Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(2):226-232

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Influence on anti-seepage efficiency of curtain by physico-chemical actions of groundwater

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ABSTRACT

The anti-seepage effect of curtain under dam foundation may be weakened by the long term physico-chemical actions of groundwater. According to seepage hydraulics and geochemistry theory, and considering seepage, solute transport, geochemistry and curtain erosion, the analysis on the behavior of the curtain under dam foundation was conducted. The analysis results of a case proved that the curtain efficiency was weakening all the time, the primary reason of which is calcium had been always in dissolution during the simulation time. The erosion is much more seriously near the bottom of the curtain than the other parts, and the same from the upstream and downstream. Calcium dissolution is mainly controlled by hydraulic condition and dispersion; it varies in a non-linear way within the domain.

Key words: Anti-seepage behavior of curtain; seepage; solute transport; geochemistry; curtain erosion

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INTRODUCTION

Seepage state is controlled by the curtain integrity and its anti-seepage efficiency. Coupled to the variations of seepage pressure and hydrochemistry, the dissolution of calcium ions from cementation zone is taken away by the fluids. The research shows that the curtain efficiency is affected greatly by the flow and chemical fields [1].

In recent years, many researchers were concerned with curtain efficiency. Dam and its curtain working state through the groundwater regime under foundation are analyzed [2-4] by Gu, Fu and Wu. The researches[5-7] by Tong, Song , and Yang indicated that revealing the consequence of water-rock interaction by analyzing the microcosmic state of groundwater around a dam foundation is helpful to evaluate the anti-seepage performance of the curtain (A model coupled of seepage field and stress one was built up by some researchers[8-12]. But it is hardly to find the coupling model for assessing the anti-seepage behavior of curtain under dam foundation, especially in which the chemical reaction was considered.

In this paper, a multi-physics model was set up, coupled of seepage field, a chemical reactive and mass transport field to integrate a description of curtain efficiency variation.

EXPERIMENTAL SECTION

Analysis model

1. Assumptions

Assumption is given as follows. 1) The saturated porous medium is homogeneous and continuum, and the flow of which obeys Darcy's law. 2) Hydraulic conductivity does not vary with time; 3) The aquifer do not contribute other components to the variation of solute; 4) The amount of ionic moles in groundwater varies only due to the dissolution/precipitation reactions.

2. Multi-physics Model

A multi-physics model is built by considering seepage [13], chemical reaction[14-15], solute transport [16-18] and curtain erosion [19].The behavior of seepage is described as,

$$\begin{aligned}
&\frac{\partial}{\partial x}\left(K\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial H}{\partial y}\right)=\mu_s\frac{\partial H}{\partial t}\\
&H(x,y,t)=f_0(x,y)\\
&H\big|\Gamma_1=f_1(x,y,t);(x,y)\in\Gamma_1\\
&K\frac{\partial H}{\partial n_\Gamma}\Big|\Gamma_2=f_2(x,y,t);(x,y)\in\Gamma_2
\end{aligned} \tag{1}$$

Where, μ_s is the specific storability; H is the hydraulic head; K is the hydraulic conductivity tensor; t is the calculate time; f_0、f_1 f_2 are the initial and boundary conditions; Γ_1、Γ_2 are the boundary conditions of prescribed head and flux; n_Γ is the outward unit normal vector on domain boundary.

The behavior of chemistry is described as,

$$\begin{aligned}
&\frac{dC}{dt}=-(X_{Eq}+\Re_{Kin}),\ \Re_{Kin}=-k_{Kin}S_{Kin}\left[1-\frac{\prod_{j=1}^{N_c}(a_j)^{v_{Kin,j}}}{K_{Kin}}\right]\prod_{j=1}^{N_c}(a_j)^{\delta_{Kin,j}}\\
&\lg a_i=\lg K_i+\sum_{j=1}^{N_c}v_{ij}\lg a_j,\ a_i=\gamma_i\cdot C_i\\
&\lg r_i=\begin{cases}-Az_i^2\sqrt{I} & (I<0.005mol/L)\\ -\dfrac{Az_i^2\sqrt{I}}{1+Ba_i\sqrt{I}} & (I<0.1mol/L)\\ -0.5z_i^2\dfrac{\sqrt{I}}{1+1.4\sqrt{I}} & (I<0.2mol/L)\\ -Az_i^2(\dfrac{\sqrt{I}}{1+\sqrt{I}}-0.3I) & (I<0.5mol/L)\\ -\dfrac{Az_i^2\sqrt{I}}{1+Ba_i\sqrt{I}}+b_iI & (I<1mol/L)\end{cases}\quad ,\ I=\frac{1}{2}\sum Z_i{}^2C_i\\
&T_j=\sum_i^{N_c}v_{ij}C_i-\sum_{Eq=1}^{N_c}v_{Eq\,j}X_{Eq}dt,\quad \sum_{i=1}^{N_c}Z_iC_i=0
\end{aligned} \tag{2}$$

