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A STUDY ON LANDSLIDE EARLY WARNING SYSTEM CONSIDERING THE EFFECT OF ANTECEDENT RAINFALL ON SLOPE STABILITY

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This study discusses the applicability of landslide early warning method considering the effect of antecedent rainfall on slope stability. First, as a typical example of the method, the antecedent precipitation index, API method, which has been developed to use as the index for landslide early warning by covering the wide landslide prone areas in Thailand is introduced. Second, the basic concept of newly-developed Modified API, MAPI method, which considers the reduction of moisture stored into subsoil by antecedent rainfall records observed in Nakhon Nayok, Thailand, is presented. The results present that there are similarities not only between pore water pressure at the old sliding plane and API but also between API and MAPI.

Key Words: *landslide, early warning system, antecedent rainfall, API, slope stability*

1. INTRODUCTION

Landslide which may cause loss of lives and properties damage is one of the most serious natural in the mountainous and suburban areas in Asian countries. These might be due to the torrential rainfall in the tropical monsoon/squall. Thailand is one country that faces with the squall and has landslide events. Moreover, it seems to have an increasing of the damaged worth for both of lives and properties from the past. Also, in Japan, the guerrilla-like rainfall has caused landslide damaging properties and societies.

In order to reduce losses, various methods and solutions have been developed. In the past, the early warning system which was developed by clarifying a warning envelope in the plane of hourly rainfall and accumulated rainfall based on the historical rainfall records was adopted in Japan as shown in Fig. 1[1)]. Recently in Thailand, the researchers used the relation between the antecedent/accumulated rainfall and daily rainfall to establish the landslide early warning system. The method is the Antecedent Precipitation Index, API.

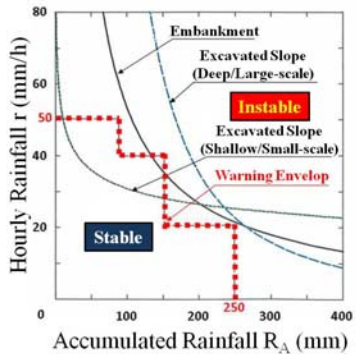

Fig. 1 An example of early warning system adopted in Japan

As the occurrence of torrential rainfall is relatively new in Japan, it is wondering whether the conventional method can be applied for the early warning system. In addition, it is doubtful whether the system requires taking account of an effect of antecedent rainfall on slope stability as proposed in Thailand.

This paper reviewed an application of API to the landslide prone-area in Thailand in addition to the basic concept of that. The Modified API, MAPI was proposed and calculated based on the modified reduction rate of moisture in the purpose of application to the early warning system in the specific area. The measurement data were obtained from Nakhon Nayok site. The correlation of MAPI and API was presented and discussed.

2. REVIEW AN APPLICATION OF API TO LANDSLIDE-PRONE AREA IN THAILAND

(1) Basic concept of API used in Thailand

According to the basic concept of API, it is the moisture of soil at any time that is measured. The research suggested that the soil moisture which has relation to the accumulated rainfall will decrease by time after the end of rain storm[2]. An equation of API defined by them could be shown in Eq. (1) as follows:

$$API_t = (K_t \times API_{t-1}) + P_t \qquad (1)$$

where API_t is the API on day *'t'* (mm), API_{t-1} is the API on day *'t-1'* (mm), K_t is recession constant (dimensionless), and P_t is precipitation on day *'t'* (mm). K_t used to calculate API is presented in Eq. (2) and they have been used for landslide early warning in Patong City, Phuket province in Thailand[3), 4)].

$$K_t = EXP(-E_t/W_m) \qquad (2)$$

where E_t which is calculated by using Thornthwaite (1948) model denotes the potential evaporation at day *'t'*. W_m is the maximum soil moisture available for evaporation. It is the function of soil water holding capacity *(WHC)*, bulk density *(BD)*, and *100 mm* is the soil depth as shown in Eq. (3).

$$W_m = (WHC/100) \times BD \times 100 \ (mm) \qquad (3)$$

(2) Development of landslide warning system and application of API for warning system in Thailand

Recently, in case of shallow mass movement, various factors have been involved to consider the rainfall-induced landslide by many researchers and several techniques have been used for developing the warning system[5), 6), 7), 8)]. They also suggested that the antecedent rainfall and soil moisture are very important in predicting landslide occurrence. In addition, the model of soil shear strength was applied to evaluate the critical API (API_{cr}) for each of soil slope in 37 provinces of Thailand[9), 10), 11)]. The API_{cr} contour for Thailand was then calculated and presented. The present API at time of consideration which was calculated based on Eq. (1) has been used such as Patong City, Phuket[3)]. However, the purpose is to apply for the large area. An example of the present API at the time of consideration against API_{cr} is shown in Fig. 2. It can be interpreted that if the curve goes beyond the critical line, the landslide may likely occur.

