A new approach for landslide mitigation for sustainable development of the transport sector

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Abstract:

The phenomenon of landslides is a strong example of natural disasters that directly affect the development of mountainous areas in general, and the traffic and transportation sectors in particular. By observing the damages caused by typical landslides in Vietnam, it can be recognized that the response to this dangerous phenomenon is often quite passive. This paper proposes a new strategy to proactively prevent and mitigate the occurrence of this natural disaster for sake of new design and management of roads, especially in mountainous terrain areas. The core of the new strategy is to identify an area's vulnerability to landslide using a landslide hazard map (LHM), created through a combined use of the landslide risk assessment map (LRAM) and the landslide susceptibility map (LSM). LRAM is outlined based on landslide inventory maps and is used for evaluation of an area's re-activeness to land sliding. LSM is created using landslide manifestation data collected about landslide causative factors such as topography, geomorphology, geology, climate and human impact as a basis for predicting the future of a particular area. The establishment and use of LHM will contribute to landslide mitigation.

Keywords: **landslide, risk assessment, susceptibility, transport, Vietnam.**

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Introduction

Landslides are considered as a persistent problem in mountainous regions, especially along transportation corridors. Landslides not only cause damages to property (houses, buildings, vehicles, etc.) and large numbers of casualties, but also disrupt utility services and economic activities. Located on the Eastern Indochina Peninsula, Vietnam has an expanse of mountainous terrain up to 3/4 area of its territory covered by steeply sloped terrain as created from the earth's crust's powerful tectonics. Moreover, it also has a complex geological structure and a tropical monsoon climate with an average annual rainfall of as much as 3,000 to 4,500 mm/year in some regions. Consequently, Vietnam is a typical tropical country with serious landslide disasters in both Southeast Asia and the Mekong sub region.

The vulnerability of landslide hazards is referred to as the portability of slopes by land sliding. There are many causes of landslide-vulnerability, including the conditions of topography, geomorphology, geology, climate and artificial activities. Landslide-vulnerability assessment is a major component of a risk assessment of re-active landslides and landslide susceptibility [1]. In order to mitigate the affect that landslides have on human life, landslide risk assessment is an absolute requirement.

Recent strategies for reducing the affect of landslides

As can be seen from the recent bouts of damage from landslides in Vietnam, specifically on Highway No. 37 (at Chen Pass), Son La Province; Nam Non Bridge on the Western Route, Nghe An Province; Hai Van Pass Station; on Highway No. 6; and along the Ho Chi Minh Highway in the central region; the response to this dangerous phenomenon is quite passive.

The preparation efforts for new mountainous road projects, specifically with the selection of road alignment designed to prevent landslides and landslide-damage has not been effective due to a significant lack of necessary tools, including landslide inventory, risk assessment maps, and landslide susceptibility maps. As well, the landslide identification conducted by site surveyors is insufficient and uncredible. Due to these issues, new roads are susceptible to problems with landslides. Regarding existing road management, the most recent strategies seem too passive. This can be seen in the large number of landslides that have occurred along Vietnam's traffic arteries, especially in the raining season, including National Highway No. 2, No. 3, and Ho Chi Minh Highway; landslides that damage the roads cause havoc with traffic and hurt the economy. Often, the biggest effort of landslide risk mitigation is to recover those roads after landslides have occurred. Fig. 1 presents some pictures of landslides that have occurred along Vietnamese roads.

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Fig. 1. Some pictures of landslides along Vietnamese roads.

The vulnerability of landslide hazard

Landslides are a natural phenomenon strongly tied to the topography and slope formation processes. These processes are affected by climatic and crustal movement occurring over a very long time. However, looking at a slightly shorter time-scale, the earth's topography is essentially formed by a combination of rock strength, weathering processes, and erosion stress [2].

The natural formation of slopes depends on both internal impacts and external factors. These Internal factors are also often changes by actions occurring on the outside such as weather, metamorphosis, organization and other geological and morphological phenomenon. External factors include rain, earthquakes, and steam, and contribute to the increased strain and decreased shearing strength of the crust's surface. As a result, balance is thrown off and landslides are created. Slopes can be made unstable by both internal and external factors, but not always at the same levels of contribution.

A country's vulnerability of landslide hazard is caused by the portability of slopes by landslides. Slope portability includes the pitch of the original slope (the slope that during the period of creation was only affect by erosion) and the slope has caused landslide in the past. Slopes that have experienced previous landslides may be susceptible to more future landslides. So when discussing the vulnerability of landslide hazard this paper will mention two scientific concepts: landslide risk assessment to re-active landslides and landslide-susceptibility due to slope pitch.

