



NUMERICAL SIMULATION OF A CREEPING LANDSLIDE INDUCED BY A SNOW MELT WATER

D. R. Bhat and A. Wakai

Graduate School of Science and Technology, Gunma University

5-1 Tenjin-cho, Kiryu, Gunma 376-8515, JAPAN

e-mail: deepakrajbbhat@gunma-u.ac.jp

ABSTRACT

In this study, a finite element based numerical method has been considered to evaluate the creeping behavior of a landslide induced by snow melt water. A two-dimensional elasto-viscoplastic constitutive model was used to simulate the creeping behavior owing to groundwater level fluctuations of the Tomuro landslide of Gunma, Japan as a case study. Two new control constitutive parameters were incorporated in the numerical model for the first time to better understand the creeping behavior of a landslide induced by snow melt water. Such control constitutive parameters are estimated based on the relation between the total factor of safety, calculated by the Janbu's Simplified Method (i.e., Limit Equilibrium Method), and the field monitoring displacement rate of the Tomuro landslide of Gunma prefecture, Japan. The snowfall precipitation was also considered during the calculation of total factor of safety. Others required material parameters for landslide simulation were obtained from the field investigation and laboratory tests of the collected blocked samples. The simulation results of deformation pattern and shear strain pattern were presented and discussed to understand the creeping behaviour of the Tomuro landslide. Moreover, the predicted and measured time histories of horizontal displacement of the Tomuro landslide were compared for the validity of the proposed numerical model, and found in good agreements with each other. Therefore, it is believed that the proposed numerical method will be applicable to understand the creeping behavior of a landslide induced by snow melt water in the future and at the same time, long-term monitoring and management of such landslide will be much easier.

KEYWORDS : *Finite element simulation, snow melt water, groundwater level fluctuation, creeping behaviour, Tomuro landslide*

INTRODUCTION

Creeping landslides are one of the major geotechnical hazards. Most of creeping landslide sites accommodate human settlement and agricultural fields, roads and highways,

bridges and tunnels, nature conservation sites, and so on (Bhat *et al.*, 2017a, 2014a). When the displacement rate of such landslides is suddenly increased and accelerated, then; it leads a huge mass failure which damages

human life, property, nature, and environment. If a numerical approach to predict the creep displacement behavior of a landslide is possible, a huge damage of human life, property, nature, and the environment can be prevented (Bhat *et al.*, 2017a, b). Therefore, study of creeping behavior of a landslide and associated geotechnical hazards issues are important. Terzaghi (1950) was most likely the first to consider the relationship between soil creep and landslides. Ter-stepanian (1963) has introduced the threshold approach to explain soil creep in simple natural slopes by considering the zone of creep and its rate as being dependent on the groundwater level. Calvello *et al.* (2008) have presented an extensive study using a numerical model that focuses on active landslides controlled by rainfall-induced pore pressure fluctuations with movements concentrated within a relatively narrow shear zone above which the sliding mass moves essentially as a rigid body. Fernández-Merodo *et al.* (2014) have proposed a two-dimensional viscoplastic finite element model for slow-moving landslides and also applied this model to the Portalet landslide of Spain as a case study. Bhat *et al.* (2016) have proposed a new regression model to understand the creeping behavior of clayey soils at the residual-state of shear.

Creeping landslides are controlled by the groundwater level fluctuations (e.g., Conte *et al.*, 2014; Van Asch *et al.*, 2007; Picarelli *et al.*, 2004; Ter-stepanian, 1963) therefore; groundwater level fluctuations should be incorporated in the numerical simulation of such landslides. However, most of previous

numerical approach (Yin *et al.*, 2010; Picarelli *et al.*, 2004; Patton, 1984; Ter-stepanian, 1963) of soil creep and associated problems are focused on the laboratory creep tests (i.e., consolidation/oedometer test and triaxial test), which could not address the effect of groundwater level fluctuation. Based on the theoretical, experimental, and numerical models, a few researches such as Bhat *et al.* (2016, 2014b); Huvaj and Maghsoudloo (2013); Yin *et al.* (2010); Picarelli *et al.* (2004); Patton (1984); Ter-stepanian (1963) have tried to address these issues till 1950 to until now; but they are not fully understood, especially in relation to the displacement behavior of a creeping landslide. Huvaj and Maghsoudloo (2013) have simulated the fluctuation of groundwater level in different phases to understand of displacement behavior of a slow-moving landslide, but the exact value of the deformation at any required point (location) couldn't be captured perfectly. Recently, a few researchers (e. g., Savage and Chleborad, 1982; Ishii *et al.*, 2012; Conte *et al.*, 2014; Fernández-Merodo *et al.*, 2014) have proposed a 2D-Elasto-viscoplastic constitutive model using finite element method based on the field instrumentation and monitoring results, but they are only considered the single control constitutive parameter based on the trial and error method, which could not control the displacement rate of a landslide, and also far to address the realistic field problem of creeping behavior of a landslide. Therefore, if a new numerical approach, which can incorporate the more than one control constitutive parameters for directly controlling the displacement rate and total factor of safety of a landslide, can