3. BRIEF EXPLANATION OF MONITORING SITE

Fig. 3 shows the study area and the layout of field instruments at the monitoring site in Nakhon Nayok, Thailand. Monitoring equipments installed at the site consist of the moisture meters, the tensio-meters, the water level sensors, the tipping bucket type rainfall gauge, and Doppler radar rainfall gauge. The detail of equipment installation and data measurement was explained in the previous research[8), 12), 13)].

Geological condition of monitoring site is composed of weathered rhyolite. The slope was reclaimed by fail soil mass after it had failed in 2004. The geotechnical properties obtained from the field and laboratory tests presented that subsoil covering the shallow region at that site is mainly filled material (compacted residual soil) and classified with ranging from the medium plastic clay (CL-CH) to medium plastic silt (MH-ML)[14), 15)]. The soil mantle has been estimated to be 2-3 meters in the thickness and below the soil mantle lies bedrock of volcanic origin of which is referred to the old sliding plane.

The instruments were installed into the geological condition as shown in Fig. 4[15)]. The tensio-meters were installed related to the old sliding plane failure by Kasetsart University in 2007; the depth of -1.0m and -2.15m at the toe part and upper portion, respectively. The research suggested that the instruments at the middle part (No.1) were mainly installed in homogeneous residual soil layer. The others at the toe part (No.2) were installed relatively in heterogeneous soil layer, which was the high permeability zone comprising sand and gravel.

Regarding the rainfall-induced shallow slope failure that occurs in weathered rock mass, the variation of permeability in depth affected by the degree of weathering condition is the key factor of the shallow slope failure. During rainfall, the moisture infiltrates into subsoil vertically in the relatively shallow area comprising the residual soil and completely weathered rock; the pore pressure is generated because of low permeability in the deeper area. As for this mechanism, slope may fail because the moisture infiltrates through the high permeable zone at the shallow level and the pore pressure generates in the low permeable zone at the deeper level.

According to the monitoring site, it can be predicted that the moisture infiltrate into the filled residual soil and pore pressure may be generated near the old sliding plane. Therefore, in this study, pore water pressure observed in the middle portion at GL-2.15m and in the toe portion at GL-1.0m are regarded as trigger of slope failure and used to compare to API and MAPI. The consideration is that if the relations between pore water pressure and API and between API and MAPI are found, an effect of antecedent rainfall on slope stability could be taken into account for the landslide early warning system. Furthermore, MAPI may be used to be another index for the system.

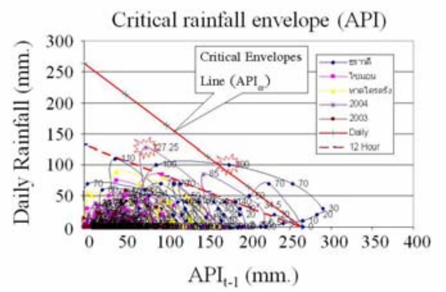

Fig. 2 Verification of API value against API_{cr} [10)]

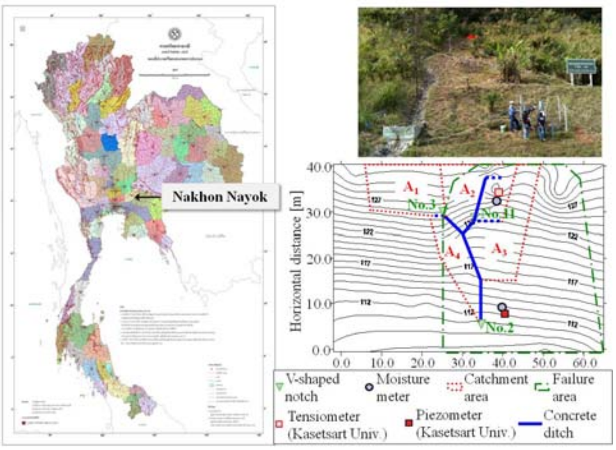

Fig. 3 Study area, layout of instruments and catchment areas

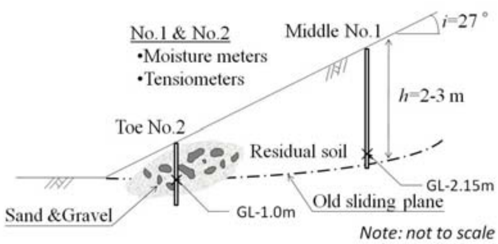

Fig. 4 Layout of instruments together with geological condition

4. RESULT AND DISCUSSION

(1) Reduction ratio

In this study, the reduction rate of moisture was recalculated based on the concept of previous study[13)]. Data observed within 1.0 m at the middle portion in year 2008 was used. The reduction ratio could be evaluated as shown in Eq. (6).

