Ground Water Monitoring for Review of Drainage Works Plan in Large-Scale Landslide

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Abstract

The amount of counter measure works for landslide is usually designed based on the prior investigation result and the planning safety factor. In large-scale landslide, the construction period tends to be long. Therefore, it is necessary to rationalize the planning method further. We examined indices for evaluating the effect of ground water drainage works and reviewing drainage works plan. Flow rates at collecting borings show that there are several patterns of drainage flow, and that not only the difference of the maximum flowing quantity of each boring but also the difference of total flowing quantity after rainfall is great. Since comparatively steady observation is possible in even creeping landslide, monitoring flow rate at collecting boring is promising as a method of obtaining index for successive reviewing the design of ground water drainage works. The result suggests potentiality of modification method of scale of counter measure works plan by doing flow rates monitoring, successive review of the design, and evaluating the effect of counter measure.

Keywords: landslide, ground water, drainage works, monitoring

Introduction

On the present Japanese system, the amount of counter measure works for landslide is usually designed based on the prior investigation result and the planning safety factor. Even if the effect of counter measure works is indicated more than the plan, it is rarely reflected in the plan when the landslide's phenomena are not clearly understood. As a result, plan of counter measure works is not wholly revised by all cases.

Many studies have been performed to develop evaluation method of the effect of drainage works, for example examination of water mass balance (Terakawa *et al.*, 1982). However, the empirical value obtained through case studies (Okuzono and Ogata, 1985; Hata *et al.*, 1995) has been practically used as planning lowering height of ground water level for slope stability calculation. In large-scale landslide, the construction period tends to be long because of the amount of drainage works, *etc.* Therefore, it is necessary to rationalize the planning method further by considering the effect of installed facilities.

Since the amount of ground displacement and ground water level are also affected by rainfall depth, we have mainly examined the possibility of making a rational plan based on conditional probability distributions of ground displacement and ground water level given daily rainfall depth. Here we report the results in a large-scale landslide, and discuss method of evaluation and modification of drainage works plan.

Study area

In order to investigate the function of drainage wells and examine indices for evaluating the effect of ground water drainage works, we observed flow rates and summarized monitoring data in the Taninouchi landslide area (Ochi Town, Kochi Prefecture).

Taninouchi Landslide has a total area of 131.2 ha with average angle of 23 degree, and extends 1,200m toward southeast. Vertical distance is about 450m from top of scarp to toe. The landslide is subdivided into 5 blocks (Fig. 1). Depth of the landslide is 60 m in average and it reaches 150m or more in the deepest part. The geology consists mainly of slate with chert and maffic tuff formation of the Northern Subbelt of the Chichibu Belt (Permian). The geological structure is estimated to be a gentle dip slope.

The counter measure project has continued since 1959. The present total plan is based on the plan of control works that was deliberated in the committee held from 1999 to 2001. The drainage wells W-13 and W-16 were constructed in 2003 and 2005, respectively.

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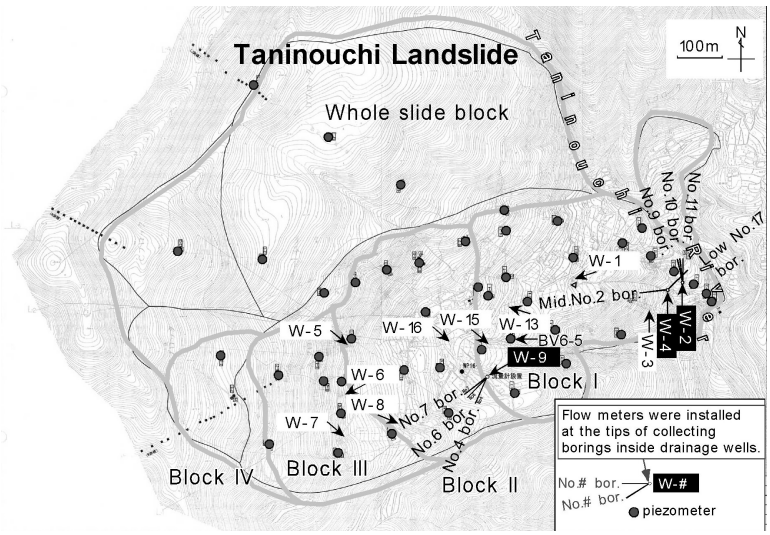

Fig. 1. Taninouchi Landslide showing locations of hydrometric instrumentation and drainage wells.