be developed, such approach may be useful for investigating the realistic field problem of creeping behavior of a landslide in the future (Bhat *et al.*, 2017a, b). The main objective of this study is to develop a new numerical tool for numerical simulation and analysis of a creeping landslide induced by snow melt water, and its implication to understand the creeping behavior of Tomuro landslide as a case study.

installed at the location of BV-1 and VB-2 for monitoring the groundwater level of the landslide body. The results of the groundwater level fluctuations at the boreholes (BV-1, BV-2) are presented in **Figure 4**. In this study, the results of groundwater fluctuations during the period of 2014/1/14 to 2015/7/6 are considered.

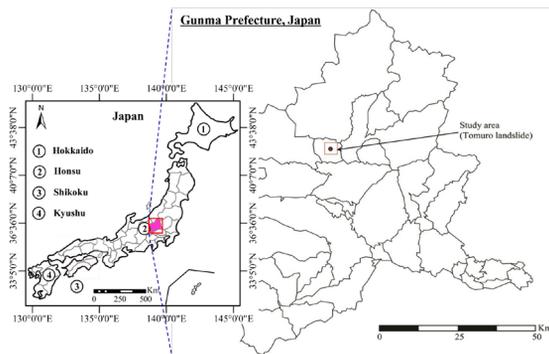


Figure 1. Location of study area (Tomuro landslide)

STUDY AREA

Figure 1 shows the location of Tomuro landslide of Gunma, Japan. The size of Tomuro landslide has been measured approximately 135 m X 110 m. The simplified topographical map showing the location of sampling point, Piezometers and Extensometer is presented in **Figure 2**. **Figure 3** shows the variation of the rainfall and snowfall precipitation. The snow has accumulated at a thickness of 2 to 73 cm on the surface of the landslide body during the period of 2014/2/8 to 2014/2/25. The maximum snowfall was recorded up to 73 cm on 2014/2/15 (**Figure 3**). After 2014/2/25, the deposited snow was starting to melt and the groundwater level was also starting to rise. The Piezometers were

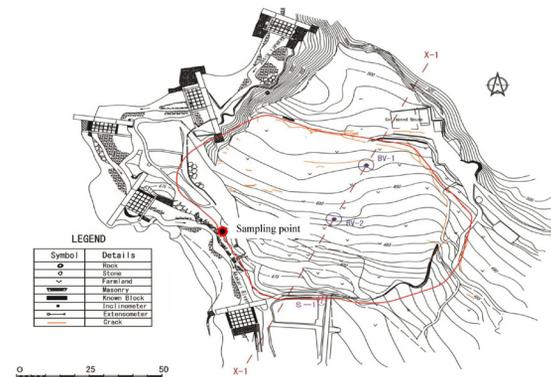


Figure 2. Simplified topographical map of Tomuro landslide, showing the location of sampling Piezometers and Extensometer

The extensometer was installed at S-1 to measure the horizontal displacement of the landslide body (**Figures 2 & 5**). The variation of the displacement rate during the period of 2014/1/14 to 2015/7/6 was considered because all necessary field monitoring data for further detail study are available during that period. The maximum displacement rate of 9.9 mm/day was recorded on 2014/3/4, where the groundwater level was also recorded maximum at the VB-1 and VB-2 (**Figure 4**). From the comparative study of groundwater level and displacement rate with various time periods, it is understood that the displacement rate also depends upon the fluctuation of the groundwater level by snow melt water. When the groundwater level is rising, the displacement rate is also increased and vice

versa. The creep displacement of the landslide as directly related to the groundwater condition (Patton 1984). Eberhardt *et al.*, (2007) have also agreed with Ter-stepanian (1963) and Patton (1984). The fluctuation of groundwater should be considered to better understand the creeping behavior of a landslide (Bhat *et al.*, 2017a, b). In this study, the groundwater level fluctuation is considered for the stability analysis using the Janbu's Simplified Method (1973) (i.e., Limit Equilibrium Method), as well as the numerical simulation of the Tomuro landslide.

