Rock slope stability management along the road by machine learning through databasing disaster prevention records

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ABSTRACT: In the maintenance of roads through mountainous terrain, inspections for rockfall and rock collapse are not conducted on all the targeted roads, thus resulting in disasters outside the scope of the inspections. In this study, 0.5 m Laser Profiler (LP) along National route 210, Oita, Japan, with a total length of 100 km is applied to generate Digital Elevation Model, and the division of slope units is created based on the inclination angles and their distribution. Secondly, the database is prepared by the inspection records (2006-2021) that machine learning will use as training data to create a risk evaluation model. Finally, we were able to extract potentially dangerous slopes that have not been inspected so far in the study area and clarified the inspection priority.

Keywords: steep cliff, rockfall, rock collapse, road disaster prevention record, supervised learning.

1 INTRODUCTION

1.1 Study area

National route 210 in Oita prefecture runs along the Kusu River in the mountainous area from Hita city to Oita city and down the northern side of Mt. Tsurumidake, Kuju, and Aso volcanoes are located in the vicinity of National route 210 (Figure 1, Total length 100km). Along the route, fused tuff such as Aso-4 pyroclastic flow deposits, which are easily weathered, is widely distributed. The rockfalls observed along National route 210 are not only the common dropout type and avulsion type, but also a special type called the Akaiwa type (Figure 2 (a)). In the Akaiwa type, the bottom part of the dissolving tuff is eroded by river erosion, and the upper part is unstable due to the loss of support, resulting in an overhang and free fall of the rock mass. Even in recent years, although countermeasure works have been placed (Figure 2 (b)), many rockfalls and rock collapse have occurred on steep cliffs with such topography and geology, resulting in human casualties and property damage.

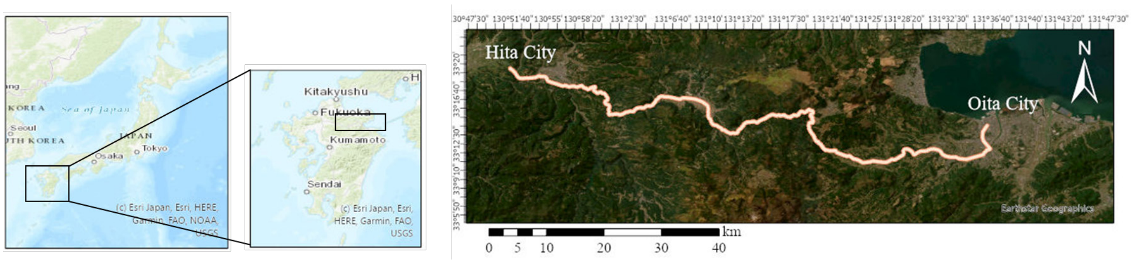


Figure 1. Study area.

(a) Akaiwa type rock cliff (b) Example of a target slope and its countermeasure works

Figure 2. Examples of target slope.

1.2 *Road slope inspection and disaster prevention record*

From the above, in the management of slopes along National route 210, prevention of disasters related to rockfall and rock collapse is important. Road disaster prevention inspections are conducted to ensure and improve the safety of roads and road users against disasters, by inspecting the condition of road facilities such as earthwork facilities and slopes around roads from the viewpoint of "experts in road disaster prevention". In road disaster prevention inspections (Figure 3 (a)), a desk-based screening of the surveyed slopes is first conducted, followed by a stability survey through a field investigation. Based on the results of this stability survey and the perspectives of “disaster factors”, “effectiveness of countermeasure works”, and “damage history”, the experts classify the survey target into three categories; “Countermeasures required”, “Monitoring the progress”, and “Countermeasures not required” as comprehensive evaluation. In this paper, these three categories are referred to as Type A, B, and C, respectively. Only slopes classified as Type A and B are created in the records and inspected annually for abnormalities (Figure 3 (b)). The records contain field sketches and experts’ comments (Figure 3 (c)).

