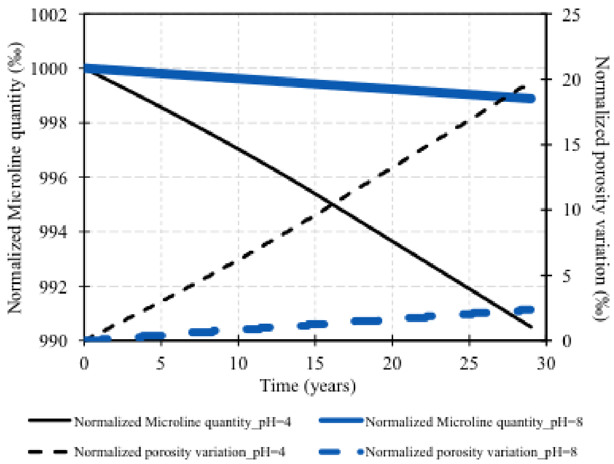

Fig. 3 Normalized microline quantity and normalized accessible porosity variation over time (years).

In the Fig. 3, the solid line shows the normalized quantity of microline over time and the dash line shows the normalized accessible porosity variation over time in the two cases: exposing to acid mining drainage solution pH=4 and to seawater pH=8. It is worth noting that the microline is dissolved in the two case. That leads to increase the accessible porosity. Porosity increase is relatively high in long term. In fact, the variation of microline quantity or of porosity is more powerful in the acid mining drainage solution with increasing 2% of accessible porosity after 30 years of exposure. The powerful increase depends strongly on pH solution. Moreover, pH affection on variation accessible porosity is shown in the Fig. 4.

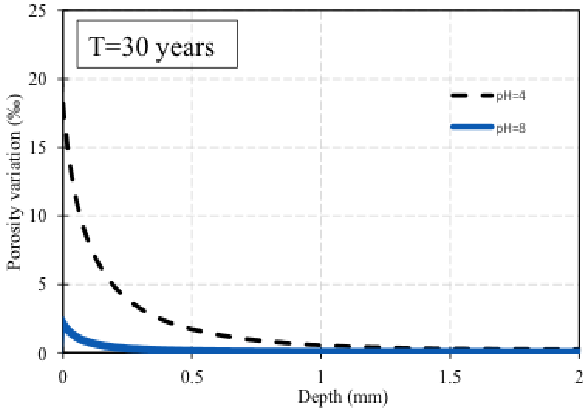

Fig. 4. Accessible porosity variation over depth.

Lower pH increases the mineral dissolution and media porosity. It is worth noting that the accessible porosity increases more powerful as one approaches the surface of rock particle. The increase seems to lead modification surface contact of two particle as well as the volumetric rockfills dams. The volumetric deformation increases over time, that induces the settlement in the long-term.

IV. CONCLUSIONS

In this paper, geochemical model is proposed to investigate volumetric deformation as well as settlements irreversible of rockfill dams caused by chemical reactions between rock particle and contact solution such as acid mining drainage solution and seawater in the long term. The model shows that the chemical reactions leads to dissolution mineral of rock as well as increase the accessible porosity. Growth of volumetric deformation depends on time and space. Approaching nearer the surface of particle and for the long term, the accessible porosity increases more powerfully. The powerful variation of porosity depends on as well as pH contact solution. Low pH increases porosity stronger than high pH. The model can predict relatively the long-term material performance of rockfill dams exposure to different environment such as acid mining drainage and seawater.

However, different comparisons between numerical and experimental results need to be performed to verify feasibility of the model. The model needs to performed in the longer time.

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Quang Hung Nguyen was born in 1975 in Hanoi, Viet Nam. He received the Engineering's degree and M.S. degrees in hydraulic construction from the Thuyloi University of Vietnam, in 1997 and 2000 and the PhD. degree in hydraulic structure from Wuhan University, China. Since 1998, he is a lecture in Faculty of Civil Engineering, Thuyloi University and becomes Associate Professor since 2009. From 2007 to 2013, he was Deputy Director of the Institute of Civil Engineering, designed and built many key projects of Vietnam. He is also principal investigator and member of many national science projects as well as Vietnam Ministry of Agriculture and Rural Development. Since 2013, he has been a senior expert in hydraulic construction of Vietnam Ministry of Construction. He is the Advisor of more than 200 bachelors, 40 masters, 2 PhD specialized in hydraulic construction.

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