$$K_t^* = Q_{res}/Q_{inf} \tag{6}$$

In which, K_t^* denotes the reduction ratio of moisture, Q_{res} denotes the residual amount of water before the following rain, and Q_{inf} denotes the amount of water infiltrated into subsoil at the end of previous rain. Fig. 5 shows the relation between the variation of K_t^* and the elapsed time after the end of antecedent rainfall, *t*; the reduction function is presented in Eq. (7) as follows:

$$K_t^* = 6.561E\text{-}08t^2 - 5.265E\text{-}04t + 1.000 \tag{7}$$

According to Eq. (7), at 3100 minutes or approximate 2 days, K_t^* is corresponding to zero. As a result, within approximately two days after the end of rainfall, an antecedent precipitation is significant for considering together with the following rainfall.

(2) Recession constant

Based on Eq. (2) and (3), K_t is the constant monthly value for 1 day recession. It is estimated by considering the moisture reduction that can evaporate within the upper and lower limits. The soil depth was determined as 0.1 m. K_t (Table 1) provided by DWR and obtained from Mooban Suan Hong, Tambon Sarika, Amphoe Muang Nakhon Nayok that is not so far from the monitoring site was used for consideration and discussion[16)].

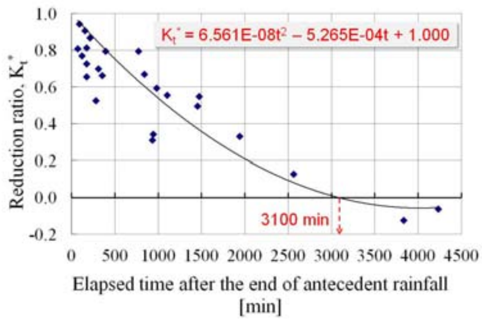

Fig. 5 Variation of reduction ratio K_t^* related to elapsed time

Table 1 Monthly recession constant K_t values[16)]

Month	Jan	Feb	Mar	Apr	May	Jun
K_t	0.727	0.746	0.720	0.728	0.749	0.789
Month	Jul	Aug	Sep	Oct	Nov	Dec
K_t	0.793	0.801	0.800	0.794	0.765	0.746

(3) Comparison of recession constant and reduction ratio

This part, K_t and K_t^* were compared and discussed based on the values, equations, and behavior of volumetric moisture content (VMC) during drying process by using data year 2008.

Regarding the behavior of VMC after the end of rain, when each rain storm was considered; the decreasing of VMC was found at the upper level (-0.1m and -0.2m) but at the deeper levels, VMC increased at the prior time and then decreased by time. Fig. 6 shows the variation of VMC during the drying process for each depth and time step. At the shallow level, an evapotranspiration could be observed as VMC noticeably decreased. At the deeper level, the increasing of VMC might be due to the infiltration from the upper level; however it decreased when the time went by. It implies that the decreasing of VMC at the shallow level consists of the evapotranspiration and infiltration.

The comparison between K_t and K_t^* with regard to the behavior of VMC, it can be concluded that K_t considers only evaporation but K_t^* includes both of evapotranspiration and infiltration into subsoil. Furthermore, as K_t^* was obtained by measuring the variation of VMC, it probably nears the real situation when K_t^* is applied to observe the antecedent precipitation at the specific site. The near initial antecedent precipitation can also be estimated by the moisture reduction function of K_t^* as shown in Eq. (7).

The next consideration is the comparison between K_t and K_t^* with regard to values, K_t values vary between 0.72 and 0.801 but K_t^* values depending on time vary from 0 to 1. If one day is considered, the reductions of VMC calculated from K_t and K_t^* decrease with the rate of around 0.8 and 0.4, respectively. As a result, there will be the difference between API and MAPI when K_t and K_t^* are applied.

(4) Calculation and comparison of API and MAPI

For this study, the reduction ratio, K_t^* was recalculated and evaluated based on the ten-minute observation data, therefore the antecedent precipitation index was a little bit modified as shown in Eq. (8):

$$MAPI_t = (K_t^* \times MAPI_{t-1}) + P_t \tag{8}$$

Where $MAPI_t$ is the Modified API at time 't', K_t^* is the reduction rate, $MAPI_{t-1}$ is the Modified API at time '$t-1$', and P_t is the 10 minute rainfall intensity.