The principles of research methodology

1) The primary conditions that cause landslides are identified, and most can be shown on a map. There are many causative factors affecting landslides and those factors usually can be divided into four groups: topo-morphologic, geologic, climatic and artificial actions. However, ten factors that usually directly relate to landslides include slope angle, weathering, land use, geomorphology, fault density, drainage distance, elevation, precipitation and human actions. For each landslide, the weight of distribution contributing to the landslide may be different. The main

causes that trigger landslides can be identified. Landslide position, boundary and micro feature can be realized mostly through aerial photographs through stereoscopic projection, or based on field surveys [3, 4].

2) For landslides, "the past and the present are the keys to the future" [5, 6]. The causation of landslides is a changing processes affected by morphological factors over time, which are impacted by many other natural morphologic, geologic and climatic factors. On the other hand, human capacity of landslide recognition is limited. So when considering the natural rule of landslides, landslide occurrences will be recognized as often as possible. Per region, landslides in the future may occur in the same geologic, geomorphologic and hydrogeologic conditions as it happened before. From studying identified landslides and the causes of landslides, predictions of future landslides can be made. Therefore, to understand clearly about the movement of landslides in the past is very importance to assess landslide causes.

3) Each region is at risk for landslides at different probabilities. In an ideal situation, landslide risk would be considered according to all causative factors. Sorted by different probabilities can be gathered and used to build predictive models for landslides using different landslides phenomena controlled by the laws of mechanics, by which we can determine empirically, and statistical probability of occurrences. However, depending on the availability of relevant data, individual causative factors may be used for evaluation. From landslide occurrence data, there are many method for evaluation, including AHP, fuzzy, and a combination of both.

Proposing a flow chart for approach and discussions

The research methodology that was applied is outlined in a flowchart in Fig. 2. The chart is based on the idea that "for landslides, the past and the present are the keys to the future" [7]. By this notion, landslide occurrences can be recognized as often as possible,
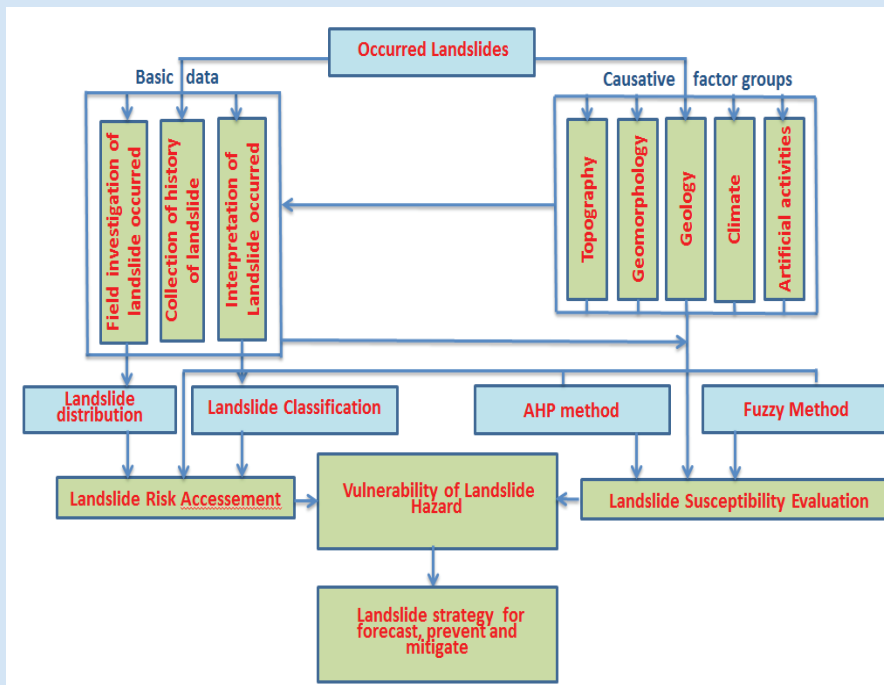
Fig. 2. Flow chart for vulnerability of landslide hazard research.
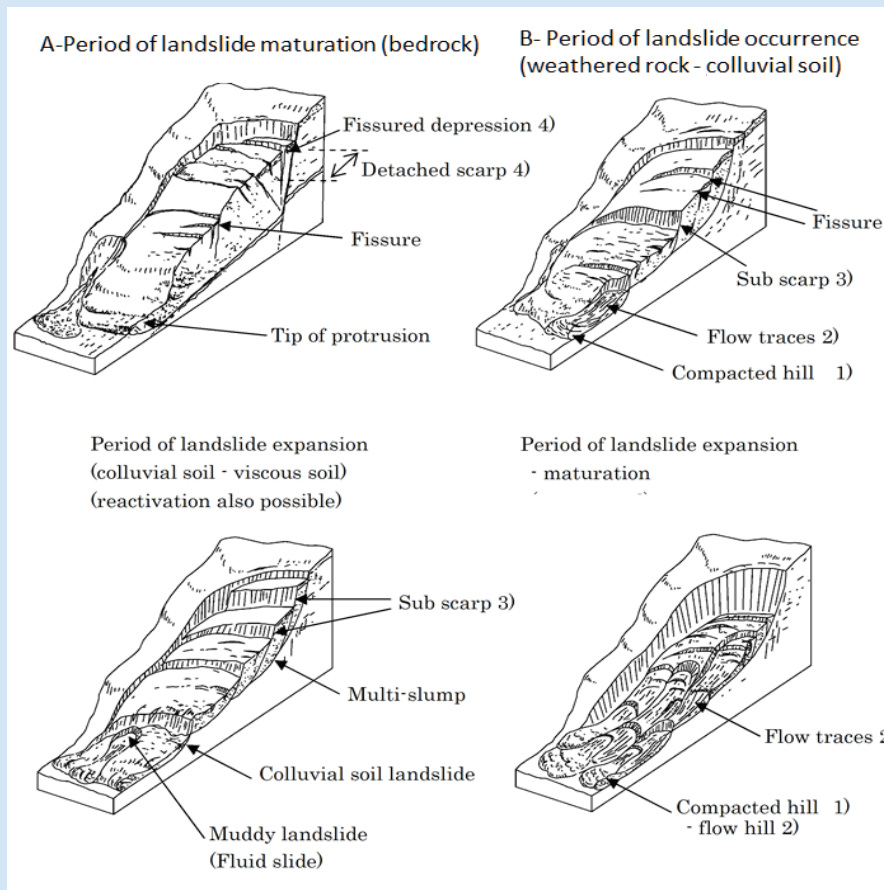