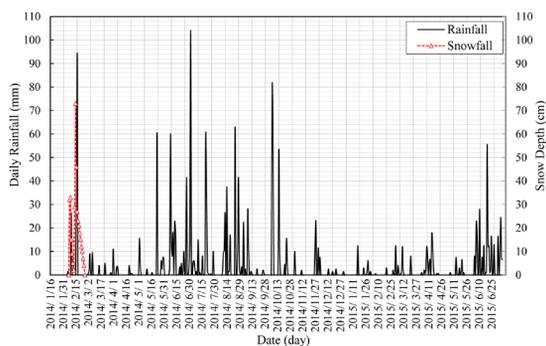


Figure 3. Variation of the rainfall and snowfall precipitation

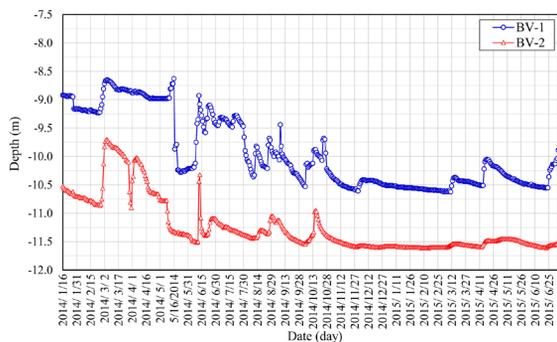


Figure 4. Groundwater level fluctuation in the boreholes (BV-1 and BV-2)

NUMERICAL SIMULATION

The proposed numerical model is applied to analyse the creeping behavior of Tomuro

landslide of Gunma, Japan. **Figure 5** shows the 2D-finite element mesh used for the analysis, which is prepared based on the geological x-section of the slope of such landslide site. The major three representative materials (layers) are observed from the boreholes details of such landslide. The weakest material (i.e., indicating by red colour in the **Figure 5**) is named as “Sliding Surface”. The thickness of this layer is about 1.0 m. The strongest material (i.e., green colour) consists at the bottom of model, which is referred as “Pumice Tuff”. The remaining material (i.e., yellow colour) is stronger than sliding surface, but weaker than pumice tuff, which is named as “Weathered Soil/Rock”. It is assumed that the creeping behavior of a landslide body only exhibits on sliding surface/layer. Therefore, the constitutive parameters are varied for the sliding surface in the cases I-IV (**Table 1**). The mesh adopted in the calculations consists of a rectangular element with eight nodes. The total number of 2445 nodes, 760 elements, and 181 boundary conditions exist in the finite element model of the landslide body (**Figure 5**). The base of the model is assumed to be fully impervious and fixed, and the lateral side (right) is constrained by rollers. The hydraulic head is imposed at the lateral boundaries based on the field monitoring results of groundwater level fluctuation. The variation of the groundwater level fluctuations of 0-1.99 m was recorded from 2014/1/14 to 2015/7/6 (**Figure 4**). 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 (**Figure 5**).

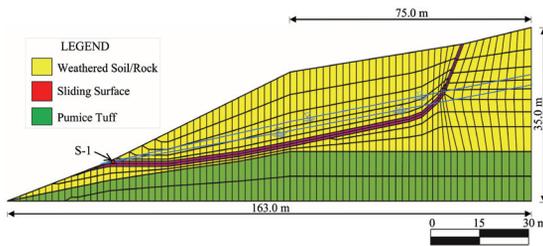


Figure 5. Finite element model of Tomuro landslide

In general, the parametric study has been done to obtain the two new unknown control constitutive parameters (α, n). Initially, the total factor of safety (F_s) is calculated using the Limit Equilibrium Method (LEM). In Limit Equilibrium Method, Junbu's Simplified method (1973) is used to calculate the total factor of safety (F_s) of Tomuro Landslide of Gunma, Japan. This method is simplified, very efficient, and applicable to any shape of the slip surface, and also applicable for horizontal external loads. Therefore, this method has been used in this study. From 2014/1/14 to 2015/7/6, systematic measurements of groundwater level fluctuation and displacement of the landslide body was performed every day. Such field monitoring results of displacement were used to calculate the displacement rate (\dot{Y}_{max}). The groundwater level fluctuation at the VB-1 and VB-2 (Figure 4) are used during the calculation of the total factor of safety (F_s). Moreover, the maximum snow at the thickness of 73 cm was recorded during 2014/2/8 to 2014/2/24 (Figure 3). Matsuura *et al.* (2017) have highlighted the influences of snow cover on landslide displacement in winter period in Japan. Matsuura *et al.* (2003) have also

reported that snow melt water and/or rain water are closely related to groundwater level and landslide displacement. Therefore, the snowfall precipitation is also considered during the calculation of the total factor of safety (F_s) of the landslide body. After the calculation of total factor of safety (F_s), the relations between the displacement rate (\dot{Y}_{max}) and the total factor of safety (F_s) have been established. After that, the general equations are obtained based on the well fitted curve between the displacement rate (\dot{Y}_{max}) and total factor of safety (F_s). Then, the unknown two new control constitutive parameters (α, n) were estimated by solving of these general equations for each case. The summary of the material parameters for landslide simulation are tabulated in Table 1.