Where, C is the total concentration, while C_i is the special one from the mineral dissolution concerned; X_{Eq} is the change of concentration related to thermodynamics; N_c is the amount of species; a_i is the activity of component i; K_i is the stoichiometric coefficient of species i; v_{ij} is the stoichiometric coefficient of species j in reaction i; a_j is activity of species j in groundwater; T_j is moles of species j; $\Re_{Kin}$ is a temporal variation related to kinetics; k_p is the rate of reaction p; S_p is the specific surface area of mineral p; K_p is the equilibrium constant of reaction p; Eq and Kin refer to thermodynamics and kinetics, respectively.

The behavior of solution transport is described as,

$$
\begin{aligned}
&\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}\left[D_L\frac{\partial C}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_T\frac{\partial C}{\partial y}\right]-\frac{\partial(u_xC)}{\partial x}-\frac{\partial(u_yC)}{\partial y}+W\\
&C(x,y,0)=f_0(x,y,t),\ C\left|B_1=f_1(x,y,t);(x,y)\in B_1\right.\\
&D_L\frac{\partial C}{\partial x}n_1+D_T\frac{\partial C}{\partial y}n_2-\frac{\partial(u_xC)}{\partial x}-\frac{\partial(u_yC)}{\partial y}\left|B_2=f_2(x,y,t);(x,y)\in B_2\right.
\end{aligned}
\tag{3}
$$

Where, u_x and u_y is the fluid velocity along x and y axis, respectively; D_L is the longitudinal hydrodynamic dispersion coefficient; D_T is the transverse hydrodynamic dispersion coefficient; W denotes the source/sink term caused by all chemical reactions; B_1 B_2 are the boundary conditions; $(n_1\ )n_2$ is the outward unit normal vector on domain boundary.

The behavior of curtain erosion is described as,

$$\frac{\partial\theta\cdot C}{\partial t}+\frac{\partial C_{solid}}{\partial t}=div\left[D(C)\cdot grad(C)\right] \tag{4}$$

Where, θ is the curtain porosity; C_{solid} is the ionic concentration concerned; $D(C)$ is the ionic dispersion.

So, the analysis model simulating curtain efficiency is consists of above four modules. In this paper, as numerical simulation, the separately coupling which is often used in solving separately coupled models with solving equations in certain order, was adopted , which reduces calculation time and improve efficiency.

An example

1. General description

The dam site, 60 m wide in foundation and divided into 17 sections, is located on a series of limestone and dolomite. The level was 135 m in upstream, while 15 m in downstream. And the curtain constructed at upstream is 100 m deep and 5 m wide to reduce leakage.

2. Parameters

The simulation parameters are shown in table 1, table 2 and table 3.

Table 1 Chemical compositions of the water (unit: mg/L)

Sample	K^++Na^+	Ca^{2+}	Mg^{2+}	HCO_3^-	CO_3^{2-}	SO_4^{2-}	Cl^-	pH
Reservoir-water	7.73	16.19	1.89	53.42	/	14.25	4.20	8.44
4#	15.24	36.00	3.81	/	32.87	15.70	4.23	11.31
5#	41.59	25.93	3.90	/	44.22	14.72	4.21	11.44
6#	20.31	16.95	4.18	64.10	10.46	14.23	7.39	9.37
7#	17.77	98.13	2.99	/	31.52	14.97	4.48	12.03
8#	23.49	82.18	3.10	/	36.90	15.47	4.52	11.94
9#	55.76	92.41	3.76	/	28.28	14.98	4.69	12.19
10#	20.11	20.63	2.27	/	31.67	15.08	2.12	10.42

Table 2Hydro geological parameters of modeling area

parameters	K	D_L(cm^2/sec)	θ
value	3.557E-05	4.56 E-07	8%
parameters	μ_s	D_T(cm^2/sec)	A
value	0.2	0.439 E-07	0.51
parameters	C_{solid} (mol/m^3)	D(C)(cm^2/sec)	B
value	1.53 E+04	0.196 E-07	0.33

Table 3 Geo-chemical reactions among water-rock-curtain and their thermodynamic parameters in the area