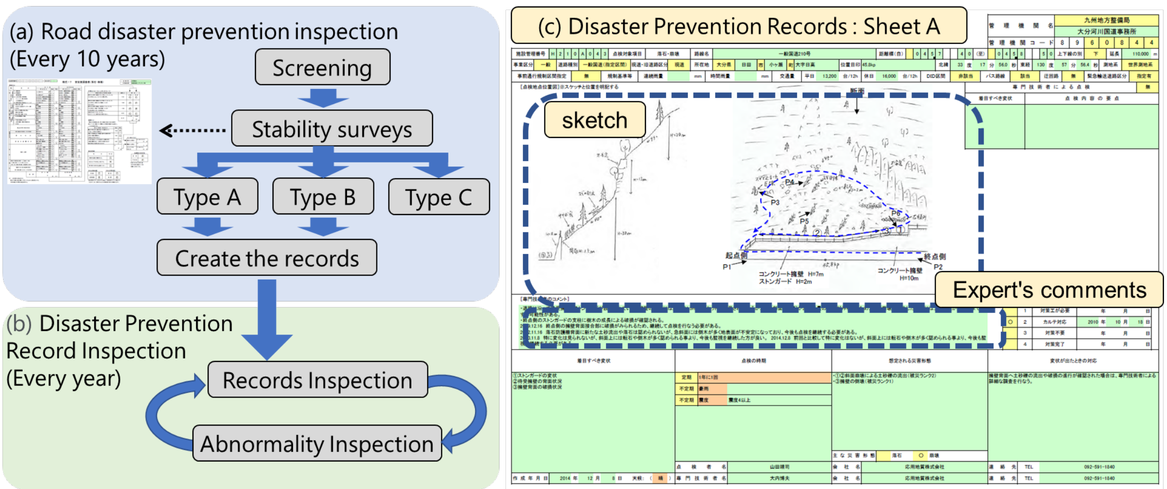


Figure 3. Road disaster prevention inspection and example of disaster prevention record.

1.3 Purpose of this study

Along roads with steep cliffs, such as National route 210, it is difficult to manually select all hazardous areas from the slopes of the extensive management area. In fact, there have been many reported cases of disasters occurring in hazardous areas that have been overlooked due to retaining walls and plants. Therefore, it is desirable to comprehensively identify slopes at risk of rockfall and rock collapse and to identify slopes that should be inspected on a priority basis. Despite the fact that there is a mixture of areas of different hazard levels in the created records, it is unclear which areas are hazardous, as each record is managed with a single comprehensive evaluation. Therefore, it is necessary to define the slope assessment unit in detail.

In this study, the assessment unit of slopes based on topographical features for National route 210 is defined and a method to identify priority slopes for inspection by extracting slopes with similar topography and geology to slopes with disaster prevention records using supervised learning, which is one of the machine learning methods is proposed.