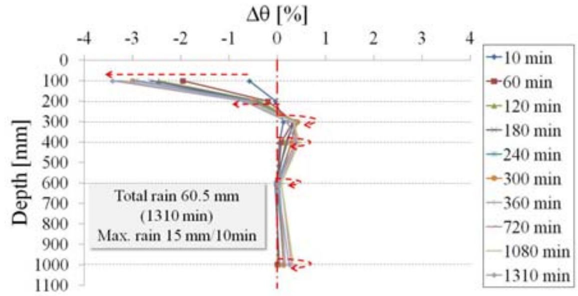

Fig. 6 Variation of VMC from the end of rain (9/8 14:00) to the following rain (9/9 11:50) for each depth and time step

Eq. (1) and (8) were respectively used to calculate API and MAPI based on the different methods of moisture reduction. K_t^* was calculated by using Eq. (7) and K_t was obtained from Table 1. Data used to calculate and discuss were the record of rainfall and pore water pressure in 2008 from May 10 until October 30. The rainfall was measured in every 10 minutes interval but the pore water pressure was observed in one day interval.

Fig. 7 shows the relation among API, daily rainfall, and pore water pressure. Levels of -2.15m at the upper slope and -1.0m at the lower part were presented and compared because those levels were assumed to be close to the old sliding plane as mentioned in 3. Although the data is limitation, the similarity between variations of pore water pressure and that of API is found.

As shown in Fig. 7, during the period of high rainfall intensity on September, the relation between rainfalls measured in one day and 10 minutes monitoring intervals and pore water pressure is used to consider and presented in Fig. 8. It can be seen that in unsaturated condition, pore water pressure has a little bit variation but after it becomes saturated condition, it increases and varies obviously; this might be due to soil water retention. Moreover, the increase of pore pressure during September 13-20 implies the effect of antecedent rainfall on generation of pore pressure.

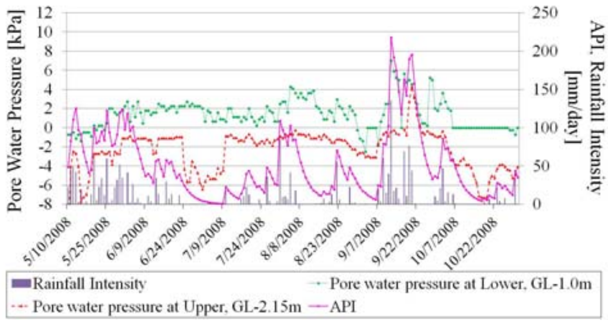

Fig. 7 Relation of API, pore water pressure and rainfall in one day monitoring interval

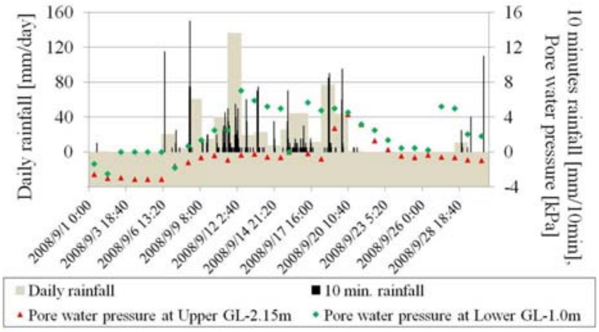

Fig. 8 Relation of daily rainfall, 10 minute rainfall and pore water pressure in 1 day monitoring

As there is a similarity between pore water pressure and API, it implies that an effect of antecedent rainfall on slope stability can be taken into account for landslide early warning system. Next consideration is that if the similarity between API and MAPI is found, MAPI can be used as an index for warning system.

The comparison between MAPI and API together with rainfall is shown in Fig. 9. It presents that MAPI also corresponds to rainfall and all values of MAPI are less than API. However, the curve of MAPI is likely to have the same trend comparing to the discrete value of API. Therefore, in order to clarify that relation, the correlation between MAPI and API is presented in Fig. 10. It showed the positive correlation between them of which the data was obtained at the same time (e.g. exact date and time).

As MAPI differs from API, it is due to the difference of values between K_t^* and K_t as discussed in 4(3). In addition, MAPI method considers precisely the effect of dissipation of moisture during antecedent rainfall and following one in a day with 10 minute interval, while API focuses on recession of daily rainfall only. As a result, API has value higher than MAPI.