Reactant	Chemical reaction equation	Log K
calcite	$CaCO_3=CO_3^{2-}+Ca^{2+}$	-8.48
dolomite	$CaMg(CO_3)_2=2CO_3^{2-}+Ca^{2+}+Mg^{2+}$	-17.09
calcium oxide	$Ca(OH)_2+2H^+=Ca^{2+}+2H_2O$	22.80
$CaOH^+$	$Ca^{2+}+H_2O=CaOH^++H^+$	12.78
$CaHCO_3^+$	$Ca^{2+}+CO_3^{2-}+H^+=CaHCO_3^+$	11.43
$CaCO_3$	$Ca^{2+}+CO_3^{2-}=CaCO_3$	3.33
HCO_3^-	$CO_3^{2-}+H^+=HCO_3^-$	10.33
CO_2	$CO_3^{2-}+2H^+=CO_2+H_2O$	16.68
H_2O	$H_2O=OH^-+H^+$	-14.00

RESULTS AND DISCUSSION

The domain was divided into triangular mesh elements of 16258. As the head of the upstream and downstream is constant, the steady-state seepage is simulated for calculating the hydraulic head and fluid velocity within the domain. Secondly, chemical reactive transport module was used for describing the curtain behavior. Fig. 1 to Fig. 5 shows some results at different stress time from simulation of section 6.Traffic information is difficult to share. Traffic information collection, management, processing, and release system have not unified interaction interface, so it is difficult to integrate various systems. Due to the independence of the systems, each system has its own set of databases and data formats, resulting that the data cannot be shared between the systems. So there are numerous data "islands" in traffic system.

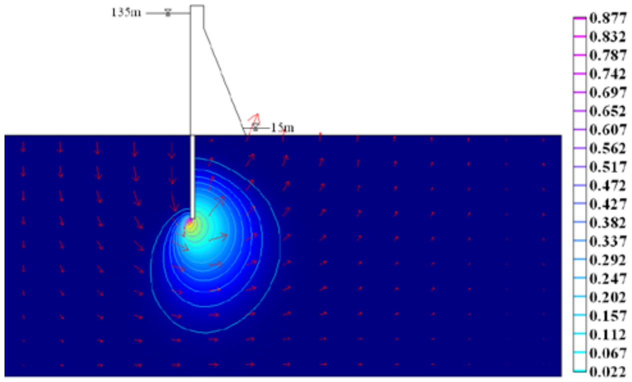

Fig.1: Distribution of Ca^{2+} concentration after 360 days in cross section 6 (unit: kg/m^3)

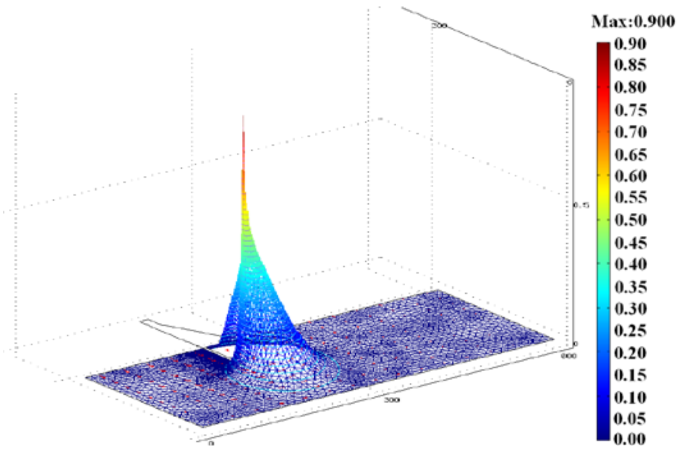

Fig.2: The Distribution of Ca^{2+} concentration after 360 days along vertical direction in the domain (unit: kg/m^3)

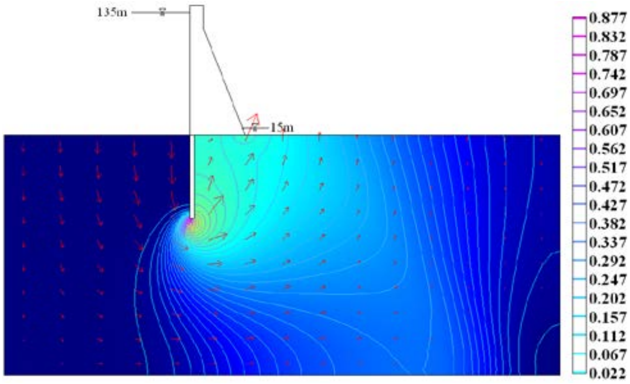

Fig.3: Distribution of Ca^{2+} concentration after 7200 days in cross section 6 (unit: kg/m^3)

