A COMPARATIVE STUDY OF TWO NEWLY DEVELOPED NUMERICAL MODELS TO UNDERSTAND THE CREEPING BEHAVIOUR OF A LANDSLIDE

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1. INTRODUCTION

Creeping landslides are one of the major natural hazards in mountainous regions. Based on the theoretical, experimental and numerical models, a few researchers have tried to address the issues of creeping landslides till 1950 to until now; but they are not fully understood, especially in relation to the displacement behavior of a creeping landslide. It is believed that study of creeping landslides and associate geotechnical issues are difficulty due to: i) most of these movements occur in isolated and remote areas, ii) they are difficult to measure (as the movement rate vary from zero to a few centimeters per year) and instrumentation is usually complex, iii) laboratory tests are far from being representative of long-term in situ behaviors because of taking long time such as several weeks, months or years, iv) it is difficult to incorporate hydrological factors and real soil behaviors in the mathematical and numerical models, etc. Therefore, the main objective of this study is to address the above mentioned problems to understand the creeping behavior of a landslide. However, the specific objectives are: i) to propose a simplified procedure for the determination of two new control constitutive parameters for both Model A and Model B, ii) to estimate such new control constitutive parameters based on the relation between the displacement rate ($\dot{\gamma}_{max}$) and total factor of safety (Fs) using the LEM and FEM methods, iii) to propose two new numerical models to evaluate the creeping behavior of a landslide owing to ground water fluctuations, iv) to compare the two newly developed models and apply these models to study the creeping behavior of the Tomuro landslide of Gunma Prefecture, Japan as a case study.

2. NUMERICAL MODELS

In this study, we assumed that all the plastic strain components occurring at the time of yielding are vicoplastic components. Suppose, the Eq. (1) represent the flow law based on plastic potential.

$$\dot{\varepsilon}^{p} = \dot{\Lambda}\frac{\partial g}{\partial \sigma} \quad (1)$$

Where, $\dot{\varepsilon}^{p}$ = plastic strain increment per unit time, $\dot{\Lambda}$ = function varies according to the effective stress, and g = plastic potential. Based on the extensive literature survey (e.g., Sugawara 2003; Vulleit & Hutter 1988, etc.), we have found the two major methods to establish the relation between the displacement rate ($\dot{\gamma}_{max}$) and total factor of safety (Fs) [i.e., i. log ($\dot{\gamma}_{max}$) Vs log (Fs), ii. log ($\dot{\gamma}_{max}$) Vs Fs]. Therefore, we have proposed the following Eq. (2) for Model A and the Eq. (3) for Model B to represent the above mentioned methods.

$$\dot{\gamma}_{max} \leq \frac{\dot{\alpha}}{F^{n}_{s,local}} \quad (2)$$

$$\dot{\gamma}_{max} \leq \dot{\beta} \times 10^{m(1-F_{s,local})} \quad (3)$$

Where, $\dot{\gamma}_{max}$ = displacement rate, $F_{s,local}$ = local factor of safety, $\dot{\alpha}$, n = new control constitutive parameters for Model A, and $\dot{\beta}$, m = new control constitutive parameters for Model B.

In numerical simulation, the Eq. (1) must be satisfied for the Eqs. (2 & 3) for all elements. In other words, the mobilized viscous resistance at each element is automatically adjusted to satisfy the Eqs. (2 & 3) during the whole time history. In previous 2D- Elasto-viscoplastic constitutive model (e.g., Conte et al. 2014), one parameter is considered, however; this model has incorporated two new control constitutive parameters for the first time to perform the realistic field problem of a creeping landslide. In addition, the displacement rate can be directly controlled by the newly proposed models in this study. However, most of the usual previous visco-plastic formulations/models provided that the displacement rate can be estimated only after the calculations of a result. Therefore, such usual approaches may need troublesome trial and errors to achieve the appropriate parameters for better simulation.

3. COMPARISON OF MODELS

The proposed numerical models are applied to analysis the creeping behavior of Tomuro landslide of Gunma, Japan. Fig. 1 shows the 2D-finite element mesh used for the analysis, which was prepared based on the geological x-section of the slope of such landslide site. The hydraulic head is imposed at the lateral boundaries based on the field monitoring results of groundwater fluctuation. The variation of the groundwater fluctuations of 0-1.99 m was recorded from 2014/1/14 to 2015/7/6 (Fig. 1). S-1 represents the location of point (i.e., node 199), where the maximum displacement of the landslide body was measured in the field during the period of 2014/1/14 to 2015/7/6.

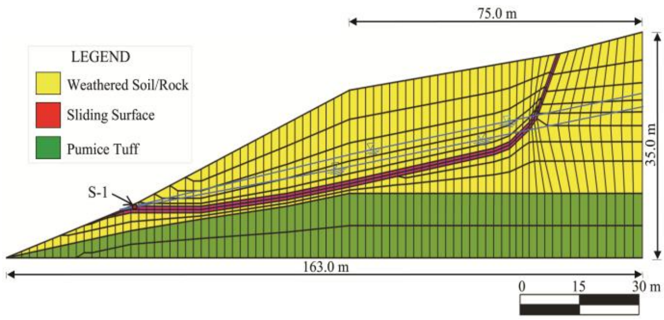

Fig. 1: Finite element model of Tomuro landslide

Keywords: Numerical models, Landslides, Ground water fluctuations, Creeping behavior
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Table 1: Material parameters for landslide simulation (Model A & Model B)

