Influence of Rising of a River Water Level on Groundwater Flow and Stability of a Landslide

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Abstract. This paper took certain a landslide in Sichuan province as a research object and focused on characteristics of groundwater flow and stability of the landslide with changes of conditions. Three-dimensional conceptual model was established for groundwater flow in the landslide with weak permeable media. Results show that there is good agreement between numerical calculation and observed groundwater table and that relative error of groundwater table calculated from the model is less than 0.13%. During the rising of the river water level, groundwater table in the slope body increases gradually and the landslide stability coefficient changes from rising, then declining to rising. The minimum stability coefficient of the landslide is 3% lower than that of the natural condition. The results can provide stability evaluation and engineering prevention treatment of the landslide with scientific basis.

Introduction

Groundwater can flow in different kinds of porous rock and soil media [1, 2]. It involves geological engineering and geotechnical engineering. Several researchers have investigated problems on groundwater flow and stability of the landslide such as Mao [3] and Zheng *et al.* [4]. Mao *et al.* [3] reviewed development and current situation on methods of calculation and control of seepage. Zheng *et al.* [4] present methods of calculation of seepage forces and phreatic surface under draw down conditions. Chen and Cascini *et al.* [5, 6] researched effect of rainfall on slope stability in mountainous area.

In this paper, we take certain a landslide in Sichuan province as a research object and focused on groundwater flow and stability of the landslide. We will establish a three-dimensional conceptual model for groundwater flow in the landslide with weak permeable media. Moreover, we will calculate characteristics of groundwater table and stability of the landslide with the river water level rising. All the researches will provide stability evaluation and engineering treatment of the landslide with scientific basis.

Conceptual Model for Groundwater Flow

Certain a landslide with weak permeable media was selected. Range of the research area is shown in Fig. 1. The landslide is porous media with weak permeable media. The quaternary loose media are permeability media. Sliding zone soil is weak permeable media. Boundaries of the landslide are made up of impermeable boundary of the left and right sides, the constant head boundary of trailing edge and the variable head boundary of leading edge boundary.

Mathematical Model of Groundwater Flow

A partial differential equation for groundwater flow in the landslide is given by equation (1) provided that the coordinate axes are assumed oriented parallel to the principle axes of the landslide porous media.

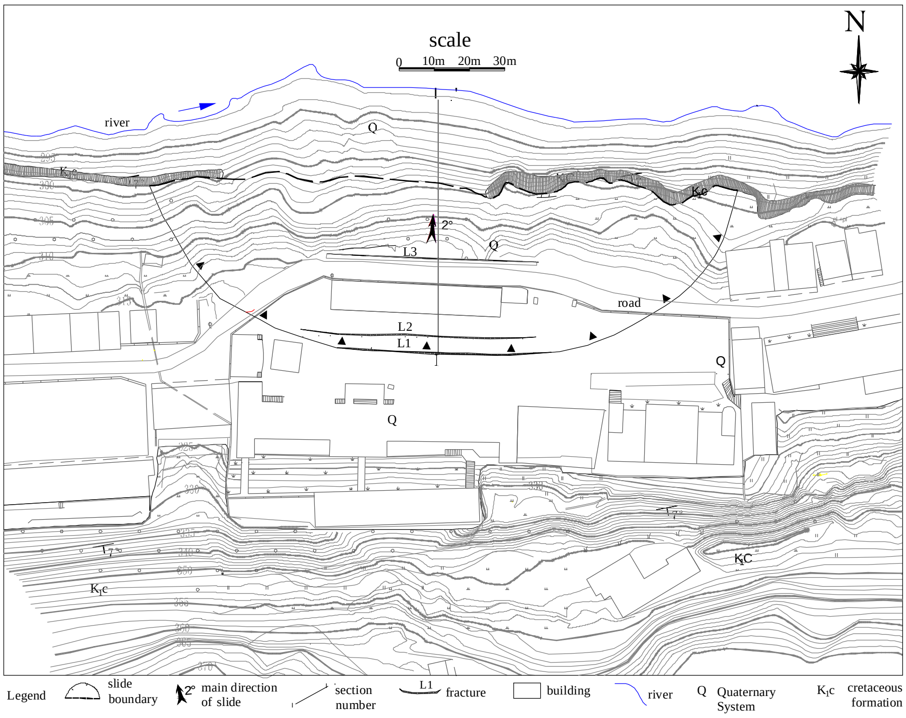

Fig. 1 Research area range (N: North)

$$\sum_{i=1}^{3}\frac{\partial}{\partial x_i}(K_i\frac{\partial H}{\partial x_i})+W=S_s\frac{\partial H}{\partial t} \tag{1}$$