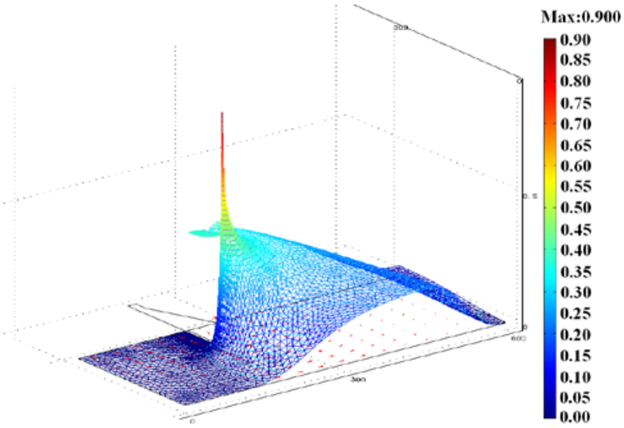

Fig.4: The Distribution of Ca^{2+} concentration after 7200 days along vertical direction in the domain (unit: kg/m^3)

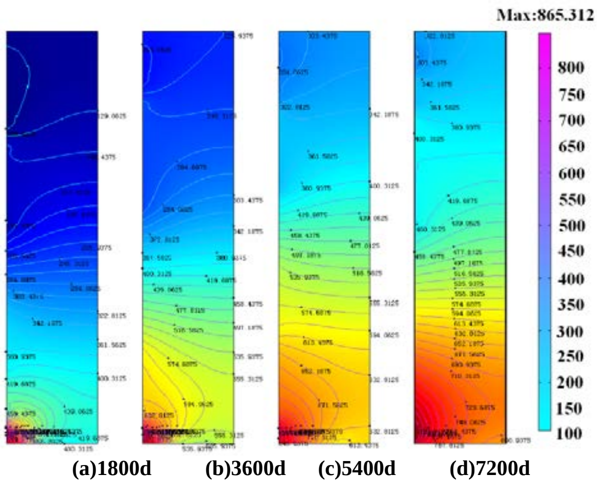

Fig.5: Distribution of Ca^{2+} concentration within the curtain at different times (unit: kg/m^3)

It is known from the figures that reaction extent differs in different parts of the curtain that the dissolution of Ca (OH) 2 accounts to 877.884 g/m3 near the bottom and is much higher than the other parts (Fig.1 and Fig.3). Aqueous calcium had been always in dissolution during the time stress period for simulation that leads to the increasing amount in groundwater reaching by 846.35 ~ 865.312 g /m3(Fig.2 and Fig.4).The erosion is much more seriously near the bottom of the curtain than the other parts, which is the same from the upstream to downstream (Fig. 5).Calcium dissolution mainly takes place at the bottom of the curtain and transports in three sub-zones. The highest concentration is behind the curtain and toward the downstream in 45 degree , and the secondly highest concentration is at the curtain bottom and toward the upstream in 45 degree, are the consequence of both hydraulic condition and dispersion The lowest concentration is behind the curtain and toward downstream in 135 degree, which is caused by the dispersion of calcium concentration nearby the upstream. Water-rock-curtain interaction is slowing in thermo-dynamics. However, at the bottom of the curtain the long-term reaction is more aggressive. It could be deduced that the anti-seepage efficiency of the curtain is weakening with time.

To analyze the variation of concentration field and velocity with time, Fig. 6 shows the calcium concentration that is 5maway from the curtain bottom, respectively.

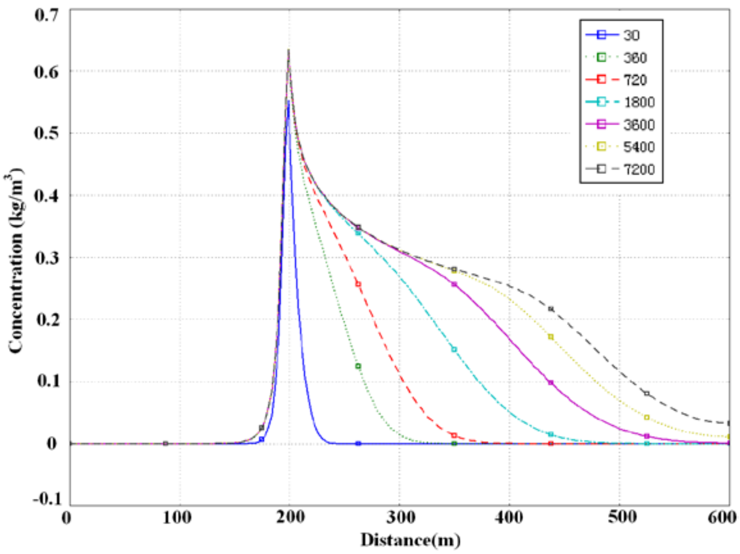

Fig.6: Distribution of Ca^{2+} concentration at 5m from curtain after different times(unit: kg/m^3)

Fig. 6 shows the variation of Ca2+ concentration with times at the curtain bottom along the river. It reaches the highest value at the bottom of the curtain, which is 0.558 kg/m3 at 30d and 0.637 kg/m3 at 7200d; And it increase much more slowly far away from the local, the most slow rate at the upstream according to the hydraulic condition.