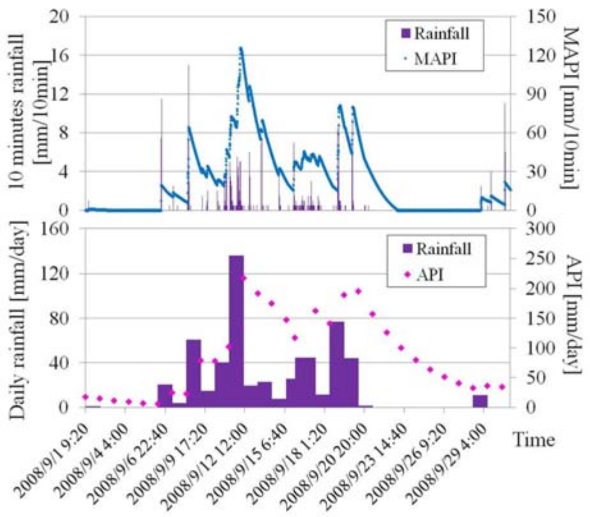

Fig. 9 Relation of API, MAPI, and rainfall

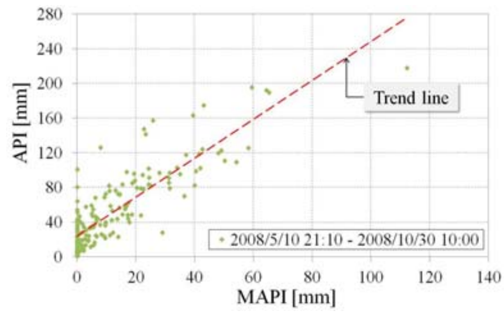

Fig. 10 Correlation between MAPI and API based on the same time observation

K_t and API are the values used to measure the antecedent precipitation in one day interval; however, when they are applied to the early warning system, the critical condition may occur within the day before the daily rainfall and API are monitored. In other word, K_t^* and MAPI are measured 10-minutes interval, the establishment of early warning system will have more accurate than one day interval.

In sum, as MAPI is adopted to consider the effect of both evapotranspiration and seepage into deeper zone and the comparison of API to MAPI shows the positive correlation, it can be pointed out that MAPI may be applicable to the another index so as to be adopted for the establishment of early warning system

(5) Establishment of early warning system

This section is the proposed idea about establishment of the early warning system by using MAPI associated with K_t^* for the other site in Japan. The relation between hourly rainfall and MAPI will be proposed as shown in Fig. 11 and the expected relations between the reduction ratio and the elapsed time are shown in Fig. 12.

The condition of slope at Nakhon Nayok site was found that it consists of weathered rhyolite under the high temperature and humidity, it can be implied that there will be the high rate of evaporation as well. For the area that dominated by the granite type of which it has permeability higher than rhyolite, the curve proposed in that area is expected to line lower than Nakhon Nayok site. In case of Japan, rhyolite and granite are also spread over the area of western Japan but the weather is different from Thailand. It might be that Thailand has higher rate of evaporation than Japan, therefore, the curve is expected to line between Nakhon Nayok and the granite area.

Finally, it can be said that the field monitoring each of specific area so as to investigate an effect of antecedent rainfall and evaluate the moisture reduction will be useful for establishment of landslide early warning system.

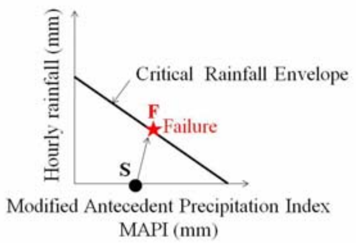

Fig. 11 Critical rainfall envelope based on the MAPI

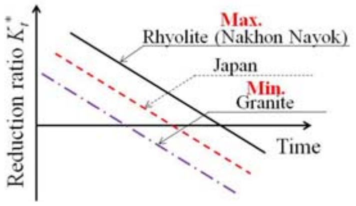

Fig. 12 Expected relations of reduction ratio and elapsed time

5. CONCLUSIONS

In this study, the typical example of API method was presented and compared to the newly-developed MAPI method. The results found from this study could be summarized as follows:

1) It can be concluded that K_t considers only potential evaporation but K_t^* includes both of evapotranspiration and infiltration into subsoil. In addition, it probably nears the real situation when K_t^* is applied to observe the antecedent precipitation at the specific site.

2) The variation of API is similar to that of pore pressure observed at GL-2.15m and GL-1.0m, which is regarded as the trigger of slope failure at the slope. It implies that the antecedent rainfall affects the generation of pore pressure.

3) As MAPI is adopted to consider the effect of both evapotranspiration and seepage into deeper zone and the comparison of API to MAPI shows the positive correlation, it can be pointed out that MAPI may be applicable to the another index so as to be adopted for the establishment of early warning system.

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