Validation of topographical and geological conditions involved in shallow landslide using statistic methods

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Abstract

It has been reported in the previous studies that topographical and geological conditions are involved in the shallow landslide. Some of the conditions have been explained qualitatively and the applicability of them has not been shown statistically. Therefore, the authors conducted statistical surveys using topographical and geological data in order to validate the applicability of the topographical and geological conditions to detection of unstable slopes reported in the previous studies. First, the authors reviewed the topographical and geological conditions involved in shallow landslides reported in the previous studies. Secondly, the authors conducted field observations in Chuetsu, Niigata Pref. and Hofu, Yamaguchi Pref., Japan where a number of shallow landslides recently occurred. In both the areas, the authors checked whether or not each landslide site and non-landslide site satisfied the topographical and geological conditions. Additionally, the authors obtained topographical and geological data in the study areas by map interpretation, and applied Hayashi's quantification method II to the obtained data. As a result of the analysis, some of the conditions were confirmed to contribute to discrimination between the landslide sites and the non-landslide sites. Finally, the following conditions were confirmed to be involved in shallow landslides in the study areas: 1) convex break of slope, 2) valley slope, 3) angle of over 40 degrees and 4) spring.

Keywords: shallow landslide, topographical and geological condition, field observations, map interpretation, Hayashi's quantification method II

1. Introduction

The occurrence of the shallow landslide is affected by topographical and geological conditions. Therefore, these conditions are important clues to detecting unstable slopes susceptible to shallow landslides. Various conditions involved in shallow landslide have been reported in the literatures based on the analysis of the past slope disasters (e.g., Suzuki, 1997). Some of the conditions have been explained qualitatively, and the applicability of them has not been shown statistically. Therefore, in this study, the authors conducted statistical surveys using topographical and geological data in order to assess the conditions involved in the shallow landslide. These data were obtained by means of field observation and map interpretation in the study areas where a number of shallow landslides recently occurred.

2. Review of the previous studies

The authors reviewed the topographical and geological conditions involved in shallow landslides reported in the previous studies. These conditions were categorized in the view of the following two points (Table 1).

[1] The acquisition method of topographical and geological data

- The conditions are classified into two categories based on the acquisition method of topographical and geological data; one is mainly obtained by map interpretation, and the other is obtained by field observation. Some of the conditions are classified into both the categories.

[2] The relationship between shallow landslide and the conditions

- The conditions are classified into three groups, namely "factor", "sign" and "result" based on the relationship with shallow landslide. The conditions

| Araa | Topographical and | Deferrer | (a) The acquis | ition method | (b)The relationship with shallow landslide | | | |
|------------------------------|---|------------|-----------------------|----------------------|---|------|--------|--|
| Alea | geological conditions | Kelelence- | Map interpretation | Field observation | Factor | Sign | Result | |
| Whole slope | Angle of over 30 degrees | 1 | 0 | 0 | 0 | | | |
| | Concave slope | 2 | 0 | 0 | 0 | | 0 | |
| | Valley slope | 2 | 0 | 0 | 0 | | 0 | |
| | Outfacing | 3 | | 0 | 0 | | | |
| | Weathered soil | 3 | | 0 | 0 | | | |
| | Tree lean | 4 | | 0 | | 0 | | |
| Source area | Convex break of slope | 2 | 0 | 0 | 0 | | | |
| | Steep rock slope | 5 | 0 | 0 | 0 | | | |
| | Spring | 3, 6 | | 0 | 0 | 0 | | |
| | Crack on slope | 6 | | 0 | - | 0 | | |
| | Soil creep | 4 | | 0 | - | 0 | | |
| Moving area /Settled area | Fan-like gentle slope beneath a steep escarpment | 5 | 0 | | | | 0 | |
| | Mound beneath a steep escarpment | 5 | 0 | | | | 0 | |

 Table. 1 Topographical and geological conditions

 involved in the shallow landslide

1: Yasue and Okubo (1974); 2: Hatano (1974); 3: Chigira (2002); 4: Sasaki et al. (1994); 5: Suzuki (2000); 6: Kato (2008)

which are susceptible to cause the occurrence of shallow landslide are classified as "factors". The ones which are recognized before the occurrence of shallow landslide are classified as "signs". The ones which are recognized after the occurrence of shallow landslide are classified as "results".