CONCLUSION

(1) An analysis model was built for simulating water-rock-curtain interaction in this study, which could be used to describe the evolution of both a curtain and groundwater in components, which represents the physico-chemical damage of the curtain in both spatial and temporal scales.

(2) The curtain anti-seepage efficiency is weakening all the time. Aqueous calcium from the curtain had been always in dissolution during the time stress period for simulation that leads to the increasing amount in groundwater. The erosion is much more seriously near the bottom of the curtain than the other parts.

(3) Calcium dissolution mainly takes place at the bottom of the curtain and transports mainly in three sub-zones. The first is behind the curtain and toward the downstream in 45 degree with the highest concentration .The second is at the curtain bottom and toward the upstream in 45 degree. And the last is behind the curtain and toward downstream in 135 degree.

(4) The reaction between fluid and solid phase may lead to variation of curtain permeability, porosity and calcium leaching quantity, which represents the weakening trend of the curtain's anti-seepage. And it's of great significance in both theory and practice.

Acknowledgments
The authors wish to thank the National Natural Science Foundation of China for contract 51279064 and 41061046, and Open Fund of China Institute of Water Resources and Hydropower Research of China for contract IWHR-SKL-201110, under which the present work was possible.

REFERENCES

[1] Yang Ou. *Ren Min Chang Jiang/Yangtze River,***1995,**6(5), 10-15.
[2] Gu C. S., and Zhang Q. F.. *Journal of Hydrodynamics*, **2003**,16(1), 62-74.
[3] Fu, J. F.,and Jin, S.. *Journal of Hydrodynamics*, **2009**,21(5), 434-442.
[4] Wu, Z. R., and Wang, Z. R.. *International Symposium on monitoring technology of dam safety*,**1992**, 8(5),

215-224.
[5] Tong, H. T., Song, H. Z.. *Chinese Journal of Rock Mechanics and Engineering*,**2004**, 23(12), 2010-2014.
[6] Song, H. Z., Zhou, J., and Wang F. B.. *Journal of Hydroelectric Engineering*, **2004**, 23(3),74-78.
[7] Yang, G. Z., Peng, H. X., and Ma, X. H.. *Journal of Hydroelectric Engineering*, **2000**, 11(4),33-39.
[8] Chen, X. P., Qian, P. Y., and Liang, Z. S.. *Rock and Soil Mechanics*, **2008**, 29(11), 74-78.
[9] Shen, Z. Z., Chen, X. H., and Xu, L. Q.. *Rock and Soil Mechanics*, **2008**, 29(1), 34-42.
[10] Ding, X. L., and Sheng, Q.. *Chinese Journal of Rock Mechanics and Engineering*, **2000**, 19(2), 1001-1005.
[11] Chai, J. R., and Li, S. Y..*Chinese Journal of Rock Mechanics and Engineering*, **2002**, 21(5), 2322-2325.
[12] Sheng, J. C., Su, B. Y., and Zhao J.. *Rock and Soil Mechanics*, **2000**, 21(4), 410-415.
[13] Chan, D. Y. C., and Hughes, B. D.. *Transport in Porous Media*, **2003**, 10(1), 137-152.
[14] Babu, D. K., and Bansal P. P.. *Transport in Porous Media*, **2005**, 12(7),17-19.
[15] Zhao, M. D., Li, T. R., and Huai, W. X.. *Journal of Hydrodynamics*, **2005**,17(1), 47-53.
[16] Zhou, Y. Z., and Zhou Z. F.. *Journal of Hydrodynamics*, **2009**, 21(5),647-657.
[17] Tan, Y. F., and Zhou, Z. F.. *Journal of Hydrodynamics*, **2008**, 20(3), 365-372.
[18] Zhang, Q. F., Lan, S. Q., and Xu, Y. F.. *Journal of Hydrodynamics*, **2008**, 20(3), 356-364.
[19] Gérard, B., Pijaudier-Cabot, G., and Borderie, C. L. *International Journal of Solids and Structures*, **1998**, 35(30), 4107-4120.