Method of flow rate monitoring

Eight electromagnetic flowmeters were installed in drainage wells W-2, W-4, and W-9 and flow rates of each collecting boring were observed since 2005 (Fig. 1).

Observation results

Flow rates of collecting borings (Fig. 2) show 3 patterns; they greatly increase over several days after rainfall (f, g, h), they present sharp peaks within all day long after rainfall (a, b, c), and they are usually relatively large and the increases after rainfall are small (d, e). Besides, not only the difference of the maximum discharge but also the difference of total discharge after rainfall is great.

Investigation on function of drainage well by monitoring flow rate

Even if maximum discharge can be forecasted to some degree based on geological survey and situation in the construction etc., observation is the only way to identify total discharge. Therefore, additional construction based on monitoring of flow rate is necessary to enhance the drainage in landslide after rainfall.

Since pore water pressure at slip surface is not observable in creeping landslide, we cannot elucidate the exact relationship between reduction in pore water pressure and volume of drained water. However, concerning flow rate, comparatively steady observation is possible in even creeping landslide. Previous studies have showed that macropore flow, slope water table development, and lateral pipe flow enable large volumes of stored water to discharge (e.g. McDonnell, 1990). And the change in runoff of ground water component by drainage works can be detected through runoff analysis (Suemine *et al.*, 1995). Therefore, it is concluded that monitoring flow rate at collecting boring is promising as a method of obtaining index for successive reviewing the design of ground water drainage works.

Methods of statistical analysis of monitoring data

In order to examine indices for evaluating the effect of drainage works, we gathered and summarized monitoring data of 10 borehole extensometers and 22 piezometers. The terms of data are 1996–2005 for extensometers and 4 piezometers and 2002–2005 for other 18 piezometers, respectively.

We calculated antecedent precipitation index (API) and 3 types of threshold APIs for the frequency of variation in monitoring systems (Suzuki and Fujisawa, 2005) as briefly described below.

Daily API [mm] is given by the following equation.

$$\mathrm{R_G} = \mathrm{R} + \mathrm{R'_G} \times 0.5^{1/\mathrm{T}} \tag{1}$$

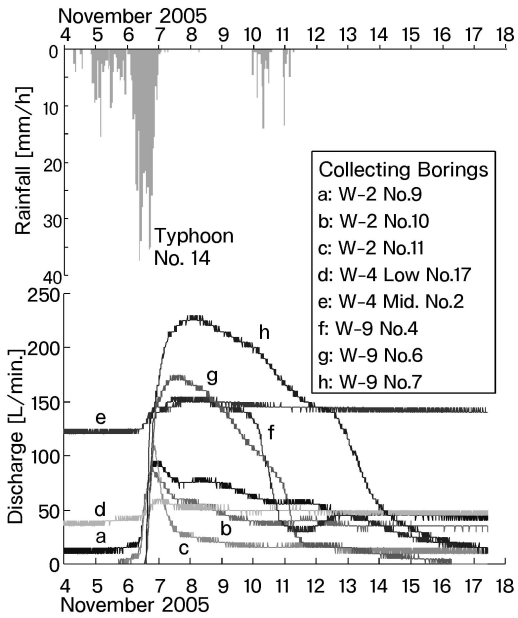

Fig. 2. Response of discharge of drained water for the Typhoon No.14.

where R_G = antecedent precipitation index of the day [mm]
R'_G = antecedent precipitation index of the preceding day [mm]
R = daily rainfall depth of the day [mm]
T = a half-life [day] = 5 [day] in this study

First, frequencies of API of the days with/without ≥ 0.1 mm/day ground displacement were counted. The class interval was 1 mm from 0 to 299 mm, and the classes of ≥ 300 mm were grouped, therefore the number of classes was 300. The maximum difference between the cumulative distribution function of API of the days with ground displacement and the cumulative distribution function of API of the all-monitoring days was searched. We define **the threshold API for ground displacement** as the numerical value of API at the maximum difference. The threshold API for ground displacement signifies the numerical value of API when probability of ground displacement increases.