2 METHODS

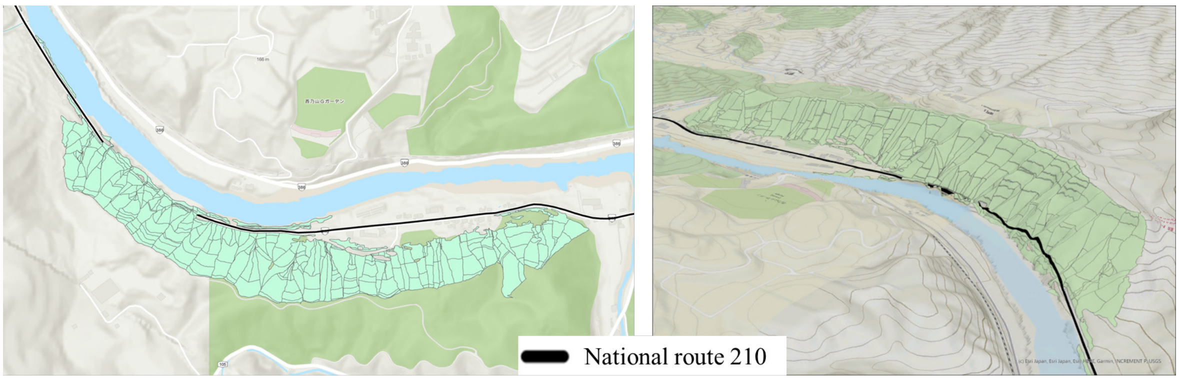
2.1 Slope unit

A "slope unit" (Zhou et al. 2003) is defined as a single slope that consists of areas with similar slope angles and directions that are significantly related to the type of slope hazard. In this study, the method of creating the slope unit is developed using a geographic information system (GIS) and Laser Profiler (LP). This slope unit is applied as the evaluation unit of the slope.

To create slope units only in mountainous areas, an area 1 km from the target roadside is classified as flat or mountainous. For the classification, areas with a high density of slopes (13 degrees or less) are extracted as plains, and other areas are classified as mountains.

Next, the area bounded by the ridge line is classified into three slope units based on the valley line: convex slope (slope with no valley), the slope along the valley (slope adjacent to valley), and concave slope (slope above slope along valley). This is because the type of slope hazard differs depending on the unevenness of the slope and the presence or absence of valleys. In the typified slope units, there exist slopes that are excessively divided or slopes that have both gentle and steep slopes in one. Therefore, the process of combining slope units with similar mean slope directions of adjacent convex slopes is repeated. Then, by repeating clustering based on the average slope angle within each slope unit, the slope units are divided by the knick line (convex and concave). Finally, only slopes affecting the subject road are extracted.

As a result, as shown in Figure 4, a slope unit is defined as a region with similar slope angles and directions. The total number of slope units was 9,081.



(a) 2D view (b) 3D view

Figure 4. Examples of created slope units.

2.2 Comprehensive evaluation prediction model

Slopes at risk of rockfall and rock collapse are extracted by supervised learning. First, the following were input to all slope units as explanatory variables related to topography and geology; Average slope angle, 250 m mesh topographic classification, 1:200,000 geology, 1:200,000 topographic classification, soil classification, surface geology. Slope units with disaster prevention records will also contain the latest comprehensive evaluation with reference to the disaster prevention records for rockfall and rock collapse. Not all slopes in the disaster prevention records are hazardous, and there is a mix of hazardous and non-hazardous slopes in a record. Therefore, the comprehensive evaluation "Monitoring the progress (Type B)" is imputed in the slope units where exposed rock and collapse sites are determined to be at risk for rockfall and rock collapse. In the target area, there were a total of 394 slope units with disaster prevention records (84: "Countermeasures required (Type A)", "Monitoring the progress (Type B)", and 212: "Countermeasures not required (Type C)". Using the above as supervised data, hazardous slopes are extracted by Random Forest, one of the supervised learning methods (Breiman 2001).

For validation of the accuracy of the hazardous slope extraction model, 70% of the data set is trained, and the remaining 30% is classified and examined for agreement with the actual comprehensive evaluation. This procedure was repeated three times, and accuracy, precision, recall, F-Measure of the prediction are calculated. After validating the model, the built model is used to predict the comprehensive evaluation from the topography and geology of the slope without the disaster prevention record. Use all of the data set as training data when predicting the comprehensive evaluation.

3 RESULTS AND DISUCUSSIONS

3.1 Accuracy of the model

The accuracy of the comprehensive evaluation prediction model for all three trials shows in Table 1. Although there was some variation in accuracy, the model showed a prediction accuracy of about 70 %.

