A prediction model of landslide occurrence and its scale using numerical-regression equations

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1. INTRODUCTION

Generally, the methods of predicting landslides can be divided into two types - statistical model and numerical model. Compared with the statistical model, the numerical model can provide more detail and precise result, but is difficult to employ on a basin-scale because of time-consuming calculation. This paper proposed a new method, which was based on numerical model and multiple regressions, to predict the landslides on a basin scale. This method used a new warning indicator, critical water content (W_{cr}), and it had great performance on calculation to predict the occurring time, locations and scale of landslides. The heavy rainfall disaster occurring in the Shizugawa basin in 2012, located in Uji, Kyoto, was simulated by the new method.

2. METHOD

This study used the Integrated Rainfall Infiltration Slope stability (IRIS) model to conduct the slope stability analysis[1)]. The IRIS model can be divided into several modules. The rainfall-infiltration module adopts the Richard's equation to simulate the infiltration and water flow in the soil. The result of infiltration analysis, which was calculated by the finite-element method, was then used to conduct a slope stability analysis simultaneously. A simplified Janbu method and dynamic programming method were used to determine the safety factor and the critical slip surface. However, the IRIS model is difficult to be used on a basin scale because of time-consuming.

Because the previous research found that the water content in the slope was very similar when the slope collapsed under different rainfalls (see **Table 1**), this study adopted the water content as the warning indicator for landslide prediction[2)]. Because the IRIS model is time-consuming, this study used multiple regression formulas, which was based on the IRIS model, to calculate W_{cr} and W_t. If W_t was larger than W_{cr}, the slope unit would be judged as a collapse. The flowchart was shown as **Fig. 1**. The regression formulas were shown as **Table 2**.

Table 1 The water content of the tentative slope unit when the landslide happened during 8 different rainfall patterns

Rainfall (mm/h)	W_{cr} (m^3/m)	Landslide occurring time (min)	Profile of the slip surface (m^2)
I=10	140.84	1359	123.25
I=20	140.77	809	77.42
I=30	140.45	638	68.25
I=40	140.06	556	68.25
I=50	139.74	509	68.25
I=60	139.41	479	68.25
I=80	138.84	445	57.42
I=100	138.20	427	57.42
mean	139.79	652.75	73.56
Standard deviation (SD)	0.936	311.16	21.11
SD/mean (%)	0.670	47.67	28.69

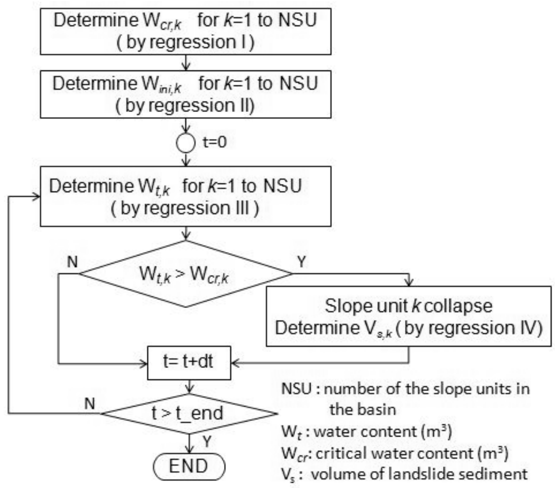

Fig. 1 The flowchart of predicting landslides by the W_{cr} method

Table 2 The water content of the tentative slope unit when the landslide happened during 8 different rainfall patterns

I

$$\theta_{cr} = c_1 + c_2 \cdot L + c_3 \cdot \alpha + c_4 \cdot I_{60} \quad (1)$$

$$W_{cr} = \theta_{cr} \cdot V \quad (2)$$

II

$$\theta_{\text{ini}} = c_1 + c_2 \cdot L + c_3 \cdot \alpha \quad (3)$$

$$W_{ini} = \theta_{ini} \cdot V \quad (4)$$

III

$$d\theta_t = c_1 + c_2 \cdot L + c_3 \cdot \alpha + c_4 \cdot I_t + c_5 \cdot \theta_{t-1} \quad (5)$$

$$W_t = (\theta_{t-1} + d\theta_t) \cdot V \quad (6)$$

IV

$$R_s = c_1 + c_2 \cdot L + c_3 \cdot \alpha + c_4 \cdot I_{60} \quad (7)$$

$$V_s = R_s \cdot V \quad (8)$$

where c_1 *to* c_5 are regression coefficients, L is the length of the slope unit (m), α is the inclination of the ground surface (deg), I_{60} is the rainfall intensity in 60 minutes, θ_{cr} is the critical water content ratio (m^3/m^3), V is the soil volume of the slope unit in unit width (m^3/m), θ_{ini} is the initial water content ratio (m^3/m^3), W_{ini} is the initial water content in the unit width (m^3/m), I_t is the rainfall intensity (mm/h) at time t, θ_t is the water content ratio of the soil (m^3/m^3), θ_{t-1} is the water content ratio at the previous time-step, $d\theta_t$ is the change of the water content ratio (m^3/m^3), W_t is the water content of the soil in unit width (m^3/m), R_s is the landslide volume ratio (m^3/m^3), V_s is the volume of the landslide sediment in unit width (m^3/m).