Where H is head of groundwater in the landslide, K_i is permeability coefficient of x_i direction, x_i (i=1, 2, 3) is component of a spatial position $\mathbf{x}$, W is a source or sink, S_s is specific storage, t is time. Initial condition is

$$H\big|_{t=0}=H_0(\mathbf{x}),\ \mathbf{x}\in(R) \tag{2}$$

Boundary conditions are

$$H\big|_{\Gamma_1}=j_1(\mathbf{x},t),\ \mathbf{x}\in(\Gamma_1),\ t\in(0,t) \tag{3}$$

$$K_i\frac{\partial H}{\partial x_i}n_i\bigg|_{\Gamma_2}=j_2(\mathbf{x},t),\ \mathbf{x}\in(\Gamma_2),\ t\in(0,t) \tag{4}$$

where $H_0(\mathbf{x})$ is initial head of groundwater in the landslide, $j_1(\mathbf{x},t)$ is a known function on the boundary Γ_1, $j_2(\mathbf{x},t)$ is a known function on the boundary Γ_2, Γ_1 is the first kind boundary, Γ_2 is the second kind boundary, n_i is component of a unit vector in the direction of the outer normal, t is time span.

Method of Calculating Stability Coefficient of a Landslide

The stability coefficient is defined as

$$F_s=\frac{\sum_{i=1}^{n-1}((W_i((1-r_U)\cos a_i-A\sin a_i)\tan f_i+C_iL_i)\prod_{j=i}^{n-1}j_j)+R_n}{\sum_{i=1}^{n-1}((W_i(\sin a_i+A\cos a_i))\prod_{j=i}^{n-1}j_j)+T_n} \tag{5}$$

Here

$$R_n = (W_n((1-r_U)\cos a_n - A\sin a_n))\tan f_n + C_n L_n \tag{6}$$

$$T_n = W_n(\sin a_n + A\cos a_n \tag{7}$$

$$\prod_{j=i}^{n-1} j_j = j_i j_{i+1} j_{i+2} \cdots\cdots\cdots j_{n-1} \tag{8}$$

Here j_j can be defined as equation (9)

$$j_j = \cos(a_i - a_{i+1}) - \sin(a_i - a_{i+1})\tan f_{i+1} \tag{9}$$

where W_i is weight of bar i, C_i is cohesion of bar i, L_i is length of sliding surface of bar i, f_i is angle of internal friction of bar i, a_i is slip angle of bar i, A is earthquake acceleration, r_U is pore pressure ratio, F_s is stability coefficient of a landslide.

Basic Parameters

The parameters are shown in the table 1.

Table 1 Basic parameters of a model

Formation	K_x (m/d)	K_y (m/d)	K_z (m/d)	specific yield	effective porosity	storage coefficient
sliding body	4.22	4.22	4.22	0.09	0.41	0.22
sliding zone	0.62	0.62	0.08	0.06	0.38	0.15
residual slope soil	1.61	1.61	1.61	0.06	0.39	0.12
highly weathered	0.086	0.086	0.02	0.05	0.26	0.06
moderate weathered	0.003	0.003	0.001	0.03	0.22	0.001

Results and Discussion

Validation of the model was examined so that the model can be in agreement with hydrogeological conditions. Relative error of groundwater table calculated from the model is less than 0.13%. There is good agreement between numerical calculation and observed results, as is shown in table 2.