Materials (→) / Parameters (↓)	Weathered Soil/Rock	Sliding Surface				Pumice Tuff	Remarks
		Case I	Case II	Case III	Case IV		
Young's modulus, E (kN/m^2)	5000	1000				50000	Model A & Model B
Poisson's ratio, ν	0.40	0.30				0.45	
Cohesion, c′ (kN/m^2)	50	0				5000	
Internal friction angle, ϕ′ (deg.)	35	15.2				30	
Dilatancy angle, ψ (deg.)	0	0				0	
Unit weight, γ (kN/m^3)	24	20				26	
$\dot{\alpha}$ (day^-1))	-	0.00089	0.000489	0.00023	0.0011	-	Model A
n	-	53.398	46.4900	55.833	67.233	-	
$\dot{\beta}$ (day^-1))	-	0.000899	0.000498	0.00023	0.001122	-	Model B
m	-	22.850	20.093	24.478	28.938	-	

In general, the parametric study has been done to obtain the two new unknown control constitutive parameters for both Models A & B. Initially, the Fs is calculated using the various Limit Equilibrium Methods (LEM) based on the slices and Finite Element Method (FEM). In LEM, three frequently used methods are used to calculate the Fs of Tomuro Landslide. At first, the ordinary method of Slices is used, which is referred as "Case I". Then, Bishop's method (1955) is used to address the limitation of the ordinary method of slices, which is referred as "Case II". Again, Junbu's Simplified method (1973) is also used to incorporate the drawback of the Bishop's method (1955), which is referred as "Case III". Finally, the FEM is also used to address the drawback of the LEM, which is named as "Case IV". In FEM method, Shear Strength Reduction Method is used to estimate the Fs. After the calculation of Fs, the relations between log ($\dot{\gamma}_{max}$) and log (Fs) for Model A and log ($\dot{\gamma}_{max}$) and Fs for Model B have been established for the cases I-IV. Then, the unknown two new control constitutive parameters for both models A & B have been estimated by solving the general equations for each case, which are obtained from the well fitted curves between these relations. The summary of the material parameters for landslide simulation of both models A & B are tabulated in Table 1.

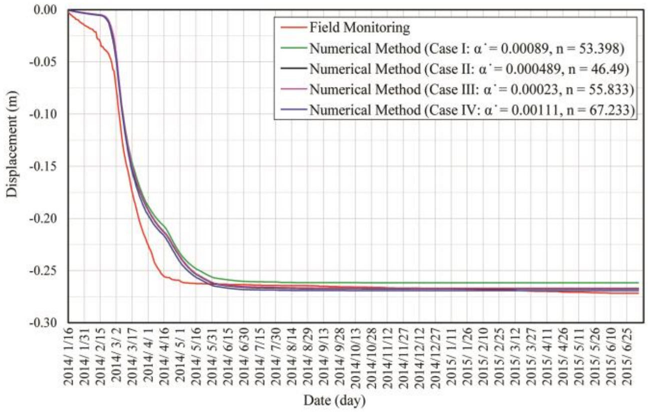

Fig. 2: Comparison of predicted and measured time histories of horizontal displacement at S-1 (Model A)

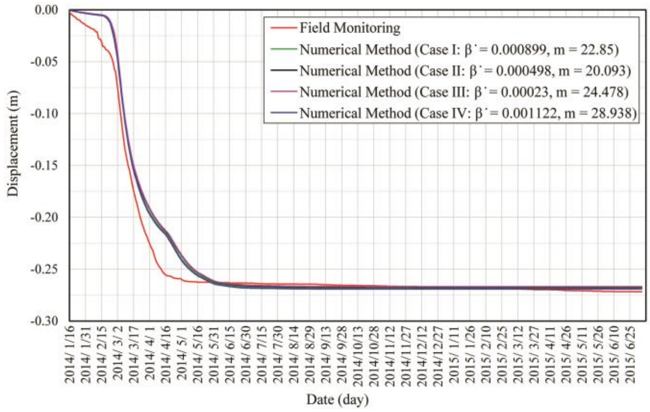

Fig. 3: Comparison of predicted and measured time histories of horizontal displacement at S-1 (Model B)

Figs. 2 & 3 show the comparison of predicted time histories of displacement in models A & B and measured displacement in the field. Here, the predicted time histories of displacement were measured at the same point S-1, where the displacement was measured in the field. Moreover, the horizontal component of displacement was considered for predicting time histories of displacement in the models. In field monitoring, the measured time histories of horizontal displacement at S-1 has slightly increased from 2014/1/14 to 2014/2/14. After that, it was rapidly increased until 2014/4/29. Then, it has almost constant from 2014/4/29 to 2015/7/6. Similarly, the results of maximum horizontal displacement at the same point (i.e., S-1) is almost same and they are also following the similar trends with respect to time in case of both numerical models A & B (Figs. 2 & 3). Therefore, any one case and model can be used to understand the creeping behaviour of a landslide in the future.

4. CONCLUDING REMARKS

In this study, two new numerical models are developed to evaluate the creeping behavior of a landslide owing to ground water level fluctuations. These two models are compared and applied to predict the creeping behavior of the Tomuro landslide of Gunma Prefecture, Japan as a case study, and found in good agreements with each other. Therefore, it is believed that anyone numerical model can be applied to study the creeping behaviour of a landslide in the future.

REFERENCES

Conte, E., Donato, A., and Troncone, A.: A finite element approach for the analysis of active slow-moving landslides, Landslides, 11 (4), 2014, pp. 723-731.

Sugawara, N.: Variation of surface displacement rate with factor of safety for creep-type landslides (As a consequence from reviewing literatures), Annual Report on Applied Geology Technology, No. 23, 2003, pp. 1-18. (Japanese)

Vulleit, L., and Hutter, K.: Viscous-type sliding for landslides, Can. Geotech. J., Vol. 25 (3), 1988, pp. 467-477.