Fig. 3. Landslide micro topography [8].

depending on the test's ability to identify the influencing factors and basic data about landslides (because landslides are a phenomenon affected by time, and the capacity to recognize landslides is limited, along with other topography and slope formation phenomena, vegetation from tropical forests often cover and hide valuable signals used for landslide recognition).

To gather basic data about landslides, three basic methods used to create landslide inventory maps should be employed: field recognition methods to investigate landslide occurrences, evaluation of historical records of landslides, and study of landslide occurrences from aerial photographs. From investigations of prior landslides, the relationship between causative factors such as topography, geomorphology, geology, climate and artificial activities and landslide distribution, micro-topography can be studied. Rules regarding landslide distribution can be used for landslide classification, risk assessment and landslide susceptibility.

The conventional method of classifying landslides is based on evaluating the characteristics of the area's makeup and movement type. A recent method of classification also evaluates other factors including the affect of weather on the ground, geological features, and landslide scale. The fuzzy nature method can also be applied for this classification.

Landslide risk assessment evaluates the sensitivity of an area to re-activate landslides from previously investigated landslides. Landslide micro-topography is the interior of the landslide body, head, side, and toe. For each landslide, the internal micro-topography of landslide bodies include compacted hill, flow traces/flow hills, sub scarp, and detached scarp/fissured depression, which is very useful information used to understand the landslide phenomenon history of an area. Fig. 3 presents landslide micro topography (A) for a period of landslide maturation (bedrock) and (B) for a period of landslide occurrence on weathered rock - colluvial soil. The information observed through basic data concerning
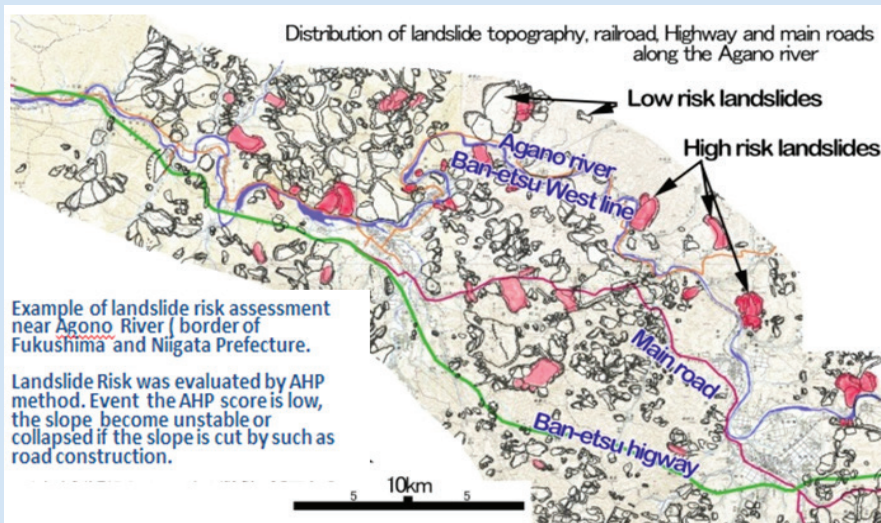
Fig. 4. Design of highways Ban-Etsu, Japan which was designed to avoid sensitive landslides.

to position, micro features and causative factors is very important for landslide assessment. For comparison and evaluation, the analytical hierarchical process approach or the fuzzy relation approach are applied. Depend on the results of the assessment; the sensitivity of an area to reactive landslides can be divided into groups of low, moderate of high classes.