3. Study areas

The study areas having a size of 5 km \times 5 km each are located in Chuetsu, Niigata Pref. and in Hofu, Yamaguchi Pref., respectively in Japan. In Chuetsu, a series of earthquakes including three large ones whose magnitude were more than 6.2 on the Japanese Meteorological Agency scale occurred on 23 October 2004 (Sidle et al., 2005). The earthquakes triggered a number of shallow landslides in Chuetsu (Yagi, 2005). Additionally, this area had experienced heavy rainfalls before the earthquake in 17 July 2004. The heavy rainfalls also triggered some shallow landslides in Chuetsu (Iwahashi et al., 2008).

In Hofu, heavy rainfalls observed on 21 July 2009. The daily rainfall in Hofu reached 275 mm. The heavy rain induced a number of shallow landslides and mud flows (Fukuoka et al., 2009; Wakatsuki et al, 2010).

The study area in Chuetsu is located in a hill region with the altitude of 300-350m, and mostly consists of alternate layers of Miocene-Pliocene sandstones and mudstones. The study area in Hofu is located in a mountain region with the altitude of 250-400m, and mostly consists of late Cretaceous granitic rocks.

4. Selection of the landslide sites and the non-landslide sites

Landslide sites in the study areas were selected by interpreting aerial photos taken before and after the disasters. The number of the selected landslide sites was 106 in Chuetsu and 193 in Hofu.

Additionally, non-landslide sites were selected in



*The shown areas are extracted from the study areas.

Fig. 1 The selected landslide sites and non-landslide sites

order to compare the topographical and geological settings between the landslide sites and the non-landslide sites. The non-landslide sites were selected by generating random numbers on the coordinates on maps of the study areas excluding areas of landslides, pond and artifact. 400 non-landslide sites were randomly selected in each study area. The locations of the landslide sites and the non-landslide sites in a part of the study area are shown in Fig. 1.

5. Field observation

5.1 Methods

The authors conducted the field observation and checked whether or not each landslide site and non-landslide site in both the study areas satisfied the topographical and geological conditions reviewed in Chapter 2.

5.2 Results

The result of the check of the conditions is shown in Table 2. The check was conducted at 44 landslide sites and 36 non-landslide sites in Chuetsu, and 5 landslide sites and 2 non-landslide sites in Hofu (Photo. 1). Because of the situations of vegetation and location, the authors could not check whether respective sites satisfied all the topographical and geological conditions. The "satisfaction ratio" in the Table 2 is the ratio of sites where each condition was

| | | Landslide site | | | | Non-landslide site | | | | | | |
|--------------|--|----------------|------|------------|------|--------------------|---------|------|------------|------|--------------|----------|
| Area | Topographical and geological conditions | Checked | | Recognized | | Satisfaction | Checked | | Recognized | | Satisfaction | P-value* |
| | | Chuetsu | Hofu | Chuetsu | Hofu | ratio | Chuetsu | Hofu | Chuetsu | Hofu | ratio | |
| Whole slope | Angle of over 30 degrees | 44 | 5 | 43 | 3 | 93.9 | 36 | 2 | 22 | 2 | 63.2 | < 0.001 |
| | Concave slope | 25 | 4 | 3 | 0 | 10.3 | 34 | 2 | 6 | 0 | 16.7 | 0.72 |
| | Valley slope | 40 | 5 | 20 | 5 | 55.6 | 34 | 2 | 7 | 1 | 22.2 | < 0.001 |
| | Tree lean | 8 | 4 | 5 | 0 | 41.7 | 17 | 2 | 9 | 0 | 47.4 | 0.4 |
| Source area | Convex break of slope | 42 | 4 | 37 | 3 | 87.0 | 35 | 2 | 8 | 1 | 24.3 | < 0.001 |
| | Steep rock slope | 11 | 0 | 4 | 0 | 36.4 | 35 | 2 | 4 | 0 | 10.8 | 0.068 |
| | Spring | 22 | 4 | 10 | 1 | 42.3 | 15 | 1 | 1 | 0 | 6.3 | 0.015 |
| | Crack on slope | 5 | 4 | 0 | 0 | 0.0 | 9 | 0 | 0 | 0 | 0.0 | 1 |
| | Soil creep | 2 | 3 | 1 | 0 | 20.0 | 9 | 0 | 1 | 0 | 11.1 | 1 |
| Moving area/ | Fan-like gentle slope beneath a steep escarpment | 23 | 5 | 10 | 3 | 46.4 | 25 | 2 | 1 | 0 | 3.7 | < 0.001 |
| Settled area | Mound beneath a steep escarpment | 21 | 5 | 1 | 0 | 3.8 | 26 | 2 | 0 | 0 | 0.0 | 1 |