Second, frequencies of the maximum API during 30 days after ≥ 20 mm/day rainfall event with/without $\geq$ n time(s) of ground displacement were counted ($1 \leq n \leq 5$). The maximum difference between the cumulative distribution function of the maximum API during 30 days with $\geq$ n time(s) of ground displacement and the cumulative distribution function of the maximum API of the all monitoring events was searched. We define **the threshold API for frequency of ground displacement** as the numerical value of API at the maximum difference. The threshold API for frequency of ground displacement signifies the numerical value of API when probability of ground displacement after rainfall increases.

Thirdly, **the threshold API for ground water rise was calculated in the same** way as the calculation for the threshold API for ground displacement. The threshold APIs for ground water rise of ≥ 0.1 m/day, ≥ 0.5 m/day, and ≥ 1.0 m/day were computed.

Nevertheless the counter measure works in Taninouchi landslide are still under construction, monitoring data were divided according to the construction period of the drainage well W-13 in order to study the method. Since there are many piezometers of which water level fell obviously after the construction of the drainage well W-13, ante- and post- construction periods were defined as days before 10 November 2003 and days after 23 March 2004, respectively.

Results of analysis

The medians of the threshold APIs for each block are shown in Figs. 3–5.

According to Figs. 3 and 4, the threshold API for ground displacement and the threshold API for frequency of ground displacement are lower in the block I than those in the block III.

Fig. 4 suggests the difference of occasion for ground displacement in each block after rainfall. In the block III, ground displacement occurs almost continuously when API is high because of rainfall immediately before. In the block II, the maximum API during 30 days after rainfall with ≥ 5 times of ground displacement

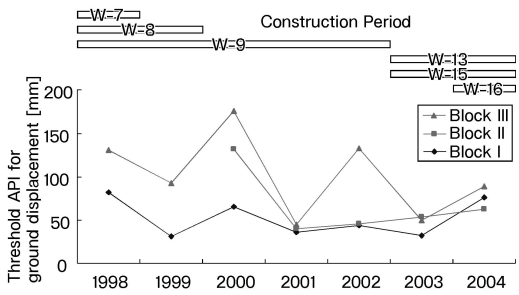

Fig. 3. The threshold API for ground displacement of each block.

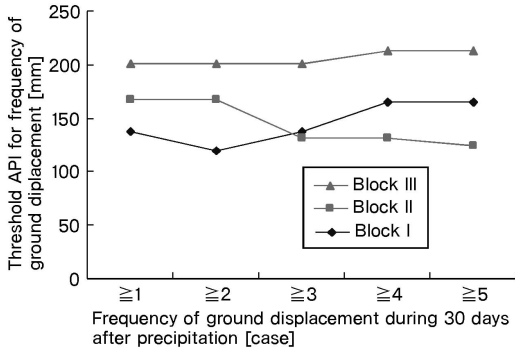

Fig. 4. The threshold API for frequency of ground displacement.

is lower than the value with ≥ 1 time of ground displacement. In other words, ground in the block II usually moves lagging behind rainfall when API greatly falls. In the block I, ≥ 1 time of ground displacement occurs when API is relatively low, and ≥ 5 times of ground displacement occurs when API is high. The cause of these behaviors is unclear, but it should be primarily related with local difference in the ratio of usual and critical water pressure.

These results are summarized as below.

1) At the lower part of the landslide rather than the upper part, ground displacement occurs at even low API.
2) In the block III, occurrence of ground displacement concentrates on peak of rainfall.
3) In the block II, peak of the landslide movement comes a little later than peak of rainfall.
4) In the block I, it is rare for the landslide to halt; besides the movement is active when API is high.

Finally, we calculated the threshold API for ground water rise to investigate API of the day when water table rises. The threshold APIs for ground water rise in 2004 are higher than those in 2002 when it is ante-construction of the drainage well W-13 (Fig. 5).