Table 1 Material parameters for landslide simulation

Parameters (↓) Materials (→)	Weathered Soil/Rock	Sliding Surface	Pumice Tuff
Young's modulus, E (kN/m ²)	5000	1000	50000
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
α (day ⁻¹)	-	0.00023	-
n	-	55.833	-
Unit weight, γ (kN/m ³)	24	20	26

Figure 6 shows the results of deformation pattern at the end (i.e., 2015/7/6) as a representative result. The dot (red) line shows the result of a maximum deformation pattern of each node at the end of the numerical simulation with compare to without the deformation (i.e., initial condition). The maximum displacement of 0.26683 m was recorded at node 199 (i.e., S-1). Moreover, the maximum deformation was occurring at the same node 199, where the maximum displacement of the landslide body was recorded during field monitoring.

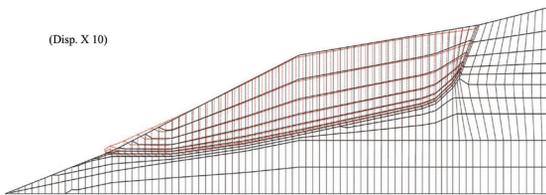


Figure 6. Results of deformation pattern

Similarly, **Figure 7** show the results of the shear strain pattern at the end (i.e., 2015/7/6) as a representative result. The maximum shear strain of 0.90419 was obtained at element 278 at the end of the numerical simulation. Based on the comparative study of the results of shear strain pattern, it is confirmed that the maximum shear strain value is also almost same and occurred at the same element 278, where the maximum displacement rate of the landslide body was recorded during the field monitoring. From the overall comparisons of the results of the deformation pattern and shear strain pattern, it clearly shows that the maximum shear strain and maximum deformation occur along the sliding surface of such landslide.

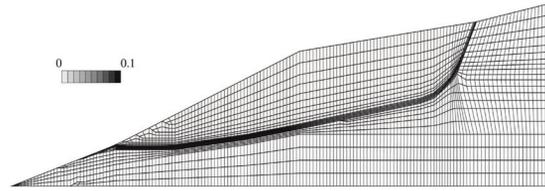


Figure 7. Results of shear strain pattern

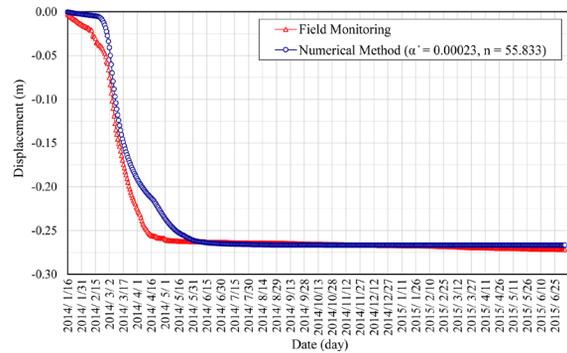


Figure 8. Comparison of predicted and measured time histories of horizontal displacement at S-1.

CONCLUSIONS

The creeping behaviour of Tomuro landslide induced by snow melt water has been studied using the finite element method. A newly developed two-dimensional Elasto-viscoplastic constitutive model has been used to simulate the creeping behavior of clayey soil along the sliding surface of the Tomuro landslide. A simplified procedure has been used for the determination of new control constitutive parameters for numerical simulation of that landslide. Two control constitutive parameters have been incorporated for the first time to perform the realistic field problem of a creeping landslide. The simulation results of deformation pattern and shear strain pattern have been presented to evaluate the creeping behavior

of clay soils along the sliding surface of the Tomuro landslide owing to groundwater level fluctuations by snow melt water. Finally, the results of predicted and measured time histories of the horizontal displacement at S-1 has been compared, and found in good agreements with each other. Therefore, it is believed that this model can be applied as a replicable numerical model/tool to understand the creeping behaviour of a landslide induced by snow melt water in the future.

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