Table. 2 Result of the filed observation in Chuetsu and in Hofu

* P-value was calculated by the Fisher's exact test (two-sided test).

satisfied, defined by Equation (1). It was calculated both in the landslide site and the non-landslide site.

$$R = 100 N_{satisfied} / N_{checked} \tag{1}$$

where *R* is the "satisfaction ratio" (%); $N_{satisfied}$, the number of sites where each condition was satisfied; $N_{checked}$, the number of sites where the satisfaction of the condition could be checked.

The authors carried out the Fisher's exact test to examine the significant difference between the satisfaction ratio of the landslide site and that of the non-landslide site. The Fisher's exact test (Fisher, 1935) is a statistical significance test used in the analysis of contingency tables, and is valid for all sample size. As a result of the test, the significant difference at 5 % significant level was confirmed in the satisfaction ratios of the following conditions: [1] angle of over 30 degrees, [2] valley slope, [3] convex break of slope, [4] spring and [5] fan-like gentle slope beneath a steep escarpment.

6. Map interpretation and Hayashi's quantification method II

6.1 Acquisition of topographical and geological information

Topographical and geological information of slopes where the landslide sites and the non-landslide sites located was acquired using 1:25,000 topographical maps and published geological maps. The topographical information of the landslide site was interpreted using topographic maps drawn before the landslides occurred. The items of the topographical information were described below based on the topographical classification reported by Onda et al. (1996) and Suzuki (2000).

[1] Vertical cross-section shape of slope (Fig. 2(a))

[2] Horizontal cross-section shape of slope (Fig. 2(b))[3] Slope angle

[4] Location on vertical cross-section of slope (Fig. 2(c))

The items of geological information interpreted using 1:50,000 geological maps were the followings. [5] Rock facies

[6] Distance from a syncline axis or an anticlinal axis

[7] Relationship between the direction of dip of slope and that of geological structure (Fig. 3)

The information on topography and geology of the landslide site was obtained from the top of landslide. The items of geological information [6] and [7] were not obtained in Hofu because information on the geological structure such as the direction of bedding plane and the fold structure could not



(a) Chuetsu





(c) Hofu (near the crest)

Photo. 1 Shallow landslides in Chuetsu and in Hofu







*Arrow shows a direction of water flow.

(c) Location on vertical cross-section of slope



Fig. 2 The classification of topographical information



Fig. 3 Relationship between the direction of dip of slope and that of geological structure

interpreted in the geological map.

6.2 Method of Hayashi's quantification method II

The contribution of the condition to discrimination between the landslide sites and the non-landslide sites was analyzed by Hayashi's quantification method II (Hayashi, 1954) using the interpreted topographical and geological data. Hayashi's quantification method II is a method of multivariate discrimination analysis to manipulate qualitative data as explanatory variables. In this study, the presence or absence of landslide (landslide site or non-landslide site) was used as the objective variable, and the items of topographical and geological information were used as the explanatory variables. Before the analysis, the explanatory variables were selected based on the criterion of correlation among explanatory variables or that between an objective



Fig. 4 Result of Hayashi's quantification method II

variable and an explanatory variable by Kan (1993). As the procedure of Hayashi's quantification method II, the authors followed Kan (1993), and Kan and Fujikoshi (2011).