Table 2 Difference between observed results and calculated results

Well of serial number	Observed (m)	Calculated (m)
1	302.90	302.89
2	306.30	306.44
3	302.65	302.79
4	304.38	304.77

Fig. 2 shows calculated groundwater contour lines in the landslide. Fig. 3 shows changes of stability coefficient of the landslide with water level changing from 302m to 316m when river water level rises at a speed of 2.8 m/d. Groundwater table in the slope body increases gradually with the river water level increasing. The landslide changes from the slope surface to a deep place because of coefficient of permeability of the slope body. During the rising of the river water level, the landslide stability coefficient shows a trend from rise, then decline to rise. The minimum stability coefficient of the landslide is 3% lower than that of the natural condition.

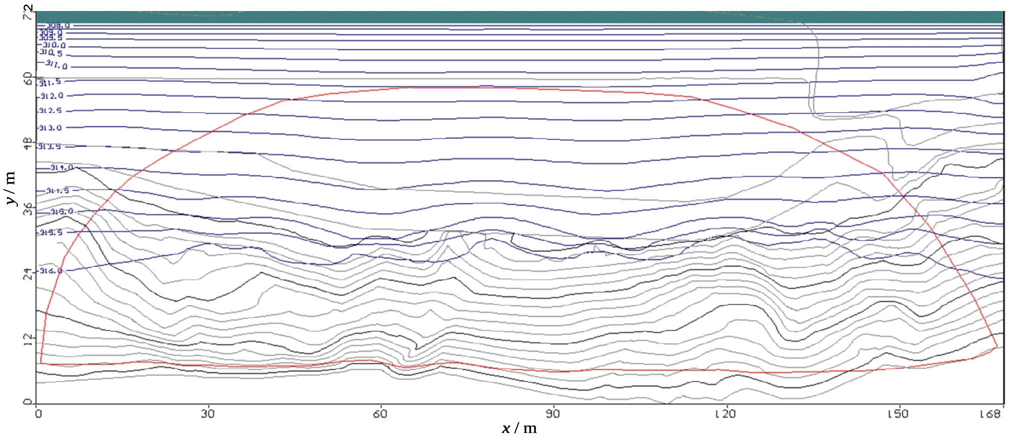

Fig. 2 Calculated groundwater table contour lines in the landslide

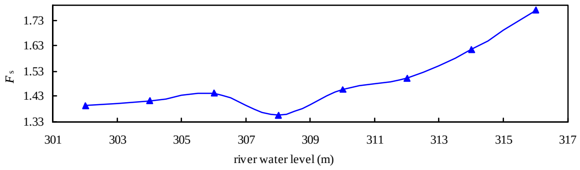

Fig. 3 Stability coefficient of the landslide changes with river water level

Conclusions

Three-dimensional conceptual model was established for groundwater flow in the landslide with weak permeable media. There is good agreement between numerical calculation and observed groundwater table. During the rising of the river water level, groundwater table in the slope body increases gradually and the landslide stability changes from rising, then declining to rising. The minimum stability coefficient of the landslide is 3% lower than that of the natural condition.

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References

[1] M. Bai, D. Elsworth, J.C. Roegiers: Water Resour Res Vol. 29 (1993), p.1621.

[2] S.P. Neuman, W.A. Illman, V.V. Vesselinov, D.L. Thompson, G. Chen, and A. Guzman: Conceptual Models of Flow and Transport in the Fractured Vadose Zone (National Academy Press, Washington, D.C. 2001).

[3] C.X. Mao: Calculation and control of seepage (Second edition). Beijing: China Water Conservancy and Hydropower press, 2003. (In Chinese)

[4] Y.R. Zheng, W.M. Shi, W.X. Kong: Chinese Journal of Rock Mechanics and Engineering, Vol.23 (2004), p.3203. (In Chinese)

[5] J. Chen, Z.F. Yang, X. LI: Chinese Journal of Rock Mechanics and Engineering, Vol.24 (2005), p.3052-3056. (In Chinese)

[6] L. Cascini, M. Calvello, G.M. Grimaldi: Journal of Geotechnical and Geoenvironmental Engineering, Vol.136 (2010), p.1220.