3. RESULTS AND DISCUSSIONS

The simulation result indicated 131 slope unit collapsed. Compared with the location of the 35 added naked-slope in the satellite image, 25 naked-slope were predicted to collapse, and the others were not. The comparison of prediction and actual cases was shown in **Table 3** and **Fig. 2**. Moreover, the occurring time of predicting landslides was about 4:40~05:50. It is very similar to the survey results. In addition, the warning hit rate (WHR) and the accuracy of landslide prediction (*ALP*) can be assessed by Eq.(9) and (10).

$$WHR = PC/AC \times 100\% \quad (9)$$

$$ALP = (PCAC + PNAN)/NSU \times 100\% \quad (10)$$

where *PC* is the number of the slope units which were predicted occurring collapse, *AC* is the number of actual collapse, *PCAC* is the number of the slope units which were predicted occurring collapse and collapse occurred actually; *PNAN* is the number of the slope units which were predicted non-collapse and no collapse occurred actually; *NSU* is the number of slope units. In this case, *WHR* is 71.4% and *ALP* is 73.3%.

Table 4 showed the comparison of the difference of predicting landslides by the IRIS model and the W_{cr} method. The results indicated that using the W_{cr} method to predict landslides instead of the IRIS model on a basin scale is feasible. Moreover, while the causes of soil moisture distribution, which will affect the scale of landslides, are very complicated, this study only used I_{60} as the representative indicator. Compared with the occurring time and location of landslide prediction, the prediction result of landslide scale is poorer. It needs further studies.

Table 3 The comparison of prediction and actual landslides in the Shizugawa basin

Number of the slope units		Prediction: Collapse	Prediction: Non-Collapse
Actuality	Collapse	25	10
	Non-Collapse	106	294

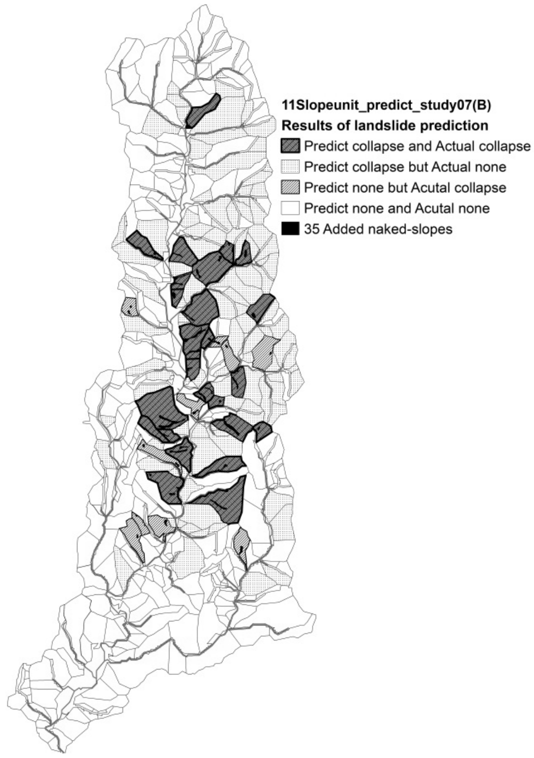

Fig. 2 The result of comparing prediction with actuality for the landslides in the Shizugawa basin

Table 4 The comparison of landslide prediction by the IRIS model and the multiple regression formula

Case	No. Slope	L(m)	α (deg)	Actual collapse	Calculated by IRIS model: Occurring time	Calculated by IRIS model: Slip surface area (m2)	Predict by regression: Occurring time	Predict by regression: Slip surface area (m2)	Difference of occurring time (min)	Difference slip surface area (%)
1	366	200	31.8	Y	8/14 4:31	51.3	8/14 4:40	64.4	9	25.5
2	134	228	30.7	Y	8/14 4:42	74.8	8/14 4:34	73.8	-8	-1.4
3	309	230	29.2	Y	8/14 4:41	115.4	8/14 4:38	101.9	-3	-11.7
4	192	71	33.3	N	8/14 5:35	54.2	8/14 5:30	42.5	-5	-21.6
5	43	102	32.8	N	8/14 4:46	44.0	8/14 5:02	60.4	16	37.5
6	424	248	28.4	N	No collapse		No collapse		same	

4. CONCLUSIONS

This study proposed a new approach to predict the landslide occurring time, location and scale effectively. This new method cannot only retain the characteristics of the numerical model, but also has the advantage of high performance on calculation. It could provide the foundation of developing the multi-modal disaster simulation.

Keywords: landslide, warning, basin scale, water content, prediction

References

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