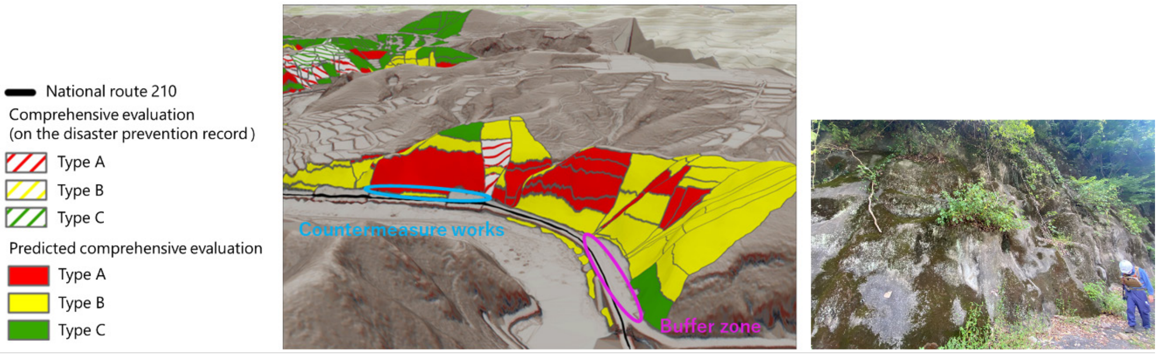
The predicted results of the comprehensive evaluation of slope units without the disaster prevention records are shown in Table 2. It can be indicated that the slope units predicted to be equivalent to Type A and B account for about 85 % of the total. A field survey of the extracted hazardous slopes revealed some rock bodies that could cause rockfall and rock collapse on the slope right beside the road, as shown in Figure 5 (a). Consequently, the developed model can extract hazardous slopes that have been overlooked so far. On the other hand, some of the extracted slopes are already protected by rockfall protection fences or other measures, or the flat area between the road and the slope functions as a buffer zone for rockfall and rock collapse, as shown in Figure 5 (b). Therefore, in order to identify inspection priorities for slopes, the extracted hazardous slope units need to be subdivided by the presence or absence of countermeasure works.

Table 1. Accuracy of the comprehensive evaluation prediction model.

No.	Accuracy (%)	Precision (%)	Recall (%)	F-Measure (%)
1	72.3	69.7	67.4	68.3
2	77.3	75.8	75.5	75.6
3	80.1	73.0	73.9	73.4

Table 2. Predicted comprehensive evaluation on slope units without the disaster prevention record.

Type A	Type B	Type C	Total
850	6,389	1,280	8,519



(a) An example of Predicted comprehensive evaluation (b) Countermeasure works

Figure 5. An example of the results of hazardous slope extraction by Random Forest.

3.2 Assignment of inspection priority to the extracted hazardous slopes

In order to identify priority slopes for inspection based on the existence of countermeasure works and buffer zones, GIS data for countermeasure works are created to clarify the presence or absence of countermeasure works on each slope unit. In particular, the following rules are used to create the countermeasure works data.

- For the existence of a buffer zone (flat area), the distance that functions as a buffer zone is defined as 10 m or more in the disaster prevention records.
- For rockfall protection works such as rockfall protection fences (Countermeasure works 1), a polygon representing the area from the location of the countermeasure to the ridge is created, and the slope unit completely included in the polygon is defined as "CW-1: Yes".
- For rockfall, prevention works such as covered rockfall protection net and slope protection works such as mortar spraying (Countermeasure works 2), a polygon is created to represent the extent of the countermeasure, and the slope unit that touches the polygon is defined as "CW-2: Yes".

The above "Flat areas acting as buffer zones" and "Countermeasure works" are added to the "Predicted comprehensive evaluation " to assign inspection priorities to slopes as shown in Table 3. Table 3 shows that the A1 and A2 hazardous slopes, which are close to roads and likely to lack countermeasures, were narrowed down to about 24 % (2,023 slopes: yellow hatching in Table 3) of the 8,519 slopes without medical records as the highest priority slopes to be inspected.