6.3 Results of Hayashi's quantification method II

As a result of the selection of the explanatory variables, "rock facies" and "distance from an anticlinal axis" in Chuetsu and "rock facies" and "slope angle" in Hofu were excluded. That is because they did not satisfy the criterion of the correlation. The result of the analysis with the exception of these explanatory variables was shown in Fig. 4. The category score shows the magnitude of the contribution to the discrimination between the landslide site and the non-landslide site. Categories whose category score are positive are estimated to contribute to landslide sites. In Chuetsu, "convex" in the vertical cross-section shape of slope, "valley" in the horizontal cross-section shape of slope and "over 40 degrees" in the slope angle showed large contribution to landslide sites. In Hofu, "convex" in the vertical cross-section shape of slope and "valley" in the horizontal cross-section shape of slope showed large contribution to landslide sites. The result of analysis in Chuetsu showed 84.6% classification accuracy and that in Hofu showed 74.0% classification accuracy. The classification accuracy



Fig. 5 Location of landslide sites and topographical conditions which contribute largely to shallow landslide in Chuetsu

was defined as the percentage of the number of sites correctly classified to the total number. According to Kan and Fujikoshi (2011), classification accuracy of over 75% shows high accuracy. The classification accuracy in Chuetsu was higher than the criterion value and that in Hofu was near it.

7. Discussions

The selection of the explanatory variable before Hayashi's quantification method II in both the areas was thought to be reasonable, judging from the classification accuracies. As a result of the analysis, the conditions of "convex" in the vertical cross-section shape of slope and "valley" in the horizontal cross-section shape of slope were confirmed to contribute largely to shallow landslides both in Chuetsu and in Hofu. In Chuetsu, the condition of "over 40 degrees" in the slope angle was also confirmed to contribute largely to shallow landslides.

The condition of "convex" in the vertical cross-section shape of slope corresponded to the convex break of slope in the field observation. The positional relation between landside sites and the topographical conditions which contribute largely to shallow landslides in Chuetsu is shown in Fig. 5. This figure shows that most landslide sites locates at slopes with these conditions.

"Slope angle" was confirmed to contribute to the discrimination between the landslide site and the non-landslide site only in Chuetsu. In Hofu, a lot of shallow landslides occurred at the lower slopes (valley walls) whose angles are around 40 degrees (Photo. 1(b)) and at gentle slopes near crests (Photo. 1(c)). Weathered granitic bedrock was distributed in lower slopes, and decomposed granitic soil was



Fig. 6 Topographical and geological conditions which contribute largely to shallow landslide

distributed near the crests. Weathered granitic bedrock was distributed in the lower slopes, and decomposed granite soil was distributed near the crests. It is considered that the reason why "slope angle" was excluded from the explanatory variables applied to the analysis is because a lot of shallow landslides occurred at not only steep slopes but also shelving slopes in Hofu.

Among the topographical conditions reported in the previous studies, some conditions, which showed the significant difference in the satisfaction ratios (Section 5.2), were confirmed to be involved in shallow landslide. Among the selected conditions, "valley slope" and "convex break of slope" were also confirmed to contribute largely to shallow landslides by Hayashi's quantification method II in Chuetsu and in Hofu. Therefore, both the conditions would be largely involved in shallow landslide and important clues to detecting unstable slopes.

"Angle of over 30 degrees" was picked out as the condition involved in shallow landslide according to the result of the review of the previous studies. Furthermore, the slope angle which would contribute to shallow landslides in Chuetsu was over 40 degrees as the result of Hayashi's quantification method II. These results verify that the angle of over 30 degrees, especially over 40 degrees, is a condition involved in shallow landslide.

The conditions of "spring" and "fan-like gentle slope beneath a steep escarpment" are also confirmed to be involved in shallow landslide. The former shows the "sign" of the occurrence of shallow landslide, and the latter shows the "result" of that (Table 1). Conditions which show the "sign" of the occurrence of shallow landslide is important to detecting unstable slopes. Therefore, the spring should be checked in the field observation for detecting unstable slopes.

8. Conclusions

In this study, the authors validate some of the topographical and geological conditions involved in shallow landslide reported in the previous studies. These conditions are important clues to detecting unstable slopes susceptible to shallow landslides.

The authors conducted the field observation in Chuetsu and Hofu where a number of shallow landslides recently occurred. In both the study areas, the authors checked whether or not each landslide site and non-landslide site satisfied the topographical and geological conditions. Additionally, the authors obtained topographical and geological data in the study areas by map interpretation and applied Hayashi's quantification method II to the obtained data. Consequently, the following conditions were confirmed to contribute largely to shallow landslides in the study areas: 1) convex break of slope, 2) valley slope, 3) angle of over 40 degrees and 4) spring (Fig. 6).

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