As a example of the effect of the drainage well W-13, the threshold API and piezometric level of the piezometer BV6-5 from 2002 to 2004 are shown in Fig. 6. A drop in the slope water table was observed in 2004. The API of the day when the piezometric level of BV6-5 rose 1.0m/day in 2004 is higher than that in 2002. In consequence, the threshold API for 1.0m/day ground water rise of BV6-5 in 2004 is 279mm that is 76mm higher than that in 2004.

Discussion

Target of drainage works plan

It is common to decide the planning ground water level based on stability analysis. However, feasibility of this method is limited to small-scale landslide.

In some landslides, the relationship between API and the amount of displacement over 10 years is reported (Hokuriku Regional Development Bureau, 2004). Hokuriku Regional Development Bureau (2004) points out that the amount of displacement at the same API decreased after the installation of counter measure

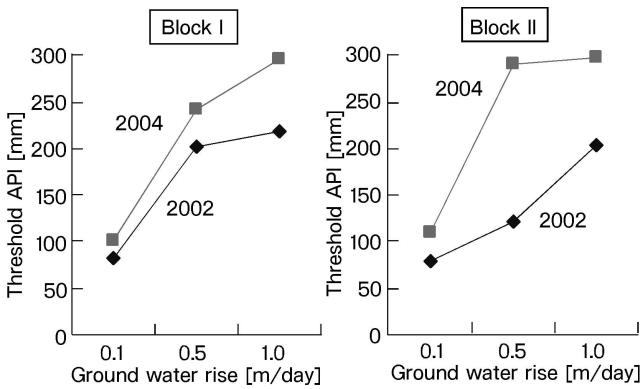

Fig. 5. The threshold API for ground water rise. The graph of the block III is omitted since there is insufficient number of case to calculate the index.

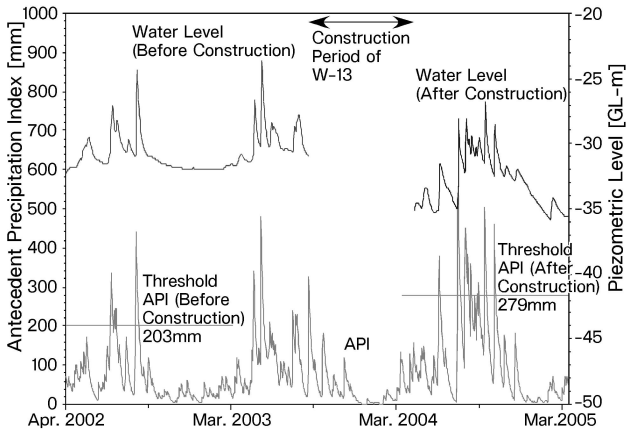

Fig. 6. The piezometric level and threshold API for ground water rise of 1.0 m/day in the piezometer BV6-5.

in a landslide. However, as the preliminarily research in this study we checked data in 10 landslide areas, and didn't find general correlation between the amount of displacement and the probability of the occurrence of a given precipitation event. Moreover, Tohoku Regional Development Bureau (2004) points out the shortage of hydrometric data and concluded that it is unable to apply the frequency distribution of ground water level to extreme value distribution.

Therefore, if it is possible to express the effect of drainage works in the unit of rainfall depth, it is practical to set the target of drainage works plan to the value based on consideration of local circumstances and analysis of the relationship between frequency of landslide's movement and rainfall depth. This method requires monitoring periods of ante- and post- construction that contain several times of precipitation of nearly equal intensity.

Indices for evaluating the effect of drainage works

So far, we have examined monitoring data to relate landslide's movement with hydrological data. The results are summarized as below.

1) The trends of ground displacement in each landslide block after rainfall can be identified by counting frequency of ground displacement.

2) For a comparative study of each observation point, it is effective to look at frequency of rise in piezometric head after rainfall.

It should be possible to evaluate the effect of drainage works by comparing the threshold APIs of ante-construction with those of post-construction based on monitoring over a several year period.

Summary

1) We propose a evaluation method of the effect of drainage works through monitoring of the dynamic response of landslide and calculating threshold precipitation indices.
2) On the above framework, achievement of drainage works plan can be estimated from increment of the index.
3) For successively reviewing the design of ground water drainage works, it is a promising way to perform flow rate monitoring, runoff analysis, and evaluation through precipitation index.

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