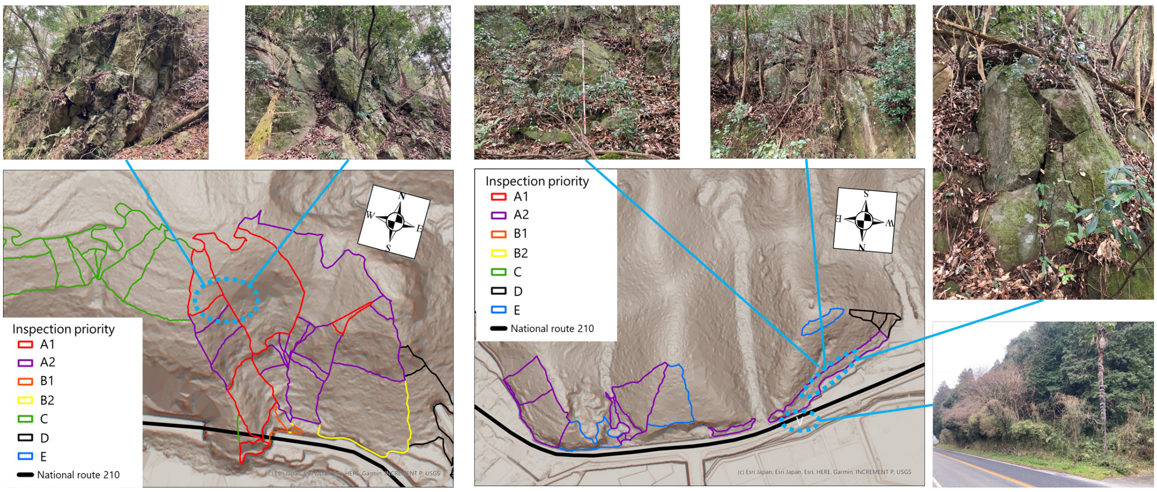
3.3 Verification of inspection priority slopes by on-site survey

The on-site survey was conducted to verify the extracted hazardous slopes. As survey targets, 17 slope units (A1:8, A2:9) were randomly selected for the surveys among the hazardous slopes predicted as A1 and A2 for inspection priority.

As a result of the survey, 3 clearly hazardous slopes were confirmed in A1 slopes and 5 in A2 slopes. In particular, on slopes A1 and A2 in Figure 6 (a), there are groups of loose rocks over 2 m in height, which are not safe with the existing countermeasures. In addition, a number of loose rocks of about 2 m in height were observed on slope A2 in Figure 6 (b), and if these stones fell, there is a high possibility that these stones would reach the road. On the other hand, there was no significant difference between the hazards of A1 and A2 slopes, it is desirable to evaluate these areas as the slopes that should be inspected with the highest priority without distinguishing between them. In addition, slopes that are distant from roads and have a low possibility of disaster, and gentle slopes that are not considered hazardous, were also evaluated as A1 slopes. In the future, it is necessary to consider adding "distance from the road to the slope" as an evaluation item for inspection priority.

Table 3. Inspection priority of slope units.

Inspection priority	Buffer zone	CW-1	CW-2	Predicted comprehensive evaluation	Slope units
A1	None	None	None/ Partially none	A	255
A2				B	1,768
B1			Yes	A	32
B2				B	294
C1		Yes	None/ Partially none	A	53
C2				B	195
D1			Yes	A	5
D2				B	18
E	Yes	-	-	-	4,619



(a) A1 and A2 slopes (b) A2 slope

Figure 6. An example of the results of hazardous slope extraction by Random Forest.

4 CONCLUSIONS

In this study, supervised learning method was used to identify potentially hazardous slopes that had not been targeted for inspection on Japan's long national route running through mountainous areas. Slope units were newly defined as an evaluation unit for slopes with similar topography features. After that, the areas on slopes without disaster prevention records that had similar topography and geology to slopes with disaster prevention records were extracted using Random Forest. In addition, inspection priority was assigned based on the presence or absence of countermeasure works and buffer zones, and approximately 24% of the slopes without disaster prevention records were selected as the highest priority slopes for inspection.

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