To assess landslide susceptibility, the identification of causative factors, which are classified as dynamic factors (e.g. pore-water pressure) and passive factors (e.g. rock structure), might also be considered in terms of their roles as pre-conditioning factors (e.g. slope angle), preparatory factors (e.g. deforestation), and triggering factors (e.g. rain fall), which are usually targets of studies. Actually, the landslide process depends on many causative factors, such as topography and geomorphology, geology, climate, and human impact. However, depending on a full research study of the area, the relevance, availability and scale of a map [9] with necessary factors should be used. Therefore, as objects of analysis were used for this research, minor and indirect factors were ignored in favour of ones such as elevation, slope angle, land use, rock type, total annual average precipitation, fault density, and distance to the road.

For landslide susceptibility mapping, causative factors must be prepared by causative-factor maps, in which each factor map of the study area is classified into many different class groups. The weight of each factor is studied based on the results of the analytical relation between landslide occurrences with each class' factor map using GIS. Methods of analytical hierarchical process approach or fuzzy relation are applied for evaluating the contribution weight of each factor, then overlay causative maps with calculation weighs. The result of this is landslide susceptibility mapping is created. The landslide susceptibility map, in which its indicator will be divided into four classes from low to very high landslide sensitivity will be used for forecast, prevent and mitigation for a region.

Conclusions

To best assess the vulnerability of landslide hazard, the LRAM and LSM are the most effective tools for forecast, prevention and mitigation of negative impacts caused by landslides and used for planning, land use, and construction of infrastructure. The combination of LRAM and LSM will give us a full picture of landslide risk regarding the sensitivity of reactive landslides and the landslide susceptibility of a giving slope. The application of LRAM has been

found in the transport sector of developed countries. Fig. 4 shows an example of the application LRAM in Japan. In the scope of the technical cooperation project named "Development of landslides risk assessment technology along transport arteries in Vietnam", the LRAM and LSM was developed and announced [10]. The application of LHM as discussed above is feasible.

REFERENCES

[1] D.V. Tien, Toyohiko Miyagi, Eisaku Hamasaki, Shinro Abe, Nguyen Xuan Khang (2014), "Landslide prevention and mitigation for road in humid tropical region", *The 4th volume of World Landslide Forum 3 (WLF3)*, Beijing.

[2] M. Toyohiko (2012), "TXT-tool 1.081-2.1. Landslide topography mapping through aerial photo interpretation", *In ICL, Landslide teaching tools*, pp.1-10, Tokyo: ICL.

[3] D.J. Varnes (1978), "Slope Movement Types and Process", *In Transport research board, Landslides, Analysis and Control, Special report176*, pp.11-33, Washington, D.C.: National Academy of Sciences.

[4] A. Hansen (1984), "Landslide Hazard Analysis", *In D.B. (editors), Slope Instability*, pp.523-602, New York: John Wile & Sons.

[5] D. Vaners (1984), *Landslide hazard zonation: a review of principles and practice*, Paris: UNESCO.

[6] Carrara, et al. (1991), "GIS Techniques and Statistical Models in Evaluating Landslide Hazard", *In Earth Surface Processes and Landforms*, **5(16)**, pp.427-445, New York: John Wiley & Sons.

[7] D.V. Tien, Toyohiko Miyagi, Shinro Abe, Eisaku Hamasaki, Hiroyuki Yoshimatsu (2016), "Landslide susceptibility mapping along the Ho Chi Minh route in central Vietnam - an application of an AHP approach to humid tropical area", *Transactions, Japanese Geomorphologic Union*, **37-1**.

[8] Kyoji Sassa, Hirotaka Ochiai, Toyohiko Miyagi, D.V. Tien, N.X. Khang (2015), "Development of Landslide Risk Assessment Technology along Transport Arteries in Vietnam", *Abstracts of the 54th annual meeting of the Japan landslide society*.

[9] Sassa, Toyohiko Miyagi, Hirotaka Ochiai (2016), *Project report for final evaluation*.

[10] Le Hong Luong, Toyohiko Miyagi, Shinro Abe, Eisaku Hamasaki, D.V. Tien (2014), "Detection of active landslide zone from aerial photograph interpretation and field survey in central provinces of Vietnam", *Proceedings of World Landslide Forum 3*, Beijing.